AQUIS RESORT AT THE GREAT BARRIER REEF PTY LTD

ENVIRONMENTAL IMPACT STATEMENT

VOLUME 6

APPENDIX F

AQUATIC BIODIVERSITY

Aquis Resort Technical Study: Aquatic Ecology

Stage 1 and 2 Reports: Existing Situation, Preliminary Impact Assessment and Mitigation.

Prepared for:

Flanagan Consulting Group

frc environmental

PO Box 2363, Wellington Point QLD 4160
Telephone: + 61 3286 3850
Facsimile: + 61 3821 7936

frc reference: 130702

freshwater estuarine marine

Document Control Summary

Project No.:	130702
Status:	Final Report
Project Director:	Carol Conacher
Project Manager:	Craig Chargulaf
Title:	Aquis Resort Technical Study: Aquatic Ecology
Project Team:	C. Chargulaf, C. Conacher, C. Dix, A. Lea, J. Thorogood
Client:	Flanagan Consulting Group
Client Contact:	David Rivett
Date:	4 December 2013
Edition:	v
Checked by:	Carol Conacher
Issued by:	Craig Chargulaf

Distribution Record

Flanagan Consulting Group:	1 pdf; 1 word document
Environment North:	1 pdf; 1 word document

Contents

Tables

Figures

Maps

Glossary

AMPA	aminomethylphosphonic acid
ANZECC & ARMCANZ	Australia New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand
Aquis	Aquis Resort at the Great Barrier Reef Pty Ltd
ASS	acid sulfate soils
AUSRIVAS	Australian River Assessment System
BOD	biochemical oxygen demand
BTEX	benzene, toluene, ethyl benzene and xylene
EHP	Queensland Department of Environment and Heritage Protection
EIS	Environmental Impact Statement
EP Act	*Environmental Protection Act 1994*
EPBC Act	*Environmental Protection and Biodiversity Conservation Act 1999*
EPP Water	Environmental Protection (Water) Policy 2009
EV	environmental values
Fisheries Act	*Fisheries Act 1994*
GBRWHA	Great Barrier Reef World Heritage Area
GVP	gross value of production
IDAS	Integrated Development Assessment System
ISQG	Interim Sediment Quality Guideline
Land Protection Act	*Land Protection (Pest and Stock Management) Act 2002*
NA	not available
NATA	National Association of Testing Authorities
NCWR	Nature Conservation (Wildlife) Regulation 2006

ND	no data
NTU	nephelometric turbidity unit
PAH	polycyclic aromatic hydrocarbon
PASS	potential acid sulfate soils
PCB	polychlorinated biphenyls
the Project	The proposed development of the Aquis Resort at the Great Barrier Reef
QLD	Queensland
QWQG	Queensland Water Quality Guidelines
SDPWO Act	*State Development and Public Works Organisation Act 1971*
SEWPAC	Department of Sustainability, Environment, Water, Population and Communities
sp.	species (singular)
spp.	species (plural)
SIGNAL	stream invertebrate grade number - average level
TOR	terms of reference
TPH	total petroleum hydrocarbons
the proposed development site	Lot 1 RP724792, Lot 1 RP800898, Lot 2 RP745120, Lot 2 RP800898, Lot 3 RP746114, Lot 4 RP7461141, Lot 4 RP749342, Lot 4 RP713690, Lot 60 RP835486, Lot 2 RP746114 and Lot 100 NR3818
the Resort	Aquis Resort at the Great Barrier Reef
Water Act	*Water Act 2000*
WQO	water quality objective

Summary

A new resort and tourist facility south of Yorkeys Knob, Queensland, approximately 13 km north of Cairns has been proposed by Aquis Resort at the Great Barrier Reef Pty Ltd (Aquis). The proposed development site is between Half Moon Creek, Yorkeys and Thomatis / Richters Creek in the Barron River Catchment.

This report consists of a Technical Study with respect to aquatic ecology. This is one of a suite of Technical Studies that will be used to inform an environmental impact statement (EIS) under the *State Development and Public Works Organisation Act 1971*.

The Technical Studies were undertaken in two stages: Stage 1 in which opportunities and constraints were identified based on the project description in the Initial Advice Statement and Stage 2, in which potential impacts and mitigating measures were assessed. The results of the Stage 1 Technical Studies were used to refine the project design, and the refined project design was used in the assessment of impacts in the Stage 2 studies.

This Technical Study is based on a literature review and field surveys.

Stage 1

Literature Review

Aquatic Habitat

Habitats along the lower Barron River Catchment have been impacted by extensive urban development and sugar cane plantations in the region. Creek and river riparian zones are dominated by mangroves, while there are coastal dunes and beach systems at the mouths of each waterway.

In Trinity Inlet marine habitats are dominated by muddy sediment. These muddy habitats provide refuge for a variety of benthic invertebrates including polychaetes, molluscs and crustaceans. Historically there has also been some seagrass in Trinity Inlet however there is currently very little seagrass.

Water and Sediment Quality

The water quality of the Barron River Catchment is highly impacted by anthropogenic sources including agriculture, stormwater run-off from urban areas and discharge from a wastewater treatment plant. There is also a prawn farm upstream of the proposed development site that discharges into Thomatis / Richters Creek.

Water quality in the Barron River Catchment is not high and the following parameters frequently do not comply with Queensland Water Quality Guidelines (QWQG) and / or ANZECC & ARMCANZ trigger values, including:

- dissolved oxygen
- turbidity
- chlorophyll *a*
- particulate phosphorous
- total suspended solids, and
- some metals and metalloids (e.g. aluminium, iron and nickel).

The water quality of Richters Creek was monitored in 1990 and 1991 by BMT WBM and the data is summarised in the report *Aquis Resort at Great Barrier Reef Water Quality Assessments Report*.

The land within the proposed development site has historically been used for sugar cane production. Chemicals used on and near the proposed development site include fertilisers, fungicides, herbicides and insecticides and may have an impact on aquatic organisms. Sediment within the proposed development site contains acid sulfate soils (ASS). Disturbance of ASS can negatively impact aquatic ecological communities.

Macroinvertebrates

Historical studies of benthic macroinvertebrates in Cairns region indicate that benthic invertebrate composition within habitat types is not spatially variable. Filter-feeding organisms such as polychaetes, molluscs and crustaceans were the dominant species, comprising over 90 percent of the species abundance.

Macroinvertebrates were monitored in Avondale Creek and Moon River between 2001 and 2009. Macroinvertebrate taxonomic richness ranged from one to 16 taxa and macroinvertebrate abundance ranged from two to 1 084 individuals.

Fish and Fisheries

The creeks surrounding the proposed development site provide valuable habitat for many species of estuarine and marine fish, as well as mud crabs, blue swimmer crabs, yabbies and prawns. The sandy beaches downstream of the proposed development site are likely to contain large populations of small pipis, and oysters are likely to colonise hard intertidal substrates. Several species of stingrays and sharks are common in the estuarine and lowland river / creek systems of the Wet Tropics region.

The Cairns region is a very important commercial fishing ground, and was worth approximately $9 million in gross value of production in 2005. In recognition of their importance to fisheries, many waterways, including Richters Creek, Yorkeys Creek and Half Moon Creek are declared Fish Habitat Areas.

Marine Mammals and Reptiles

Seven dolphin species have been recorded from coastal waters downstream of the proposed development site; however, the habitats adjacent to the proposed development site are unlikely to provide significant habitat for any of these species, due to the shallow water.

As there is no seagrass in the creeks surrounding the proposed development site or offshore, there area is unlikely to provide significant habitat for dugong.

The small creeks surrounding the site of the proposed development do not provide habitat for any whale species.

Six species of marine turtles have been recorded from the estuarine waters adjacent to and downstream of the proposed development site. Some turtles, including green turtles, may feed in the mangrove habitats in the creeks surrounding the proposed development site. However, there is little significant habitat for marine turtles in these creeks. There may be some sparse nesting of turtles on the beach to the east of the proposed development site, however the area is not recognised as a major nesting area.

Field Surveys

The aquatic ecology of the proposed development site and surrounding creeks was surveyed between 30 July and 2 August 2013. This survey included an assessment of:

- the condition of the aquatic habitat condition
- water quality (with measurements taken in situ and samples collected for laboratory analysis)
- sediment quality (with samples collected for laboratory analysis)
- freshwater and estuarine macroinvertebrates (with samples collected for laboratory analysis), and
- aquatic plants (excluding mangroves).

Aquatic Habitat

Half Moon Creek, Yorkeys Creek and Thomatis / Richters Creek are mangrove lined estuaries that provide habitat for a range of aquatic flora and fauna, including nursery grounds for juvenile fish. There were tidal flaps or culverts in many of the tributaries to the creeks that are likely to impede natural water flow and fish passage. The creeks support abundant macroinvertebrate populations, and fish were observed in all waterbodies, including isolated pools.

No seagrass was observed in any of the creeks, nor at the mouth of the creeks. No seagrass has been recorded offshore of the creek mouths. The nearest recorded seagrass beds in Trinity Inlet are approximately 9 km south-east of the proposed development site. In the past four years, above average wet season rainfall combined with the 2010/11 La Niña and tropical cyclone Yasi has resulted in a major decrease in the distribution of seagrass along the north Queensland coast.

Water Quality

Turbidity throughout Half Moon Creek was generally high, which was likely to be related to stormwater runoff from the surrounding catchment. As in previous surveys of the creek, the percent saturation of dissolved oxygen was relatively high in downstream reaches, and poor in upstream reaches and upstream of tidal gates. The concentration of nutrients was relatively high in Half Moon Creek, except at the mouth.

Water quality in Yorkeys Creek was relatively poor: the concentration of dissolved oxygen did not comply with guidelines, and the concentrations of total nitrogen and phosphorous were high.

Water quality in Thomatis / Richters Creek was relatively good, with turbidity and dissolved oxygen complying with guidelines. However, the concentrations of total phosphorous and ammonia were relatively high at the most upstream site sampled, and chlorophyll *a* was high at all of the sites. In previous surveys the median concentrations of nutrients were generally relatively high. The lower values in this survey may be related to lower stormwater runoff in the dry season.

Water quality in the cane drain on the proposed development site was generally poor: the concentration of dissolved oxygen, nutrients and chlorophyll *a* did not comply with guidelines.

Water quality of the dune lakes and the farm dam on the proposed development site was also poor, with a high concentration of nutrients.

The concentrations of metals, metalloids faecal coliforms, chlorophyll *a*, herbicides, pesticides, and total petroleum hydrocarbons (TPH) were low at all the sites that were surveyed.

Sediment Quality

The sediment quality of the sites in the survey area was generally good, except for high concentrations of antimony, chromium and nickel. The high concentrations of these metals may be associated with acid sulphate soils. These metals may be bioavailable to aquatic organisms. All other parameters were either below applicable ISQG-low trigger values or below laboratory limits of reporting.

Estuarine Benthic Invertebrates

Estuarine benthic invertebrate communities were abundant. In Half Moon Creek these communities were dominated by capitellid and spionid polychaetes, particularly in the upstream reach. This is likely to be associated with high concentrations of nutrients and may be associated with the discharge from the wastewater treatment plant.

Communities in Yorkeys and Thomatis / Richter's Creeks were dominated by a variety of polychaete families.

Freshwater Macroinvertebrates

Freshwater macroinvertebrate communities were dominated by non-biting midge larvae: which are tolerant of changes in water quality and disturbances and tolerant of poor water quality conditions. The comparison of community composition with typical biological guidelines in Queensland indicates that these macroinvertebrate communities were likely to be influenced by high salinity and high concentrations of nutrients (which may be natural) or by urban and agricultural pollution.

Opportunities and Constraints

There are a number of legislative constraints to the proposed Aquis development. These include:

- Matters of National Environmental Significance including the Great Barrier Reef Word Heritage Area, Listed threatened aquatic species, and the Great Barrier Reef Marine Park
- the Great Barrier Reef Coastal Marine Park

- marine plants protected under Queensland's *Fisheries Act 1994*
- Barr Creek, Half Moon Creek, Trinity Inlet and Yorkeys Creek Fish Habitat Areas
- species protected under Queensland's *Nature Conservation Act 1992*
- constraints under the *Coastal Protection and Management Act 1995,* and
- the protection of the environmental values of waterways under *Queensland's Environmental Protection Act 1994.*

Impacts associated with the proposed development may include:

- impacts from the disturbance of acid sulfate soils, which are known to be prevalent in the area
- impacts associated with changes to water quality and flows, and the flow on impact to aquatic flora, fauna and ecosystems, including the water quality in the surrounding creeks and in the Great Barrier Reef Marine Park and World Heritage Area
- impacts of erosion and sedimentation
- potential impacts to listed species (such as saltwater crocodile listed under NCWR and migratory marine species, such as marine turtles)
- disturbance of Fish Habitat Areas (as a minimum by works associated with the inlet and outlet structures and pipelines)
- impacts to marine turtle breeding due to excess light generated by the proposed Aquis Resort, and
- impacts to the freshwater communities on site, particularly on the small freshwater pools within the woodland of Lot 100, which are likely to be highly sensitive to change.

It is anticipated that specific management plans will be required for:

- mosquito and midge management, and
- fish, shark, marine stinger and crocodile management.

Opportunities that the proposed Aquis Resort could incorporate include:

- stocking the man-made lake with native fishes to improve ecological value in the area

- removing tidal gates in Yorkeys (in particular), Half Moon and Thomatis / Richters creeks, which would improve tidal flushing and increase the value of the estuaries to fisheries by increasing habitat for nursery grounds and spawning, and enhancing local conservation values, and
- improving water quality in the creeks.

Stage 2

Potential Impacts and Mitigation

In the absence of effective mitigation, development in the coastal environment such as the proposed Aquis Resort can have a variety of impacts on coastal processes and aquatic organisms. Direct impacts, such as the disturbance, removal or burial of marine plants and soft sediment aquatic habitats, may occur during the process of construction. A number of indirect impacts may also occur during construction and operation. Potential indirect impacts to aquatic ecology may occur through:

- changes to water quality of the surrounding environment, including the release of nutrients and potential contaminants from disturbed sediments
- increases in the concentration of suspended sediments, and consequent sediment deposition
- acidic leachate from disturbed acid sulfate or potential acid sulfate soils
- alterations to local hydrology (i.e. both increased and decreased flows and creek diversions)
- colonisation of the lake by pest species
- changes to the light regime, and
- increased litter and waste.

All of these direct and impact impacts may also impact fish and fisheries of the area, and there may be additional impacts via the release of fish from the lake.

Where appropriate mitigation measures are put into place, these impacts will be minimised.

Major potential risks to aquatic ecosystems include changes to water quality and flows, colonisation by exotic species, sedimentation and damage to marine plants. The risks to the receiving environment through the release of nutrient rich water will be minimised through design of the resort, and in particular of the lake and stormwater management.

The risk of increased sedimentation and increased turbidity in the surrounding creeks will be minimised by best practice in the design of sediment control on the proposed development site, including the:

- retention of all natural vegetation and buffers
- Water Sensitive Urban Design, and
- appropriate management during construction and operation that minimises this risk.

While construction of the proposed development will result in the disturbance to and removal of less than 1 ha of marine plants, significant areas of marine plants will be restored.

The proposed design and management of the proposed lake relies on the recirculation of water by pumping and discharging from Richters Creek and exchanging internal water via propellers and aerators (e.g. water fountains). Failure of any of these systems poses a risk to aquatic flora and fauna in the lake as well as in the receiving and surrounding environments, particularly in periods of rainfall when overtopping is likely to occur.

Further Baseline and Monitoring Requirements

The surveys summarised in this report were designed to provide input into the design of the proposed development, rather than as baseline surveys for a known development. They did not include any seasonal components, the sampling of fish, nor macroinvertebrates in the mangrove forests.

Further aquatic ecological studies are recommended prior to development commencing, to describe seasonal changes in aquatic ecosystems that may be affected by the proposed development, and to better describe some of the communities. In addition, it is recommended that baseline data is collected prior to construction commencing. Baseline data should be collected in areas that may be impacted by the proposed development and in nearby reference sites. This data can then be used to data collected in ongoing monitoring programs to assess potential impacts of the proposed development during and after construction.

Recommended surveys to describe the existing aquatic environment, including seasonal variation, include surveys of:

- water quality
- sediment quality

- estuarine macroinvertebrates in the sediment of the receiving environment
- macroinvertebrates in mangrove ecosystems
- estuarine fish
- freshwater habitat and aquatic plants
- freshwater macroinvertebrate
- freshwater fish, and
- mosquitoes and biting midge larvae.

It has also been recommended the area is surveyed for use by marine turtles.

1 Introduction

1.1 The Proposed Development

A new resort and tourist facility south of Yorkeys Knob, Queensland, approximately 13 km north of Cairns has been proposed by Aquis Resort at the Great Barrier Reef Pty Ltd (Aquis). The proposed development site is between Half Moon Creek and Thomatis / Richters Creek in the Barron River Catchment. The proposed development site comprises:

- Lot 1, RP724792
- Lot 1, RP800898
- Lot 2, RP745120
- Lot 2, RP800898
- Lot 2, RP746114
- Lot 3, RP746114
- Lot 4, RP7461141
- Lot 4, RP749342
- Lot 4, RP713690
- Lot 60, RP835486, and
- Lot 100, NR3818.

The proposed Aquis Resort at the Great Barrier Reef (the Resort) has been declared a coordinated project under the Queensland *State Development and Public Works Organisation Act 1971* (SDPWO Act), which will require an environmental impact statement (EIS).

The Resort will be designed to attract international tourists as well as international meetings and conferences. It is expected the Resort will assist in the economic growth of North Queensland through government taxes (e.g. gaming taxes once operational) and by increasing job opportunities (approximately 26 700 jobs when fully operational). If approved, the Project will begin significant works mid 2014, and completion is set for late 2018.

1.2 Scope of This Report

This report consists of a Technical Study with respect to aquatic ecology, excluding the distribution and condition of mangrove flora and fauna, wetland flora, and excluding stygofauna. This is one of a suite of Technical Studies that will be used to inform an EIS being conducted under the SDPWO Act.

The Technical Studies were undertaken in two stages: Stage 1 in which opportunities and constraints were identified based on the project description in the Initial Advice Statement (IAS) (Aquis 2013); and Stage 2, in which potential impacts and mitigating measures were assessed. The results of the Stage 1 Technical Studies were used to refine the project design, and the refined project design was used in the assessment of impacts in the Stage 2 studies.

This Technical Study is based on a literature review and field surveys. The Study Area for the literature review incorporates the proposed development site (i.e. the Aquis lots defined above) and the broader area including the Barron River Catchment and delta, and matters associated with the Great Barrier Reef World Heritage Area. In the brief field survey, the proposed development site, the surrounding creeks, and near-shore areas were assessed.

1.3 Constraints and Limitations

Completion of this Technical Study was constrained by time. The field survey was designed to inform the design of the proposed development, and as such is not a complete baseline survey. The field survey did not include any seasonal components, the sampling of fish (estuarine or freshwater), macroinvertebrates in mangrove ecosystems, or sampling of stygofauna.

Stage 1 Existing Situation

2 Project Description from the IAS

In the IAS (Aquis 2013), the proposed development was described as a $4.2 billion tourist destination comprising:

- 3750 hotel rooms configured within 9 luxury hotel brands
- 1200 centrally managed apartments
- 135 centrally managed villas
- a 13 500 m^2 commercial outlet (e.g. shops and restaurants)
- a casino
- an aquarium
- 2 theatres
- a 13 hectare reef lagoon
- a 65 hectare lake
- an 18 hole championship golf course
- a 25 000-seat sports stadium designed for rugby / soccer
- a 45 000 m^2 convention and exhibition centre
- 1800 staff accommodation units
- a cultural heritage centre, and
- a 13 hectare water park.

Discharge waters from the lake, aquarium and water park were expected to be into Richters, Yorkeys and Half Moon creeks. Water intakes were not identified (Aquis 2013).

3 Methods

3.1 Literature Review

The Study Area for the literature review incorporates the Barron River Catchment and delta, including:

- the Cattana wetlands
- Half Moon Bay, and
- the waters seaward of Thomatis / Richters Creek in the east.

The Study Area for the literature review also incorporated nearby waters such as Trinity Inlet and the Russell-Mulgrave River Catchment, and other estuaries in the Wet Tropics of Queensland.

The Barron River Catchment is approximately 210 000 hectares, and drains into the Coral Sea north of Cairns, Queensland. The Barron River Catchment contains five major dams and / or weirs with an extensive irrigation network, and there are approximately 1 100 hectares of tidal wetlands. The estuary of the Barron River is a significant spawning and nursery ground for fish and crustaceans, and supports a wide range of commercial fisheries, including barramundi (*Lates calcarifer*) and flathead (*Platycephalus fuscus*) (Russell et al. 2000).

Water quality, sediment quality and the condition of aquatic habitats were reviewed for the Barron River Catchment. All literature that is cited is listed in Section 15 and all databases that were searched in Section 16. Source documents that were publically available included, but not limited to, were the:

- *Environmental Literature Scan of the Barron River* (Connolly et al. 1996)
- *Water Quality Improvement Plan for the Catchment of the Barron River and Trinity Inlet* (Barron & Haynes 2009)
- *Water Quality Issues in the Barron WQIP Area* (Mitchell et al. 2008)
- *East Trinity Acid Sulfate Soils: Part 1* (Hicks et al. 1999)
- *Natural Resources of the Barron River Catchment 1* (Russell et al. 2000)
- *Natural Resources of the Barron River Catchment 2* (Cogle et al. 2000)
- *Sources of Sediment and Nutrient Exports to the Great Barrier Reef World Heritage Area* (Brodie et al. 2003)

- *Cairns Regional Council Water and Waste Mulgrave River Aquifer* (GHD 2007)
- *Reef Rescue Marine Monitoring Program* (Schaffelke et al. 2001), and
- *Sediments and Nutrients in North Queensland Tropical Streams* (Brodie & Mitchell 2006).

A detailed list of agency and public engagement is presented in Section 17.

3.2 Field Survey

The proposed development site and the surrounding creeks were surveyed between 30 July and 2 August 2013. The survey was lead by Dr John Thorogood of frc environmental and included an assessment of:

- the distribution and condition of aquatic habitat
- water quality (with measurements taken in situ and samples collected for laboratory analysis)
- sediment quality (with samples collected for laboratory analysis)
- freshwater and estuarine macroinvertebrates (with samples collected for laboratory analysis), and
- aquatic plants (excluding mangroves).

Twenty-five sites were surveyed in detail comprising:

- 3 sites in Yorkeys Creek
- 6 sites in Thomatis / Richters Creek and their tributaries
- 7 sites in Half Moon Creek and its tributaries
- 2 freshwater pool sites, south of Yorkeys Creek
- 2 cane drains
- an unnamed creek on the site, and
- 4 man made dams (Map 130702SM, Table 3.1).

Of these, 13 sites were within the proposed development site.

Table 3.1 Sites sampled in detail in the current survey.

Site	Location	Details	Data and Samples Collected	Easting [a]	Northing [a]
1	Yorkeys Creek	downstream of the proposed development site	habitat assessment, in situ water quality, water and sediment samples for laboratory analysis	364 139	8 140 035
1a	Pool south of Yorkeys Creek	Lot 100, NR3818	habitat assessment, in situ water quality, water samples for laboratory analysis[b], freshwater macroinvertebrates	364 591	8 139 864
1b	Pool south of Yorkeys Creek	Lot 100, NR3818	habitat assessment, in situ water quality, water samples for laboratory analysis[b], freshwater macroinvertebrates	364 632	8 139 881
2	Yorkeys Creek	near the proposed development site	habitat assessment, in situ water quality, water samples for laboratory analysis, estuarine benthic invertebrates	363 543	8 139 096
3	Thomatis / Richters Creek	near the mouth	habitat assessment, in situ water quality, water and sediment samples for laboratory analysis, estuarine benthic invertebrates	364 912	8 139 637
3a	Yorkeys Creek	mouth	habitat assessment	364 868	8 139 997
3b	Thomatis / Richters Creek	mouth	habitat assessment	364 975	8 139 782
4	Thomatis / Richters Creek	adjacent to the proposed development site	habitat assessment, in situ water quality, water and sediment samples for laboratory analysis, estuarine benthic invertebrates	364 146	8 138 171
5	Half Moon Creek	mouth	habitat assessment, in situ water quality, sediment samples for laboratory analysis, estuarine benthic invertebrates	362 833	8 141 883

Site	Location	Details	Data and Samples Collected	Easting [a]	Northing [a]
5a	Half Moon Creek	near Half Moon Bay marina	habitat assessment, water samples for laboratory analysis	363 230	8 142 137
6a	Half Moon Creek tributary	Lot 60, RP835486	habitat assessment, in situ water quality, water and sediment samples for laboratory analysis, estuarine benthic invertebrates	363 135	8 138 864
7	Unnamed freshwater creek (cane drain) on the proposed development site	Lot 100, NR3818	habitat assessment, in situ water quality	364 514	8 139 306
7a	Man-made dam on the proposed development site	Lot 100, NR3818	habitat assessment, in situ water quality, water samples for laboratory analysis[b], freshwater macroinvertebrates	364 556	8 139 395
8a	Half Moon Creek	downstream of the proposed development site	habitat assessment, in situ water quality, water and sediment samples for laboratory analysis, estuarine benthic invertebrates	362 972	8 140 079
9	Wetland	Lot 60, RP835486	habitat assessment, in situ water quality, water samples for laboratory analysis [b]	363 033	8 139 347
10	Unnamed creek (cane drain)	Lot 100, NR3818	habitat assessment, in situ water quality, water and sediment samples for laboratory analysis	363 918	8 138 903
11	Freshwater tributary to Thomatis / Richters Creek	Lot 100, NR3818	habitat assessment, in situ water quality, water samples for laboratory analysis[b], freshwater macroinvertebrates	364 690	8 138 985
12	Freshwater tributary to Thomatis / Richters Creek	Lot 100, NR3818	habitat assessment, in situ water quality, freshwater macroinvertebrates	364 694	8 138 904

Site	Location	Details	Data and Samples Collected	Easting [a]	Northing [a]
13	Half Moon Creek	Lot 2, RP745120	habitat assessment	362 761	8 138 553
14	Half Moon Creek	Lot 2, RP745120	habitat assessment, in situ water quality	362 820	8 138 741
15	Half Moon Creek	upper reaches, near the proposed development site	habitat assessment, in situ water quality	362 784	8 138 851
16	Tributary to Thomatis / Richters Creek	Lot 100, NR3818	habitat assessment	364 670	8 138 659
SD	Man-made dam	Lot 1, RP800898	habitat assessment	363 506	8 137 988
ELD	Man-made dam	Lot 1, RP800898	habitat assessment, in situ water quality	363 565	8 138 272
LD	Man-made dam	Lot 1, RP800898	habitat assessment	363 986	8 138 046

[a] GPS (WGS 84, zone 55K)

[b] reduced suite of parameters

frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702SM:
Sites surveyed on and adjacent to the proposed Aquis Resort

SOURCES

© Copyright Commonwealth of Australia (Geoscience Australia) 2001, 2004 Sourced from http://www.ga.gov.au/meta/ANZCW0703005241.html#distinfo. Australian boundary, roads, locations
© The State of Queensland (Department of Natural Resources and Mines) 2013
Updated data available at http://dds.information.qld.gov.au/dds/. Coastline
Cadastral boundaries are approximate only and have been sourced from the Digital Cadastral Database 2013

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_site_map_13-09-11_CAC.mxd

LEGEND

- Sites Surveyed
- Lot Boundary
- Watercourse

N

SCALE

0 0.5 1
Kilometres

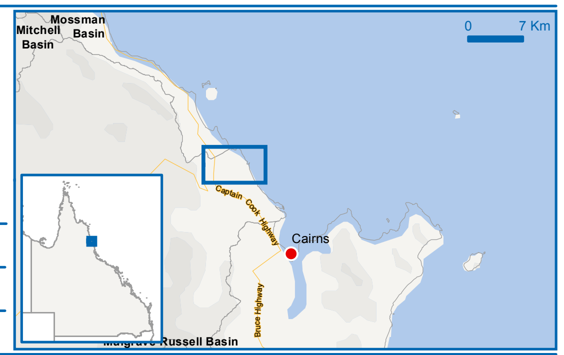
Scale: 1:20,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL, CF

VERSION
04



Water Quality

Sample Collection

Turbidity was measured in situ using a HACH 2100Q portable turbidity meter, and a Hydrolab QUANTA multi parameter water quality probe was used in situ to measure:

- water temperature
- pH, and
- dissolved oxygen.

Water samples were collected from thirteen sites (Table 3.1). Two samples were collected from one of the sites to assess within site variation and a blank sample (deionized water) was collected from another site to assess quality control of sampling in the field. All samples were analysed by Symbio Alliance (a NATA accredited laboratory). Samples from five of the sites (sites 1a, 1b, 7a, 9 and 11) were analysed for:

- electrical conductivity
- the concentration of total nitrogen, and
- the concentration of total phosphorous.

Samples from the remaining eight sites were analysed for:

- electrical conductivity
- biochemical oxygen demand (BOD)

and for the concentration of:

- nutrients (total phosphorous, total nitrogen, ammonia, nitrate, nitrite and filterable reactive phosphate)
- total suspended solids
- total organic carbon
- dissolved metals and metalloids
  - aluminium
  - antimony
  - arsenic

  - barium
  - beryllium
  - boron
  - cadmium
  - cobalt
  - chromium
  - copper
  - gallium
  - iron
  - lanthanum
  - lead
  - manganese
  - mercury
  - molybdenum
  - nickel
  - selenium
  - silver
  - tin
  - uranium, and
  - vanadium
- total petroleum hydrocarbons (TPH)
- benzene, toluene, ethyl benzene and xylene (BTEX)
- organochloride and organophosphorous pesticides
- phenoxy acid herbicides
- glyphosate and aminomethylphosphonic acid (AMPA)
- polycyclic aromatic hydrocarbons (PAHs)
- phenols
- polychlorinated biphenyls (PCBs)
- tributyltin

- faecal coliforms, and
- chlorophyll *a*.

All sampling was in accordance with the *Monitoring and Sampling Manual 2009* (DERM 2010a).

Data Analysis

To assess within site variation, the relative percent difference (RPD) between the two samples collected from one site was calculated.

Water quality data was compared to the laboratory limits of reporting and preliminary water quality objectives (WQO), based on available guidelines.

The proposed development site is in the Wet Tropics Water region. The Department of Environment and Heritage Protection is working with stakeholders to identify environmental values and water quality objectives for fresh waters, estuarine and coastal waters of this region. The proposed development site is within the Barron Trinity Inlet Water Quality Improvement Plan area. Draft WQO have been derived for this area (Barron & Haynes 2009), based on the Queensland Water Quality Guidelines for the wet tropics region (DERM 2009).

Preliminary WQOs used in this report are based on the:

- *Water Quality Improvement Plan for the Catchments of the Barron River and Trinity Inlet* (Barron & Haynes 2009)
- *Queensland Water Quality Guidelines* (DERM 2009) – wet tropics region, and
- *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC & ARMCANZ 2000a).

The WQOs used in the Water Quality Improvement Plan for the Catchments of the Barron River and Trinity Inlet are based on a combination of the QWQG and ANZECC & ARMCANZ WQOs. There are also Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009b). However, the Commonwealth and state governments have agreed that the Queensland Guidelines will be adopted for all waters inshore of and within the Enclosed Coastal Zone (i.e. all water analysed in this study), with the exception of pesticides in waters of the Great Barrier Reef Marine Park. There are no guidelines for pesticides in the QWQG so the Great Barrier Reef Marine Park guidelines are used for pesticides in these waters (DERM 2009).

The QWQG values are for annual medians (DERM 2009), and consequently the comparison of data from only one sampling event should be used with caution.

Any laboratory results less than the laboratory limits of reporting were entered as half the laboratory limit of reporting for graphical and analytical purposes, which is recommended in the *Australian Guidelines for Water Quality Monitoring and Reporting* (ANZECC & ARMCANZ 2000b).

Sediment Quality

Sample Collection

Sediment samples were collected for laboratory analysis. Sediment was collected from the top 0.3 m of sediment using a stainless steel trowel, and transferred directly into the sample containers provided by the analytical laboratory. Sediment samples were collected from the wet channel bed and where possible from accreting banks, at seven sites (Table 3.1).

All sampling was in accordance with the *Monitoring and Sampling Manual 2009* (DERM 2010a).

Sediment samples were analysed by Symbio Alliance (a NATA-accredited laboratory) for:

- moisture content
- particle grain size

and for the concentration of:

- total organic carbon
- nutrients (total nitrogen and total phosphorous)
- total metals and metalloids
  - antimony
  - aluminium
  - arsenic
  - cadmium
  - chromium
  - cobalt

  - copper
  - iron
  - lead
  - manganese
  - mercury
  - nickel
  - selenium
  - silver
  - vanadium, and
  - zinc.
- total petroleum hydrocarbons
- benzene, toluene, ethyl benzene and xylene
- PCB
- PAH
- organochloride and organophosphorous pesticides
- herbicides
  - metribuzin
  - pendimethalin
  - diuron
  - ametryn
  - atrazine
  - deisoproply atrazine
  - desethyl atrazine
  - bromacil
  - hexainone
  - prometryn
  - simazine
  - methoxychlor
  - tebuthiuron

  - imidacloprid
  - deildrin
  - diquat
  - paraquat
  - amitrole
  - 2,4 D
  - MCPA
  - dicamba
  - fluroxypyr
  - picloram
  - triclopyr
- Pesticides
  - bifenthrin
  - permethrin
- organotins, and
- volatile chlorinated hydrocarbons.

Data Analysis

Data was compared to the:

- laboratory limits of reporting, and
- ANZECC & ARMCANZ (2000b) trigger values for sediment (Interim Sediment Quality Guideline (ISQG) low and high trigger values).

Any results less than the laboratory limits of reporting were entered as half the laboratory limit of reporting for graphical and analytical purposes, as recommended by the *Australian Guidelines for Water Quality Monitoring and Reporting* (ANZECC & ARMCANZ 2000b).

Aquatic Plants

Aquatic plants growing in the waterways were visually assessed at each site. Aquatic plants were identified in situ, with samples retained for confirmation in the frc environmental laboratory. The mouths of each creek were also surveyed for seagrass.

The distribution of freshwater wetlands, mangroves and saltmarsh communities, are addressed in a separate report (Biotropica Australia 2013).

Estuarine Benthic Invertebrates

A suite of factors, including nutrient loads, sediment grain size and turbidity, influence the structure of benthic invertebrate communities. Differences 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.

Polychaetes occur in almost all benthic marine and estuarine sediments and are often the dominant component of the macrobenthos in terms of number of species and individuals (Hutchings 1998). Polychaetes play a major role in the functioning of benthic communities in terms of recycling and reworking of benthic sediments, bioturbating sediments and in the burial of organic matter. They are also important component of the food web, with birds, fish, crustaceans and gastropods feeding on them (Hutchings 1998).

Polychaetes of the family Capitellidae are often present in high numbers in organic rich sediments or highly modified systems (Hutchings 1998; Dafforn et al. 2013). A high, abundance of Capitellid polychaetes can indicate organic enrichment of sediments (ANZECC & ARMCANZ 2000b). This can be due to natural causes, such as settlement of wrack (i.e. stranded mats of dead plant material) (Rossi & Underwood 2002), or by the input of nutrients from anthropogenic sources such as wastewater treatment plants (Del-Pilar-Ruso et al. 2010) or aquaculture facilities (Martinez-Garcia et al. 2013). Polychaetes have been recognised as useful indicators of environmental quality and are recommended for this purpose, especially to nutrient enriched environments (ANZECC & ARMCANZ 2000b).

Sample Collection

Benthic invertebrates were sampled from the accreting shallow subtidal sediments of estuarine waters. Eight cores were collected from the benthos at six estuarine sites

(Table 3.1) using a 2 L stainless steel Eyre's corer. All samples were collected at approximately 0.5 m below lowest astronomical tide. Sediment composition was similar at each site, comprising sand and silt and / or clay. Cores were sieved in the field through a 1 mm sieve and the benthic fauna, sediment and detritus retained on the sieve were preserved in methylated spirits, and sent to the frc environmental biological laboratory for identification.

Laboratory Analysis

Six samples from each site were stained with Rose Bengal and invertebrates were picked, counted and identified to family level. The taxonomic richness and total abundance of each taxon was recorded for each sample. The two remaining samples are held in storage, in the event further analysis is required (e.g. if there was high variation between samples).

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 six samples from each site) and mean abundance of abundant taxa (i.e. the average number of individuals from each abundant taxa in the six samples from each site) was calculated. Mean abundances were converted to individuals per square metre.

Freshwater Macroinvertebrates

Macroinvertebrate communities are an important part of freshwater aquatic ecosystems and are key components of many aquatic food webs. They also directly influence many aquatic ecological processes such as primary production, sedimentation and the processing of organic matters (e.g. shrimps and crabs).

The composition of macroinvertebrate communities in an aquatic ecosystem varies according to the physical, biological and chemical attributes of the waterbody. The spatial and temporal distribution of macroinvertebrate communities within an aquatic ecosystem is dependent on a variety of factors, such as: the hydrological conditions of the waterway (flow, depth); the composition and structural complexity of the habitat (presence of pools and riffles, snags and water plants, substrate composition); and the chemical and physical components of the water.

Freshwater macroinvertebrates are a key component of aquatic ecological communities, and respond to short-term and long-term changes in the environment.

AUSRIVAS Samples

One sample from the bed habitat and one sample from the edge habitat were collected at each site, where these habitats were present. This sampling followed 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 bed or edge habitat was disturbed, and a sample collected by sweeping the net through the disturbed area.

Sample Processing

All samples were preserved in methylated spirits and returned to the frc environmental 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

Taxonomic richness, abundance, PET richness and SIGNAL 2 scores were calculated for each sample. These indices were used to indicate the current ecological health of surveyed waterways. There are no biological WQO for the Wet Tropics region in the QWQG (DERM 2009).

Taxonomic richness is the number of taxa (in this assessment, families). Taxonomic richness is a basic, unambiguous and effective diversity measure. However, it is 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. Taxonomic richness does not take into account the relative abundance of each taxon, so rare and common taxa are considered equally.

Abundance is the total number of macroinvertebrates sampled.

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 (Stream Invertebrate Grade Number — Average Level [version 2]) scores are also based on the sensitivity of each macroinvertebrate family to pollution or habitat degradation. The SIGNAL system has continually developed for over 10 years, with the current version known as SIGNAL 2. Each macroinvertebrate family has been assigned a grade number between one 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 or 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 taxon, and
- divided by the total of the weight factors for each taxon.

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 3.1). Quadrants were determined using the 20th percentile ranges for taxonomic richness and SIGNAL 2 and compared to the suggested interim quadrant boundaries in edge habitat (Chessman 2001). There are no guidelines for bed habitat.

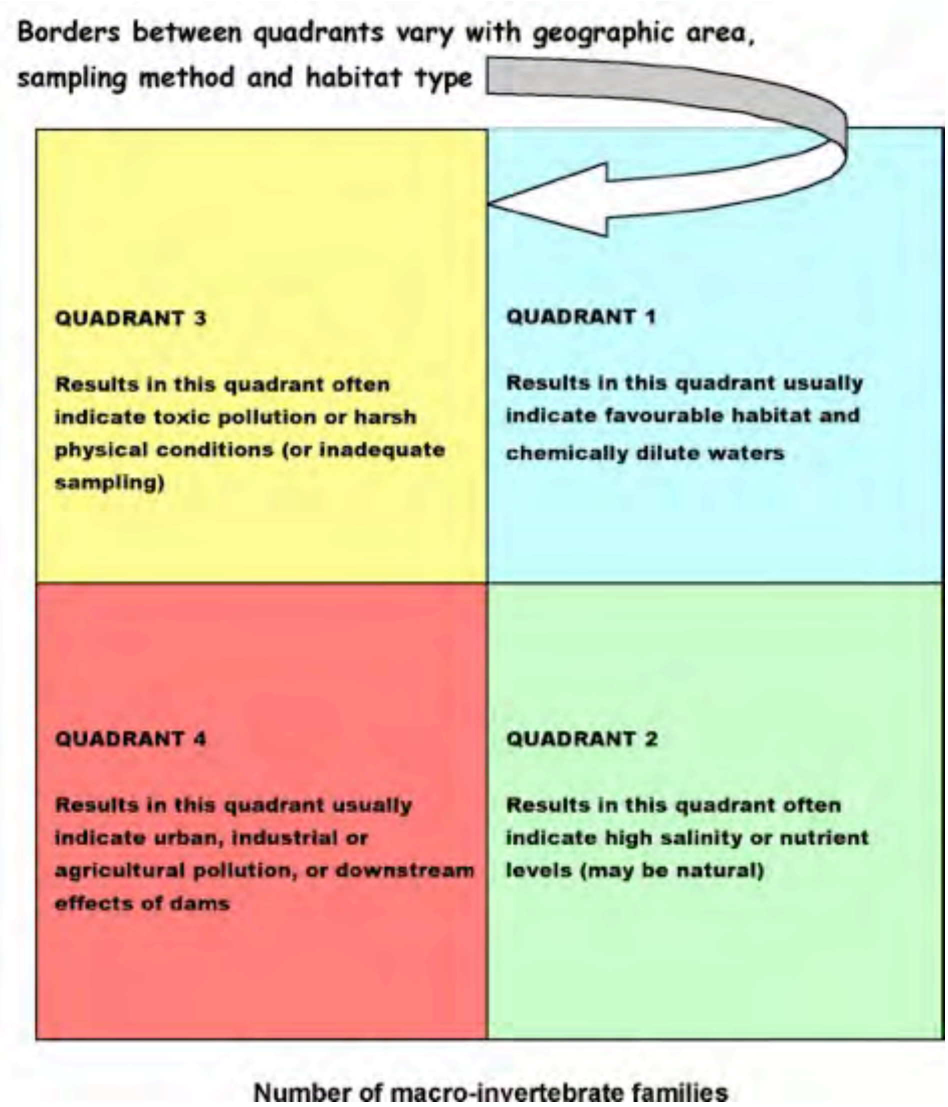


Figure 3.1 Quadrant diagram for SIGNAL 2 / Family Bi-plot.

4 Literature Review

4.1 Aquatic Habitat

Habitats along the lower Barron River Catchment (tributaries and waterways downstream of the Barron Gorge to the mouth of the Barron River) have been impacted by extensive urban development and sugar cane plantations. Mangroves dominate the riparian zones of rivers and creeks, while there are coastal dunes and beach systems at the mouths of each waterway (Connolly et al. 1996). Beyond the mangrove lined creeks, most of the remaining riparian zone is cleared of remnant vegetation for sugar cane and other agriculture, leaving little available habitat for aquatic organisms. In other reaches of the Barron River Catchment, riparian zones are either vine forests or eucalypt and paperbark woodlands with a large portion of the upper catchment in the protected Wet Tropics World Heritage Area (Connolly et al. 1996). Weeds are common along the waterways with rubber vine (*Cryptostegia grandiflora*) choking the riparian flora throughout the catchment (Connolly et al. 1996).

Three species of aquatic plant declared under the Queensland's *Land Protection (Pest and Stock Route Management) Act 2002* (the Land Protection Act) are recorded in the region (EHP 2013a); however, they were not recorded in the field surveys nor by Biotropica Australia (2013), and are unlikely to occur on the proposed development site (Table 4.1).

Table 4.1 Queensland pest aquatic plants recorded within 5 km of the proposed development site and the likelihood of occurrence in the proposed development site and surrounding waters.

Family	Species	Common Name	Unlikely	Likely but not observed	Observed
Cabombaceae	*Cabomba caroliniana*	cabomba	X	–	–
Poaceae	*Hymenachne amplexicaulis*	hymenachne	X	–	–
Salviniaceae	*Salvinia molesta*	salvinia	X	X	–

Most of the seabed habitats within and surrounding the Port of Cairns, including the habitats offshore of the proposed development site, are within a narrow strip of the Great Barrier Reef's High Nutrient Coastal Strip, which is characterised by muddy sediment and elevated nutrients (GBRMPA 2001). In 2007, frc environmental surveyed Half Moon Creek and did not find any seagrass in or adjacent to the creek mouth (frc environmental

2007). There are no other known records of seagrass in Half Moon, Yorkeys or Thomatis / Richters Creek, nor in the waters offshore of these creeks.. The closest recorded seagrass bed is at the mouth of Trinity Inlet, approximately 8 km south-east of the proposed development site (DAFF 2013). The seagrass beds in Trinity Inlet are a small portion of the total area of seagrass along the tropical Queensland coast and their limited distribution, and localised relative abundance, provides a disproportionately important nursery ground for prawns and other commercially and recreationally important species (Lee Long et al. 1993; Rasheed et al. 2013). However, in the past four years rainfall in the wet season has been above average, which, combined with the 2010/11 La Niña and tropical cyclone Yasi, have resulted in major decreases in the distribution and abundance of seagrass along the north-eastern coast of Queensland, including the seagrass beds in Trinity Inlet. Seagrass density in Trinity Inlet are currently the lowest since monitoring began in 2001 (Rasheed et al. 2013). Thirteen seagrass species are recorded from the region, with seagrass meadows around Cairns Harbour usually dominated by *Zostera meulleri* subsp. *capricorni* (Seagrass Watch 2013). Seagrass meadows typically have a greater distribution and are denser in the dry season (October to November) when light and temperature conditions are most favourable.

4.2 Water Quality

Regional Overview

The water quality of the region is highly impacted by anthropogenic sources including agriculture, stormwater run-off from urban areas and discharges from wastewater treatment plants. There is also a prawn farm upstream of the proposed development site that discharges into Thomatis / Richters Creek.

Nutrients (e.g. nitrogen and phosphorous) in waterways of the Wet Tropics region of the Barron River Catchment are easily transported downstream in periods of high flow (Brodie et al. 2003). Due to increased grazing pressures and associated soil erosion, the Barron River Catchment has been impacted by increased nutrients, including dissolved nutrients that are more bioavailable to aquatic organisms (Mitchell et al. 2008). Nonetheless, the median concentrations of total nitrogen and total phosphorous were below the draft ANZECC & ARMCANZ trigger values at sites in the lower subcatchments (i.e. downstream of Lake Tinaroo) (Cogle et al. 2000). The median concentration of ammonia in Thomatis / Richters Creek (bordering the southern end of the proposed development site) was high when compared to other subcatchments in the Barron River Catchment (Cogle et al. 2000), but complied with the QWQG value.

There are no Department of Environment and Heritage Protection gauging stations within or downstream of the proposed development site (DERM 2012). Electrical conductivity and turbidity data, was obtained from gauging station 110001D (Barron River at Myola). The median electrical conductivity was 109 µS/cm. The median for turbidity was 294 NTU and was above the QWQG value for lowland streams in the wet tropics (15 NTU).

Between 2000 and 2006, the Holloways Beach Environmental Education Centre (HBEEC) collected monthly water quality data from one site on the Barron River (Site 10; Map 130702HBSM). Data was collected in the morning and evening at the water surface and at 1 m depth (Holloways 2000). The following were recorded:

- concentration of dissolved oxygen
- pH
- salinity, and
- temperature.

The median concentration of dissolved oxygen was low and did not comply with the QWQG values, while the median pH complied with the QWQG values (Table 4.2).

In 2006, GHD surveyed surface water quality in the Mulgrave River, approximately 30 km south of the Barron River, and found that pH and turbidity, were always within or below QWQG values (GHD 2007). The concentration of dissolved oxygen was low and did not comply with the QWQG values at all sites in the lower reaches of the river; however, concentrations in upper reaches complied with the QWQG values. Although the Mulgrave River is in a different catchment to the proposed development site, the aquatic ecosystem is subject to similar climatic and anthropogenic influences.

frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resot Technical Study: Aquatic Ecology

Map 130702HBSM:
Holloways Beach Environmental Education Centre
monitoring sites

SOURCES

© Copyright Commonwealth of Australia (Geoscience Australia) 2001, 2004
Sourced from http://www.ga.gov.au/meta/ANZCW0703005241.html#distinfo. Australian boundary, roads, locations
© The State of Queensland (Department of Natural Resources and Mines) 2013
Updated data available at http://dds.information.qld.gov.au/dds/. Coastline, Waterways

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_Holloways_beach_13-08-29_CF.mxd

LEGEND

Monitoring Site
Watercourse

N

SCALE

0 0.5 1
Kilometres

Scale: 1:20,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL

VERSION
02

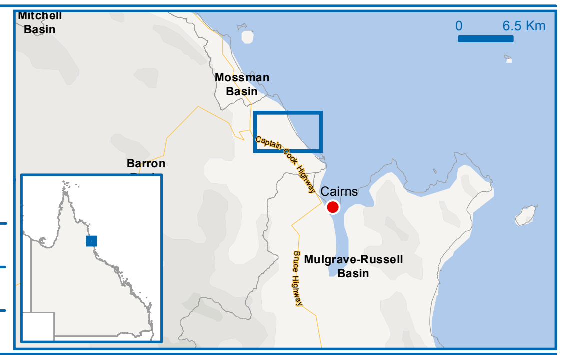


Table 4.2 Summary of water quality data collected by the HBEEC between 2000 and 2006.

Parameter	Prelim. WQO [a]	Count	Min.	Max.	Median	20th Percentile	80th Percentile
Richters Creek site 1 (near the mouth)							
dissolved oxygen (mg/L)	6.5–8.5 [b]	40	4.8	8.2	6.5	5.1	6.4
pH	6.5–8.4	40	7.5	8.21	7.9	7.71	8.08
salinity (ppt)	–	40	11.3	37.1	8	21	31.4
Richters Creek site 4							
dissolved oxygen (mg/L)	6.5–8.5 [b]	40	3.7	8.4	4.4	4.7	6.1
pH	6.5–8.4	40	7.2	8.10	7.7	7.5	8.0
salinity (ppt)	–	40	8.1	39.8	23.2	18.5	28.0
Thomatis Creek site 7							
dissolved oxygen (mg/L)	6.5–8.5 [b]	40	2.9	7.2	5.26	4.4	6.0
pH	6.5–8.4	40	7.34	8.01	7.68	7.66	7.9
salinity (ppt)	–	40	8.1	31.7	20	15.4	25.9
Barron River site 10 (at the confluence with Thomatis Creek)							
dissolved oxygen (mg/L)	6.5–8.5 [b]	40	2	6.5	5	4.5	5.7
pH	6.5–8.4	40	7.1	7.8	7.5	7.4	7.7
salinity (ppt)	–	40	6.5	21.2	14.4	10.8	17.7

Shading denotes values that do not comply with WQOs

[a] QWQG WQO for mid-estuarine and tidal canals in the Wet Tropics Region

[b] based on precent saturation of dissolved oxygen converted to mg/L at 25 °C

Half Moon Creek

The Marlin Coast Wastewater Treatment Plant discharges treated wastewater to the upstream reaches of Half Moon Creek. The plant has recently been upgraded to reduce the nutrient loading to the marine environment, and increase opportunities for the use of recycled water, such as toilet flushing and irrigation. The upgrade will result in reducing both the volume and the nutrient concentration of water discharged to Half Moon Creek (CRC 2013).

Cairns Regional Council (CRC) has monitored water quality at eight sites in Avondale and Half Moon Creeks from 2005 and has nutrient data at these sites from 1999 (Lloyd et al. 2011). Water quality is monitored each month, except for interruptions due to factors such as construction and upgrading of facilities. Typically, pH has been within WQO ranges and was similar between sites, except in 2007 when it was slightly acidic at six sites. The concentration of dissolved oxygen was typically low at upstream sites and in 2007 was low at seven of the eight sites (Lloyd et al. 2011).

The concentrations of total nitrogen and total phosphorus have varied between sites and surveys, typically with high concentrations at the upstream sites (Lloyd et al. 2011). Concentrations of total nitrogen and total phosphorus are often above 2 mg/L, but have been below 2 mg/L since 2009. Since 1999, the concentration of ammonia has typically been low (<0.5 mg/L) at each site, except between 2005 and 2009. The concentration of faecal coliforms has varied between sites and surveys with peaks of up to 10 000 cfu/100mL. However, since 2010 the concentration of faecal coliforms at most sites has been below 1000 cfu/100mL.

Yorkeys Creek

No historical water quality data could be sourced for Yorkeys Creek.

Thomatis / Richters Creek

HBEEC also collected monthly water quality data from three sites on Thomatis / Richters Creek between 2000 and 2006 (sites 1, 4 and 7; map 130702HBSM). Data was collected in the morning and evening at the water surface and at 1 m depth (Holloways 2000). The following data was recorded:

- concentration of dissolved oxygen
- pH

- salinity, and
- temperature.

The median concentration of dissolved oxygen complied with QWQG values near the mouth of the creek, but did not comply at the other sites (Table 4.2). The pH at each site was always within the QWQG values.

The water quality of Richters Creek was monitored in 1990 and 1991 by BMT WBM and the data is summarised in the report *AQUIS Resort at Great Barrier Reef Water Quality Assessments Report* (BMT WBM 2013). Data collected between 1983 and 1988 by the former Department of Environment and Heritage is also summarised in this report. In summary:

- turbidity is highest near the mouth of the creek, and is also high near the confluence with the Barron River
- during dry weather, Richters Creek behaves as a ‘double ended’ estuary
- during wet weather, the creek turns fresh except at the mouth, where it mixes with seawater
- the median concentrations of nutrients in both dry and wet weather are generally not compliant with the QWQG values, with the exception of nitrogen, oxidised nitrogen and phosphorous near the mouth of the creek in dry weather
- concentrations of dissolved oxygen in the lower reaches of Richters creek are compliant with QWQG values
- concentrations of dissolved oxygen are typically highest in the dry season and lowest in the wet season, and
- pH generally complies with QWQG values; however, during a dry weather period pH did not comply with, and was below, QWQG values (BMT WBM 2013).

Offshore

Over the long-term, water quality offshore of Yorkeys Knob has been above guideline values for the concentrations of chlorophyll *a*, particulate phosphorous and suspended solids (Schaffelke et al. 2011). Turbidity, measured using a secchi disc, is also high, due to the proximity to the Barron River and local creeks discharging into the off-shore waters (Schaffelke et al. 2011).

The concentrations of many metals and metalloids in water from the Barron River Catchment and Trinity Inlet were above ANZECC & ARMCANZ (2000b) guidelines, including aluminium, arsenic, copper, iron and nickel (Mitchell et al. 2008). In particular, aluminium, has been recorded at high concentrations in Freshwater Creek and in Trinity Inlet, south of the proposed development site. High concentrations of aluminium and iron are most likely related to the acid sulfate soils in the area, with acid releases mobilising these metals (Hicks et al. 1999).

4.3 Sediment Quality

There are extensive areas of acid sulfate soils (ASS) in the lower Barron River Catchment, particularly around Yorkeys Knob and Trinity Inlet (Mitchell et al. 2008; Barron & Haynes 2009). The high acidity and high concentrations of metal contaminants are a major threat to aquatic ecological communities. The formation of ASS is greatest in low-lying mangrove areas with low energy environments and high tidal exchange (Manders 2010), typical of creeks such as Half Moon, Thomatis / Richters and Yorkeys Creeks.

The land within the proposed development site has historically been used for sugar cane production. Chemicals known to have been used in the area include fertilisers, fungicides, herbicides and insecticides, M. Savina pers. comm.) (Table 4.3). At high concentrations these chemicals can impact aquatic flora and fauna. A survey of potential contaminants in the area in 1995 found that residual concentrations of organophosphate pesticides and metals and metalloids were unlikely to result in an adverse affects on crustaceans and fish (Fisheries Research Consultants 1995).

Table 4.3 Chemicals previously used on and in the vicinity of the proposed development site.

Product Name	Chemical Constituents
Fertilisers	
CB44678	nitrogen/potassium/phosphorous/sulfur
CB83350	nitrogen/potassium/phosphorous/sulfur
66S	nitrogen/potassium/phosphorous/sulfur
murate potash	potassium chloride
Nitra King	nitrogen, phosphate, potash, iron, calcium and sulfur
Urea	nitrogen

Product Name	Chemical Constituents
Herbicides	
Agroxone	MCPA (a phenoxy herbicide)
Barrage	diuron and hexazinone
Glyphosate 360	glyphosate
Round up	glyphosate
Shirquat	paraquat
Shirweed 500	2,4–dichloro–phenoxy–acetic acid
Strane	2,4–dichloro–phenoxy–acetic acid
StompXtra	pendimethalin
Soccer	metribuzin
Tordon 75D	picloram
Insecticides	
Suscon Blue	chloropyrifos
Telstar	bifenthrin
Fungicides	
Shirtan 120	methoxy ethyl mercury chloride
Throtel	hydrocabons

Pesticides can pose a high risk to the aquatic environment, with concentrations exceeding water quality guidelines in may fresh and estuarine waterbodies downstream of cropping lands (Brodie et al. 2013). The toxicity and bioaccumulation of all of pesticides listed in Table 4.3 can affect aquatic organisms depending on their use and applications (Bellas et al. 2005; Botelho et al. 2012; Danion et al. 2012).

MCPA is a herbicide that acts as a synthetic hormone, and is toxic to aquatic organisms. While it is insoluble in water, it has a degradation half life of over 30 days. In soil exposed to sunlight it photo-degrades relatively slowly, with a half life of 67 days. It is recommended it is not used close to waterways, with buffer zones of 5 to 30 m recommended for ground application and from 5 to 600 m for aerial application, depending on the formulation (APVMA 2010).

Diuron is a herbicide that inhibits photosynthesis. In the aquatic environment it has a relatively long half-life. The risk to aquatic organisms via run off is the main concern with the use of diuron, and buffer zones to waterways of 25 m are recommended when used in sugarcane (APVMA 2012). Diuron is reported to have negative impacts on coral, microalgae and seagrass (Brodie et al. 2013). It appears to be primarily removed by chemical and biological degradation (van Dam et al. 2012; cited in Brodie et al. 2013).

Hexazinone is very poorly adsorbed to soil particles, and very soluble in water. Soil half-lives of 30 to 180 days have been reported. Hexazinone is slightly toxic to fish and other freshwater organisms.

Glyphosate is a broad-spectrum herbicide, with a low toxicity to fish and aquatic invertebrates. Glyphosate adsorbs strongly to soil and is readily degraded by soil microbes. Neither glyphosate or its breakdown product are likely to move to groundwater as they both strongly adsorb to soil particles (USAEPA 1993).

Paraquat is strongly adsorbed to soils and sediments and in biologically unavailable in that form. In surface soils it its loss through photodecomposition is about 50% in 3 weeks. In freshwater ecosystems, loss from the water column is rapid, about 50% in 36 hours, and 100% in 4 weeks. In marine ecosystems 50-70% of paraquat is lost within 24 hours. It is not soluble in fat, and is not bio-concentrated in aquatic fauna. Typical soils contain paraquat at about 300 mg/kg after treatment at recommended applications (Eisler 1990).

The toxicity of the herbicide 2,4–dichloro–phenoxy–acetic acid is dependent on the formulation used; however, it is poorly taken up and rarely retained by aquatic fauna and has a low accumulation factor in fish (Sigmon 1979).

Pendimethalin is highly toxic to fish and aquatic invertebrates. It is moderately persistent in soil, with a half-life of approximately 40 days. It is almost insoluble in water, and presents a minimal risk to groundwater contamination. In water it is degraded by sunlight, and rapidly degraded under aerobic conditions once precipitated to the sediment (Extoxnet 1993).

The herbicide, metribuzin, is moderately toxic to aquatic invertebrates and vertebrates (CCME 1999); however, concentrations typically measured in the environment are lower than acute toxicity values reported for fish, but can have adverse effects with increased exposure (Štěpánováa et al. 2012).

Picloram is moderately toxic to fish and slightly toxic to aquatic invertebrates. It is extremely persistent in soil, and has a high potential to leach to groundwater with a high water solubility and high mobility through soil (NCAMP 1988).

Chlorpyrifos is a chlorinated organophosphate, and is toxic to aquatic invertebrates and fish (Harford et al. 2005). Organophosphates are a synthetic insecticide (derived from phosphoric acid) that act on the nervous system of both vertebrates and invertebrates. Chlorpyrifos is effective by contact, ingestion and vapour action (Blair 1979). At concentrations used to control insect pests chlorpyrifos is likely to be toxic to a range of crustacea, including prawns (Fisheries Research Consultants 1995).

The application of chlorpyrifos may also lead to increased phytoplankton growth rates, resulting from a combination of increased nutrient availability (phosphorous) and decreased grazing pressured (due to related mortality in herbivorous zooplankton) (Birmingham & Colman 1977). Chlorpyrifos' slow solubility suggests a moderate potential for bioaccumulation (Schimmel et al. 1983; Metcalf et al. 1975; cited in Murty 1986).

Bifenthrin is a pyrethroid insecticide that It is highly toxic to aquatic invertebrates and fish, however it is poorly soluble in water, and often remains in soil (Johnson et al. 2010).

The fungicide methoxy ethyl mercury chloride is typically inorganic, but may be converted in situ to an organic form (e.g. methyl mercury) that may be readily bioaccumulated in aquatic fauna.

The sediment was tested for the presence of herbicides, insecticides and fungicides in Table 4.3 in the current survey. All were below detectable limits, with the exception of paraquat in one of the cane drains on site (Section 7.4).

4.4 Macroinvertebrates

Macroinvertebrates in the Sediment

Studies of benthic infauna in the Cairns region indicate there is a ubiquitous benthic invertebrate community (Neil et al. 2003; Environment North 2005; Worley Parsons 2010). Filter-feeding organisms such as polychaetes, molluscs and crustaceans are typically dominant, comprising over 90 percent of the species abundance (Neil et al. 2003).

Macroinvertebrates were monitored in Avondale Creek and Moon River between 2001 and 2009. Taxonomic richness ranged from one to 16 taxa, with a general increase in taxonomic richness between each survey (ALS 2011a). The abundance of macroinvertebrates varied from 2 to 1 084 individuals per m^2.

Macroinvertebrates in Mangrove Habitats

The mangrove lined sections of Half Moon, Yorkeys and Thomatis / Richters Creeks provide habitat for an abundant and diverse invertebrate assemblage. Many species found here are only found in association with estuarine mangroves. Crustaceans are typically one of the most prominent faunal groups in mangrove vegetation and are found in logs and burrows (Trenerry 1991). Macroinvertebrates likely to occur in the estuaries adjacent to the proposed development site include those listed in (Table 4.4).

Table 4.4 Macroinvertebrates in mangrove habitats of the Wet Tropics and their relative abundance in the region.

Family / Scientific Name	Common Name	Relative Abundance
Alpheidae		
Alpheus sp.	–	+
Atyidae	shrimps	++++
Calappidae		
Calappa hepatica	common box crab	+++
Callianassidae		
Callianassa australiensis	yabby	+++
Camptandriidae		
Paracleistostoma wardi	Ward’s hairy-legged crab	+++
Cerithidae		
Bittium laceteum	–	+
Clypeomorus coralium	–	+
Corbiculidae		
Polymesoda coaxans	mud mussel	++
Diogenidae		
Clibanarius spp.	hermit crab	++
Diogenus spp.	hermit crab	++++
Paguristes spp.	hermit crab	++++
Dotillidae		
Scopimera inflata	sand bubbler	++++
Ellobidae		
Cassidula anguilifera	angulate shoulder ear shell	+++
Cassidula nucleus	–	++
Cassidula rugata	rugose cassidula	+
Ellobium aurisjudae	Judas’ ear shell	++++
Melampus striatus	–	+++
Ophicardelus quoyi	–	+++
Ophicardelus sulcatus	–	++++

Family / Scientific Name	Common Name	Relative Abundance
Pythia scarabaeus	common pythia	+
Gecarcinidae		
Cardisoma carnifex	giant shore crab	++
Grapsidae		
Australoplax tridentata	furry-clawed crab	++
Grapsus tenuicrustatus	tropical rock crab	+++
Helice leachii	purple and cream mud crab	++
Metapograpsus frontalis	broad-fronted mangrove crab	++
Metagrapsus latifrons	purple broad-fronted crab	++
Neosarmatium trispinosum	scarlet mangrove crab	+
Parasesarma erythrodactyla	red-fingered marsh crab	++
Perisesarma messa	maroon mangrove crab	+++
Litorinidae		
Littorina littorea	periwinkle	+++
Macrophthalmidae		
Australoplax tridentata	furry-clawed crab	++
Macrophthalmus setosus	Australian sentinel crab	+++
Matutidae		
Ashtoret granulosa	red-banded sand crab	++
Menippidae		
Myomenippe fornasini	slow-moving shore crab	+++
Mictyridae		
Mictyris livingstonei	–	+++
Mictyris longicarpus	soldier crab	+
Nassaridae		
Nassarius olivaceus	olivaceous nassa	+
Neritadae		
Nerita articulata	lined nerite	++++
Nerita chameleon	chameleon nerite	++
Nerita planospira	flat-spired nerite	++++

Family / Scientific Name	Common Name	Relative Abundance
Nerita violacea	violet nerite	+++
Clithon oualaniensis	Guamanian nerite	+
Ocypodidae		
Australoplax tridentata	furry-clawed crab	+++
Cleistostoma wardi	Ward's hairy-legged crab	+++
Macrophthalmus crinitis	–	++
Macrophthalmus crassipes	orange-spined sentinel crab	++
Macrophthalmus latreillei	giant sentinel crab	+
Ocypode ceratophthalma	horn-eyed ghost crab	++
Uca capricornis	Capricorn fiddler crab	+
Uca coarctata	orange-clawed fiddler crab	++++
Uca dussumieri	sunburst fiddler crab	++
Uca perplexa	yellow-clawed fiddler crab	+
Uca polita	pink-clawed fiddler crab	+++
Uca signata	distinctive fiddler crab	++
Uca seismella	–	+++
Uca vomeris	two-toned fiddler crab	+
Ostreidae		
Saccostrea / Striostrea spp.[1]	oyster	+++
Oziidae		
Epixanthus dentatus	long-fingered shore crab	++
Palaemonidae		
Macrobrachium sp.	–	+++
Penaeidae		
Penaeus esculentus	tiger prawns	++++
Penaeus merguiensis	banana prawns	++++

[1] The taxonomy of oysters is being reviewed. It is likely the species recorded were *Saccostrea cucullata* (milky oyster) and *Striostrea mytiloides* (blacklip oyster) (QLD Government 2013, Klingbunga et al 2005, Lam & Morton 2005, Liu et al 2011).

Family / Scientific Name	Common Name	Relative Abundance
Penaeus monodon	giant tiger / leader prawns	++++
Penaeus semisulcatus	green tiger prawns	++++
Phallomedusidae		
Phallomedusa solida	solid amphibian snail	+++
Porcellanidae		
Pachycheles sp.	–	+++
Petrolisthes haplodactylus	rounded porcelain crab	++
Portunidae		
Portunus pelagicus	sand crab	++++
Scylla serrata	mud crab	+++
Thalamita integra	swimmer crab	+++
Thalamita sima	four-lobed swimming crab	+++
Potamididae		
Cerithidea anticipata	–	++
Cerithidea cingulata	girdled horn shell	+++
Cerithidea largillierti	–	++
Pyrazus ebeninus	mud whelk	++
Telescopium telescopium	telescope mud creeper	+++
Terebralia sulcata	sulcate mud creeper	++
Terebralia palustris	–	+++
Terebralia sulcatus	sulcate swamp cerith	+++
Velacumantus australis	Australian mud whelk	+
Sesarmidae		
Bresedium brevipes	banded mangrove crab	+++
Clistocoeloma merguiense	cadaver crab	+++
Sarmatium crassum	–	++
Sarmatium germaini	mound crab	+
Perisesarma brevicristatum	–	++++
Sesarma brocki	–	++
Sesarma fourmanoiri	–	+++

Family / Scientific Name	Common Name	Relative Abundance
Sesarma kraussi borneensis	–	+++
Sesarma leptosoma	*tree-climbing crab*	+
Sesarma messa	–	+++
Sesarma moluccensis	–	+
Sesarma semperi	–	++
Sesarma smithi	–	+++
Thalassinidae		
Thalassina anomola	mud lobster	+
Thalassina squamifera	mangrove lobster	+++
Xanthidae		
Epixanthus dentatus	longfingered peeler crab	+++
Heteropanope glabra	–	+

Source: (Trenerry 1991; Queensland Museum 2000a; frc environmental 2006).

+ rarely sighted
++ uncommonly sighted
+++ commonly sighted
++++ very commonly sighted

4.5 Fish and Fisheries

Estuarine and Marine Fin Fish

The creeks surrounding the proposed development site are likely to provide valuable habitat for a range of estuarine and marine fish species. In particular they are likely to be important nursery grounds for a range of commercially and recreationally important species, with an influx of juvenile fish in summer (Doherty & Sheaves 1994). A diverse assemblage of estuarine fish have been recorded from the Barron River Catchment (EHP 2013a), of which several species are commercially and / or recreationally important including:

- barramundi (*Lates calcarifer*)
- mullet (*Mugil cephalus*), and
- garfish (Hemiramphidae).

Marine and estuarine fish recorded within and downstream of mangrove-lined waterways in the Wet Tropics of Queensland are detailed in Table 4.5. These fish are likely to occur in the estuarine reaches of the creeks surrounding the proposed development site, and downstream. Some of these species are marine vagrants that are occasionally found in estuaries. Other estuarine species may also be found in these estuaries. Fish in the table that are most likely to be found in the estuaries surrounding the proposed development site are shaded.

Table 4.5 Estuarine and marine fish from mangrove lined waterways in the Wet Tropics region [a].

Family / Scientific Name	Common Name	Of noted commercial / recreational significance (excludes 'baitfish')
Ambassidae		
Ambassis gymnocephalus	bald glassy	
Ambassis interrupta	long-spined glass perchlet	
Ambassis nalua	scalloped perchlet	
Apogonidae		
Apogon ceramensis	humpback cardinal	
Apogon hyalosoma	mangrove cardinal fish	
Ariidae		
Arius graeffei	blue salmon catfish	x
Arius macrocephalus	long snouted catfish	x
Netuma thalassina	giant catfish	x
Atherinidae		
Atherinomorus lacunosus	wide-banded hardyhead	
Atherinomorus vaigiensis	Ogilby's hardyhead	
Pranesus eendrachtensis	Eendracht land silverside	
Bathysauridae		
Saurida undosquamis	brushtooth lizardfish	
Belonidae		
Tylosurus crocodilis	hound needlefish	
Tylosurus leiurus	banded needlefish	
Strongylura strongylura	spottail needlefish	

Family / Scientific Name	Common Name	Of noted commercial / recreational significance (excludes 'baitfish')
Bothidae		
Pseudorhombus arsius	largetooth flounder	x
Pseudorhombus jenynsii	smalltooth flounder	x
Carangidae		
Alectis indicus	Indian threadfish	x
Caranx ignobilis	giant trevally	x
Caranx melampygus	bluefin trevally	x
Caranx sexfasciatus	bigeye trevally	x
Scomberoides lysan	double spotted queenfish	x
Scombermorus semifasciatum	broad-barred king mackerel	x
Scomberoides tala	barred queenfish	x
Scomberoides tol	needlescaled queenfish	x
Ulua mentalis	longrackered trevally	x
Carcharhinidae		
Carcharhinus leucas	bull shark	
Carcharhinus amboinensis	pigeye shark	
Carcharhinus fitzroyensis	creek shark	
Galeocerdo cuvier	tiger shark	
Chanidae		
Chanos chanos	milkfish	x
Chirocentridae		
Chirocentrus dorab	dorab wolf-herring	x
Clupeidae		
Anodontostoma chacunda	chacunda gizzard shad	
Escualosa thoracata	white sardine	
Herklotsichthys castlenaui	Castelnau's herring	
Herklotsichthys quadrimaculatus	bluestripe herring	
Hyperlophus vittatus	sandy sprat	

Family / Scientific Name	Common Name	Of noted commercial / recreational significance (excludes 'baitfish')
Nematolosa come	bony bream	
Pellona ditchela	Indian pellona	
Cynoglossidae		
Cynoglossus bilineatus	fourlined tonguesole	
Dasyatidae		
Dasyatis fluviorum	estuary stingray	
Neotrygon kuhlii	blue spotted stingray	
Pastinachus sephen	cow tailed stingray	
Drepanidae		
Drepane punctata	spotted sicklefish	
Echeneidae		
Echeneis naucrates	live sharksucker	
Eleotridae		
Bunaka gyrinoides	greenback gauvina	
Butis butis	duckbill sleeper	x
Giuris margaritacea	snakehead gudgeon	
Elopidae		
Elops australis	Hawaiian ladyfish	
Engraulidae		
Stolephorus carpentariae	Gulf of Carpentaria anchovy	
Encrasicholina devisi	Devis' anchovy	
Thryssa hamiltoni	Hamilton's thryssa	
Thryssa setirostris	longjaw thryssa	
Gerridae		
Gerres abbreviatus	deep-bodied mojarra	
Gerres argyreus	common silver-biddy	
Gerres filamentosus	thread-finned silver-biddy	
Gerres longirostris	strongspine silver-biddy	

Family / Scientific Name	Common Name	Of noted commercial / recreational significance (excludes 'baitfish')
Gerres punctatus	whipfin silver-biddy	
Gerres subfasciatus	roach silver-biddy	
Gobiidae		
Ctenogobius sp.	–	
Drombus globiceps	Kanji drombus	
Favonigobius sp.	–	
Gobiopterus sp.	–	
Glossogobius circumspectus	circumspect goby	
Glossogobius giuris	tank goby	
Periopthalmodon schlosseri	giant mudskipper	
Periophthalmus argentilineatus	common mudskipper	
Periopthalmus barbarus	Atlantic mudskipper	
Parvigobius sp.	–	
Psammogobius biocellatus	sleep goby	
Stigmatogobius sp.	–	
Haemulidae		
Plectorhynchus gibbosus	Harry hotlips	x
Pomadasys argenteus	silver grunt	x
Pomadasys kaakan	javelin grunter	x
Pomadasys opercularis	smallspotted grunt	x
Hemiramphidae		
Arrhamphus sclerolepis	northern snubnose garfish	x
Hyporhampus affinis	tropical garfish	x
Hyporhamphus dussumieri	Dussumier's halfbeak	x
Hyporhamphus neglectissimus	black-tipped garfish	x
Hyporhamphus quoyi	Quoy's garfish	x
Rhynchorhampus georgii	long billed half beak	x
Zenarchopterus buffonis	Buffon's river garfish	x

Family / Scientific Name	Common Name	Of noted commercial / recreational significance (excludes 'baitfish')
Kuhliidae		
Kuhlia rupestris	rock flagtail	x
Latidae		
Lates calcarifer	barramundi	x
Leiognathidae		
Leiognathus berbis	Berber ponyfish	
Equulites novaehollandiae	whipfin ponyfish	
Gazza minuta	toothpony	
Leiognathus bindus	orangefin ponyfish	
Leiognathus decorus	decorated ponyfish	
Leiognathus equulus	common ponyfish	
Leiognathus splendens	splendid ponyfish	
Secutor insidiator	pugnose ponyfish	
Secutor ruconius	deep pugnose ponyfish	
Lethrinidae		
Lethrinus nebulosus	spangled emperor	x
Lutjanidae		
Lutjanus argentimaculatus	mangrove jack	x
Lutjanus fulviflamma	black-spot sea perch	x
Lutjanus johnii	golden snapper	
Lutjanus russelli	Russell's snapper	x
Megalopidae		
Megalops cyprinoides	Indo-Pacific tarpon	x
Menidae		
Mene maculata	moonfish	
Monodactylidae		
Monodactylus argenteus	silver moony	
Mugilidae		
Chelon subviridis	greenback mullet	x

Family / Scientific Name	Common Name	Of noted commercial / recreational significance (excludes 'baitfish')
Ellochelon vaigiensis	squaretail mullet	x
Moolgarda cunnesius	long arm mullet	x
Moolgarda seheli	blue spot mullet	x
Mugil cephalus	sea mullet	x
Myxus elongatus	sand mullet	x
Paramugil georgii	silver mullet	x
Valamugil buchanani	blue-tail mullet	x
Mullidae		
Upeneus vittatus	yellow striped goatfish	
Muraenidae		
Gymnothorax favagineus	laced moray	
Gynothorax polyuranidon	freshwater moray	
Orectolobidae		
Stegostoma fasciatum	zebra shark	
Platycephalidae		
Platycephalus fuscus	dusky flathead	x
Platycephalus indicus	bartail flathead	x
Polynemidae		
Eleutheronema tetradactylum	fourfinger threadfin	x
Polydactylus multiradiatus	Australian threadfin	x
Polydactylus sheridani	king threadfin	x
Rhinobatidae		
Rhinobatus batillum	giant shovelnose ray	
Scatophagidae		
Scatophagus argus	spotted scat	
Selenotoca multifasciata	striped scat	
Sciaenidae		
Nibea soldado	soldier croaker	
Otolithes argenteus	tigertooth croaker	

Family / Scientific Name	Common Name	Of noted commercial / recreational significance (excludes 'baitfish')
Siganidae		
Siganus guttatus	goldlined spinefoot	x
Siganus spinus	happy moment	
Sillaginidae		
Sillago maculata	trumpeter sillago / whiting	x
Sillago sihama	silver sillago / whiting	x
Soleidae		
Aesopia heterohinus	black-tip sole	x
Paradicula setifer	–	x
Sparidae		
Acanthopagrus berda	pikey bream	x
Sphyraenidae		
Sphyraena barracuda	great barracuda	x
Sphyraena jello	pickhandle barracuda	x
Sphyraena putnamae	sawtooth barracuda	x
Sphyrnidae		
Sphyrna lewini	hammerhead shark (juveniles)	
Syngnathidae		
Hippichthys spicifer	bellybarred pipefish	
Tetraodontidae		
Arothron hispidus	white-spotted puffer	
Arothron immaculatus	narrow–lined toadfish	
Chelonodon patoca	milk-spotted toadfish	
Sphaeroides hamiltoni	Hamilton's toado	
Torquigener pleurotictus	banded toado	
Marilyna pleurosticta	–	
Teraponidae		
Terapon puta	small-scaled terapon	

Family / Scientific Name	Common Name	Of noted commercial / recreational significance (excludes 'baitfish')
Terapon jarbua	Jarbua terapon	
Terapon theraps	largescaled terapon	
Trichiuridae		
Trichiurus lepturus	largehead hairtail	
Trichiurus savala	Savalai hairtail	
Toxotidae		
Toxotes chatareus	spotted archerfish	
Toxotes jaculatrix	banded archerfish	
Triacanthidae		
Triacanthus biaculeatus	short-nosed tripodfish	

Shaded entries indicate species that are more likely to be in estuaries, as either juveniles or adults.

[a] Sources: (Blaber 1980; Robertson & Duke 1990; frc environmental 2006; Russell et al. 2011) P. Aubin pers. comm. 2013, M. Trenerry pers. comm. 2013.

Crustaceans

Juveniles of many commercially important crustacean species are common estuaries in the region. Mud crabs, blue swimmer crabs, yabbies and various prawns are known to occur within and around the creeks surrounding the proposed development site (P. Aubin pers. comm. 2013) and are of fisheries value to the area. Species of commercial importance include:

- swimmer crabs (*Thalamita integra*)
- mud crabs (*Scylla serrata*)
- banana prawns (*Penaeus merguiensis*)
- tiger prawns (*Penaeus esculentus*) (Robertson 1988; Coles et al. 1993; Klumpp & Kwak 2005).

Molluscs

The sandy beaches downstream of the proposed development site are likely to contain large populations of small pipis (*Plebidonax* spp.) (P. Aubin pers. comm. 2013). Sydney rock oysters are likely to be found on hard intertidal substrates, but most other molluscs are of little commercial value (Trenerry 1991). Squid are also highly likely to occur in the region and be recreationally fished for bait.

Sharks and Rays

Several species of stingrays, including river stingrays (*Dasyatis fluviorum*), blue-spotted stingrays (*Neotrygon kuhlii*) and cowtail stingrays (*Pastinachus sephen*) occur in coastal rivers in the Wet Tropics (Herbert & Peeters 1995; Queensland Museum 2000b).

Bull sharks (*Carcharhinus leucas*) are also common in coastal streams and are known to migrate upstream in freshwater (Herbert & Peeters 1995). Other sharks common in tropical enclosed waters include pig eye shark (*Carcharhinus amboinensis*), creek shark (*Carcharhinus fitzroyensis),* tiger shark (*Galeocerdo cuvier*) and juveniles of the hammerhead (*Sphyrna lewini*). Other sharks may occur at the mouths of streams and rivers, but are only likely to enter freshwater areas for short periods of time (Herbert & Peeters 1995).

Commercial Estuarine and Marine Fisheries

The Cairns region is a very important commercial fishing ground, worth approximately $9-million in gross value of production (GVP) in 2005 (there is no specific grid data after 2005) (Table 4.6) (DAFF 2013). In recognition of their importance to fisheries, many waterways , including the Richters Creek, Yorkeys Creek and Half Moon Creek adjacent to the proposed development site are declared Fish Habitat Areas (Section 10.4).

Commercial fishing is undertaken using a variety of different methods, including trawling (otter and beam trawl), netting, pot and line fishing (DAFF 2013). Of these, the trawl fishery is the most productive, with 380 boats catching over $6 million worth of seafood in 2005 (Table 4.6).

Trawling is not permitted within Richters Creek, Yorkeys Creek or Half Moon Creek, but netting, line fishing (including trolling) and crabbing are permitted.

Table 4.6 Catch and fishing data for commercial fisheries in the Cairns offshore area in 2005.

Fishery [a]	Tonnes	Boats	Days	GVP (AUD)
line	25.6	52	393	204100
net	181.7	35	1060	882600
pot – crab	14.9	10	879	156400
trawl – beam	284.6	191	1875	3903900
trawl – otter	283.2	189	1867	3883200
total	790	447	6074	9030200

[a] data sourced from commercial catch grids G15, H15 and H16. Data was not available for fisheries fished by fewer than 5 boats (DAFF 2013)

The trawl fleet catches:

- threadfin bream (*Nemipteris* sp.)
- squid (family Loliginidae)
- octopus
- cuttlefish (family Sepiidae)
- bugs (*Thenus* sp.)
- bugs (*Ibacus* sp.)
- blue swimmer crabs (*Portunus pelagicus*)
- mud scallops (*Amusium* sp.)
- banana prawns (*Penaeus merguiensis*)
- eastern king prawns (*Penaeus plebejus*)
- tiger prawns (*Penaeus esculentus, P. semisulcatus and P. monodon*), and
- endeavour prawns (*Metapenaeus endeavouri* and *M. ensis*) (DAFF 2013).

Of these, endeavour and tiger prawns had the highest GVP in 2005 (DAFF 2013).

The net fishery targets:

- sharks
- threadfin (*Nemipteris* sp.)

- mullet (*Mugil* sp.)
- garfish (Hemiramphidae)
- grunter (Terapontidae)
- barramundi (*Lates calcarifer*)
- grey mackerel (*Scomberomorus semifasciatus*), and
- queenfish (*Scomberoides* sp.) (DAFF 2013).

Commercial boats setting crab pots target mud crabs (*Scylla serrata*) and blue swimmer crabs (*Portunus pelagicus*) (DAFF 2013).

The line fishery catches mixed coral reef and pelagic fish species including:

- coral trout (*Plectropomus* spp.)
- spangled emperor (*Lethrinus nebulosus*)
- cod (Serranidae)
- trevally (Carangidae)
- red emperor (*Lutjanus sebae*)
- Spanish mackerel (*Scomberomorus commerson*), and
- jobfish (Lutjanidae) (DAFF 2013).

Recreational Fisheries

Recreational fisheries target approximately 60 species of fish, molluscs and crustaceans in the Far North Queensland region (DAFF 2013). Recreational fishing has historically included, but is not limited to:

- squid
- crabs
- trevally
- whiting
- barramundi
- bream, and
- cod.

In Richters and Half Moon Creeks recreational fishers target a variety of marine and estuarine fish species including:

- barramundi
- mangrove jack
- threadfin
- flathead
- trevally, and
- whiting.

Thomatis / Richters Creek is recognised as an important area by local recreational fishers, who understand the importance of maintaining good water quality in the creek (P. Aubin pers. comm. 2013).

Crabs and prawns are also target by recreational fishers, including mud and blue swimmer crabs (P. Aubin pers. Comm. 2013).

Offshore, recreational fishers target a range of reef-associated species, many of which have an estuarine juvenile phase (e.g. tropical snappers (family Lutjanidae)).

Freshwater Fish

Freshwater fish of lowland areas of the Wet Tropics are listed in Table 4.7. Fish most likely to be found in the freshwater bodies on or near the proposed development site are highlighted.

Table 4.7 Freshwater fish of lowland areas of the Wet Tropics.

Family / Scientific Name	Common Name	Barron River	Trinity Inlet and Cairns Creeks
Ambassidae			
Ambassis agassizii	Agassiz's glassfish	X	–
Ambassis agrammus	sailfin glassfish	X	–
Ambassis gymnocephalus	bald glass perchlet	X	X
Ambassis interruptus	long-spined glassfish	X	–
Ambassis miops	flag-tailed glassfish	X	–
Ambassis vachellii	Vachelli's glassfish	X	–
Denariusa australis	pennyfish		
Anguillidae			
Anguilla obscura	pacific short-finned eel	X	–
Anguilla reinhardtiii	long-finned eel	X	–
Apogonidae			
Glossamia aprion	mouth almighty	X	–
Atherinidae			
Craterocephalus stercusmuscarum	fly-specked hardyhead	X	–
Cichlidae			
Astronotus ocellatus	oscar	X	–
Hemichromis bimaculatus	jewel cichlid	–	X
Oreochromis mossambicus	tilapia	X	X
Tilapia mariae	black mangrove cichlid	X	X
Clupeidae			
Nematalosa erebi	bony bream	X	–
Eleotridae			
Bunaka gyrinoides	greenback gauvina	X	–
Butis butis	crimson-tipped gudgeon	X	X
Eleotris fusca	brown gudgeon	X	–
Eleotris melanosoma	ebony gudgeon	X	–

Family / Scientific Name	Common Name	Barron River	Trinity Inlet and Cairns Creeks
Giurus margaritacea	snakehead gudgeon	X	–
Hypseleotris compressa	empire gudgeon	X	–
Hypseletoris spp.	common carp gudgeon	X	–
Mogunda adspersa	purple-spotted gudgeon	X	–
Ophiocara porocephala	spangled gudgeon	X	X
Oxyeleotris lineolatus	sleepy cod	X	–
Gobiidae			
Awaous acritosus	Roman nose goby	X	–
Chlamydogobius ranunculus	tadpole goby	X	X
Glossogobius bicirrhosis	bearded goby	X	–
Glossogobius circumspectus	circumspect goby	X	–
Glossogobius giuris	flathead goby	X	X
Glossogobius sp. 1	false celebes goby	X	–
Psammogobius biocellatus	mangrove goby	X	X
Redigobius bikolanus	specked goby	X	–
Schismatogobius sp.	scaleless goby	X	–
Sicyopterus lagocephalus	rabbithead cling-goby	X	–
Stenogobius psilosinionus	–	X	–
Hemiramphidae			
Arramphus sclerolepis	snub-nosed garfish	X	X
Kuhliidae			
Kuhlia rupestris	jungle perch	X	–
Latidae			
Lates calcarifer	barramundi	X	X
Megalopidae			
Megalops cyprinoides	tarpon	X	X

Family / Scientific Name	Common Name	Barron River	Trinity Inlet and Cairns Creeks
Melanotaeniidae			
Melanotaenia maccullochi[1]	McCulloch's rainbowfish	X	–
Melanotaenia splendida	eastern rainbowfish	X	X
Mugilidae			
Mugil cephalus	sea mullet	X	X
Plotosidae			
Neosilurus ater	narrow-fronted catfish	X	–
Neosilurus hyrtlii	Hyrtl's tandan	X	–
Porochilus rendahli[3]	Rendahl's catfish	X	–
Tandanus tandanus	eel-tailed catfish	X	–
Poeciliidae			
Gambusia holbrooki	mosquitofish	X	X
Poecilia reticulata	guppy	X	X
Xiphophorus helleri	swordtail	X	X
Xiphophorus maculatus	platy	X	X
Pseudomugilidae			
Pseudomugil gertrudae[2]	spotted blue-eye	X	–
Pseudomugil signifer	Pacific blue-eye	X	X
Scorpaenidae			
Notesthes robusta	bullrout	X	–
Synbranchidae			
Ophisternon gutturale	swamp eel	X	X
Synbranchidae spp.	unidentified swamp eel	X	–
Terapontidae			
Amniataba percoides	barred grunter	X	–
Hephaestus fuliginosus	sooty grunter	X	–
Hephaestus tulliensis	khaki grunter	X	–
Leiopotherapon unicolor	spangled perch	X	–

Family / Scientific Name	Common Name	Barron River	Trinity Inlet and Cairns Creeks
Toxotidae			
Toxotes chatereus	seven-spot archerfish	X	X
Toxotes jaculatrix	banded archerfish	X	–

Source: (Pusey et al. 2004); Cook pers. com. 2013.

– not recorded

X recorded

[1] While McCulloch's rainbowfish was described from a specimen form the lower Barron it is likely to be locally extinct in this area

[2] Spotted blue eye is a known wetland species from the region and was more widely spread throughout the region before systematic development / loss of wetlands for agriculture / urban development. It is known to co-occur with MacCulloch's rainbow fish, and given that the MacCulloch's rainbow fish is known to used to have been in the Barron, it is likely this species is (or has been) in the catchment in suitable habitat.

[3] Rendahl's catfish has a patchy distribution, and may or may not occur in the Barron.

Fish Species of Significance to Conservation

Fin Fish

The Lake Eacham rainbowfish, a freshwater fish, is listed on the online Protected Matters Search Tool for Commonwealth protected species (DSEWPC 2013b) and Queensland's EHP *Wildlife Online* search tool (EHP 2013d), as likely to occur within 5 km of the proposed development site (Table 12.2). There is no suitable habitat for this species near the proposed development site, and it is highly unlikely to occur near or on the proposed development site.

The opal cling goby (*Stiphodon semoni*), is listed as critically endangered under the EPBC Act, and has been recorded both to the north and south of the proposed development site (Ebner & Thuesen 2010). While larvae migrate to the ocean through small coastal streams, adults are usually found in pristine rainforest streams, consequently the waters surrounding the proposed development site are unlikely to provide significant habitat for this species.

Three species of fish that are rare, but not classified under the EPBC Act or the NCWR, which may occur within the sand dune lakes of, and adjacent to, the proposed development site are spotted blue-eye (*Pseudomugil gertrudae*), pennyfish (*Denariusa australis*) and MacCulloch's rainbowfish (*Melanotaenia maccullochi*) (Cook et al. (in press)).

Sharks and Rays

Four species of sharks and rays are listed on the online Protected Matters Search Tool for Commonwealth protected species (DSEWPC 2013b) and Queensland's EHP *Wildlife Online* search tool (EHP 2013d), as likely to occur within 5 km of the proposed development site (Table 12.2). The whale shark (*Rhincodon typus*) and porbeagle (*Lamna nasus* are oceanic species.. The green sawfish (*Pristis zijsron*) lives in estuarine to freshwaters, and has been recorded near Cairns (Stevens et al. 2005): this species may occur in the vicinity of the proposed development site. The dwarf sawfish (*Pristis clavata*) inhabits coastal waters and estuarine habitats, and rarely enters freshwater areas (Thorburn et al. 2007). This species is known from the Cairns region, but may now be locally extinct (TSSC 2009; DSEWPC 2013a), and is therefore unlikely to occur in the vicinity of the proposed development site.

Pest Species

Nine exotic non-indigenous species are recorded from the Barron River Catchment (EHP 2013a), with one species, mosquitofish, observed in the project area (Table 4.8). Several other pest species are likely to occur on the proposed development site and within the proposed development footprint.

Table 4.8 Non-indigenous species recorded from the Barron River Catchment and the likelihood of occurring on the proposed development site or adjoining creeks.

Family	Species	Common Name	Unlikely	Likely but not observed	Observed
Cichlidae	*Astronotus ocellatus*	oscar	X		–
Cichlidae	*Oreochromis mossambicus*	tilapia / Mozambique mouthbrooder	–	X	–
Cichlidae	*Tilapia mariae*	spotted tilapia / black mangrove cichlid	–	X	–
Poeciliidae	*Gambusia holbrooki*	mosquitofish	–	–	X
Poeciliidae	*Poecilia reticulate*	guppy	X	–	–
Poeciliidae	*Xiphophorus helleri*	swordtail	X	–	–
Poeciliidae	*Xiphophorus maculatus*	platy	X	–	–
Salmonidae	*Oncorhynchus mykiss* [a]	rainbow trout	X	–	–
Salmonidae	*Salmo trutta* [a]	brown trout	X	–	–

Source: (EHP 2013c)

[a] These species were last recorded in the Barron catchment in 1959. Both species prefer cool, upland streams and lakes, and are highly unlikely to be in the region. While the validity of the record is questionable, it is included for completeness.

4.6 Marine Mammals and Reptiles

Marine Mammals

Seven dolphin species have been recorded from coastal waters downstream of the proposed development site:

- inshore bottlenose dolphins (*Tursiops truncatus*)
- common dolphin (*Delphinus delphis*)
- Risso's dolphin (*Grampus griseus*)

- Irrawaddy dolphin (*Orcaella brevirostris*)
- Indo-Pacific humpback dolphin (*Sousa chinensis*)
- spotted dolphin (*Stenella attenuata*), and
- Indian Ocean bottlenose dolphin (*Tursiops aduncus*).

The habitats adjacent to the proposed development site are unlikely to provide significant habitat for any of these species, due to the shallow waters and high potential for the creeks to be cut off from the ocean at low tide.

Dugong are most often seen amongst or above seagrass beds (Lanyon 2003). There is no seagrass in the estuaries adjacent to the proposed development site, or offshore. There are no Dugong Protection Areas near the proposed development site. The waterways surrounding the proposed development site are unlikely to provide significant habitat for dugong.

Whales have been recorded offshore of Cairns, with five species recorded as likely to occur downstream of the proposed development site on the online Protected Matters Search Tool for Commonwealth protected species (DSEWPC 2013b) and Queensland's EHP *Wildlife Online* search tool (EHP 2013d) (Table 12.2):

- humpback whale (*Megaptera novaeangliae*)
- minke whale (*Balaenoptera acutorostrata*)
- Bryde's whale (*Balaenoptera edeni*)
- blue whale (*Balaenoptera musculus*), and
- killer whale (*Orcinus orca*).

The small creeks surrounding the site of the proposed development do not provide habitat for any whale species.

Marine Reptiles

Six species of marine turtles have been recorded from estuarine waters adjacent to and downstream of the proposed development site (DSEWPC 2013b) (Table 4.9). There is little significant habitat or food for marine turtles in the vicinity of the proposed development site. Never the less, some species, including green turtles, may forage in these creeks, particularly in the mangrove habitats (Bunce pers. comm. 2013). The beaches of Trinity Bay are not recognised as major nesting areas for any marine turtle species (Worley Parsons 2010). Further, technical staff from the Queensland Department of Environment and Heritage are not aware of the results of any surveys of marine turtles nesting in the vicinity of the proposed development. However, it is likely that there is some sparse nesting of marine turtles on the beaches in the vicinity of the proposed development (Bunce pers. comm. 2013, Trenerry 2013 pers. comm.).

Table 4.9 Marine turtles in the region and their likelihood of occurrence in the creeks or oceanic beaches near the proposed development site.

Species	Common Name	Preferred Habitat	Likelihood of Occurrence
Caretta caretta	loggerhead turtle	This species has a tropical and subtropical distribution and inhabit subtidal and intertidal coral and rocky reefs and seagrass meadows as well as deeper soft-bottomed habitats of the continental shelf. In Queensland, breeding and nesting is mainly in the southern Great Barrier Reef (Capricorn/Bunker group) and adjacent coastal areas near Bundaberg (e.g. Mon Repos, Wreck Rock and Tryon Island).	possible, but not likely to be common
Chelonia mydas	green turtle	This species has a tropical and subtropical distribution in seaweed rich coral reefs and inshore seagrass beds. Eastern Australian populations nest around the Capricorn Bunker Group of the southern Great Barrier Reef. Northern Great Barrier Reef populations nest on islands of the outer edge of the reef (e.g. Raine Island).	possible, but not likely to be common

Species	Common Name	Preferred Habitat	Likelihood of Occurrence
Dermochelys coriacea	leatherback turtle	Leatherback turtles are found in all oceans of the world. Their feeding grounds are mainly in temperate waters but they breed in tropical areas. Leatherback turtles are most commonly found in temperate waters feeding primarily on macroplankton (jellyfish, salps). Leatherback turtles are oceanic and are rarely found close to shore in Australia. Leatherback turtles feed and occasionally nest within the Great Barrier Reef Marine Park with nesting recorded at Wreck Rock and adjacent beaches near Bundaberg. There is sporadic nesting at other widely scattered sites in Queensland.	highly unlikely
Eretmochelys imbricate	hawksbill turtle	This species has a tropical and temperate distribution, typically found in tidal or subtidal coral and rocky reefs. In Australia, hawksbills feed in rocky areas and on coral reefs. They are commonly seen around the Great Barrier Reef including Torres Strait islands. There are three main breeding areas in Australia: the far northern section of the Great barrier Reef Marine Park and the Torres Strait region, north eastern Arnhem land and Western Australia.	possible, but not likely to be common

Species	Common Name	Preferred Habitat	Likelihood of Occurrence
Lepidochelys olivacea	olive ridley turtle	This species has a tropical and subtropical distribution, and is found in shallow soft-bottomed habitats in protected waters. These turtles are solitary, preferring the open ocean. The olive ridley is mostly carnivorous, feeding on jellyfish, snails, crabs, and shrimp. They are found from southern Queensland and the Great Barrier Reef to Torres Strait. There are two main breeding areas for olive ridley turtles in Australia, one in the Northern Territory with about 1000 nesting females per year, and the other in the Gulf of Carpentaria with less than 100 nesting females per year. No nesting by the species has been recorded in the Great Barrier Reef World Heritage Area.	unlikely
Natator depressus	flatback turtle	Flatback turtles are only found on the continental shelf of Australia. Although they feed around Papua New Guinea and Indonesia as well as within the Great Barrier Reef Marine Park, they nest only in Australia. Breeding is centred in the southern Great Barrier Reef around Peak, Wild Duck, Curtis and Facing Islands. However, there is low density nesting on many mainland beaches and offshore islands north of Gladstone. Most nesting occurs on Crab Island in western Torres Strait.	unlikely

Source: (DOE 2013)

There are several species of seasnake in the coastal waters downstream of the proposed development site. This includes the olive seasnake (*Aipsurus laevis)* and yellow-bellied seasnake (*Pelamis platurus).* The creeks surrounding the proposed development site are unlikely to provide significant habitat for these species.

The shallow waterways surrounding the proposed development site provide ideal habitat for estuarine crocodiles (*Crocodylus porosus*), and they have been recorded on site (Biotropica Australia 2013).

5 Description of Aquatic Habitat on and Around the Proposed Development Site

The proposed development site adjoins Half Moon Creek to the west, Yorkeys Creek to the north and Thomatis / Richters Creek to the south (Map 130702WW). Agricultural drains have been constructed over the site and a number of dams have been constructed on Lot 100 and Lot 1. There are a number of natural freshwater pools within the relic dunes of Lot 100, which are filled following heavy rainfall.

Each of these waterways and waterbodies provide habitat for a range of aquatic flora and fauna.

frc environmental
AQUATIC ECOLOGISTS
deep thinking.science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702WW:
Lot Boundaries and Waterways in and adjacent to the proposed Aquis Resort

SOURCES

Sourced from http://www.ga.gov.au/meta/ANZCW0703005241.html#distinfo. Australian boundary, roads, locations

Updated data available at http://dds.information.qld.gov.au/dds/. Coastline, Lot Boundaries, Waterways

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_lot_creek_map_13-08-29_CF.mxd

LEGEND

Site Boundary
Project Area
Lot Boundary
Watercourse

N

SCALE

0 0.5 1
Kilometres

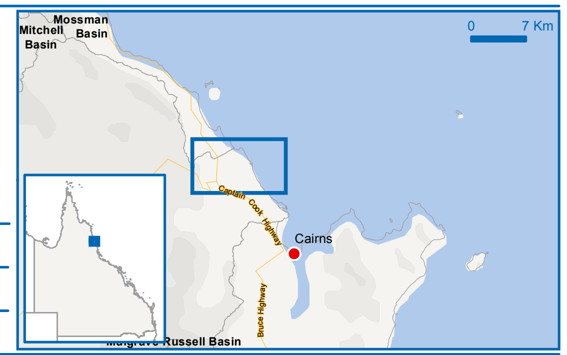
Scale: 1:30,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL

VERSION
02



5.1 Half Moon Creek Subcatchment

Half Moon Creek flows from the Cattana Wetlands to the east of the Captain Cook Highway at Smithfield, east and then north crossing Dunne Road before entering a dense mangrove wetland through which it meanders before discharging to the Coral Sea, approximately 300 m north-west of the Yorkeys Knob Marina. Seven sites were surveyed including three sites within the project area (Table 5.1).

As Half Moon Creek flows onto the site at Lot 2, its primarily fresh waters are reflected in the riparian vegetation (site 13). A moderate riparian corridor substantially protects the creek from the impacts of agricultural activity: the waters appear clear and little polluted. It is likely the creek supports an abundant and moderately diverse community of macro- and microinvertebrates, fishes and turtles.

Evidence of a saline (tidal) influence is first noted as the creek heads north. As the creek approaches Dunne Road, mangroves are a significant component of the riparian flora, the water is distinctly brackish in character and marine crabs are abundant within the intertidal zone (site 15). Tidal flaps significantly impede tidal penetration (and fish passage) above Dunne Road and a number of flaps leak, allowing some tidal flow in.

Downstream of Dunne Road, mangroves form an increasingly dense canopy as the creek meanders north (site 14). Substrates vary from clean coarse sand to fine silty sand and clay with abundant detritus.

Adjacent to Lot 60, Half Moon Creek is strongly tidal, whilst water quality is still influenced by freshwater inflow from the upper reaches. Dense mangroves provide complex habitat structure within the extensive intertidal zone, where crabs and fish are abundant (site 8a).

Half Moon Creek breaks out to form an expansive hypersaline wetland to the east, adjoining (or perhaps encroaching) Lot 60 (site 9). While water quality is poor, benthic invertebrates are abundant and waterfowl feed here. To the north, a minor tributary flows from Lot 60 (site 6a).

At the mouth of Half Moon Creek, water quality is currently impacted by dredging (site 5). Dense mangroves continue to line the banks and extend landwards. Sediments range from clean coarse sands to fine silty sands and silty clays. Crabs and fish are abundant. There is little evidence of pollution.

The shore offshore of Half Moon Creek is shallow and onshore winds resuspend sediments (silty sand) in the water column.

Table 5.1 Aquatic Habitat along Half Moon Creek

Site	Description	Photographs
5 Half Moon Creek mouth	Inside the mouth of Half Moon Creek. Note dredging activity at the mouth. Fine sandy silt substrate. Mangroves provide complex habitat structure. No seagrass or macroalgae present. Abundant macroinvertebrate burrows; fish and waterfowl. Recreational fishing and crabbing in the area.	 View downstream, dredging at creek mouth  Dense mangroves lining the bank
5a Half Moon Creek near Half Moon Bay marina	Off the entrance to Yorkeys Knob Marina (within the navigation channel; water depth <3.0 m). Silty coarse sand substrate. No seagrass or macroalgae present (although may be present in waters further offshore). Recreational fishing in the area.	 View of marina  View towards Half Moon Creek mouth  View north-east

Site	Description	Photographs	
6a Half Moon Creek on Lot 60, RP835486	Tributary to Half Moon Creek. Dense mangroves on both banks reflect tidal influence. Substrate of silty clay with abundant detrital material. Abundant macroinvertebrate burrows and abundant juvenile fish indicating potential nursery habitat. Tidal flap prevents tidal ingress beyond the culvert and impedes fish passage.	 Dense pneumatophores in-stream	 View upstream
		 View downstream	 Macroinvertebrate burrows
8a Half Moon Creek downstream of the proposed development site	Upper estuarine reaches of Half Moon Creek. Substrate varies from silty coarse sand to sandy, clayey silt with high levels of detritus. Mangroves provide complex intertidal habitat. Dense macroinvertebrate burrows within the intertidal zone; juvenile fishes observed swimming in-stream indicating potential nursery habitat.	 View upstream	 View downstream

Site	Description	Photographs	
13 Half Moon Creek on Lot 2, RP745120	Upper (freshwater) reaches of Half Moon Creek with vegetation indicating upper limit of tidal influence. Abundant para grass (Urochloa mutica), a weed.	 View upstream	 View downstream
14 Half Moon Creek on Lot 2, RP745120	Mid (brackish) reaches of Half Moon Creek (upstream of Dunne Road). Silty sandy loam substrate. Mangroves provide complex intertidal habitat. Tidal gates impede tidal exchange and fish passage. Abundant macroinvertebrate burrows. Recreational fishing in the area.	 View of left bank	 View downstream
15 Half Moon Creek upper reaches, near the proposed development site	Mid (brackish) reaches of Half Moon Creek (immediately downstream of Dunne Road). Tide flaps impede tidal exchange (but leak) and fish passage. Silty sandy loam substrate. Mangroves provide complex intertidal habitat. Abundant macroinvertebrate burrows. Recreational fishing in the area.	 View upstream	 View downstream

5.2 Yorkeys Creek Subcatchment

Three sites were surveyed along Yorkeys Creek, near the mouth, in the mid reaches and upstream of the culverts under Yorkeys Know Road (Table 5.2). Yorkeys Creek flows east from Lot 2, passing under Yorkeys Knob Road south of the township of Yorkeys Knob (site 2). This creek is tidal for its entire length. In the vicinity of Yorkeys Knob Road, the creek is braided and breaks out to form areas of wetland. Water quality above Yorkeys Knob Road is generally poor and the series of box culverts under Yorkeys Knob Road are likely to present an impediment to fish passage on all but 'high' high tides.

Yorkeys Creek flows along the boundary between Lot 4 on RP749342 and Lot 100. New, functioning tidal gates have the capacity to restrict tidal flow and fish passage approximately 300 m upstream of the mouth (site 1). Mangroves provide a dense canopy and habitat structure, while sediments are silty clays. There are abundant crabs and fishes within the creek.

Approaching the sea, Yorkeys Creek forms a large, shallow estuarine lagoon (site 3a). The mouth of the lagoon is substantially blocked by wave-driven sand. A modest outflow was observed, but tidal exchange is likely to be minimal. The shallow silty sand substrate of the lagoon supports abundant algal mats and highly abundant crab populations. There is little evidence of pollution.

Table 5.2 Aquatic Habitat along Yorkeys Creek.

Site	Description	Photographs
1 Yorkeys Creek downstream of the proposed development site	Mid-reaches of Yorkeys Creek. Dense mangroves on both banks reflect the strong tidal influence. Silty substrate with detritus. Mangroves on both banks shade the watercourse and provide complex intertidal habitat. Abundant macroinvertebrate burrows; juvenile fish (both below and above the tidal gate) indicating potential nursery habitats. Tidal gate prevents fish passage.	 View upstream  Tidal gate  View downstream
2 Yorkeys Creek near the proposed development site	Braided, upper estuarine reach of Yorkeys Creek at Yorkeys Knob Road, upstream of culverts. Tidal exchange may not be daily. Mangroves with elongated pneumatophores. Mangrove canopy, roots and snags provide physically complex in-stream habitat. Substrate is fine silty clay with high level of detritus. Benthic algae film; hypoxia likely to occur at night. Dense macroinvertebrate burrows; juvenile fishes indicating potential nursery habitat. Culverts an impediment to fish passage.	 View upstream  View of left bank

Site	Description	Photographs	
3a Yorkeys Creek mouth	Lower reaches of Yorkeys Creek. Tidal exchange is minimal as a consequence of sand accreting in the creek mouth. Behind the frontal dunes, a shallow lagoon extends for several hundred meters. Algal mats are common. Macroinvertebrate burrows are abundant both inter- and sub-tidally. The presence of juvenile fish indicates potential nursery habitat. Waterfowl common on-site.	 View of shallow lagoon  View upstream	 View of right bank  Frontal dunes

5.3 Thomatis / Richters Creek Subcatchments

The Thomatis / Richters Creek system is on the delta of the Barron River. Thomatis Creek is a tidal creek that flows north-east from the Barron River to Richters Creek. Richters Creek discharges into Trinity Inlet approximately 5.6 km north-west of the mouth of the Barron River, and adjacent to the mouth of Yorkeys Creek. The proposed discharge point for the proposed man-made lake is into Thomatis / Richters Creek between sites 4 and 16. Three sites were surveyed in the Thomatis / Richters Creek system, all of which were strongly influenced by the tides (Table 5.3).

Immediately downstream of the junction of the two creeks, Thomatis / Richters Creek is wide and up to 5 m deep (i.e. site 4). The water is highly stratified with less saline waters overlaying water approaching oceanic salinity. The banks support dense mangrove forest providing substantial habitat complexity for a wide range of estuarine species. Significant accretion and erosion characterise inside and outside banks. Bank sediments vary from silty coarse sand to silty clay. There is little evidence of pollution.

At the mouth of the creek tidal velocities are accelerated by a naturally forming series of bars. Sediments within the channel are clean, coarse sand, while the accreting bank is composed of fine silty sand and clay. The western shore is sharply eroded.

The beaches to the north and south of Thomatis / Richters Creek are clean graded sands. Along the strand line, shells provide evidence of abundant bivalve communities off shore. Ghost crabs (family Ocypodidae) are common on the foredunes.

These waters are popular for recreational fishing and are also used for environmental education (a good boat ramp serves the creek at Holloways Beach).

Table 5.3 Aquatic habitat along Thomatis / Richters Creek.

Site	Description	Photographs	
3 Thomatis / Richters Creek near the mouth	Moderately strong tidal currents indicate significant tidal exchange. Outside banks are eroded whilst inside banks are accreting silt. The channel substrate is mobile coarse (terrigenous) sand. No seagrass or macroalgae present. Dense macroinvertebrate burrows on both eroding and accreting banks; abundant fish activity; waterfowl. Recreational fishing occurs at this site.	 View upstream  View downstream, right bank	 View downstream

Site	Description	Photographs
3b Thomatis / Richters Creek mouth	The beach to the north of Thomatis / Richters Creek. A shallow sloping beach with extensive intertidal flats. Wind and waves contribute to a dynamic profile and some erosion of the upper beach. Substrate is clean coarse sand with shells. No seagrass or macroalgae in the intertidal or shallow subtidal (but may be present further offshore). Recreational fishing in the area.	 View south  Shells indicating tidal influence  Mangrove seed on shore  View of Thomatis/Richters Creek mouth

Site	Description	Photographs	
4 Thomatis / Richters Creek adjacent to the proposed development site	Mid-reaches of Thomatis / Richters Creek. Dense fringing mangroves reflect strong tidal influence; water quality profiling indicates stratification (fresh overlaying a saline wedge). Abundant macroinvertebrate burrows throughout the bank and intertidal zone. Recreational fishing in the area.	 View of left bank  View downstream	 Mangrove roots providing habitat  Fiddler crab

5.4 Waterbodies Within the Proposed Development Site

Agricultural Drains

Channels constructed to drain stormwater from the cane fields cross all lots (e.g. sites 7 and 10) (Table 5.4). These drains are typically 2–3 m wide and 1 m deep, with water quality typically reflecting the distance from the (tidal) outfall (site 16) and recent rainfall. Abundant algal mats result in a daily cycle of hyper- and hypoxia. There are patches of estuarine flora, such as *Acrostichum speciosum*, along the drains, that appear to be periodically cleared. Crabs are common in sections subject to brackish waters.

Natural Pools

There are some natural freshwater pools in the north-east and east of Lot 100, that are in native woodland on relict dunes (sites 1a, 1b, 11 and 12) (Table 5.4). While the pools that were surveyed were physically similar (relatively small, shallow, with a sandy substrate and high detritus load), the floral and faunal communities within them were significantly different. Aquatic plants, including *Blyxa* sp., *Najas* sp., and *Azolla pinnata* augmented fallen brush and root mats to provide habitat complexity. A number of pools supported abundant invertebrate life together with native rainbowfish and gudgeons.

Man-made Dams

There are man-made dams on Lot 100 (site 7a) and Lot 1 (sites LD, ELD and SD) (Table 5.4). These dams are of varying stages of maturity (construction appears ongoing). Waterfowl are abundant on each dam, and they each support a variety of aquatic plants. The dam on Lot 100 supports both native and exotic fishes. The dams on Lot 1 are likely to have a discharge point into Thomatis / Richters Creek; however, this was not observed during the survey.

Table 5.4 Aquatic habitat of waterbodies on the proposed development site.

Site	Description	Photographs	
1a Freshwater pool south of Yorkeys Creek	Freshwater pool (approximately 5 m diam. x 1.1 m deep) amongst melaleuca woodlands on relict dunes. Silty coarse sand substrate with abundant leaf litter. Fibrous roots of Melaleuca form floating mats. Moderate tannin staining and oily film on water surface. No aquatic plants present. Macroinvertebrates and fish (e.g. gudgeons and rainbowfish) were abundant in pool.	 View of pool	 Macroinvertebrate sampling in pool
1b Freshwater pool south of Yorkeys Creek	Freshwater pool (approximately 5 m x 25 m x 1.2 m deep) amongst melaleuca woodland on relict dunes. Silty coarse sand substrate with abundant leaf litter. Slight tannin staining of water. No aquatic plants present. Some macroinvertebrates; no fish sighted.	 View upstream	 View of tannin stained pool

Site	Description	Photographs	
7 Cane drainage waterway on Lot 100, NR3818	Saline drain (downstream of site 10). Silty clay substrate with abundant organic matter. Benthic algal mats contributing to supersaturated concentrations of oxygen (and likely hypoxia at night). Clumps of *Schoenoplectus validus, Acrostichum speciosum* and *Typha* sp. blocking the drain. Moderately abundant macroinvertebrate burrows above the water level; water birds observed using drainage.	 View upstream  View downstream	 Aquatic plants in the drain
7a Man-made dam on Lot 100, NR3818	Man-made dam (for irrigation) (approximately 50 m x 25 m x >1.5 m deep). Silty sand substrate with abundant detritus. Dense aquatic plant beds dominated by water snowflake (*Nymphoides indica*), frogsmouth (*Philydrum lanuginosum),* and the submerged *Hydrilla verticillata*. Areas of the exotic weed para grass (*Urochloa mutica*). Abundant macroinvertebrates and fish including mosquitofish (a declared noxious pest), gudgeons and rainbowfish. Abundant waterfowl using the site.	 View west	 View east

Site	Description	Photographs
9 wetland next to Half Moon Creek on Lot 60, RP835486	A shallow hypersaline wetland connected to Half Moon Creek. Shallow silty clay substrate. Benthic algal mats contributing to supersaturated concentrations of oxygen (and likely hypoxia at night). Abundant macroinvertebrates in-stream and waterfowl observed using site.	 View west  View north  Aquatic plants along bank
10 Cane drainage waterway on Lot 100, NR3818	Saline cane drain discharging to a tributary of Thomatis / Richters Creek. Silty clay substrate with abundant organic matter (including cane trash). Benthic algal mats (forming decaying rafts on the surface) contributing to supersaturated concentrations of oxygen (and likely hypoxia at night). Moderately abundant macroinvertebrate burrows above the water level; waterfowl observed using drainage. Culverts partially impede fish passage.	 View upstream  View downstream

Site	Description	Photographs	
11 Thomatis / Richters Creek on Lot 100, NR3818	Freshwater pool (approximately 7 m x 4 m x 0.8 m deep) amongst native woodland of relict dunes. Substrate of silty coarse sand with abundant detritus. Minor snags provide structure and habitat. Abundant *Blyxa* sp., *Najas* sp. and filamentous green algae. Abundant macroinvertebrates; abundant rainbowfish (also at least one large (>400 mm) 'active' fish).	 View upstream	
12 Thomatis / Richters Creek on Lot 100, NR3818	Freshwater pool (approximately 5 m x 4 m x 0.7 m deep) amongst dense native woodland of relict dunes. Substrate of silty coarse sand with abundant detritus. Total cover of *Azolla pinnata* and some *Blyxa* sp. Very low percent saturation of dissolved oxygen. Abundant macroinvertebrates and cane toads.	 View upstream	 View downstream
16 Thomatis / Richters Creek on Lot 100, NR3818	Discharge point of cane drain (sites 7 and 10) to adjoining mangroves. Silty clay substrate; mangroves provide some habitat complexity. Dense macroinvertebrate burrows and juvenile fish indicating potential nursery habitat. Tidal flap prevents upstream fish passage.	 Drainage outlet	 View downstream

Site	Description	Photographs
LD Man-made dam on Lot 1, RP800898	Large man-made dam (approximately 150 m x 50 m) that was greater than 1.5 m deep. Species including Cape waterlily (*Nymphaea caerulea*), water snowflake (*Nymphoides indica*), *Eleocharis* sp., *Typha* sp. and knotweed (*Persicaria* sp.) dominated in-stream aquatic plant communities.	 View north
ELD Man-made dam on Lot 1, RP800898	Large man-made dam (approximately 200 m x 60 m x 2–3 m deep). Substrate of silty sand with abundant detritus. Rushes and other emergent aquatic plants line the banks; water lilies grow across the dam, including Cape waterlily (*Nymphaea caerulea*), water snowflake (*Nymphoides indica*), *Eleocharis* sp., *Typha* sp. and knotweed (*Persicaria* sp.)	 
SD Man-made dam on Lot 1, RP800898	Small man-made dam dominated by marsh aquatic plants (e.g. *Typha* sp. and *Eleocharis* sp.). Waterfowl use the site for foraging.	 Waterfowl foraging on-site  Unvegetated upper bank

5.5 Seagrass

No seagrass was observed within any of the estuarine creeks nor at the mouth of the creeks in this survey. No seagrass has been recorded in this area by Queensland Fisheries or James Cook University (Map 130702SG), although there have not been any surveys in the Yorkeys Knob area since 2007 (Rob Coles pers. comm.). Detailed surveys would be required to confirm the absence of seagrass in the deeper subtidal areas.

frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702SG:
Seagrass located close to the Aquis Resort

SOURCES

© Copyright Commonwealth of Australia (Geoscience Australia) 2001, 2004
Sourced from http://www.ga.gov.au/meta/ANZCW0703005241.html#distinfo. Australian boundary, roads, locations
© The State of Queensland (Department of Natural Resources and Mines) 2013
Updated data available at http://dds.information.qld.gov.au/dds/. Coastline
© The State of Queensland (Department of Primary Industries and Fisheries) 2007, Seagrass

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_seagrass_13-08-29_CF.mxd

LEGEND

Site Boundary
Seagrass

N

SCALE

0 1 2
Kilometres

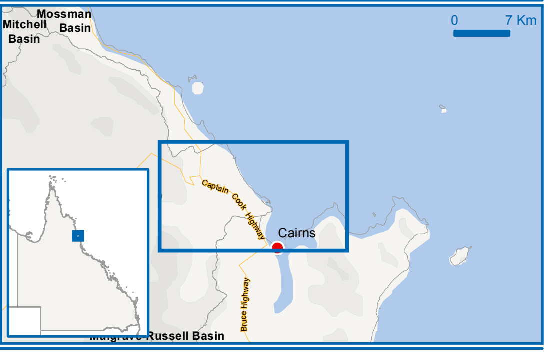
Scale: 1:60,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL

VERSION
02



6 Water Quality

6.1 Water Quality Measured In Situ

Half Moon Creek

The water quality measured in situ in Half Moon Creek and its tributaries generally did not comply with preliminary WQOs for turbidity and the percent saturation of dissolved oxygen (Table 6.1). The percent saturation of dissolved oxygen was below the WQO range at sites 6a, 8a and 15. At sites 6a and 15 this may be related to restriction of tidal inundation by the tidal gates. The percent saturation of dissolved oxygen was marginally above the WQO range at site 5a (during incoming tides). The high turbidity at all sites was likely to be related to run-off from agricultural land uses in the area, which have cleared most vegetation from the area allowing sediment to be readily transported into waterways. The pH was also below the WQO at site 6a; however, it was only 0.1 NTU lower than the WQO range and was unlikely to cause harm to aquatic organisms. The electrical conductivity was within natural ranges expected of an estuarine creek.

Yorkeys Creek

The water quality measured in situ in Yorkeys Creek did not comply with preliminary WQOs for the percent saturation of dissolved oxygen at both sites that were sampled and for turbidity at site 1 (Table 6.1). The pH was within the WQO range at both sites. The percent saturation of dissolved oxygen was below the WQO range at site 1 and above the WQO range at site 2. The culverts under Yorkeys Knob Road may be restricting tidal inundation to the upper reaches of the creek.

Thomatis / Richters Creek

The water quality measured in situ in Thomatis / Richters Creek complied with all of the WQOs (Table 6.1). The water quality measured in situ in Thomatis / Richters Creek is indicative of a natural waterway that is not polluted. This will need to be maintained during all phases of the Project particularly during operations once discharges begin.

Waterbodies on the Proposed Development Site

Four sites on the proposed development site were considered estuarine (i.e. brackish water), which were sites 7, 9 10 and ELD. The percent saturation of dissolved oxygen did not comply with the WQO range at any of these sites (Table 6.1). At each site, the percent saturation of dissolved oxygen was above the WQO. This was likely to be associated with high concentrations of nutrients and also the growth of benthic microalgae and phytoplankton at these sites (Table 6.5).

Turbidity at sites 7 and 9 was also above the WQO, while pH was within the WQO range at each site, except at site ELD. The high pH at site ELD was most likely to be due to the high cover of aquatic plants consuming carbon dioxide during photosynthesis, which can lead to an increase in pH (Moss 1973).

Five sites were considered to be freshwater: sites 1a, 1b, 7a, 11 and 12. The percent saturation of dissolved oxygen was below the WQO range at each of these sites, except at site 7a on the surface (Table 6.1). The low percent saturation of dissolved oxygen was likely to be associated with the high concentration of nutrients and the lack of flow in these isolated pools and dune lakes. The turbidity complied with the WQO at each site, except at site 12, which was likely to be due to the high abundance of detritus in-stream. The pH complied with the WQO at each site.

Table 6.1 Water quality measured in situ at each site.

Site	Depth	Location	Temperature (°C)	pH	Turbidity (NTU)	Percent Saturation of Dissolved Oxygen (%)
WQO [c]			**–**	**6.5–8.4**	**10**	**80–105**
Half Moon Creek						
5a	surface [a]	near Half Moon Bay marina	25.2	7.8	25.9	105.8
	1 m [a]		23	7.9	–	106.2
	2 m [a]		23	8	–	106.7
	surface [b]		22.9	7.9	34.3	103.2
	1 m [b]		22.6	8	–	103.1
	2 m [b]		22.5	8.1	–	103.5
6a	surface	Lot 60, RP835486	24.6	6.4	19.1	60.5
8a	surface	downstream of the proposed development site	24.6	8.3	11.7	66.5
14	surface	Lot 2, RP745120	24.8	7.6	11.4	90.4
15	surface	upper reaches, near the proposed development site	24.2	7.7	12.5	76.9
Yorkeys Creek						
1	surface	downstream of the proposed development site	22.9	7.6	14	26.3
2	surface	near the proposed development site	23	6.5	7.8	122.6

Site	Depth	Location	Temperature (°C)	pH	Turbidity (NTU)	Percent Saturation of Dissolved Oxygen (%)
Thomatis / Richters Creek						
3	surface	near the mouth	23	7.2	6.8	100
	1 m		22.6	7.1	–	98.5
4	surface	adjacent to the proposed development site	22.3	7.6	5.4	97.4
	1 m		23.3	7.7	–	98.7
	2 m		22.9	7.6	–	98.5
	3 m		22.6	7.4	–	95.8
Freshwater Waterbodies on the Proposed Development Site						
WQO [d]			**–**	**6.0–8.0**	**2–200**	**90–120**
7a	surface	Lot 100, NR3818	22.8	7.6	3.6	89.4
	1 m		23.3	7.1	–	72.2
1a	surface	Lot 100, NR3818	20.8	6.8	11.2	19.4
1b	surface	Lot 100, NR3818	20.5	6.9	9.1	14.1
	1 m		20.2	6.4	–	10.8
WQO [e]			**–**	**6.0–8.0**	**15**	**85–120**
11	surface	Lot 100, NR3818	23	7.9	5.4	69.1
12	surface	Lot 100, NR3818	21.6	6.5	51.6	3.5

Site	Depth	Location	Temperature (°C)	pH	Turbidity (NTU)	Percent Saturation of Dissolved Oxygen (%)
Brackish Waterbodies on the Proposed Development Site						
WQO [c]			**–**	**6.5–8.4**	**10**	**80–105**
7	surface	Lot 100, NR3818	29.7	7.9	11	217.5
9	surface	Lot 60, RP835486	26.4	7.8	10.8	206.3
10	surface	Lot 100, NR3818	26.1	7.2	7	141.9
ELD	surface	Lot 1, RP800898	25.7	9.3	7	151.9

shading denotes values that do not comply with WQOs

[a] water quality measured during the start of an incoming tide

[b] water quality measured during the end of the incoming tide (slack tide)

[c] QWQG WQO for mid-estuarine and tidal canals in the Wet Tropics Region

[d] QWQG WQO for freshwater lakes in the Wet Tropics Region

[e] QWQG WQO for lowland streams in the Wet Tropics Region

6.2 Water Quality Measured in the Laboratory

To assess within site variation, the relative percent difference (RPD) between the two samples collected from one site was calculated. A RPD of 50% for field replicates is considered acceptable (DEWHA 2009b). The RPD for all parameters was below 50%, except for dissolved aluminium (63%) and dissolved copper (58%). This variation was considered in the interpretation of the results.

The concentrations of all parameters in the blank water samples were typically below laboratory limits of reporting and where detected, were in low concentrations (e.g. dissolved barium = 0.1 µg/L). That is, it was unlikely that samples were contaminated during collection and processing.

Half Moon Creek

Total suspended solids ranged from 23 mg/L to 39 mg/L in Half Moon Creek (Table 6.1). The concentration of total suspended solids can be influenced by a number of factors (e.g. rainfall, flows and evaporation).

The concentration of total nitrogen, nitrate and ammonia were above preliminary WQOs at each site, except at the mouth of Half Moon Creek (site 5a) (Table 6.1). The concentration of total phosphorous was above the WQO at each site. The concentration of nitrate and nitrite were also relatively high at each site, except site 5a (mouth of Half Moon Creek). High concentrations of nutrients are likely to be associated with runoff from the sugar cane farms next to the creek and discharge from the wastewater treatment plant upstream of the sites. Concentrations were lowest at the mouth of Half Moon Creek (site 5a) where mixing from oceanic currents is most prevalent.

The concentration of total organic carbon was highest at sites 6a (5.64 mg/L) and 8a (5.44 mg/L) (Table 6.1).

The BOD was the same at each site (3 mg/L) (Table 6.1), which was indicative of natural, unpolluted waterways (SCA 2012).

The concentration of all dissolved metals and metalloids were below available ANZECC & ARMCANZ trigger values at each site (Table 6.1). The concentration of dissolved metals and metalloids were typically highest at sites 6a and 8a, except for the concentrations of dissolved boron, selenium and uranium, which were higher at site 5a.

The concentration of faecal coliforms at site 8a (upper Half Moon Creek) was relatively high (28 CFU/100 mL). The concentration of faecal coliforms was below the laboratory limits of reporting at all of the other sites in Half Moon Creek.

The concentration of chlorophyll *a* was above the WQO at site 8a, but below the WQO at sites 5a and 6a (Table 6.1). High concentrations of chlorophyll *a* at site 8a are likely to be related to the high concentrations of nutrients associated with the sugar cane farming.

The concentration of all other parameters were below laboratory limits of reporting, including:

- total petroleum hydrocarbons
- BTEX
- organochlorine and organophosphorus pesticides
- phenoxy acid herbicides
- glyphosate and AMPA
- PAHs
- phenols, and
- PCBs.

The water quality in Half Moon Creek is typical of an aquatic ecosystem affected by agricultural practices. Run-off from the adjacent sugar cane farms and discharge from a wastewater treatment plant upstream are likely to be causing the high concentrations of nutrients and chlorophyll *a* while all other parameters complied with preliminary WQOs. The downstream reaches of the creek are regularly flushed by the tide, allowing for mixing in the water column. Tidal mixing in the upper reaches and in at least one of the smaller tributaries is restricted by tidal flaps, which is likely to be detrimentally impacting water quality.

Table 6.2 Water quality in Half Moon Creek.

Parameter	Units	WQO	Site		
			5a	6a	8a
electrical conductivity	µS/cm	–	55460	26440	26420
total suspended solids	mg/L	NA	39	38	23
chlorophyll a	µg/L	3 [a]	3	3	5
BOD	mg/L	NA	3	3	3
Nutrients [a]					
total nitrogen	µg/L	250	<50	1200	1200
total phosphorous	µg/L	20	30	70	70
ammonia	µg/L	15	<5	34	42
oxides of nitrogen	µg/L	30	–	–	–
nitrate	µg/L	ID	<5	626	701
nitrite	µg/L	NA	<5	10	10
ortho-phosphorous	µg/L	NA	<5	161	159
total organic carbon	mg/L	NA	0.99	5.64	5.44
Metals and Metalloids [b]					
aluminium	µg/L	ID	<5	<5	<5
antimony	µg/L	ID	0.2	0.1	0.1
arsenic	µg/L	ID	1.4	1.2	1.1
barium	µg/L	–	6.4	14.8	11.2
beryllium	µg/L	ID	<0.1	<0.1	<0.1
boron	µg/L	ID	2010	1150	1130
cadmium	µg/L	.7	<0.1	<0.1	<0.1
chromium III	µg/L	27.4			
chromium VI	µg/L	4.4			
chromium	µg/L		<0.5	<0.5	<0.5
cobalt	µg/L	1	<0.1	0.5	0.4
copper	µg/L	1.3	1	0.9	0.9
gallium	µg/L	ID	0.4	1.4	1.1

Parameter	Units	WQO	Site		
			5a	6a	8a
iron	µg/L	ID	2.5	60.3	41.3
lanthanum	µg/L	ID	<0.1	<0.1	<0.1
manganese	µg/L	ID	0.7	179	144
mercury	µg/L	0.1	<0.1	<0.1	<0.1
molybdenum	µg/L	ID	8	14.6	18.3
lead	µg/L	4.4	0.1	<0.1	<0.1
nickel	µg/L	7	0.2	0.6	0.6
selenium	µg/L	ID	1.3	0.7	0.6
silver	µg/L	1.4	<0.1	<0.1	<0.1
tin	µg/L	ID	<0.5	<0.5	<0.5
tributyltin	µg/L	0.006	<0.5	<0.5	<0.5
uranium	µg/L	ID	2.7	0.7	0.6
vanadium	µg/L	100	1.7	1.4	1.5
zinc	µg/L	15	1.4	4.7	6.3

shading indicates values above WQOs

[a] QWQG Wet tropics regional guideline value for mid estuarine waters

[b] ANZECC & ARMCANZ trigger values for marine waters for moderately disturbed systems

ID insufficient data

NA not available

Yorkeys Creek

The electrical conductivity in Yorkeys Creek was similar between sites and was within natural ranges expected of a tidal creek (Table 6.3).

Total suspended solids ranged from 39 mg/L to 54 mg/L (Table 6.3), and was highest at site 2, which was likely to be due resuspension of the fine silty substrate at this site.

The concentrations of total nitrogen and total phosphorus were above the preliminary WQOs at each site (Table 6.3). The concentration of ammonia was below the WQO.

High concentrations of total nitrogen and total phosphorous were likely to be associated with run-off from sugar cane farms next to the creek.

The concentration of total organic carbon was highest at site 2 (6.34 mg/L) (Table 6.3).

The BOD was the same at each site (3 mg/L) (Table 6.3), which was indicative of natural, unpolluted waterways (SCA 2012).

The concentration of all dissolved metals and metalloids at each site were below available ANZECC & ARMCANZ trigger values (Table 6.3). The concentration of dissolved metals and metalloids were similar between sites; however, concentrations of boron, iron and manganese were higher at site 1.

The concentration of faecal coliforms was below the laboratory limit of reporting at site 2, and was relatively low at site 1(10 CFU/100 mL).

The concentration of chlorophyll *a* was below the laboratory limit of reporting, and therefore below the WQO, at each site (Table 6.3).

The concentration of all other parameters were below laboratory limits of reporting, including:

- total petroleum hydrocarbons
- BTEX
- organochlorine and organophosphorus pesticides
- phenoxy acid herbicides
- glyphosate and AMPA
- PAHs
- phenols, and
- PCBs.

The water quality in Yorkeys Creek is typical of an aquatic ecosystem affected by agricultural practices. The high concentrations of nutrients is likely to be associated with run-off from the cane farms, all other parameters complied with preliminary WQO, where they were available. Downstream of the culverts under Yorkeys Knob Road, the tidal influence is likely to flush the creek on a regular basis allowing for mixing in the water column, this is likely to be restricted upstream of the culverts.

Table 6.3 Water quality in Yorkeys Creek.

Parameter	Units	WQO	Site 1	Site 2
electrical conductivity	µS/cm	–	45230	45430
total suspended solids	mg/L	NA	39	54
chlorophyll a	µg/L	3 [a]	<1	<1
BOD	mg/L	NA	3	3
Nutrients [a]				
total nitrogen	µg/L	250	470	740
total phosphorous	µg/L	20	50	60
ammonia	µg/L	15	<5	15
oxides of nitrogen	µg/L	30	–	–
nitrate	µg/L	ID	<5	26
nitrite	µg/L	NA	<5	<5
ortho-phosphorous	µg/L	NA	30	22
total organic carbon	mg/L	NA	5.16	6.34
Metals and Metalloids				
aluminium	µg/L	ID	6.5	<5
antimony	µg/L	ID	0.1	0.1
arsenic	µg/L	ID	1.7	1.4
barium	µg/L	–	11.4	26.7
beryllium	µg/L	ID	<0.1	<0.1
boron	µg/L	ID	2780	1630
cadmium	µg/L	.7	<0.1	<0.1
chromium III	µg/L	27.4		
chromium VI	µg/L	4.4		
chromium	µg/L		<0.5	<0.5
cobalt	µg/L	1	0.3	0.4
copper	µg/L	1.3	0.6	1.1
gallium	µg/L	ID	1	2.2

Parameter	Units	WQO	Site 1	Site 2
iron	µg/L	ID	123	34.9
lanthanum	µg/L	ID	0.2	<0.1
manganese	µg/L	ID	215	50.9
mercury	µg/L	0.1	<0.1	<0.1
molybdenum	µg/L	ID	4.1	5.7
lead	µg/L	4.4	<0.1	<0.1
nickel	µg/L	7	0.4	1.2
selenium	µg/L	ID	1.2	0.99
silver	µg/L	1.4	<0.1	<0.1
tin	µg/L	ID	<0.5	<0.5
tributyltin	µg/L	0.006	<0.5	<0.5
uranium	µg/L	ID	1.8	1.7
vanadium	µg/L	100	1.1	0.4
zinc	µg/L	15	1.6	0.8

shading indicates values above WQOs

[a] QWQG Wet tropics regional guideline value for mid estuarine waters

[b] ANZECC & ARMCANZ trigger values for marine waters for moderately disturbed systems

ID insufficient data

NA not available

Thomatis / Richters Creek

Total suspended solids ranged from 15 mg/L to 26 mg/L in Thomatis / Richters Creek (Table 6.4).

The concentrations of total phosphorus, nitrate and ammonia were above the WQOs at site 4, which was likely to be related to discharges from the prawn farm upstream (Table 6.4).

The concentration of total organic carbon was highest at site 3 (1.66 mg/L) (Table 6.4).

The BOD was the same at each site (3 mg/L) (Table 6.4), which was indicative of natural, unpolluted waterways (SCA 2012).

The concentration of all dissolved metals and metalloids at each site was below ANZECC & ARMCANZ trigger values (Table 6.4). The concentration of dissolved metals and metalloids was similar between sites.

The concentration of faecal coliforms was below the laboratory limit of reporting at each site.

The concentration of chlorophyll *a* was above the WQO at each site (Table 6.4).

The concentration of all other parameters were below laboratory limits of reporting, including:

- total petroleum hydrocarbons
- BTEX
- organochlorine and organophosphorus pesticides
- phenoxy acid herbicides
- glyphosate and AMPA
- PAHs
- phenols, and
- PCBs.

The water quality in Thomatis / Richters Creek is typical of a moderately disturbed aquatic ecosystem. Discharges from the prawn farm upstream and run off from the cane farms are likely to be contributing to nutrients and chlorophyll *a* concentrations. The tidal influence and constant flow in Thomatis / Richters Creek is likely to maintain the optimal water quality recorded in this survey.

Table 6.4 Water quality in Thomatis / Richters Creek.

Parameter	Units	WQO	Site	
			3	4
electrical conductivity	µS/cm	–	26720	20120
total suspended solids	mg/L	NA	15	26
chlorophyll a	µg/L	3 [a]	8	11
BOD	mg/L	NA	3	3
Nutrients [a]				
total nitrogen	µg/L	250	120	250
total phosphorous	µg/L	20	20	30
ammonia	µg/L	15	11	35
oxides of nitrogen	µg/L	30	–	–
nitrate	µg/L	ID	26	42
nitrite	µg/L	NA	<5	<5
ortho-phosphorous	µg/L	NA	7	9
total organic carbon	mg/L	NA	1.66	0.97
Metals and Metalloids				
aluminium	µg/L	ID	ID	5.4
antimony	µg/L	ID	ID	<0.1
arsenic	µg/L	ID	ID	0.7
barium	µg/L	–	–	13.4
beryllium	µg/L	ID	ID	<0.1
boron	µg/L	ID	ID	918
cadmium	µg/L	0.7	0.7	<0.1
chromium III	µg/L	27.4		
chromium VI	µg/L	4.4		
chromium	µg/L		<0.5	<0.5

Parameter	Units	WQO	Site	
			3	4
cobalt	µg/L	1	0.1	0.1
copper	µg/L	1.3	0.9	0.9
gallium	µg/L	ID	1.2	1.5
iron	µg/L	ID	8.4	10.5
lanthanum	µg/L	ID	<0.1	<0.1
manganese	µg/L	ID	39.9	48.5
mercury	µg/L	0.1	<0.1	<0.1
molybdenum	µg/L	ID	3.3	2.4
lead	µg/L	4.4	<0.1	<0.1
nickel	µg/L	7	0.2	0.2
selenium	µg/L	ID	<0.5	<0.5
silver	µg/L	1.4	<0.1	<0.1
tin	µg/L	ID	<0.5	<0.5
tributyltin	µg/L	0.006	<0.5	<0.5
uranium	µg/L	ID	1.2	0.8
vanadium	µg/L	100	0.9	0.8
zinc	µg/L	15	0.7	1.9

shading indicates values above WQOs

[a] QWQG Wet tropics regional guideline value for mid estuarine waters

[b] ANZECC & ARMCANZ trigger values for marine waters for moderately disturbed systems

ID insufficient data

NA not available

Waterbodies on the Proposed Development Site

Total nitrogen, total phosphorous and electrical conductivity were analysed at all of the waterbodies on the proposed development site, and the full suite of parameters was analysed at one of the cane drains (site 10) (Table 5.4).

Sites 1a, 1b, 7a and 11 on the proposed development site were fresh water, with electrical conductivity less than 4000 µS/cm, data at these sites was consequently compared to preliminary freshwater WQOs. Sites 9 and 10 were brackish, and data from these sites were consequently compared to preliminary estuarine WQOs.

The concentrations of total nitrogen and total phosphorus were above preliminary WQOs at each site (Table 6.5 and Table 6.6). This was likely to be associated with run-off from the sugar cane farm. It is expected that these waterbodies will be removed or highly modified during construction. However, the concentration of nitrogen in sediment was below laboratory limits of reporting (Section 7) indicating that most of the nitrogen is currently being flushed into the waterways rather than accumulating in the sediment.

At the cane drain (site 10), the concentration of ammonia was above the WQO, while the concentrations of nitrate and nitrite were below laboratory limits of reporting (Table 6.5). The concentration of ammonia was lower than recorded in Half Moon and Thomatis / Richters Creeks, which suggests that sources other than sugar cane farming are having an influence on the concentration of ammonia in each creek.

The concentration of total suspended solids was relatively high at the cane drain (site 10) and was likely due to run-off from the sugar cane farms, as this site was an active cane drain (Table 6.5).

The concentration of total organic carbon was relatively high (10.2 mg/L) at the cane drain (site 10) (Table 6.5), which was likely due to the presence of sugar cane trash (i.e. leaves and cut debris) in the waterway.

The BOD was the same at the cane drain (site 10) as all other sites in this survey (Table 5.4).

At the cane drain (site 10), the concentrations of all dissolved metals and metalloids were below applicable WQOs (Table 6.5). The concentrations of all dissolved metals and metalloids were relatively low and similar to the other creeks in this survey.

The concentration of faecal coliforms at site 10 was 20 CFU/100 mL, which was relatively high compared to all of the other sites, except the upper Half Moon Creek (site 8a). The relatively high concentration of faecal coliforms at site 10 is likely to be related to stormwater run-off.

The concentration of chlorophyll *a* was above the WQO and was likely to be due to the high concentrations of nutrients and the presence of algal mats on the water surface (Table 6.5).

The waterbodies on the proposed development site are highly impacted by sugar cane farming and associated practices. Where the waterbodies are disturbed or emptied by the proposed development, the water should not be discharged into the natural waterways surrounding the proposed development site. The water should be used on-site (e.g. road watering and mobile plant weed wash-downs), where possible.

Table 6.5 Water quality of brackish waterbodies on the proposed development site.

Parameter	Units	WQO	Site	
			9	10
electrical conductivity	µS/cm	–	49300	41850
total suspended solids	mg/L	NA	–	26
chlorophyll a	µg/L	3 [a]	–	24
BOD	mg/L	NA	–	3
Nutrients [a]				
total nitrogen	µg/L	250	1760	1130
total phosphorous	µg/L	20	170	90
ammonia	µg/L	15	–	17
oxides of nitrogen	µg/L	30	–	–
nitrate	µg/L	NA	–	<5
nitrite	µg/L	NA	–	<5
ortho-phosphorous	µg/L	NA	–	140
total organic carbon	mg/L	NA	–	10.2
Metals and Metalloids [b]				
aluminium	µg/L	ID	–	6.8
antimony	µg/L	ID	–	0.3
arsenic	µg/L	ID	–	2.7
barium	µg/L	–	–	26.2
beryllium	µg/L	ID	–	<0.1
boron	µg/L	ID	–	1300
cadmium	µg/L	0.7	–	<0.1

Parameter	Units	WQO	Site	
			9	10
chromium III	µg/L	27.4		
chromium VI	µg/L	4.4		
chromium	µg/L		–	<0.5
cobalt	µg/L	1	–	<0.1
copper	µg/L	1.3	–	1.1
gallium	µg/L	ID	–	2.1
iron	µg/L	ID	–	17.4
lanthanum	µg/L	ID	–	<0.1
manganese	µg/L	ID	–	222
mercury	µg/L	0.1	–	<0.1
molybdenum	µg/L	ID	–	7
lead	µg/L	4.4	–	<0.1
nickel	µg/L	7	–	0.9
selenium	µg/L	ID	–	1.1
silver	µg/L	1.4	–	<0.1
tin	µg/L	ID	–	<0.5
tributyltin	µg/L	0.006	–	<0.5
uranium	µg/L	ID	–	5.4
vanadium	µg/L	100	–	3.3
zinc	µg/L	15	–	1.1

shading indicates values above WQOs
[a] QWQG Wet tropics regional guideline value for mid estuarine waters
[b] ANZECC & ARMCANZ trigger values for marine waters for moderately disturbed systems
ID insufficient data
NA not available

Table 6.6 Water quality of freshwater waterbodies on the proposed development site.

Parameter	Units	WQO [a]	Site 1a	Site 1b	Site 7a	WQO [b]	Site 11
Physical Water Quality							
electrical conductivity	µS/cm		3664	3111	61	NA	392
Nutrients							
total nitrogen	µg/L	350	2180	1780	1370	240	1930
total phosphorous	µg/L	10	120	100	150	10	140

shading indicates values above WQOs

[a] QWQG trigger values for freshwater lakes and reservoirs

[b] QWQG trigger values for lowland streams

6.3 Summary

Half Moon Creek

Turbidity throughout Half Moon Creek was generally high, which was likely to be related to stormwater runoff from the surrounding catchment. As in previous surveys of the creek, the percent saturation of dissolved oxygen in the downstream reaches was relatively high, however it was poor in upstream reaches and upstream of tidal gates (Lloyd et al. 2011).

In general, in this survey, the concentration of nutrients was relatively high in Half Moon Creek, except at the mouth of the creek. This is consistent with previous surveys, where concentrations were typically higher in upstream reaches (Lloyd et al. 2011).

High concentrations of nutrients are likely to be associated with runoff from the sugar cane farms next to the creek and discharge from the wastewater treatment plant upstream, lower concentrations near the mouth are likely to be a result of tidal mixing with more oceanic water.

The concentration of metals, metalloids faecal coliforms, and the other measured parameters were all relatively low.

Yorkeys Creek

Water quality in Yorkeys Creek was relatively poor, due to non-compliant concentrations of dissolved oxygen, and high concentrations of total nitrogen and phosphorous. High concentrations of total nitrogen and total phosphorous are likely to be associated with runoff from sugar cane farms next to the creek. However, the concentration of metals, metalloids faecal coliforms, chlorophyll *a*, and the other measured parameters were all relatively low.

Thomatis / Richters Creek

In this survey water quality in Thomatis / Richters Creek was relatively good, with turbidity and dissolved oxygen complying with the preliminary WQOs. This may partially be a result of sampling occurring in the dry season, as in previous surveys dissolved oxygen concentrations in the upper reaches did not always comply with QWQG, but were higher (and more compliant) in the dry season than in the wet season.

In this survey, the concentration of total phosphorous and ammonia were relatively high at the most upstream site sampled, and chlorophyll *a* was high at all of the sites that were sampled. In previous surveys the median concentrations of nutrients were generally relatively high. The relatively low values in this survey may be related to lower stormwater runoff in the dry season.

The concentration of metals, metalloids faecal coliforms, chlorophyll *a*, and the other measured parameters were all relatively low in Thomatis /Richters Creek.

Water Bodies on the Proposed Development Site

Water quality in the cane drain on the proposed development site was generally poor, with poor concentrations of dissolved oxygen and high concentrations of nutrients. The concentrations of chlorophyll *a* were also above the WQO.

Water quality of the dune lakes on the proposed development site was also poor, with high concentrations of nutrients.

Water quality of the farm dam (site 7a) on the proposed development site was poor with high concentrations of nutrients.

The high concentration of nutrients at all sites on the proposed development site was likely to be a result of runoff from the surrounding cane farms.

The results for this dry season sampling of each of these water bodies are consistent with previous surveys. Further sampling is recommended to establish seasonal variation. It is anticipated that dissolved oxygen concentrations will be poorer in the wet season, and that turbidity and nutrient concentrations increase with runoff during the wet season.

7 Sediment Quality

7.1 Half Moon Creek

The sediment in Half Moon Creek was dominated by sand and silt /clay at each site (Table 7.1). A higher percent of finer substrates can facilitate an increase in suspended solids and turbidity in periods of high flow.

The sediment quality in Half Moon Creek was generally below applicable ISQG-low trigger values, except for the concentration of antimony, chromium and nickel (Table 7.1). The concentration of nickel was above ISQG-high trigger values at site 6a. The concentration of nitrogen was below laboratory limits of reporting at each site. The concentration of phosphorus was highest at site 8a and may be bioavailable to aquatic organisms. The concentrations of all other parameters (e.g. BTEX, TPH, herbicides and pesticides known to be used in the region) were below laboratory limits of reporting.

The ISQG low trigger value is a trigger for further investigation: to determine whether antimony, chromium and nickel are having an adverse effect on aquatic ecosystems, further investigations are required (Simpson et al. 2005).

Table 7.1 Sediment quality in Half Moon Creek.

Parameter	Units	ISQG-low Trigger Value	ISQG-high Trigger Value	Site		
				5	6a	8a
Particle Size Distribution						
pebble	%	–	–	0	0	0
gravel	%	–	–	0	6	0
sand	%	–	–	2	17	2
silt / clay	%	–	–	98	77	98
Nutrients						
nitrogen	mg/kg	–	–	<0.1	<0.1	<0.1
phosphorous	mg/kg	–	–	128	197	651
organic carbon	%	–	–	22.2	24.6	36.8
moisture content	%	–	–	51.7	70.9	129.8
Metals and Metalloids						
aluminium	mg/kg	NA	NA	6515	5999	12210

Parameter	Units	ISQG-low Trigger Value	ISQG-high Trigger Value	Site		
				5	6a	8a
antimony	mg/kg	2	25	2.3	3.3	2.7
arsenic	mg/kg	20	70	7.3	8.7	10.1
cadmium	mg/kg	1.5	10	<0.5	<0.5	0.7
chromium	mg/kg	80	370	95	183	92.7
cobalt	mg/kg	NA	NA	5.3	6.7	8.8
copper	mg/kg	65	270	6.9	6.6	13
iron	mg/kg	NA	NA	12010	10610	21930
manganese	mg/kg	NA	NA	181	113	297
mercury	mg/kg	0.15	1	<0.5	<0.5	<0.5
lead	mg/kg	50	220	7	7.2	13.3
nickel	mg/kg	21	52	50.3	99.5	51.8
selenium	mg/kg	NA	NA	<1	<1	<1
silver	mg/kg	NA	NA	<1	<1	<1
vanadium	mg/kg	NA	NA	16.5	17.4	31.9
zinc	mg/kg	200	410	24.9	19.2	49.7

light shading indicates values above ISQG-low trigger values
dark shading indicates values above ISQG-high trigger values
NA not available

7.2 Yorkeys Creek

The sediment in Yorkeys Creek comprised a mixture of gravel, sand and silt / clay (Table 7.2). However, silt / clay was the most prevalent substrate type and could be transported downstream if discharges from the Resort increase flow.

The sediment quality in Yorkeys Creek was generally below applicable ISQG-low trigger values, except for concentrations of antimony, chromium and nickel (Table 7.2). The concentration of nickel was above the ISQG-high trigger value at site 1. The concentration of nitrogen was below laboratory limits of reporting. The concentration of phosphorus was similar to concentrations in Half Moon and Thomatis / Richters Creeks. The concentrations of all other parameters (e.g. BTEX, TPH, herbicides and pesticides known to be used in the region) were below laboratory limits of reporting. The ISQG low trigger value is a trigger for further investigation: to determine whether antimony, chromium and nickel are having an adverse effect on aquatic ecosystems, further investigations are required, particularly for nickel which was above the ISQG-high trigger value where biological effects are expected to occur more frequently (Simpson et al. 2005).

Table 7.2 Sediment quality in Yorkeys Creek.

Parameter	Units	ISQG-low Trigger Value	ISQG-high Trigger Value	Site 1
Particle Size Distribution				
pebble	%	–	–	0
gravel	%	–	–	38
sand	%	–	–	14
silt / clay	%	–	–	48
Nutrients				
nitrogen	mg/kg	–	–	<0.1
phosphorous	mg/kg	–	–	473
organic carbon	%	–	–	37.2
moisture content	%	–	–	127.8
Metals and Metalloids				
aluminium	mg/kg	NA	NA	15555
antimony	mg/kg	2	25	6.1
arsenic	mg/kg	20	70	10.8
cadmium	mg/kg	1.5	10	1
chromium	mg/kg	80	370	357
cobalt	mg/kg	NA	NA	10.9
copper	mg/kg	65	270	17.6
iron	mg/kg	NA	NA	24020
manganese	mg/kg	NA	NA	342
mercury	mg/kg	0.15	1	<0.5
lead	mg/kg	50	220	18.2
nickel	mg/kg	21	52	199

Parameter	Units	ISQG-low Trigger Value	ISQG-high Trigger Value	Site
				1
selenium	mg/kg	NA	NA	<1
silver	mg/kg	NA	NA	<1
vanadium	mg/kg	NA	NA	31.9
zinc	mg/kg	200	410	53.2

light shading indicates values above ISQG-low trigger values
dark shading indicates values above ISQG-high trigger values
NA not available

7.3 Thomatis / Richters Creek

The sediment in Thomatis / Richters Creek was predominantly silt / clay, with traces of sand (Table 7.3). There was also a small trace of gravel at site 4. However, turbidity and the concentration of total suspended solids in Thomatis / Richters Creek was low and below WQOs, where available. The sediment in Thomatis / Richters Creek is likely to be readily transported in periods of high flow, and turbidity and concentrations of total suspended solids are likely to vary depending on the season.

The sediment quality in Thomatis / Richters Creek was generally below applicable ISQG-low trigger values, except for the concentration of antimony and nickel at site 3 and the concentration of antimony, chromium and nickel at site 4 (Table 7.3). The concentration of nickel was above ISQG-high trigger values at site 4. The concentration of nitrogen was below laboratory limits of reporting. The concentration of phosphorus was similar to concentrations in Half Moon and Yorkeys Creeks, which was likely to be influenced by sugar cane farming and the prawn farm upstream. The concentrations of all other parameters (e.g. BTEX and TPH) were below laboratory limits of reporting. The concentrations of all herbicides and pesticides, known to be used in the region, were also below laboratory limits of reporting. The ISQG low trigger value is a trigger for further investigation: to determine whether antimony, chromium and nickel are having an adverse effect on aquatic ecosystems, further investigations are required, particularly for nickel which was above the ISQG-high trigger value where biological effects are expected to occur more frequently (Simpson et al. 2005).

Exceedence by antimony, chromium and nickel of the ISQG-low trigger values indicates further investigation to determine whether there is likely to be an adverse effect on aquatic, pa (Simpson et al. 2005).

Table 7.3 Sediment quality in Thomatis / Richters Creek.

Parameter	Units	ISQG-low Trigger Value	ISQG-high Trigger Value	Site 3	Site 4
Particle Size Distribution					
pebble	%	–	–	0	0
gravel	%	–	–	0	1
sand	%	–	–	1	6
silt / clay	%	–	–	99	93
Nutrients					
nitrogen	mg/kg	–	–	<0.1	<0.1
phosphorous	mg/kg	–	–	241	128
organic carbon	%	–	–	26.5	22.2
moisture content	%	–	–	70.1	51.7
Metals and Metalloids					
aluminium	mg/kg	NA	NA	9557	17250
antimony	mg/kg	2	25	2.1	3
arsenic	mg/kg	20	70	11.2	12.2
cadmium	mg/kg	1.5	10	0.7	0.9
chromium	mg/kg	80	370	64.8	101
cobalt	mg/kg	NA	NA	8.6	11.5
copper	mg/kg	65	270	9.6	12.8
iron	mg/kg	NA	NA	17850	27190
manganese	mg/kg	NA	NA	625	848
mercury	mg/kg	0.15	1	<0.5	<0.5
lead	mg/kg	50	220	12.2	17.2
nickel	mg/kg	21	52	34.2	54.7
selenium	mg/kg	NA	NA	<1	<1
silver	mg/kg	NA	NA	<1	<1
vanadium	mg/kg	NA	NA	23.9	37.7
zinc	mg/kg	200	410	34.2	51.7

light shading indicates values above ISQG-low trigger values dark shading indicates values above ISQG-high trigger values

NA not available

7.4 Waterbodies on the Proposed Development Site

Sediment composition and quality were analysed at one cane drain (site 10), in the proposed development site. The sediment in the cane drain was dominated by silt / clay with some sand and gravel (Table 7.4). This site is within the proposed man-made lake and construction works would have to mitigate dumping excavated materials to ensure the fine particles are not released into the surrounding environment and downstream waterways.

The sediment complied with all applicable ISQG trigger values, except for the concentration of nickel, which was above the ISQG-low trigger value but below the ISQG-high trigger value (Table 7.4). The concentration of nitrogen was below laboratory limits of reporting and the concentration of phosphorus was similar to concentrations in the creeks surrounding the proposed development site.

The concentrations of all other parameters (e.g. BTEX and TPH) were below laboratory limits of reporting. The concentrations of all herbicides and pesticides, known to be used in the region, were also below laboratory limits of reporting, except for paraquat that had a concentration of 1.3 mg/kg. While detectable, the concentration of paraquat in the sediment was low. As it strongly adsorbs to sediment and is biologically unavailable in that form, it is unlikely to be significantly negatively impacting aquatic ecosystems on the site. Paraquat degrades quickly and does not bio-accumulate, further decreasing any likely risk (Eisler 1990).

Table 7.4 Sediment quality at site 10 on the proposed development site.

Parameter	Units	ISQG-low Trigger Value	ISQG-high Trigger Value	Site 10
Particle Size Distribution				
pebble	%	–	–	0
gravel	%	–	–	1
sand	%	–	–	5
silt / clay	%	–	–	94
Nutrients				
nitrogen	mg/kg	–	–	<0.1
phosphorous	mg/kg	–	–	279
organic carbon	%	–	–	36.3
moisture content	%	–	–	148.9
Metals and Metalloids				
aluminium	mg/kg	NA	NA	12480
antimony	mg/kg	2	25	1.9
arsenic	mg/kg	20	70	5.7
cadmium	mg/kg	1.5	10	<0.5
chromium	mg/kg	80	370	72.8
cobalt	mg/kg	NA	NA	3.7
copper	mg/kg	65	270	13.9
iron	mg/kg	NA	NA	13150
manganese	mg/kg	NA	NA	63.3
mercury	mg/kg	0.15	1	<0.5
lead	mg/kg	50	220	15.6
nickel	mg/kg	21	52	31.4
selenium	mg/kg	NA	NA	<1
silver	mg/kg	NA	NA	<1
vanadium	mg/kg	NA	NA	31.2
zinc	mg/kg	200	410	34.8

light shading indicates values above ISQG-low trigger values

NA not available

7.5 Summary

The sediment quality of the survey area and within the proposed development site is generally in good condition, except for high concentrations of antimony, chromium and nickel, that may be bioavailable to aquatic organisms. High concentrations of antimony, chromium and nickel may be associated with the acid sulphate soils that are known to occur in the area. All other parameters were either below applicable ISQG-low trigger values or below laboratory limits of reporting. While more stable than water quality, sediment quality is likely to very with land-use, climate and season. In particular sediment quality may vary following rainfall in the wet season that may result in erosion from the catchment and deposition of sediment in the waterways. The presence of pesticides, and in particular those with relatively short half lives (Table 4.3) will also vary with farm practices and use of these pesticides.

8 Estuarine Benthic Invertebrates

8.1 Community Composition

Estuarine benthic invertebrate communities were dominated by Capitellid (family Capitellidae) and Spionid (family Spionidae) polychaetes. Other dominant taxa included ghost crabs (family Ocypodidae), Nereid polychaetes (family Nereidae) and gammarid amphipods (suborder Gammaridae). There were low abundances of bivalves and molluscs throughout the survey area.

Spionid polychaetes were the most common and abundant taxa. Spionid polychaetes are common and widespread in soft sediments, often in large numbers (Beesley et al. 2000). Capitellid polychaetes are also commonly recorded and are indicators of organic pollution (Beesley et al. 2000) and may reflect the high concentrations of nutrients in the water and sediment (Sections 6 and 7). The polychaete families Capitellidae and Spionidae have been identified as sensitive indicators of organic enrichment (Tsutsumi 1990; ANZECC & ARMCANZ 2000a). Both Spionid and Capitellid polychaetes occur in high densities in polluted areas and they can recolonise defaunated areas quickly and restore their populations in short periods of time (Tsutsumi 1997). The densities of capitellid polychaetes in environments with high nutrient and organic loads are typically above 1000 individuals per m^2 (Tsutsumi 1990; Hutchings et al. 1993). Such densities are generally indicative of organic enrichment and are used as the trigger values for ANZECC & ARMCANZ guidelines. These populations can also have boom and bust cycles, with very low abundances also typical of nutrient enrichment.

8.2 Half Moon Creek

The mean abundance of estuarine benthic invertebrates was highest at sites in the upper Half Moon Creek subcatchment (sites 6a and 8a) (Figure 8.1). Benthic invertebrates at these sites were dominated by spionid and capitellid polychaetes, with mean abundances over 200 individuals / m^2 at site 6a and mean abundances over 800 individuals / m^2 at site 8a (Figure 8.2), Taxonomic richness was relatively low (Figure 8.3). The mean abundance of crustaceans was high at site 6a in the tributary to Half Moon Creek (Figure 8.4), and was dominated by ghost crabs. Note the larger crustaceans (e.g. crabs) are mobile and are not caught in benthic invertebrate cores.

This abundance and dominance by spionid and capitellid polychaetes in Half Moon Creek may be indicative of nutrient enrichment in this creek (Table 6.2). Nevertheless this indicates that the Half Moon Creek Fish Habitat Area is likely to be a productive foraging ground for fish and of high ecological value. In Half Moon Creek, the abundances of macroinvertebrates were similar to abundances recorded in previous surveys (ALS 2011b).

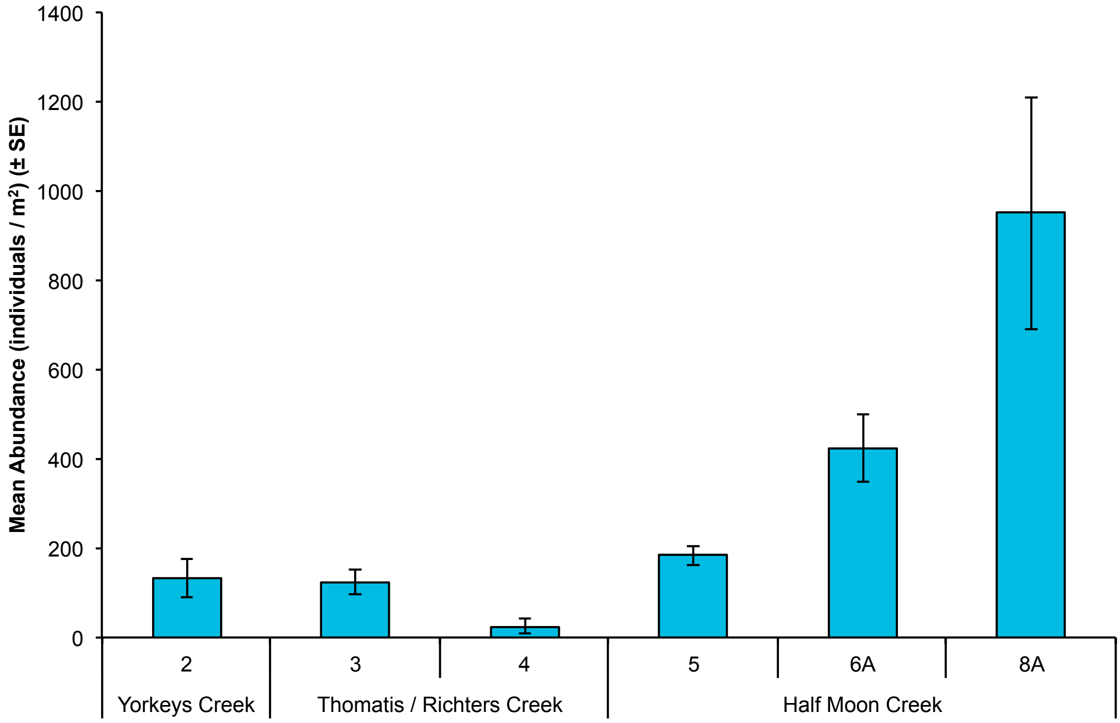


Figure 8.1 Mean abundance (± SE) of estuarine benthic invertebrates at each site.

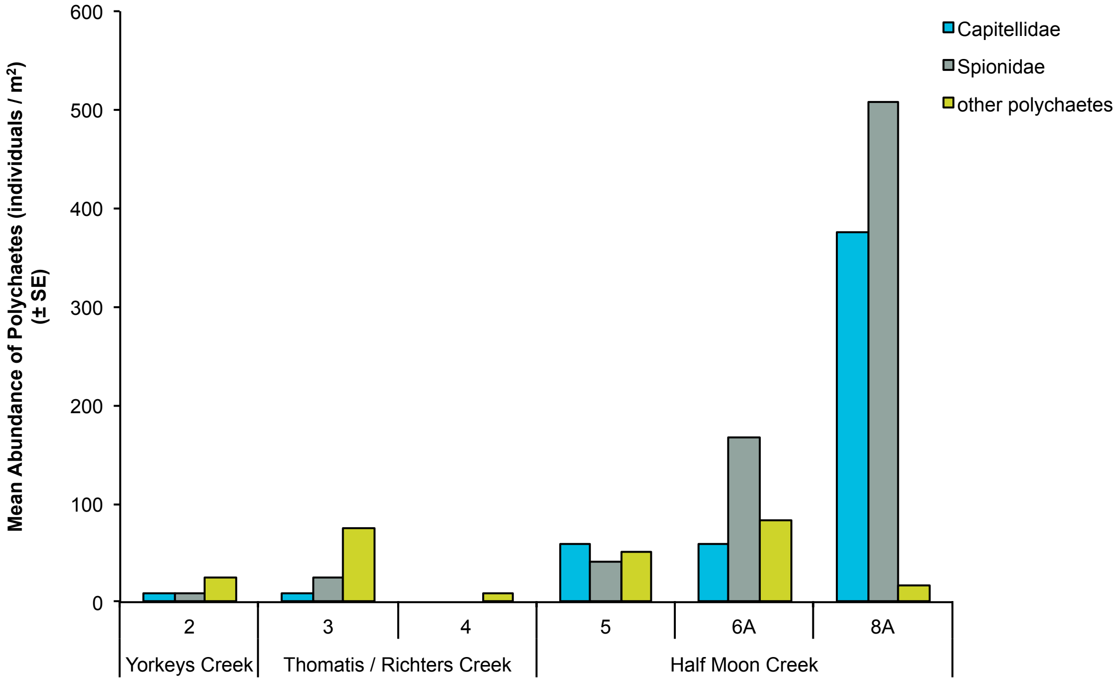


Figure 8.2 Mean abundance of capitellid, spionid and other polychaetes (± SE) at each site.

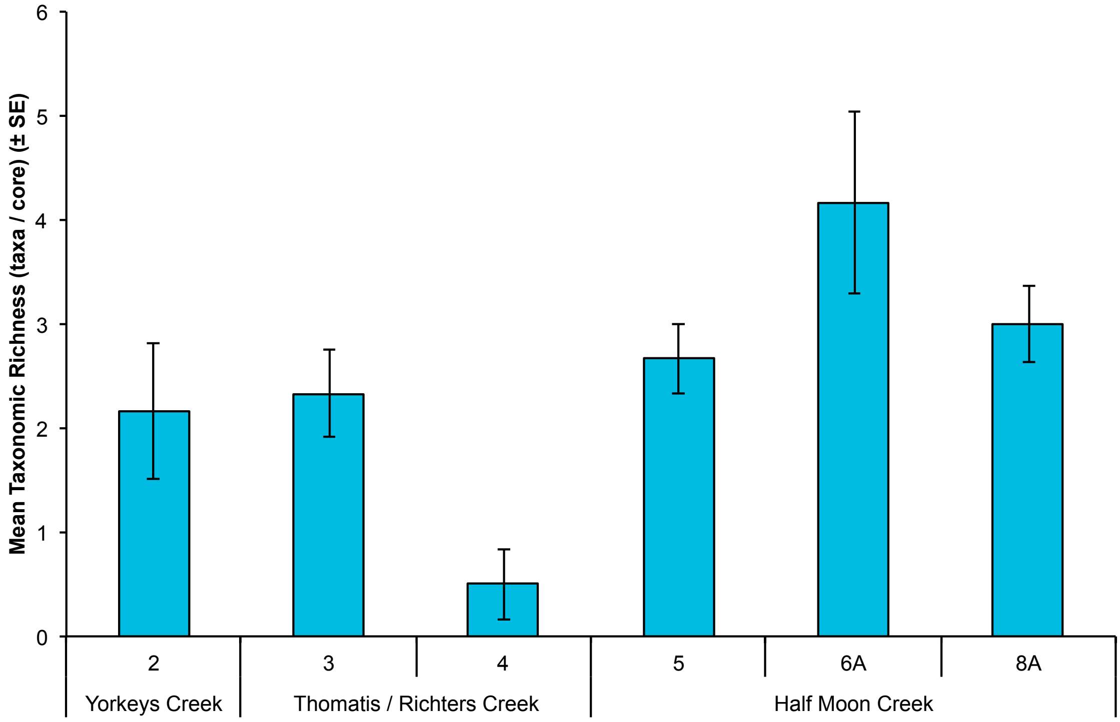


Figure 8.3 Mean taxonomic richness (± SE) of estuarine benthic invertebrates per core at each site.

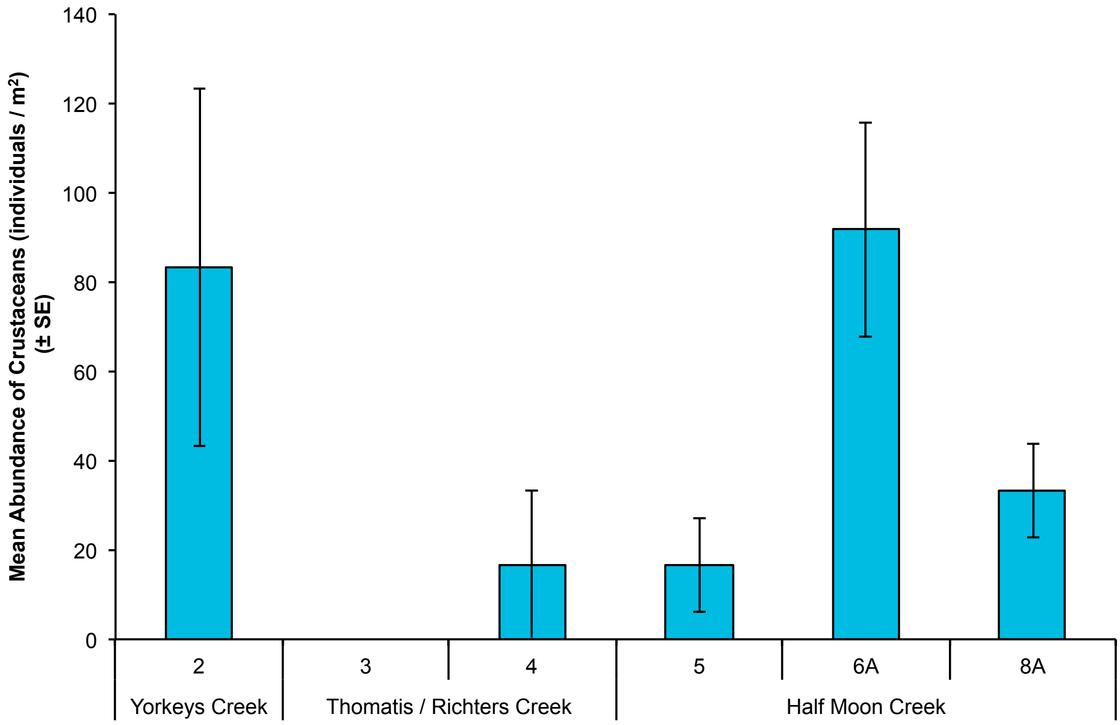


Figure 8.4 Mean abundance of crustaceans (± SE) at each site.

8.3 Yorkeys Creek

The estuarine benthic invertebrate communities in Yorkeys Creek were dominated by polychaete (comprising low abundances of Spionidae, Capitellidae, Goniadidae, Orbinidae and Amphinomidae) and crustacean invertebrates. The relative abundance of polychaetes was much lower in Yorkeys Creek than in Half Moon Creek, indicating nutrient concentrations are likely to be consistently lower in this creek than in Half Moon Creek.

The mean abundance of crustaceans was highest at site 2 in Yorkeys Creek (Figure 8.4) (Figure 8.4). Crustaceans here were dominated by Gammarid amphipods.

While taxonomic richness in estuaries and coastal wetlands is typically low (Levin et al. 2001), it was particularly low in Yorkeys Creek.

8.4 Thomatis / Richters Creek

The abundance of estuarine benthic invertebrate communities was relatively low in Thomatis / Richters Creek. The communities were dominated by polychaetes, and there were also some crustaceans. Polychaete communities comprised the families Goniadidae, Nereididae and Spionidae in low abundances. These three families are commonly found in soft sediment benthos around Australia (Beesley et al. 2000). Only polychaetes from the family Glyceridae were recorded at site 4 (mid Thomatis / Richters Creek). Glyceridae polychaetes are burrowing predatory worms that are widely distributed in soft sediments of Australian coasts (Beesley et al. 2000).

At site 4, crustaceans comprised gammarid amphipods and mysid shrimps, while no crustaceans were caught at site 3 (Thomatis / Richters Creek mouth).

One mollusc was recorded at site 3, while no molluscs were found at site 4.

8.5 Invertebrates of the Open Shore

Shell material together with burrows on the beach to the north of Richters Creek, indicate there is an abundant and diverse infaunal community within the intertidal and shallow subtidal. Occypoid (ghost crab) burrows were observed on the foredunes.

8.6 Summary

Estuarine benthic invertebrate communities were abundant and dominated by polychaetes (families Capitellidae and Spionidae) in Half Moon Creek, particularly in the upstream reaches. This is usually associated with nutrient enrichment and may be associated with the wastewater treatment plant upstream.

Yorkeys and Thomatis / Richter's Creeks had a variety of polychaete families, and did not appear to be influenced by nutrient enrichment.

Diversity of estuarine benthic invertebrates was low in each creek, but this is common in estuarine systems. The abundances of molluscs and gastropods were low. Nonetheless, the communities contribute to the fisheries values within each Fish Habitat Area providing a source of food for fishes.

The distribution and abundance of these communities is likely to vary seasonally, and in particular after major freshwater flows. Freshwater flows may be higher in nutrients and turbidity than in the dry season, which is likely to be reflected in the composition of benthic invertebrate communities. It is consequently recommended these communities are re-surveyed in the wet season.

9 Freshwater Macroinvertebrates

9.1 Community Composition

Freshwater macroinvertebrate communities were dominated by non-biting midge larvae (sub-families Chironominae and Tanypodinae). Non-biting midge larvae are tolerant taxa known to withstand a wide range of environmental conditions and are often found in moderately disturbed ecosystems (Chessman 2003). Other common taxa were:

- caddisflies (family Leptoceridae)
- biting midge larvae (family Ceratopogonidae), and
- mayflies (family Baetidae).

9.2 Taxonomic Richness

The taxonomic richness of macroinvertebrates in bed habitat was similar between each site and ranged from 10 to 12 taxa (Table 9.1).

The taxonomic richness of macroinvertebrates in edge habitat was higher at the smaller freshwater pool (site 1a) than at the man-made dam (site 7a) (Table 9.1). This was likely to be due to the more natural condition of the edge habitat (i.e. exposed roots and high canopy cover) at site 1a.

Table 9.1 Taxonomic richness of macroinvertebrates in bed and edge habitat at each site.

Parameter	Habitat	Site				
		1a	1b	7a	11	12
Taxonomic richness	bed	10	12	11	11	10
	edge	20	–	15	–	–

9.3 Abundance

The abundance of macroinvertebrates was relatively similar between sites and between habitats (Table 9.2). A variety of taxa were abundant at each site. In highly disturbed ecosystems, high abundances are typically due to large populations of one or two families. This indicates that the freshwater waterbodies on-site are in relatively good condition and contain abundant food sources for freshwater fish (i.e. rainbowfish observed on-site).

Table 9.2 Abundance of macroinvertebrates in bed and edge habitat at each site.

Parameter	Habitat	Site				
		1a	1b	7a	11	12
Taxonomic richness	bed	65	73	110	77	60
	edge	117	–	94	–	–

9.4 PET Richness

PET taxa are sensitive to pollutants and changes in water quality and / or environmental degradation. There were no PET taxa at site 12 in bed habitat, while there was a minimum of two taxa at all other sites in bed and edge habitat (Table 9.3). The low PET richness was likely to reflect the brackish nature of these sites (Section 6). The PET richness on-site is similar to the PET richness found in the mid reaches of the Barron River downstream of the Barron Falls (frc environmental 2013).

Table 9.3 PET richness of macroinvertebrates in bed and edge habitat at each site.

Parameter	Habitat	Site				
		1a	1b	7a	11	12
Taxonomic richness	bed	2	2	3	4	0
	edge	3	–	2	–	–

9.5 SIGNAL 2 Score

Total SIGNAL 2 scores varied between sites and between habitats (Table 9.4). Overall, SIGNAL 2 scores were <4 at each site, which is indicative of pollution (EHP 2004). However, low scores may also reflect the harsh physical conditions of ephemeral waterbodies and sites 1a, 1b, 11 and 12 were most likely to be ephemeral as well as the brackish nature of the water (Section 6). The low SIGNAL 2 score at site 7a in both habitats was likely to be due to the waterbody being a man-made dam.

Table 9.4 SIGNAL 2 scores of macroinvertebrate communities in bed and edge habitat at each site.

Parameter	Habitat	Site				
		1a	1b	7a	11	12
Taxonomic richness	bed	3.35	3.46	3.66	3.83	3.27
	edge	2.93	–	3.4	–	–

9.6 SIGNAL 2 / Family Bi-plot

SIGNAL 2 / family bi-plots cannot be determined for bed habitat. In edge habitat, site 1a was in quadrant 2, which is indicative of high salinity or nutrient levels (that may be natural), which were recorded at this site (Section 6). Site 7a was in quadrant 4, which is indicative of urban, industrial or agricultural pollution. The SIGNAL 2 / family bi-plots reflect the highly modified systems on the proposed development site.

9.7 Summary

Freshwater macroinvertebrate communities were dominated by non-biting midge larvae, which are tolerant of changes in water quality and disturbances. Abundances and taxonomic richness were relatively good at each site and PET richness was >2 at each site, except at site 12. SIGNAL 2 scores and the SIGNAL 2 / family bi-plot indicated that sites were likely to be influenced by high concentrations of nutrients (natural and anthropogenic) and / or urban and agricultural pollution, which was not unexpected given that each site was close to operational sugar cane farms. The water and sediment quality had high concentrations of nutrients (Sections 6 and 7) and were likely to be influencing macroinvertebrate community compositions.

10 Legislative Implications and Constraints Relevant to Aquatic Ecology

10.1 Commonwealth's *Environmental Protection and Biodiversity Conservation Act 1999:*

Matters of National Environmental Significance

Any actions that are likely to have a significant impact on a matter of national environmental significance are subject to assessment under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* [2] (EPBC Act) approval process. The nine matters of national environmental significance protected under the EPBC Act are:

- world heritage properties
- national heritage places
- wetlands of international importance (listed under the Ramsar Convention)
- threatened species and ecological communities
- migratory species protected under international agreements
- Commonwealth marine areas
- the Great Barrier Reef Marine Park
- nuclear actions (including uranium mines) , and
- a water resource in relation to coal seam development and large coal mining development.

Nuclear actions and coal seam gas water resources are not relevant to this development.

World Heritage Properties

Australia is signatory to the international "Convention Concerning the Protection of the World Cultural and Natural Heritage", adopted by UNESCO in 1972. The World Heritage

[2] Act no. 91 of 1999 as amended, prepared on 25 June 2013 taking into account amendments up to Act No. 60 of 2013. Prepared by the Office of the Parliamentary Counsel, Canberra.

Committee is responsible for implementation of this Convention. The World Heritage List denotes properties forming part of the cultural and natural heritage that the World Heritage Committee considers as having outstanding universal values.

Properties that have been inscribed on the World Heritage list are automatically declared World Heritage properties and are protected under the EPBC Act.

There are two World Heritage properties within 10 km of the proposed development site, the:

- Wet Tropics of Queensland, and the
- Great Barrier Reef.

The Wet Tropics of Queensland is one of the largest rainforest wilderness areas in Australia comprising fringing coral reefs and rainforest coastline. The Wet Tropics of Queensland is approximately 5 km upstream of the proposed development site. The aquatic ecology of this area is not expected to be impacted by the proposed development.

The Great Barrier Reef World Heritage Area (GBRWHA) covers approximately 348 000 km^2. The landward boundary is generally the coastline of Queensland at low water, and this is the case adjacent to the proposed development site. Water from the proposed development would flow downstream directly into the GBRWHA. The Great Barrier Reef Marine Park Authority has identified the declining quality of water entering the Great Barrier Reef as a major threat to the reef ecosystem.

The Great Barrier Reef was inscribed in 1981 as a World Heritage Area for all four of the natural criteria specified in the World Heritage Convention. That is, it:

- contains superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance
- is an outstanding example representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features
- is an outstanding example representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals, and
- contains the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

While climate change is the most significant long term challenge to this World Heritage Area, declining water quality from land-based sources, loss of coastal habitat from coastal development are also recognised as priority issues for management of this area (GBRMPA 2009a).

National Heritage Places

National heritage places include natural, historic and indigenous places of outstanding heritage and value. There are currently 107 sites listed on the register of national heritage places, which include the World Heritage properties.

The only natural heritage places in the vicinity of the proposed development site are the Wet Tropics of Queensland and the Great Barrier Reef.

Wetlands of International Importance (Ramsar Wetlands)

The EPBC Act regulates actions that will, or are likely to, have a significant impact on the ecological character of a Ramsar wetland (wetlands of international importance). This includes relevant actions that occur outside the boundaries of a Ramsar wetland. The closest Ramsar wetland is Bowling Green Bay, which is approximately 300 km south of the proposed development site. The Coral Sea Reserves Ramsar wetland is approximately 500 km east of the proposed development site on the outer reaches of the Great Barrier Reef.

Listed Threatened Aquatic Ecological Communities and Species

Any action that is likely to have a significant impact on listed threatened species or ecological communities under the EPBC Act must be referred to the Minister and undergo an environmental assessment and approval process. Threatened species that trigger this include extinct in the wild, critically endangered, endangered and vulnerable species. Species that are listed as conservation dependent or extinct are not matters of national environmental significance and do not trigger the EPBC Act.

Two search tools were used to determine which listed threatened aquatic ecological communities and species may occur within 5 km of the proposed development site: the online Protected Matters Search Tool for Commonwealth protected species (DSEWPC 2013b) and Queensland's EHP *Wildlife Online* search tool (EHP 2013d). These species are listed in Table 12.2.

Marine Species

Listed marine species are protected under the EPBC Act where they are found in Commonwealth Marine Waters. In general, Commonwealth Marine Areas extend from 3 nautical miles from the coast to the boundary of the Exclusive Economic Zone (200 nautical miles from the coast).

All fish from the families Syngnathidae (seahorses, seadragons and pipefish) and Solenostomidae (ghost pipefish) are listed marine species under the EPBC Act. A number of the seahorse, pipefish and pipehorse species that are listed under the Act are likely to occur downstream of the proposed development site (DEWHA 2009a). As listed marine species, they are only protected under the EPBC Act where they are found in Commonwealth Marine Waters; and are not protected under the EPBC Act in the state waters downstream of the proposed development site.

Other marine species recorded as likely to occur within 5 km of the proposed development site on the online Protected Matters Search Tool for Commonwealth protected species (DSEWPC 2013b) and Queensland's EHP *Wildlife Online* search tool (EHP 2013d) are listed in Table 12.2.

Migratory Species

Many migratory species listed under international conventions and agreements that Australia is party to are protected under the EPBC Act. Aquatic migratory species recorded as likely to occur within 5 km of the proposed development site on the online Protected Matters Search Tool for Commonwealth protected species (DSEWPC 2013b) and Queensland's EHP *Wildlife Online* search tool (EHP 2013d) are listed in Table 12.2.

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.

Commonwealth Marine Areas

Commonwealth marine areas are matters of national environmental significance under the EPBC Act, and include marine waters from the boundary of state coastal waters (3 nautical miles) to 200 nautical miles from the coast. Marine and cetacean species are listed as occurring within 5 km of the proposed development site in the online Protected Matters Search Tool for Commonwealth protected species.

An action is likely to have a significant impact on the environment in a Commonwealth marine area if there is a real chance or possibility the action will:

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

Great Barrier Reef Marine Park

Actions that may have a significant impact on the Great Barrier Reef Marine Park are regulated under the EPBC Act. The proposed development site is near the Great Barrier Reef Marine Park and is discussed in Section 10.2.

10.2 Commonwealth's *Great Barrier Reef Marine Park Act 1975*

The *Great Barrier Reef Marine Park Act 1975* is the primary Act with respect to the Great Barrier Reef Marine Park. It includes provisions that establish the Great Barrier Reef Marine Park and the Great Barrier Reef Marine Park Authority (GBRMPA), who are responsible for managing the Marine Park. The Act provides a framework for planning and management, including through zoning plans, plans of management and a system of provisions. The Great Barrier Reef Marine Park Zoning Plan 2003 ensures that the protection of habitat types by defining activities that can occur at each location. Waterways surrounding the proposed development site are in the Cairns / Cooktown Management Area (Map 130702MPa).

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 areas in the vicinity of the proposed development site are within preservation zones. The closest preservation zone in the Cairns / Cooktown Management Area is around Euston Reef, approximately 60 km east.

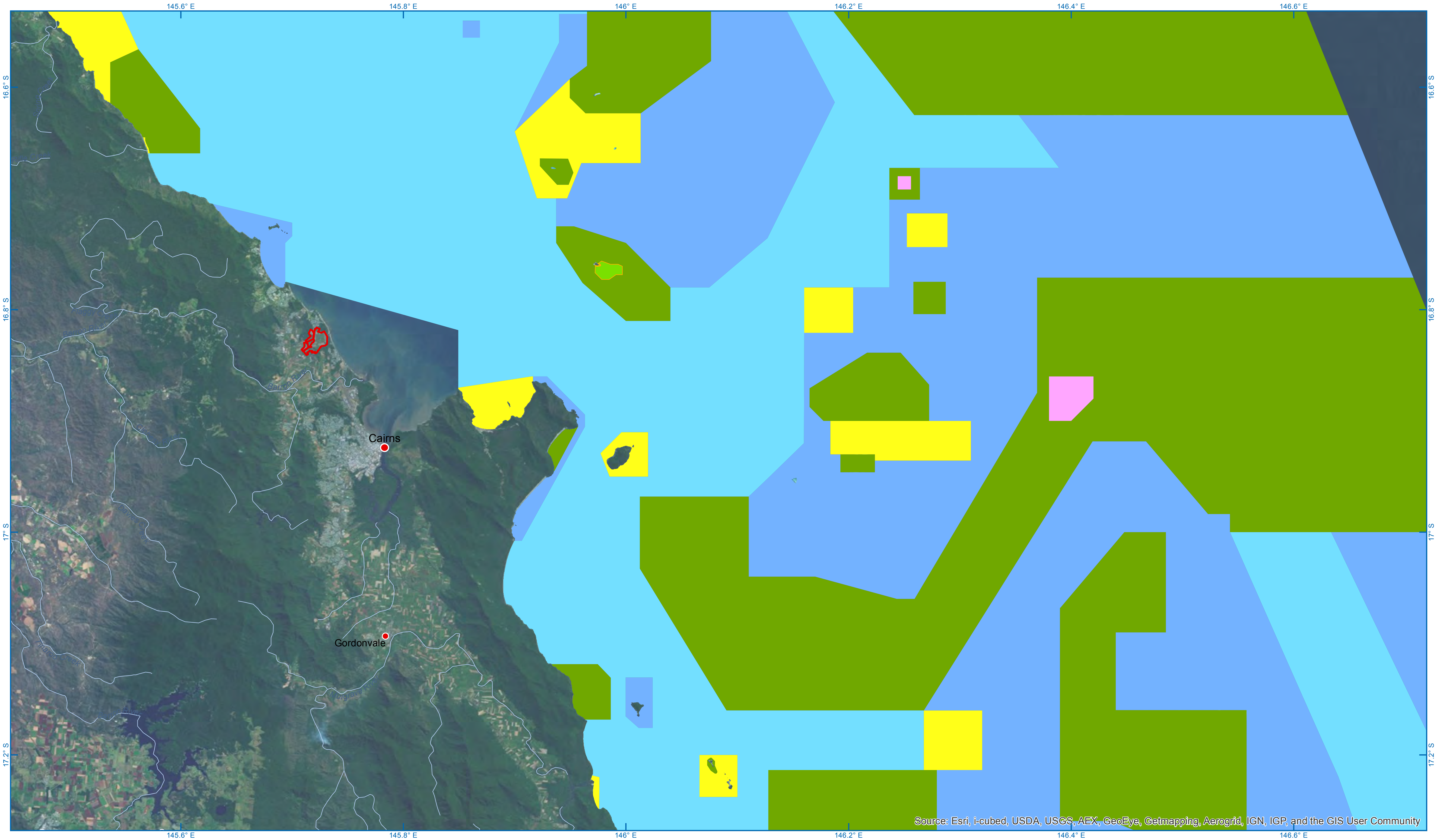
The next highest level of protection is the marine national park zone (green). This zone protects biodiversity in the Great Barrier Reef Marine Park by protecting important breeding and nursery areas, such as important seagrass beds, mangrove communities, deep-water shoals and reefs. This includes no-take areas, and while anchoring is allowed in this zone, an established mooring may be required in high use and sensitive areas. The closest marine national park areas to the proposed development are:

- Green Island National Park, located approximately 20 km east
- Unity Reef National Park, located approximately 20 km north.

The next level of protection is the conservation park zone (yellow). This zone provides protection and conservation, while providing reasonable opportunities for enjoyment and use of the area. Mission Bay, approximately 18 km to the south-east, is the closest conservation park.

To the north of Yorkeys Knob around Cook Bay and Double Island, 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 Great Barrier Reef Marine Park 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.



frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702MP:
Commonwealth Great Barrier Reef Marine Park Zones
located close to Aquis Resort

SOURCES

© Copyright Commonwealth of Australia (Geoscience Australia) 2001, 2004
Sourced from http://www.ga.gov.au/meta/ANZCW0703005241.html#distinfo. Australian boundary, roads, locations
© The State of Queensland (Department of Natural Resources and Mines) 2013 Updated data available at http://dds.information.qld.gov.au/dds/. Coastline, Waterways
© Commonwealth of Australia, Australian Government Department of Sustainability, Environment, Water, Population and Communities 2012. All rights reserved.
Sourced from http://www.environment.gov.au/webgis-framework/apps/pmst/pmst.jsf. Great Barrier Reen Marine Park

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_GBRMPA_fed_map_13-08-29_CF.mxd

LEGEND

Site Boundary
Watercourse

GBRMPA Zones 2003

General Use
Habitat Protection
Conservation Park
Scientific Research
Marine National Park
Preservation

N

SCALE

0 5 10 20
Kilometres

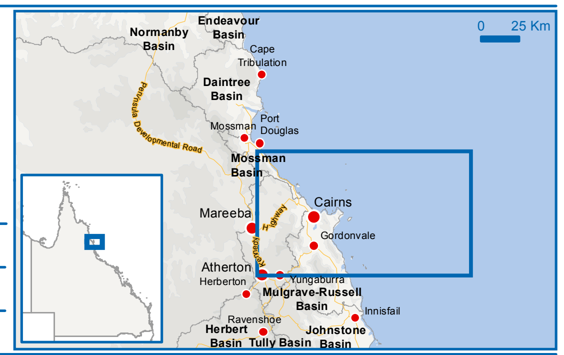
Scale: 1:350,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL

VERSION
03



10.3 Queensland's *Marine Parks Act 2004*

The Great Barrier Reef Marine Park is declared and protected under the:

- Marine Park Act 2004[3]
- Marine Park (Declaration) Regulation 2006[4], and
- Marine Parks Regulation 2006[5].

Management is jointly shared between the Commonwealth GBRMPA and the State Queensland Parks and Wildlife Service, which work together to ensure consistent zoning. A permit from GBRMPA will also cover the state marine park.

The Great Barrier Reef Coast Marine Park is a state marine park protected under the *Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004*. In general, it provides protection of areas of the Great Barrier Reef Marine Park from the edge of state coastal waters up to the highest astronomical tides, therefore protecting tidal lands and waters. The Great Barrier Reef Coast Marine Park Zoning Plan ensures the protection of habitat types by defining activities that can occur at each location (Map 130702MPb) (DNPRSR 2013).

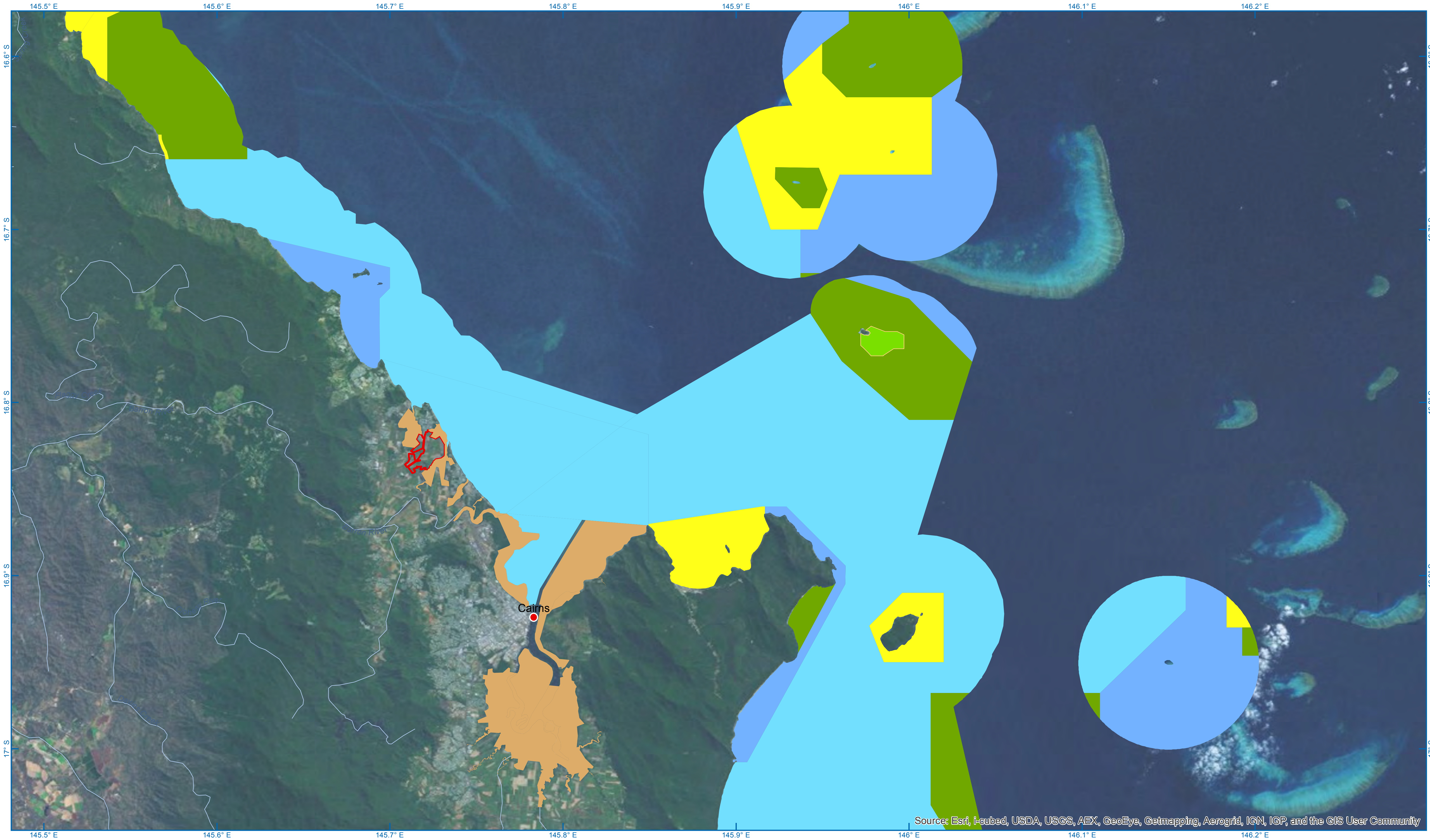
The waters adjoining the proposed development site are in an estuarine conservation zone (brown). This zone provides for the protection of areas in a natural state while allowing the public to appreciate and enjoy relatively undisturbed nature, maintaining fisheries production and use and providing for traditional hunting and gathering. The waters adjacent to the site from high water to the GBR boundary are in the General Use (Blue Zone; Map 130702MPb). A permit from the Department of National Parks, Recreation, Sport and Racing will be required to construct works in this Zone.

---

3 Reprinted as in force on 12 November 2012. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

4 Reprinted as in force on 18 December 2009. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

5 Reprinted as in force on 10 May 2013. Reprint prepared by the Office of the Queensland Parliamentary Counsel.



frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702MP:
State Great Barrier Reef Marine Park Zones
located close to Aquis Resort

SOURCES

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_GBRMPA_map_13-08-29_CF.mxd

LEGEND

Site Boundary
Watercourse

GBRMP Zones

Conservation Park Zone
Estuarine Conservation Zone
General Use Zone
Habitat Protection Zone
Marine National Park Zone
Scientific Research Zone

N

SCALE

0 5 10
Kilometres

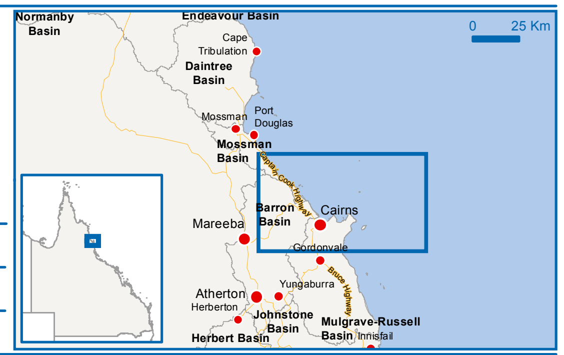
Scale: 1:225,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL

VERSION
03



10.4 Queensland's *Fisheries Act 1994*

All waters of the state are protected against degradation by direct or indirect impact under section 125 of the *Fisheries Act 1994* (Fisheries Act) [6]. 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 Agriculture, Fisheries and Forestry (DAFF) may issue a notice requiring the person suspected of causing the pollution to take action to redress the situation.

Waterway Barriers

Under Division 8 of the Fisheries Act, a waterway barrier works approval is needed to build any structure across a freshwater waterway. The purpose of this part of the Act is to provide a balance between the need to construct dams and weirs and the need to maintain fish movement. Such structures include culverts and road crossings, which will be constructed as a part of the Project. If approval is given for the Project to proceed, the Chief Executive may direct the building of a specified fishway for the barrier.

To obtain an approval, an application must be made to Fisheries Queensland, part of DAFF, and lodged with the required fees. An assessment is undertaken by Fisheries Queensland staff to see whether or not an approval should be issued and if a fishway is required to be built with the structure. To assess the requirements for a fishway on a proposed structure, the following is considered:

- Are there fish in the waterway that need to move across the site of the waterway barrier works?
- Are there habitats upstream and / or downstream of the proposed works that the fish need to move into?
- What are the effects of existing barriers (natural or man-made) up or downstream of the site of the waterway barrier works?
- Will the drown-out characteristics of the proposed waterway barrier works allow adequate fish passage?
- Can a fishway be incorporated into the proposed works?

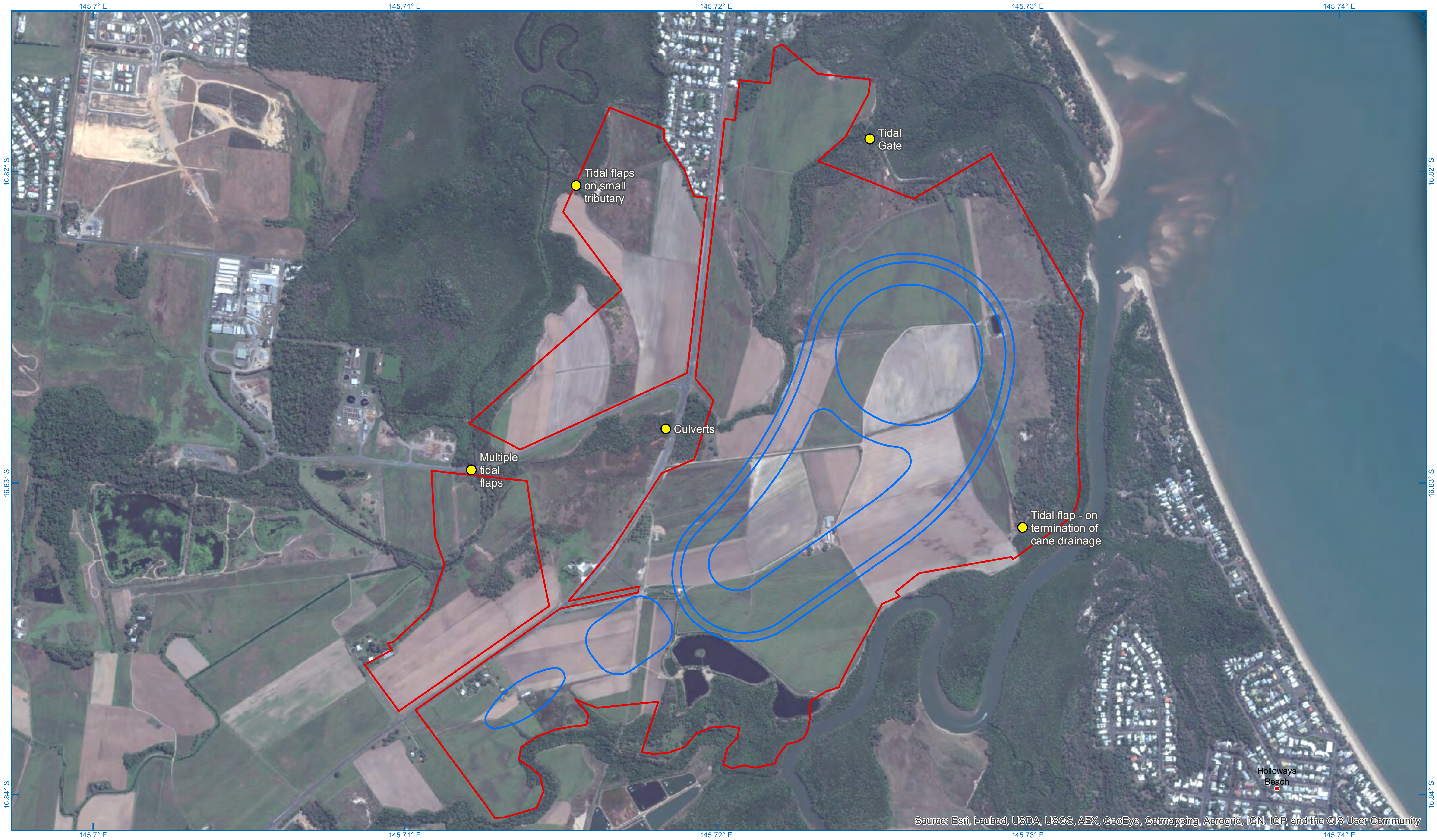
---

6 Reprint No. 7 as in force on 22 November 2012. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

When a fishway is required, Fisheries Queensland has developed a standard design process that ensures both biologists and engineers are involved in developing the fishway design. Once the fishway is built, monitoring is required to confirm that the fishway is effective, or to identify any adjustments needed.

Waterway barriers include dams, weirs or any other barrier that limits fish access and movement along a waterway. The construction and raising of a waterway barrier is classed as operational works under the *Sustainable Planning Act 2009* (SPA), and requires approval. Infilling the upper portions of Yorkeys Creek is a waterway barrier work. Several waterway barriers currently exist in the survey area and are detailed in Map 130702SMb.

The provision of effective fish passage will be required for this project where waterway barriers (temporary or permanent) will be installed. The construction or raising of a waterway barrier may be either assessable or self-assessable development, depending on the nature of works and the location of the works. This would be determined at the detailed design phase of the project.



frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702SMb:
Preliminary map of waterway barriers on and adjacent to the proposed Aquis Resort

SOURCES

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_barriers_map_13-08-13_1000_CAC.mxd

LEGEND

- Observed Waterway Barriers
- Site Boundary
- Project Area

N

SCALE

0 100 200 400 600
Metres

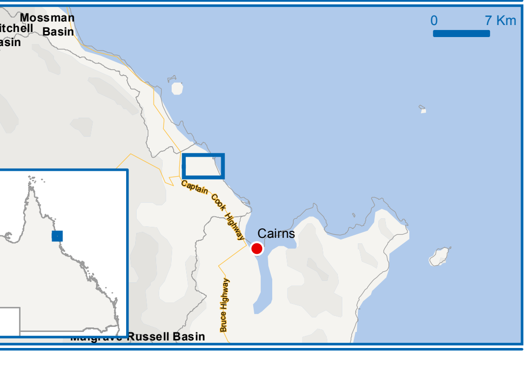
Scale: 1:12,500 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL, CF

VERSION
04



Non-indigenous Fish

Under the Fisheries Regulation 2008, 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). Some exotic non-indigenous fish from other countries can be kept without a permit as long as they cannot escape into the local waterways.

Declared Noxious Fish

Declared noxious species are listed under the Fisheries Regulation 2008[7]. 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). Mosquitofish and tilapia are declared noxious species that may occur in waterways on the proposed development site (Section 4.5). Mosquitofish were observed in the current survey.

Fish Habitat Areas

Fish Habitat Areas are declared under the Fisheries Act to enhance existing and future fishing activities and to protect the habitat for fish and other fauna. They mainly 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 fish habitat areas, any works or activities that may disturb habitats within a fish habitat area, require a specific permit under the provisions of the Fisheries Act.

Each declared Fish Habitat Area 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 the level A Fish Habitat Areas.

---

[7] Reprint No. 3G, Reprinted as in force on 1 July 2013. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

There are four Fish Habitat Areas in the vicinity of the project area:

- Barr Creek (FHA-035), Management level B
- Half Moon Creek (FHA-033), Management level B
- Trinity Inlet (FHA-003), Management level A, and
- Yorkeys Creek (FHA-034), Management level B (Map 130702FHA).

The Barr Creek Fish Habitat Area covers 64 hectares and is approximately 2 km south-east of the proposed development site. The Half Moon Creek Fish Habitat Area covers 216 hectares and is directly west of Yorkeys Knob township and borders the proposed project site. The Trinity Inlet Fish Habitat Area is 7212 hectares and is approximately 8 km south-east of the proposed project site. The Yorkeys Creek Fish Habitat Area covers 117 hectares and is adjacent to the proposed development site.

Both Half Moon Creek and Yorkeys Creek are Management Level 'B' Fish Habitat Areas. Permanent public and private structures that are assessed as having an overriding requirement to be on tidal land or within the FHA may be authorised subject to assessment. A resource allocation authority (RAA) issued under the Fisheries Act will be required for any structures or disturbance in these areas, as well as development approval with referral to Queensland Fisheries.

There are two Fish Habitat Areas downstream of, and on the boundary of the proposed project site, which are the:

- Yorkeys Creek Fish Habitat Area, and
- Half Moon Creek Fish Habitat Area.

The Fish Habitat Areas have high fisheries value and support a range of fishing, including barramundi (*Lates calcarifer*), queenfish (*Seriphus politus*) and tiger prawns (*Penaeus monodon*). Yorkeys Creek Fish Habitat Area incorporates both Yorkeys and Thomatis / Richters Creeks. The aquatic habitat is considered ideal for fisheries production comprising mangrove lined banks, woody debris and deep pools.

frc environmental
AQUATIC ECOLOGISTS
deep thinking.science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702FHA:
Fish Habitat Areas
located close to Aquis Resort

SOURCES

© Copyright Commonwealth of Australia (Geoscience Australia) 2001, 2004
Sourced from http://www.ga.gov.au/meta/ANZCW0703005241.html#distinfo. Australian boundary, roads, locations
© The State of Queensland (Department of Natural Resources and Mines) 2013
Updated data available at http://dds.information.qld.gov.au/dds/. Coastline, Waterways
© The State of Queensland (Department of National Parks, Recreation, Sport and Racing) 2011
Updated data available at http://dds.information.qld.gov.au/dds/. Queensland fish habitat areas

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_FHA_map_13-08-29_CF.mxd

LEGEND

Site Boundary
Project Area
Watercourse
Fish Habitat Area A
Fish Habitat Area B

N

SCALE

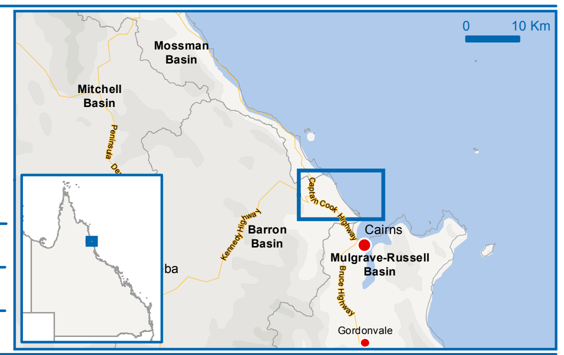
0 0.5 1 2
Kilometres
Scale: 1:40,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL

VERSION
02



Marine Plants

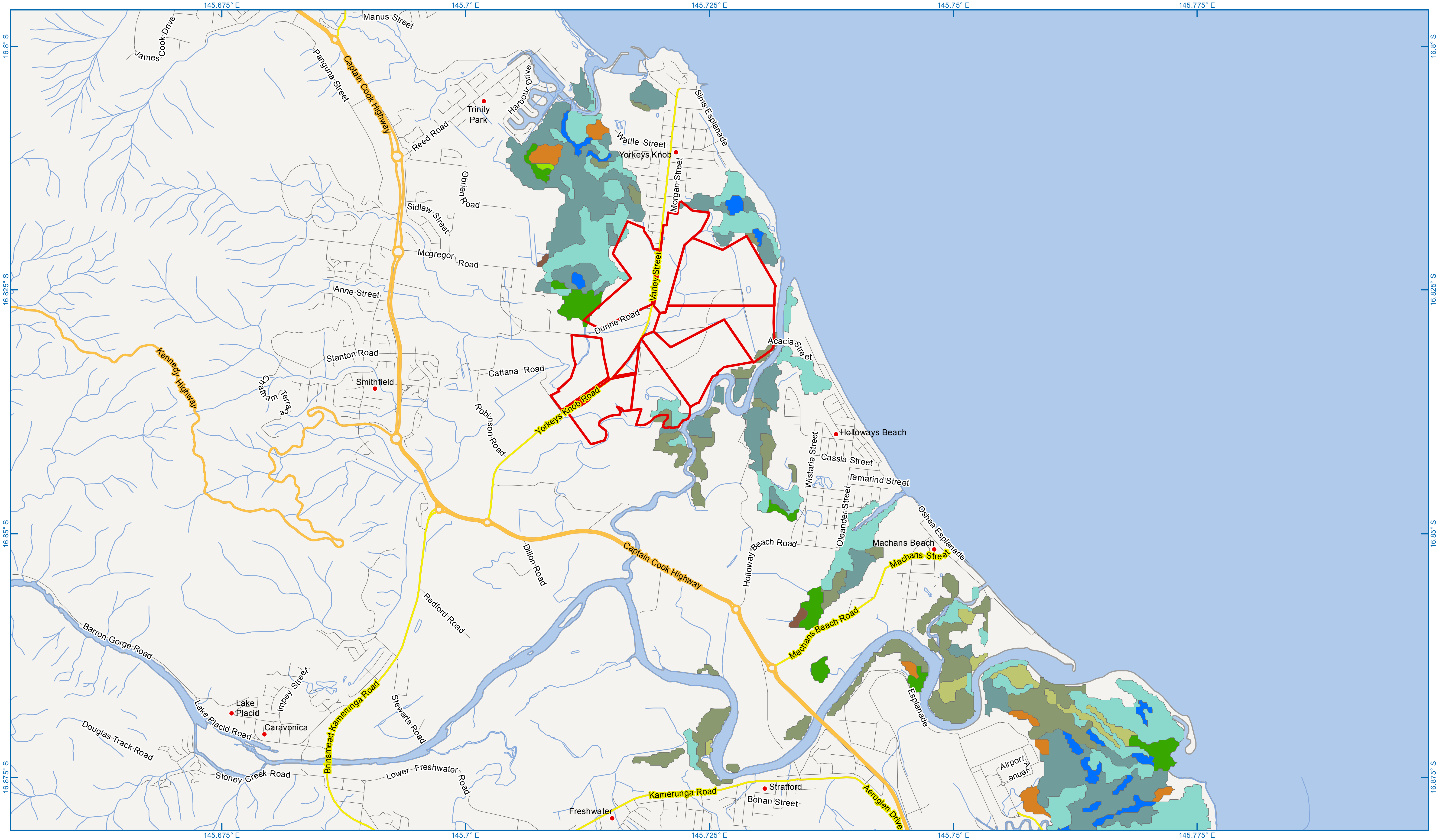
Marine plants are protected under the Fisheries Act. Under this Act marine plants include:

- a plant that usually grows on or adjacent to tidal land, whether living, dead, standing or fallen
- material of 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 level (Couchman & Beumer 2002).

Marine plants include macro- and microscopic plants such as mangroves, seagrass, samphires, saltcouch and saltmarsh plants, algae and other tidal plants growing next 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 (i.e. shelter, foraging and nurseries) for fish and invertebrates (Connolly 1999). 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 in the vicinity of the project area (Map 130702MA). Except for the freshwater dams and pools on the site, all other waterways on the site downstream of site 13 (Map 130702SM) are brackish and appear to be tidally inundated. Consequently, vegetation associated with these waterways is classed as marine plants under the Fisheries Act, and permission will be required to disturb it. Disturbance of marine plants off-site on unallocated state land will require an RAA. The distribution of mangrove and saltmarsh communities on the proposed development site is presented in Biotropica Australia (2013).



frc environmental
AQUATIC ECOLOGISTS
deep thinking.science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702Ma:
Mangrove communities on and near
the proposed Aquis Resort

SOURCES

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_coastal_wetlands_and_lot_CHRIS_map_13-11-22_AM.mxd

LEGEND

Coastal Wetlands
- Closed Avicennia
- Closed Bruguiera
- Closed Ceriops
- Closed Mixed
- Closed Rhizophora
- Open Avicennia
- Saltpan
- Samphire-dominated Saltpan
- Water and Terrestrial

- Lot Boundary
- Watercourse

Road Network
- Highway
- Main Road
- Local Road

N

SCALE

0 0.5 1 2
Kilometres

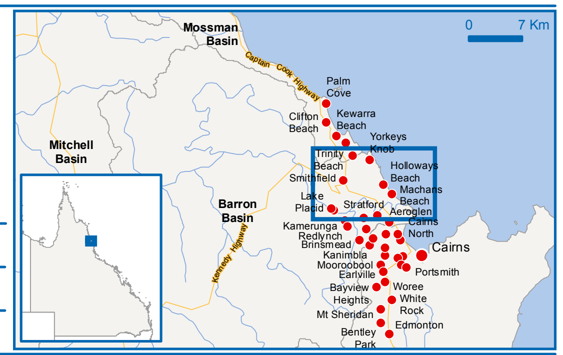
Scale: 1:40,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-12-03

DRAWN BY
CF, AM

VERSION
02



10.5 Queensland's *Nature Conservation Act 1992*

Native flora and fauna species are protected in Queensland under the *Nature Conservation Act 1992*[8]; extinct in the wild, endangered, vulnerable, near threatened and least concern species are listed in the Nature Conservation (Wildlife) Regulation 2006 [9] (NCWR) (Table 12.2, Section 10.1).

There are five aquatic fauna species listed as vulnerable recorded downstream of the proposed development site:

- humpback whale
- green turtle
- hawksbill turtle
- flatback turtle, and
- salt water crocodile.

There are three aquatic fauna species listed as endangered recorded downstream of the proposed development site:

- loggerhead turtle
- leatherback turtle, and
- olive ridley turtle.

10.6 Queensland's *Land Protection (Pest and Stock Route Management) Act 2002*

The *Land Protection (Pest and Stock Route Management) Act 2002* (the Land Protection Act) [10] provides a framework for improved management of weeds, pest animals and the

---

8 Reprinted as in force on 30 June 2013. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

9 Reprinted as in force on 27 July 2012. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

10 Reprinted as in force on 5 April 2013. Prepared by the Office of the Queensland Parliamentary Counsel.

stock route network. Declared noxious weeds in Queensland are listed under the Land Protection (Pest and Stock Route Management) Regulation 2003[11].

Class 1 declared pests are uncommon in Queensland, and if introduced, are likely to have adverse economic, environmental or social impacts. Class 1 pests established in Queensland must be eradicated from the state.

Class 2 and 3 declared pests are established in Queensland and have, or could have, adverse economic, environmental or social impacts. Landowners must take all reasonable steps to keep their land free from Class 2 pests. Landowners are not required to remove Class 3 pests, unless their land is next to an environmentally significant area, which is not the case for the project area. Declared aquatic plant pest species known to occur in the region are:

- cabomba (*Cabomba caroliniana*) a Class 2 pest
- hymenachne (*Hymenachne amplexicaulis*) a Class 2 pest, and
- salvinia (*Salvinia molesta*) a Class 1 pest (DSEWPC 2013b).

No declared aquatic plant pest species were observed in the field surveys.

10.7 Queensland's *Environmental Protection Act 1994*

The *Environmental Protection Act 1994* (EP Act) [12] is the key legislation for environmental management and protection in Queensland. The EP Act establishes a general environmental duty, and a duty to notify 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 that 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) [13].

---

[11] Reprinted as in force on 1 July 2013. Prepared by the Office of the Queensland Parliamentary Counsel.

[12] Reprinted as in force on 1 July 2013. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

[13] Reprinted as in force on 29 June 2012. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

Environmental Protection (Water) Policy 2009

The EPP Water was established to protect Queensland waters while allowing for ecologically sustainable development. The purpose of the policy is to identify environmental values for aquatic ecosystems and for human uses; and determine water quality guidelines and water quality objectives (WQOs) to protect environmental values.

Environmental values (EVs) and WQOs have been established for many waterways in Queensland under Schedule 1 of the EPP Water. The EPP Water defines an indicator for an environmental value 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 environmental value and are generally developed based on the review of the available site-specific information relevant to each environmental value.

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

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

Specific environmental values and WQOs have not been prescribed for the Barron Basin, but submissions to the Department of Environment and Heritage Protection closed on 15 July 2013 (DEHP 2013). Therefore, the environmental values and WQOs of waterways in the Barron Basin should currently be considered by addressing water quality guidelines. Local guidelines can also be determined by the selection of appropriate reference sites to represent the aquatic habitats found within the survey area, and calculating 20th and 80th percentile values for each water quality parameter, to form the basis of the trigger levels (DERM 2009). For the purposes of this report the following documents were referred to for the appropriate environmental values and WQOs for the Barron Basin:

- the Queensland Water Quality Guidelines (QWQG) (DERM 2009), and
- the Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters (ANZECC & ARMCANZ guidelines) (ANZECC & ARMCANZ 2000a).

Summary of Aquatic Ecological Values

The following EVs were identified for the study area:

- ecosystem (slightly to moderately disturbed)
- secondary recreation
- visual recreation
- suitability for irrigation, and
- suitability for farm use.

Based on our field survey, other EVs that apply to the lowland freshwaters of the catchments, such as stock water, human consumers and primary recreation, did not apply.

The biological values of aquatic ecosystems within the creeks surrounding the proposed development site are moderate to good and consistent with those of the wider catchment. Environmental values are dictated primarily by the intermittent and perennial nature of the region's waterways; although sugar cane farming and residential developments within the region have influenced water quality and the physical characteristics of aquatic habitats. Creeks in the catchment are generally in moderate condition and are characterised by low habitat diversity, tidal gates and flaps that restrict passage of fish and other aquatic fauna and invasion of terrestrial weed species, features shared by the creeks within the study area.

Physical water quality in the survey area was moderate with most parameters below applicable WQOs (Section 6). Biodiversity was relatively low, with only macroinvertebrate species that are tolerant of varying and often harsh conditions dominating communities in the study area (Sections 8 and 9). Aquatic plant cover (excluding mangroves) was nil to low at most sites and no seagrass was observed in the survey. Overall, aquatic ecosystems were in moderate condition. Nevertheless, the creeks next to the proposed development site provide dispersal habitat for fish species and possibly breeding habitat for some species.

Queensland Water Quality Guideline

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

2009). In this report the guideline values for the wet tropics region were used to set preliminary water quality objectives (WQO) and assess water quality data.

Australian Water Quality Guidelines for Fresh and Marine Waters

The ANZECC & ARMCANZ (2000a) 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 2000a). The guideline values refer to physical and chemical stressors, toxicants and biological indicators (biological indicators such as macroinvertebrates are discussed in the aquatic ecology technical report).

10.8 Queensland's *Water Act 2000*

The purpose of the *Water Act 2000* (Water Act) [14] is to provide for the sustainable management of water and other resources. The project may require approvals under the Water Act for the construction, control and management of works with respect to water conservation and protection, drainage, supply, flood control and prevention. Under Section 269 of the Water Act, a riverine protection permit is required to:

- remove vegetation in a watercourse, lake or spring
- excavate in a watercourse, lake or spring, and / or
- place fill in a watercourse, lake or spring.

10.9 Queensland's *Coastal Protection and Management Act 1995*

The *Coastal Protection and Management Act 1995* [15] (the Coastal Act) defines and protects the coastal zone. As of 26 April 2013, the Coastal Protection State Planning Regulatory Provision (the SPRP) came into effect and suspends:

---

[14] Reprinted as in force on 1 July 2013. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

[15] Reprinted as in force 31 March 2013. Reprint prepared by the Office of the Queensland Parliamentary Counsel.

- The State Planning Policy 3/11: Coastal Protection
- Part 1.2 of the Far North Queensland Regional Plan 2009 - 2031
- Part 3.3 of the Mackay, Isaac and Whitsunday Regional Plan
- Part 2.2 of the Wide Bay Burnett Regional Plan, and
- Part 1.4.3 and 2.4 of the South East Queensland Regional Plan 2009 – 2013.

The SPRP also prevails over any plan, policy or code developed under another Act, to the extent of any inconsistency (Department of State Development Infrastructure and Planning (SDIP) 2013a).

A draft State Planning Policy is currently under public consultation that will replace the SPRP. The SPRP is in effect until the new State Planning Policy comes into effect (Department of State Development Infrastructure and Planning (SDIP) 2013b).

Under the SPRP policy on nature conservation (section 3.2.3), development is to:

- preserve biodiversity through the conservation and management of habitat, including coral reefs, seagrass, soft bottom (benthic) communities, dune vegetation, salt flats, coastal wetlands and riparian vegetation
- maintain and re-establish connectivity of ecosystems
- retain native vegetation where practicable, and
- retain and manage riparian vegetation along waterways of sufficient width to provide for a self-sustainable, linked, network.

Further, under section 3.2.4 development is to be outside of, and not have a significant impact on areas of high ecological significance. However, development can occur if it is for extraction purposes within a key resource area.

Under the draft State Planning Policy development applications are assessed against a number of requirements including:

- any potential adverse environmental impacts are identified and considered
- the development avoids adverse environmental impacts, or where this is not reasonably possible, impacts are minimised and residual impacts are offset
- the development avoids or minimises adverse impacts on coastal resources and their value, and

- the development avoids or otherwise minimises adverse impacts on the environmental values of receiving waters, arising from altered stormwater quality or flow wastewater; or the creation or expansion of non-tidal artificial waterways such as urban lakes.

10.10 Wetlands of National, State or Regional Significance

Palustrine wetlands (e.g. swamps), riverine systems (e.g. river and creek channels) and estuarine wetlands have been mapped downstream of the project area in the Department of Environment and Heritage Protection's (EHP's) wetland mapping program (Map 130702WL).

Within the wetland mapping program, lacustrine wetlands (DERM 2010b):

- are wetlands and deepwater habitats in topographic depressions or dammed river channels
- have less than 30% cover of emergent perennial vegetation (including trees, shrubs and emergent aquatic plants, mosses or lichens), and
- have a total water body area exceeding 8 hectares.

Lacustrine wetlands may be smaller than 8 ha, if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part exceeds 2 m at low water (DERM 2010b).

Within the wetland mapping program, palustrine wetlands (DERM 2010b):

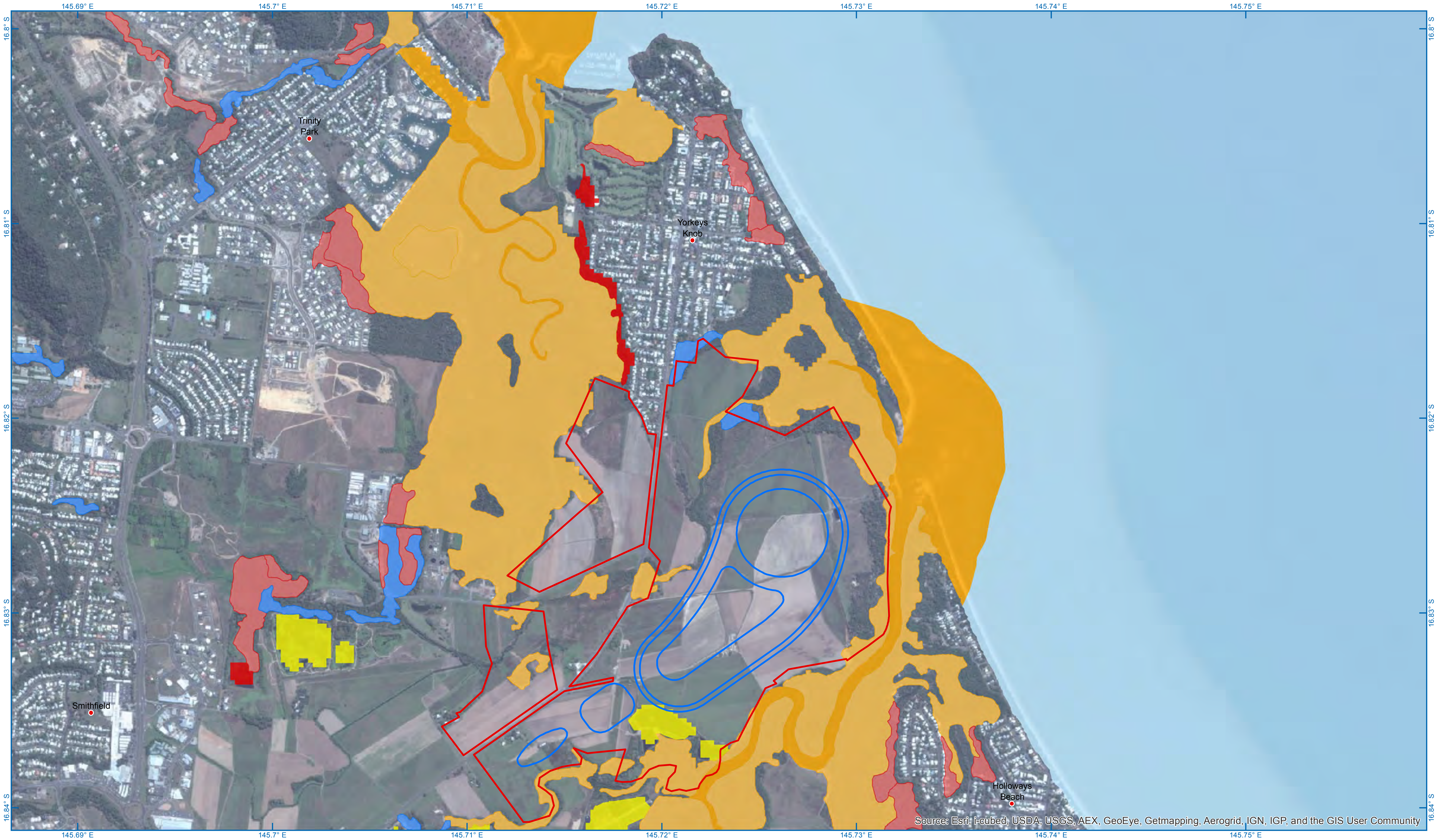
- are wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and
- occur in tidal areas where salinity is <0.5%.

Palustrine wetlands without the characteristics listed above occur:

- when active waves are formed or bedrock features are lacking
- at low water, deepest depth is <2 m, and
- when salinity is <0.5%.

Riverine systems are wetlands and deepwater habitats contained within a channel. They are dominated by emergent vegetation such as trees, shrubs, macrophytes, mosses and lichens, and do not include waters containing ocean-derived salts in excess of 0.5 ppt (DERM 2010b). Estuarine wetlands are those that are tidally influenced by oceanic water that is sometimes diluted with freshwater run-off from land.

There are wetlands within the disturbance footprint that support habitats for aquatic flora and fauna.



frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702WPAa:
Wetlands as mapped by EHP
located next to the Aquis Resort

SOURCES

© Copyright Commonwealth of Australia (Geoscience Australia) 2001, 2004
Sourced from http://www.ga.gov.au/meta/ANZCW0703005241.html#distinfo. Australian boundary, roads, locations
© The State of Queensland (Department of Natural Resources and Mines) 2013
Updated data available at http://dds.information.qld.gov.au/dds/. Coastline
© The State of Queensland (Department of Environment and Heritage Protection) 2013
Updated data available at http://dds.information.qld.gov.au/dds/. Wetlands

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_wetlands_13-08-29_CF.mxd

LEGEND

Site Boundary
Project Area
Marine Waterbody

Wetlands

Riverine RE
Lacustrine Waterbody
Palustrine Waterbody
Palustrine RE
Estuarine Waterbody
Estuarine RE

N

SCALE

0 0.5 1
Kilometres

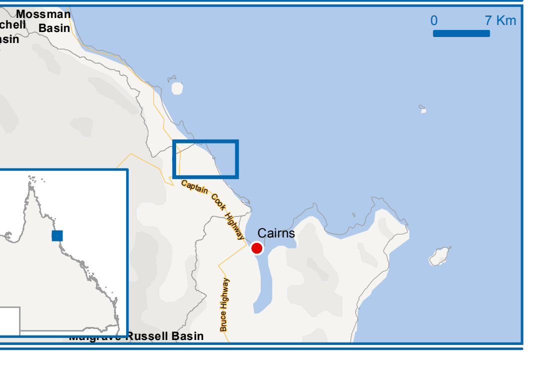
Scale: 1:20,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-09-27

DRAWN BY
AL

VERSION
03



11 Opportunities and Constraints

11.1 Opportunities

Increased Habitat for Aquatic Fauna

The proposed development has an opportunity to increase the available habitat for aquatic fauna, through the development of the lake. The area of the proposed lake is currently used for sugar cane crops and consists of some small drainages and upper reaches of creeks. The lake design could incorporate stocking of native fish species and native flora species along the banks to increase available habitat in the area. Screening the inlet and outlet pipes will reduce the number of pest fish entering the lake and prevent potentially dangerous species (e.g. sharks) from entering the lake via these pathways.

Removal of Tidal Gates

There are several tidal gate / flaps on the proposed development site that were installed to improve the site's value to agricultural values. The removal of these structures would help increase the fisheries values of the creeks by improving natural water flows, increasing habitat for nursery grounds and spawning, and improving fish passage.

11.2 Constraints

In addition to the legislative implications and constraints summarised in section0, the following constraints have been identified.

Changes to the Water Quality of, and Flows to the Receiving Waters

A number of elements in the proposed design have the potential to negatively impact water quality of the receiving water. These include:

- vegetation clearing, which may lead to an increase in runoff and turbidity
- construction earthworks
- maintenance dredging of the lake and disposal of dredged material
- discharges of lake water to surrounding creeks

- spills of contaminants e.g. fuels, fertiliser, herbicides
- management of the golf course and outdoor areas, and
- disturbance of acid sulfate soils.

These elements will need to be carefully addressed, particularly as any impact is likely to have an effect on the Great Barrier Reef Marine Park.

Freshwater Pools

The small freshwater pools within the woodland of Lot 100's eastern area support fauna and flora communities that are likely to be highly sensitive to change and should be investigated further if there is any prospect of the project altering water quality, drainage or visitation. It is understood that this area is not to be developed, but it may need to be actively protected.

Mosquitos and Biting Midges

The development of the proposed lake has the potential to increase existing freshwater breeding habitat for mosquito and biting midge larvae. Minimising breeding and roosting areas for these species, including shallow water and vegetated areas, will reduce this risk.

Potential breeding habitat may also be created in infrastructure such as dams and stormwater retention basins and in newly created intertidal areas. This potential may be reduced via careful engineering design and maintenance. Stocking the lake with native fish may also assist the control of mosquitoes.

Other Potential Nuisance and Pest Species

Management plans will also be required for other potentially nuisance species including noxious fish, sharks, marine stingers and crocodiles. Crocodiles are currently managed by the Cairns Regional Council and the project area is within a zone 2 management area (EHP 2013b). Under this zone, any crocodile greater than 2 m or any crocodile that displays aggressive behaviour, is removed. There have been nine crocodile sightings between Yorkeys Knob and Holloways Beach since 2010 (EHP 2013b). Steep banks and other physical barriers such as rock walls and weirs will minimise the risk of crocodiles entering the proposed lake.

12 Preliminary Assessment of Matters of National Environmental Significance under the EPBC Act

There are no threatened aquatic ecological communities listed under the EPBC Act within 5 km of the proposed development site.

Nineteen threatened aquatic fauna species are listed as occurring within 5 km of the proposed development site (Table 12.2) (DSEWPC 2013b; EHP 2013d). None of these species were recorded in the field surveys by frc environmental, although the saltwater crocodile was recorded in surveys by Biotropica (Biotropica Australia 2013). Saltwater crocodiles, dolphins, dugongs and turtle are likely to use the surrounding creeks (Section 4.6).

The likelihood of occurrence of these species in the area potentially impacted by the proposed development was assessed according to the criteria outlined in the *Matters of National Environment Significance Significant Impact Guidelines* (Table 12.2 and Table 12.1) (DSEWPC 2013b).

Table 12.1 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 the 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

The likelihood of any significant impact on each species was assessed using the criteria for migratory and threatened species and ecosystems in the Matters of National Environment Significance Significant Impact Guidelines (DEWHA 2009b) (Table 12.2).

An action is likely to have a significant impact to threatened species 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 [16] 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
- 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.

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

Table 12.2 Threatened and migratory species recorded within 5 km of the proposed development site on the online Protected Matters Search Tool for Commonwealth protected species and Queensland's EHP Wildlife Online search tool.

Family	**Species**	**Common Name**	**NCWR**	**EPBC Act**	**Likelihood of Occurrence in the Area Likely to be Impacted**	**Is the project likely to have a significant impact on the listed species**
Balaenopteridae	*Balaenoptera edeni*	Bryde's whale	–	M	Low	No
Balaenopteridae	*Balaenoptera musculus*	blue whale	–	E, M	Low	No
Balaenopteridae	*Megaptera novaeangliae*	humpback whale	V	V, M	Low	No
Cheloniidae	*Caretta caretta*	loggerhead turtle	E	E, M, O	Moderate	No
Cheloniidae	*Chelonia mydas*	green turtle	V	V, M, O	Moderate	No
Delphinidae	*Orcaella brevirostris*	Irrawaddy dolphin	–	M	Moderate	No
Delphinidae	*Orcinus orca*	killer whale	–	M	Low	No
Delphinidae	*Sousa chinensis*	Indo-Pacific humpback dolphin	–	M	Moderate	No
Dermochelyidae	*Dermochelys coriacea*	leatherback turtle	E	E, M, O	Low	No
Cheloniidae	*Eretmochelys imbricata*	hawksbill turtle	V	V, M, O	Moderate	No
Cheloniidae	*Lepidochelys olivacea*	Olive ridley turtle	E	E, M, O	Low	No
Cheloniidae	*Natator depressus*	flatback turtle	V	V, M, O	Low	No
Dugongidae	*Dugong dugong*	dugong	–	M, O	Low	No
Lamnidae	*Lamna nasus*	mackerel shark	–	M	Low	No
Melanotaeniidae	*Melanotaenia eachamensis*	Lake Eacham rainbowfish	–	E	Low	No
Pristidae	*Pristis clavata*	dwarf sawfish	–	V	Low	No

Family	Species	Common Name	NCWR	EPBC Act	Likelihood of Occurrence in the Area Likely to be Impacted	Is the project likely to have a significant impact on the listed species
Pristidae	*Pristis zijsron*	green sawfish	–	V	Low	No
Rhincodontidae	*Rhincodon typus*	whale shark	–	V, M	Low	No
Crocodylidae	*Crocodylus porosus*	saltwater crocodile	V	M, O	High	No

Source: (DSEWPC 2013b; EHP 2013b)

NCWR Queensland's Nature Conservation (Wildlife) Regulation 2006

E endangered

V vulnerable

M migratory species

O marine species

– not listed or not applicable

Stage 2

13 Potential Impacts and Mitigation

Based on the findings of the Stage 1 Technical Studies, the design of the Resort was refined.

The main opportunities and constraints that influenced the refinement process included:

- reconfiguration of the lake on the eastern lots to achieve flood immunity and to avoid natural vegetation and associated buffers
- associated and / or consequential changes to the location of major features such as the water park, stadium, and convention centre and the removal of the Managed Apartment complex, and
- recommendations for buffers and / or relocation of features to separate resort and adjacent land uses.

These inputs have been used to modify the project Masterplan in terms of:

- footprint (e.g. shape and orientation of the lake and location of key features)
- removal of some features altogether, and
- redefinition of some features.

The refined design now comprises:

- a 13 500 m^2 commercial outlet (e.g. shops and restaurants)
- a casino
- an aquarium
- 2 theatres
- a 13 hectare reef lagoon
- a 65 hectare lake
- an 18-hole championship golf course
- 25 000 seat sports stadium designed for rugby / soccer relocated to eastern lots
- a 45 000 m^2 convention and exhibition centre relocated to eastern lots

- a cultural heritage centre
- a 13 hectare water park relocated to eastern lots, and
- a heliport located above the defined safe refuge level (>7.5 m AHD).

The refined design also allows for ecological restoration works involving planting over 54 hectares of natural vegetation around the perimeter of the site, along Yorkeys Creek, and along the eastern frontage of Yorkeys Knob Road. This will include the removal of two flood gates on-site and the upgrading of undersized culverts to improve aquatic connectivity.

The refined design includes lake inlet and outlets near the mouth of Richters Creek and a standby lake inlet pipeline from Half Moon Bay. There are also two lake overflow points, one on Richters Creek before the confluence with Thomatis Creek and one on Yorkeys Creek. Water will overflow from the lake at these points during periods of high rainfall (Figure 13.1).

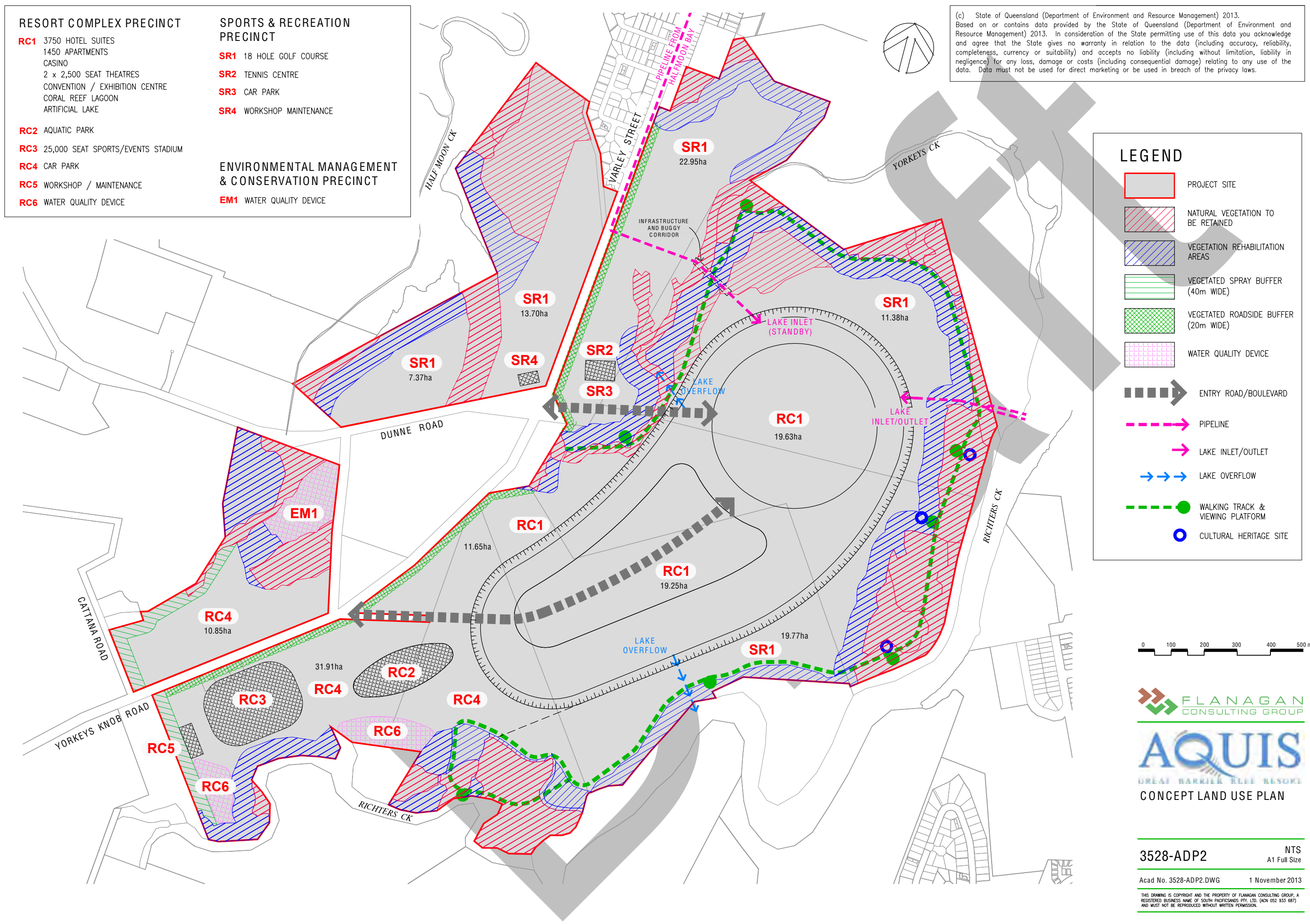


Figure 13.1 Aquis concept land use plan.

In the absence of effective mitigation, development in the coastal environment such as the proposed Aquis Resort can have a variety of impacts on coastal processes and aquatic organisms. Direct impacts, such as the disturbance, removal or burial of marine plants and soft sediment aquatic habitats, may occur during the process of construction. A number of indirect impacts may also occur during construction and operation. Potential indirect impacts to aquatic ecology may occur through:

- changes to water quality of the surrounding environment, including the release of nutrients and potential contaminants from disturbed sediments
- increases in the concentration of suspended sediments, and consequent sediment deposition
- acidic leachate from disturbed acid sulfate or potential acid sulfate soils
- alterations to local hydrology (i.e. both increased and decreased flows and creek diversions)
- colonisation of the lake by pest species
- changes to the light regime, and
- increased litter and waste.

All of these direct and impact impacts may also impact fish and fisheries of the area.

It is understood that natural values will be protected and enhanced by (Flanagan Consulting Group 2013b):

- Protecting values by design:
  - master planning to avoid impacting natural areas that currently provide buffers to natural areas (especially the adjacent Fish Habitat Areas and Marine Park)
  - avoiding activities that threaten values, such as clearing, interrupting aquatic connectivity
  - minimising the above when total avoidance is not practical
  - adopting best practices in design.
- Protecting values by construction and operational management
  - adopting a suite of construction management initiatives as outlined in the EMP (Planning) for the construction phase
  - adopting a suite of operation management initiatives as outlined in the EMP (Planning) for the operation phase
- Enhancing values by design

- master planning to include areas of restoration and additional buffers involving planting additional areas to achieve a range of biodiversity, interpretive, visual, air quality and water quality objectives
- removing existing threatening processes for example management actions to reduce invasion of pest plants and animals, removing or modifying existing structures (e.g. tide gates, undersized culverts) where this is practical and leads to better environmental outcomes
- adopting a range of technical and educational tools to present (and therefore hep to protect) environmental values.

The proposed design and management of the proposed lake relies on the recirculation of water by pumping and discharge from Richters Creek and internal water exchange via propellers and aerators (e.g. water fountains) (BMT WBM 2013). Failure of any of these systems poses a risk to aquatic flora and fauna in the lake as well as the receiving and surrounding environments, particularly in periods of rainfall when overtopping is likely to occur.

13.1 Disturbance and Removal of Marine Plants

Construction of the proposed development will result in the disturbance to and removal of less than 1 hectare of marine plants. The proposed development includes significant areas of rehabilitation with native plants, including marine plants.

13.2 Loss of Onsite Waterbodies

The water quality of onsite water bodies is poor and consequently where onsite water bodies are removed by the development, disposal of the water into the nearby creeks should be avoided.

The larger fresh water bodies on site may contain substantial populations of native fish. Loss of these waterbodies may result in the loss of fish and other aquatic invertebrates. The fresh water bodies on site should be surveyed prior to disturbance to determine the composition of the fish community. Where there are significant numbers of native fish they should be captured and translocated to similar water bodies nearby in accordance with the Queensland's Department of Primary Industries and Fisheries *Fish Salvage Guidelines*. Pest species should be destroyed.

13.3 Changes to Water Quality of the Surrounding Environment

Nutrient Enrichment of the Receiving Waters and Potential Impacts to Aquatic Ecology

Nutrients may be released into the creeks next to the proposed development site and into the downstream coastal waters from the disturbance and excavation of soil and sediment during construction, particularly for the proposed man-made lake, and during operation as a part of discharges from the man-made lake and aquarium. Nutrient enrichment of coastal waters can impact the health, composition and resilience of local floral and faunal communities. Impacts of nutrient enrichment on components of the aquatic ecosystem are described below. However the proposed resort will be designed to minimise the likelihood of an increase in nutrients exported to the receiving environment.

Aquatic Plants

Nutrient enrichment may alter the community composition (habit and species composition) and distribution of the mangrove and saltmarsh communities (Clough et al. 1983; Adam 1994). Increased nutrients can have positive impacts on the productivity of mangrove communities; commonly there is an increase in growth and productivity associated with low levels of nutrient enrichment (e.g. Onuf et al. 1977; Clough et al. 1983; McLaughlin 1987; Dunstan 1990). Increasing nutrients may lead to an initial increase in biomass of mangroves; however, this uptake may not be sustained. In northern Australia, leaf production increased with nitrogen fertilisation (Boto & Wellington 1983). In the short to medium term the production of mangroves, and to a lesser extent the more shallow-rooted saltmarsh flora, may increase. However, in the longer term this may lead to degeneration of these communities as nutrient saturation levels are reached, and as species composition changes.

Despite these positive impacts, nutrient enrichment can also negatively impact mangrove communities. For example, as a consequence of enhanced growth due to increased nutrient supply, plant uptake of other toxic chemicals may be increased (Duke et al. 2003). Further, mangrove ecosystems impacted by sewage effluent (that contains a high organic carbon content) may be affected by a reduction of soil redox potential, which can lead to anaerobic conditions. This can affect gas transport within mangrove roots, placing additional stress on the mangroves (Clough et al. 1983). Additionally, low redox potentials favour chemical transformations of a number of essential elements, in some cases improving their availability and in some cases restricting it. In extreme anaerobic conditions, hydrogen sulfide (H_2S) and other compounds that may be toxic to plants, such as sulphuric acid (H_2SO_4), can be produced (Coleman & Cook 2003). The interactions between redox potential and the availability of essential nutrients are very complex (Clough 1992). This complexity is further increased by the heterogeneous nature of mangrove soils. Consequently, the extent to which net primary production is limited by nutrients is difficult to predict (Clough 1992).

Increasing nutrient supply can also indirectly negatively impact mangroves by increasing the biomass of algae such as *Ulva* and *Enteromorpha* within the mangrove habitat. These algae can form thick mats that block natural drainage lines (e.g. Tilbury et al. 2001). They can also prevent and retard the establishment and growth of young seedlings, and smother and kill the air breathing pneumatophores of *Avicennia marina* (Connolly 1986; Edyvane 1996). *Ulva* invasion needs constant eutrophication of the water column (Cappo et al. 1998).

Invertebrate Communities

Benthic macroinvertebrate communities are distributed along a gradient of sediment organic and nutrient concentration (Pearson & Rosenberg 1978; Tsutsumi 1990). Increases in sediment organic and nutrient loads often lead to a reduction in community diversity and species richness, which is associated with a shift in community composition and trophic group structure (Pearson & Rosenberg 1978; Tsutsumi 1990; Meksumpun & Meksumpun 1999; Rossi 2003). 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 (ANZECC & ARMCANZ 2000b).

High densities of polychaetes from the family Capitellidae (≥1000 individuals/m^2) can be indicative of organic enrichment (ANZECC & ARMCANZ 2000b). Documented trends suggest that the abundance of Capitellid worms commonly increased with nutrient or organic enrichment (e.g. Cardell et al. 1999; ANZECC & ARMCANZ 2000b; Brigitte & Blake 2000; Chaiyanate & Montani 2001; López Gappa et al. 2001).

Conditions of low dissolved oxygen, high H_2S and low redox potentials usually occur simultaneously in areas of high nutrient concentration and their individual effects on macro-invertebrate communities are difficult to separate (Wu 2002). It is widely accepted that there is often a reduction in the richness and diversity of macroinvertebrate communities under these conditions, which is usually attributed to a trophic shift toward deposit feeding taxa and the dominance of polychaetes (Pearson & Rosenberg 1978; Tsutsumi 1990; Meksumpun & Meksumpun 1999; Wu 2002; Coleman & Cook 2003; Rossi 2003).

Marine Vertebrates

The effects of eutrophication on marine vertebrates are likely to be secondary impacts related to a change in habitat. For example, a reduction in mangrove cover due to high nutrients (discussed above) can reduce the habitat available for many benthic species. Increased pelagic primary growth (e.g. an increase in phytoplankton) can also lead to the sedimentation of organic material and a corresponding depletion in benthic oxygen, which can also negatively impact on benthic populations (Sandström & Karas 2002). A reduction in the species diversity and production of crustaceans and molluscs can affect fish populations, as these invertebrates are important prey for many species (Sandström & Karas 2002). Therefore eutrophication, which leads to increased turbidity, phytoplankton abundance and reduced submerged vegetation, often leads to a shift in the community structure of fish populations (Sandström & Karas 2002).

Likely Risk of Nutrient Enrichment of the Receiving Waters

The proposed inlet and outlet to the lake will be on Richters Creek, and there will be a standby inlet and an overflow outlet on Yorkeys Creek. Stormwater drainage will also be required. Changes to water quality and hydrology are addressed in a separate Technical Study by BMT WBM.

While further detailed design is required for the lake, it:

- will be generally well flushed, with performance enhanced by submerged propeller pumps
- is unlikely to stratify, and
- is unlikely to become eutrophic.

Advection / dispersion modelling indicates that:

- lake water will contribute 10 to 20% to the receiving water environment, with the latter only in the immediate vicinity of the proposed outfall
- the receiving waters will be less flushed when the mouth of Richters creek partially closes, with the increase in the order of only 2 to 4%, and
- the maximum extent of the influence of lake water in Richters Creek is approximately at the convergence with Thomatis Creek.

During flooding most of the site will be flooded by water from the Barron River, and the quality of the water leaving the site will be dominated by this flow.

Any discharges from the Aquarium and Water Park will be via a sewer. The Aquarium will have a large saltwater system, with high quality oceanic water, similar to the GBR Wonderland in Townsville.

Storm water drainage will be managed using Water Sensitive Urban Design features. The combined stormwater drainage strategy and effluent re-use allows for:

- the re-use of all of the suspended solids and nutrients in Aquis sewage after treatment
- the on-site use of an additional 240 ML/a of treated effluent, and
- the removal of most of the suspended solids and nutrient loads carried by stormwater (Flanagan Consulting Group 2013a).

It is anticipated that the proposed development will result in a 64% decrease in the total load of nitrogen, a 92% decrease in the total load of phosphorous, and a 56% decrease in the total load of suspended solids compared to the existing use (Flanagan Consulting Group 2013a).

That is, risks to the receiving environment through the release of nutrient rich water will be minimised through design of the proposed development, and in particular of the lake and stormwater management regimes.

Spills of Hydrocarbons and other Contaminants

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

Risks associated with the spillage of fuels and other contaminants can be substantially reduced, if not eliminated, where:

- vehicle maintenance areas, portable refuelling stations and storage of fuels, oils and batteries are undertaken within bunded areas that are designed and constructed in accordance AS1940 (2004) – *The storage and handling of flammable and combustible liquids* (as proposed for the project) and are above the Q100 flood level of nearby waterways and dams

- all spills of contaminants are reported to the Environmental Officer (or delegated person), and
- appropriate spill containment kits are available, and used for the clean up of spills in the field. The kits should contain equipment for clean up of both spill on land or in dry creek beds, and spills to water (such as floating booms).

13.4 Increased Turbidity, Sediment Suspension and Smothering

Construction of the Resort has the potential to contribute exposed sediments to the waters of Half Moon, Yorkeys and Thomatis / Richters Creeks and the downstream coastal environment. This risk is highest during the construction period, particularly in the wet season. Any increase in the sediment load entering the system would be expected to directly increase the levels of turbidity and suspended sediments in the water column, and may lead to enhanced sediment deposition and the smothering of benthic communities.

The potential impacts of increased turbidity, sediment suspension and smothering on local communities are:

- reduced growth of marine plants by limiting light for photosynthesis
- reduced respiration and feeding of benthic communities leading to a reduction in abundance and biodiversity
- traumatization of fish gill tissues affecting growth and survival, and
- burying of aquatic plants (including roots and mangrove pneumatophores) and invertebrate communities (burrowing polychaetes and crustaceans).

The specific impacts of smothering depend on the relative composition of the sediment being deposited and the timing of deposition.

Best practice in the design of sediment control will be used on the proposed development site, including the:

- retention of all natural vegetation and buffers
- Water Sensitive Urban Design, and
- appropriate management during construction and operation that minimises this risk.

The risk of sediment run-off to nearby waterways will be reduced where:

- an erosion and sediment control management plan is developed and implemented
- sediment dams are constructed before vegetation clearing and earthworks
- vegetation clearing and earthworks are done in stages, and
- timing of clearing and earthworks for construction is done in the dry season.

During and after construction activities, water quality and ecosystem health of nearby waterways may be protected by:

- erosion control (e.g. jute matting, rock mulching, or similar)
- contour banks, ditches or similar formed across cleared slopes to direct run-off towards surrounding vegetation and away from creeks
- monitoring water quality of waterways downstream of clearing and / or exposed soil, during periods of rainfall, and
- rehabilitation of the buffer areas to a natural condition.

13.5 Disturbance of Acid Sulfate or Potential Acid Sulfate Soils

Disturbance of intertidal and marine sediments may expose acid sulfate potential sediments to oxidising (acidifying) conditions that result in the release of acids to the ambient water. Impacts and management of acid sulfate soils are addressed in a separate Technical Study: Soils and Contamination.

As a result of exposure of acid sulfate soils the growth rate and condition of fish and invertebrates are impaired and populations may be removed from the natural environment. A relatively sudden reduction of pH can result in fish-kills, disease and other disturbances (Sammut et al. 1993). Invertebrates (including molluscs, crustacea and worms) may also suffer mass mortality. Less visible are the more common chronic affects of reduced hatching and declined growth rates (Sammut et al. 1993). This is due to the unfavourable ionic composition of acidified water, the periodic presence of finely dispersed ferric hydroxide and mobilised aluminium, and the related reduced supply of algal feed (Brinkman & Singh 1981). Repeated flows of acid water prevent fish and invertebrate populations recovering, altering the natural food chain and nutrient cycles. An example of this is the outbreak of mosquitoes that can occur because larvae-eating fish are unable to survive the acid water (Sammut et al. 1993).

A direct effect of the oxidation of pyrite is the lowering of pH. The consequences of short-term and localised acidification may be profound. Chronic low-level acidity may result in decreased vigour and increased incidence of disease. Historical fluctuations in commercial finfish and prawn catches may be in part attributable to periods of enhanced acidity in estuarine waters (Leadbitter 1993).

Other environmental effects of acidification include the:

- dissolution of clay minerals and the release of soluble aluminium, which is highly toxic to gilled animals (including fish, molluscs and crustacea) and aquatic plants
- release of soluble iron, also toxic to aquatic life in high concentration, and
- oxidation of ferrous iron causing large decreases in dissolved oxygen.

Hydrocarbons, heavy metals and other contaminants can have major impacts on estuarine communities, and can impact growth, morphology, reproduction and development of estuarine flora and fauna. The biological effects of toxicant discharge are usually greatest in low energy environments (such as within estuaries), where accumulation and retention in fine sediments occur (Gundlach & Hayes 1978; Jackson et al. 1989). Low energy, sheltered beaches show a much higher initial mortality, with the possible elimination of some species. Here, microbial degradation, rather than wave-action is the principle force for breakdown and removal.

13.6 Alteration of Local Hydrology

Construction of the proposed development is likely to have an impact on local hydrology. The creation of the lake and the planned discharge into Thomatis / Richters Creek and potential overflows into Yorkeys Creek could potentially increase the flow of freshwater (including stormwater) from the site to communities that fringe these creeks and the Great Barrier Reef Marine Park immediately downstream.

The final design of the lake and proposed discharge volumes will influence the potential impacts on hydrology. Alteration of local hydrology is under review by BMT WBM, who contributed a separate Technical Study.

Changes to groundwater, including any increases in salinity due to impoundment of saline water in the lake may also negatively impact surrounding mangrove and marine plant communities. Where the lake is constructed so it does not impact groundwater, for example by lining it or sheet piling, the risk of this impact will be low.

13.7 Proliferation of Pest Species

Pest Fish

Species of noxious fish, and in particular tilapia (*Oreochromis mossambicus*) and / or the spotted / black mangrove cichlid (*Tilapia mariae*) may colonise the lake. Both species are known to occur in lowland areas of the wet tropics (Pusey et al. 2004) and are established in the Barron River catchment. The two primary vectors of dispersal for these species are human assisted (i.e. the release of aquarium fish into waterways) and the connection of waterways containing tilapia during overland / sheet flood flows, with the latter occurring in the local catchment.

Tilapia have been identified in the Cairns City Council Pest Management Plan (2005) as a pest animal of the local government area. These species have been given a “critical” threat rating and effective control of the species rated as a “high priority”.

While the proposed lake will provide suitable habitat for colonisation by these species, there is also similar habitat nearby, including the semi-enclosed area at the mouth of Yorkeys Creek. Both species of tilapia been recorded within the lowland areas adjacent to the proposal site and wider Barron catchment (Pusey et al. 2004).

Tilapia may colonise the proposed lake via:

- the inlet and outlet pipes
- overland / sheet flood flows in extreme flood events
- human intervention, and / or
- they may already be present in the waterways on site.

Once established in the proposed lake, they may disperse to the surrounding waterways in flood flows or via the inlet and outlet pipes.

Ecological Overview

These species are hardy fish, tolerant of a wide range of temperatures and salinities, and of low dissolved oxygen concentration. In the wet tropics, they have successfully colonised a variety of habitats such as freshwater rivers and creeks, drains, swamps and tidal creeks. They are also capable of colonising lacustrine (lake or pond) habitats, particularly if water levels fluctuate in a cyclical pattern (James & Bruton 1992). They usually live in sandy to mud bottomed, well-vegetated areas, and are often seen in loose aggregations or small schools.

Tilapia are territorial bottom spawners with the capacity to reproduce under a range of ecological conditions, triggered by rising water temperatures (Bradford et al. 2011). Nests are built in predominantly sandy or muddy substrates in clusters, commonly in waters less than 1 m deep.

Management

There are a number of potential control measures to manage colonisation of the proposed lake by tilapia species. These include:

- biological controls
- physical removal
- poisoning, and
- environmental management.

Management options are summarised in Table 13.1.

Table 13.1 Potential management options for tilapia in the event of establishment in the proposed lake of the Aquis Resort.

Method	Comments	Pros	Cons
Biological control	There are a number of large native predatory fish in north Queensland estuarine and freshwaters. These include barramundi, mangrove jack, eels, sleepy cod, tarpon, fork-tailed catfish and various grunter species, of which some species undoubtedly prey on tilapia in creeks, at times. Never the less, tilapia have colonised north Queensland waters in the presence of such predators. In south-east Queensland, tilapia have established in impoundments with high densities of predatory fish, including stocked Australian bass and golden perch, and wild populations of long-finned eels and fork-tailed catfish. Stocking the lake with native predators may suppress the abundance of tilapia, but is unlikely to result in their eradication.	Can be advantageous as they will disperse on their own and provide a lasting management solution. Barramundi (*Lates calcarifer*) successfully used in control of tilapia aquaculture in the Philippines (Fortes 1979). Large native fishes may add to the 'amenity' of the lake feature.	Can adversely affect non-target species. Will become homeostatic with the target species population, if it is the only available food source, mirroring its rises and falls in abundances (Mack et al. 2000).
Physical removal	Physical removal could be considered for control of tilapia if they establish in the Aquis resort lake. There are numerous methods for the removal of invasive fish, with nets being the most effective.	Netting is the most widely used and effective method of physical removal. Gill nets, in particular, provide a simple, size selective mechanism for fish removal (Lagler 1978). Seine netting could be an effective option given the preference of these species to nest in relatively shallow waters, if suitable substrates are present.	Their use for long term control is labour intensive and not species selective (Hopkins & Cech 1992) potentially resulting in secondary stress responses (handling) and / or physical damage to non-target species.

Method	Comments	Pros	Cons
Poisoning	The use of piscicides for controlling fish has had variable success to date. Complete removal of a target species is only achievable at small spatial scales.	Useful at small spatial scales in closed systems that are shallow and free from aquatic vegetating (Hill & Chichra 2005; Lazur et al. 2006).	Complete dispersal of piscicides throughout a water body can be hampered by difficulties in dispersing the toxicant into deeper waters or where there is a heavy cover of aquatic vegetation (Ling 2003)
Environmental management	Minimise the key ecological requirements for breeding by having deep water (> 2 m), steep banks, hard substrate particularly in shallow water, minimising vegetation in and around the waterbody and minimising fluctuations in water level.	Limiting the availability of preferred habitat for breeding is likely to reduce breeding in the lake, and limit population growth.	Unforseen design elements or amendment of an already progressed lake design to incorporate those elements that would remove key habitat requirements.

Recommendations

Establishment of these species in the proposed lake will be minimised where:

- prior to construction commencing they are removed from existing onsite water bodies that may connect to the proposed lake
- onsite waterbodies are quarantined from the proposed lake development
- inlet and outlet pipes are screened
- the proposed lake has:
  - minimal area under 2 m deep
  - steep banks
  - hard substrate, particularly in shallow water
  - little vegetation in and around the waterbody, and
  - maintains a constant depth.

Further, populations may be able to be managed by:

- stocking of predatory native fish
- periodic physical removal (during the breeding season to remove fry, juveniles and adults), and / or
- a poisoning program.

A long-term pest fish management plan, developed in consultation with Queensland Fisheries and combining a number of these management elements will minimise the risk of the proposed lake becoming a focal point for tilapia dispersion in the Yorkeys Knob region.

Pest Plants

During construction, there is a high potential for mobile equipment to transport pest plants onto site. Seeds and plant material can be dislodged from material that has collected on the undersides and crevices of mobile plant equipment, which can then become a nuisance to the area.

Where mobile plant machinery, including boats and other aquatic vessels, is washed down by certified certified weed wash-down personnel off-site, this risk will be minimised.

After construction, regular monitoring and removal of pest plants will minimise the risk of these plants spreading.

Mosquitos and Biting Midges

The proposed development of the lake has the potential to increase existing freshwater breeding habitat for mosquito and biting midge larvae. Potential breeding habitat may be created in infrastructure such as dams and stormwater retention basins and in newly created intertidal areas.

Mosquito breeding on the proposed development can be minimised by:

- preventing dense growth of emergent aquatic vegetation in-stream
- minimising changes in water depth
- having steep banks, rather than shallow sloping banks
- planting suitable vegetation on walls and banks to prevent erosion and run-off of nutrients, and
- introducing native fish, after liaison with Queensland Fisheries (Queensland Health 2002).

Where the lake design includes access points, an on-going monitoring and control plan can be implemented (Queensland Health 2002).

It is recommended that a comprehensive mosquito and biting midge management plan is developed for the proposed development.

Crocodiles

The shallow waterways surrounding the proposed development site provide ideal habitat for estuarine crocodiles (*Crocodylus porosus*), and they have been recorded on site (Biotropica Australia 2013). The proposed lake may also provide ideal habitat.

New habitat created by the proposed lake will support fish communities that may in turn provide food for crocodiles. Nesting often takes place near the tidal limit of waterways and in freshwater inland waterholes, so the proposed development site is unlikely to provide nesting habitat (Read et al. 2004).

Most crocodile attacks on people are in the water or near the water's edge, and during daylight hours in the warmer months of the year. Crocodiles responsible for attacking people are mostly large males, and those responsible for fatalities are very large. The main reasons for crocodiles attacking humans are thought to be: territory defence, nest defence, hunting behaviour, mistaken identity (e.g. attacks on people with dogs by small crocodiles) and self defence (Caldicot et al. 2005).

Attacks within the proposed development would be most likely to occur on people swimming in the lake, standing near its edge, or leaning out of small boats or over pontoons. Where these activities are limited, risk will be reduced.

Crocodiles are currently managed by the Cairns Regional Council and the project area is within a zone 2 management area (EHP 2013b). Under this zone, any crocodile greater than 2 m or any crocodile that displays aggressive behaviour is removed.

Steep banks and other physical barriers such as rock walls and weirs will minimise the risk of crocodiles entering the proposed lake. Construction of the proposed lake within a barrier such as a temporary coffer dam above MHWS would minimise the risk of crocodiles entering the site. During construction, work should cease and Cairns Council be contacted if any crocodiles or evidence of crocodiles (e.g. nests or eggs) are observed on the site. Grills across the inlet and outlet entrances will minimise the risk of crocodiles entering the proposed lake through these pipes. Sturdy fencing between the estuarine waterways and the proposed development will also minimise the risk of crocodiles entering the property. Risks will be minimised where the crocodile management plan includes measures to:

- prevent crocodiles entering the site during construction
- minimise crocodile access to the proposed development
- minimise the interaction between crocodiles and humans
- monitor for the presence of crocodiles
- remove crocodiles, and
- educate the public regarding the risks.

Sharks

Sharks may be excluded from entering the lake via the inlet pipe by screening. Studies undertaken by frc environmental (2002) conclude that a vertical bar screen with a spacing of not more than 60 - 65 mm could reasonably be considered adequate to exclude all bull sharks (and other species of shark that attain a size dangerous to man). Whilst these studies focused on species found in south–east Queensland, the dominant species of southern estuaries, the bull shark (*Carcharhinus leucas*), is also the dominant shark species likely to enter tropical estuaries. Pups of other common tropical shark species, including the pig eye shark (*Carcharhinus amboinensis*), creek shark (*Carcharhinus fitzroyensis),* tiger shark (*Galeocerdo cuvier*) and the hammerhead (*Sphyrna lewini*) are of a similar size to those of the bull shark (Ritter 1999). Vertical bars were recommended by frc environmental in 2002 to exclude sharks, but permit entry of a range of fishes: a mesh of 65 mm x 65 mm is recommended for screening the inlet to proposed lake. A mesh of 65 mm x 65 mm would also exclude most adult fishes of commercial and recreational significance (e.g. barramundi, mangrove jack, threadfin).

Bull sharks can cross flooded land. Consequently screening of flood ways, and a catch and relocate plan will form part of the proposed development's environmental management plan.

Risks will be minimised where the shark management plan includes measures to:

- prevent sharks entering the site during construction
- minimise access to the proposed development
- minimise the interaction between sharks and humans
- monitor for the presence of sharks
- remove potentially dangerous sharks from the proposed lake, and
- educate the public regarding the risks.

13.8 Changed Light Regime

Light pollution at night is as a key factor negatively impacting marine turtle nesting and hatching (Environment Australia 2003). Disorientation of turtle hatchlings by street and house lights results in increased hatchling mortality from being lost in vegetation, heat exhaustion, and increased predation. Nesting turtles may also respond negatively to increased illumination of their nesting beaches (Limpus 2008). Turtles may nest on the beach near the proposed development site, albeit in low densities. Both direct light and the loom (or light glow above the local horizon) caused by a number of lights negatively impact nesting and hatching Where appropriate design features can be incorporated into the proposed development impacts to nesting and hatching marine turtles may be minimised such as. Such design features may include (EPA 2010):

- reviewing the need for each light source
- keeping lights off when not needed
- mounting lights low
- shielding lights to stop escaping upwards and outwards
- using long wave length lights (500 – 700 nanometres, orange to red)
- reducing the wattage and brightness of lights
- using natural topography to shield nesting areas from light, and
- screening interior lights with blinds, screens and/or window tinting.

13.9 Waste and Litter

Litter and waste associated with construction and operation of the proposed development has the potential to contribute to the degradation of water quality and is a direct hazard to aquatic flora and fauna.

Where an effective waste and litter management plan is developed for the site this risk will be significantly reduced.

13.10 Potential Impacts to Fish in the Proposed Lake

Water quality in the proposed lake will be maintained by exchange with Richters Creek, during normal operation. When the water quality in Richters Creek is poor, then water of better quality will be pumped from Half Moon Bay. The residence time of the water will be approximately 14 days under normal operation, with intake on the flood tide, and discharge on the ebb tide. Residence time will be as low as 7 days where necessary to maintain water quality. Additional measures to maintain water quality include destratification using a combination of propellers, aerators and water fountains and/or water bubblers. These will also improve water quality by adding dissolved oxygen to the water (BMT WBM 2013).

During normal operation of the lake, the salinity will be close to extreme marine, however during extreme flood events, the salinity of the proposed lake will drop.

Where the inlet of the lake is screened colonisation of the lake by fish will be minimised. Never the less it is expected that some fish will colonise the lake via these structures. Further, aquatic species will colonise the lake in flood conditions where there is overland flow. Fish species found in the surrounding estuaries are likely to colonise the lake (Table 4.5). In addition, some species tolerant of fresher water (Table 4.7), and pest species such as tilapia (Section 13.7) may colonise the lake .

The estuarine species likely to colonise the proposed lake have a variety of mechanisms to tolerate periods of low salinity. These include physiological adaptations to withstand low salinity, and moving away from water with low salinity (Day et al. 2012).

There has been little experimental work on the salinity tolerances of tropical estuarine fish. However, as tropical estuaries typically are subject to large changes in salinity, a considerable degree of euryhalinity is a precondition and prerequisite for their inhabitants (Blaber 1997). That is, fish that colonise the proposed lake are likely to be able to withstand some decreases in salinity. Physiological impacts of low salinities are likely to be related to how quickly salinity decrease, and how low it becomes. Consequently, where water in the proposed lake is managed to gradually decrease in salinity, and minimise the decrease, risks to fish will be reduced. Maintaining high dissolved oxygen levels (within guidelines) is likely to improve survival.

Where lake outlets and overflows are designed to facilitate the movement of fish out of the lake in flood conditions, risks to fish will also be reduced.

In extreme floods there may also be times when the salinity drops quickly, fish are unable to leave the lake, and consequently die. A management plan to remove these fish is recommended, so they do not decompose in the lake and contribute to deterioration in water quality.

13.11 Potential Impacts to Fish and Fisheries in the Surrounding Estuaries

Potential impacts to fish and fisheries in the surrounding estuaries of the proposed development include:

- loss of marine plants (Section 13.1)
- changes in water quality (Section 13.3)
- changes in sediment quality (Section 13.4)
- disturbance of acid sulphate soils (Section 13.5)
- barriers created by the discharged water
- screening of the intake structure, and
- release of pest fish and other fish fauna.

Barrier Created by the Discharged Water

The discharge of lake water to Richters Creek will be via a series of diffusers installed below low water along the northern bank of the creek and angled at 45 degrees to the alignment of the creek. The discharge will be rapidly dissipated and diluted, with no residual current or concentration gradient discernible beyond 2 - 3 metres (BMT WBM pers. comm. 2013) The discharge of lake water via diffusers will thus provide no impediment to fish passage.

Screening of the Intake Structure

The lake intake has the potential to entrain fishes. Screening the intake can both physically prevent impingement and entrainment, and even more beneficially, keep fishes at a distance where velocities are such that fishes are able to avoid entrainment. The proposed location of the primary intake structure (within the channel, as opposed to near the bank) is subject to strong tidal currents: fishes that are either resident or transient must have the ability to negotiate currents of approximately 0.2 m per second. Juvenile barramundi are able to swim at 0.66 m per second for short periods (Pusey et al. 2004), whilst most juvenile and adult fishes are able to swim at > 1.0 m per second (Kapitzke 2010). Smaller fish (with implicitly weaker swimming ability, and more likely to pass through a screen) have been shown to have a strong preference (>80% of individuals) for channel banks rather than mid-stream sites (Johnston & Sheaves 2004), and are consequently at minimal risk of entrainment. Whilst there are several variables that need to be considered to determine exact acceptable intake velocities (distant and near-field approach velocities, through-screen and sweeping velocities, swimming performance of specific species, etc.), an approach velocity at the screen of < 0.10 m per second is likely to avoid entrainment of all healthy adult fish (Swaminathan & Vaishnavi 2009; Boys 2010; Anon 2011); an approach velocity of 0.4 m per second is likely to avoid entrainment of most fish (Boys et al. 2012). The incorporation of specifically designed fish diversion screening (e.g. from Johnson Screens (see www.johnsonscreens.com)) will further reduce the likelihood of entrainment (Boys et al. 2012). A well designed fish screen will also minimize stress and injury that occur should fish impact the screen or are subjected to changes in water velocity and direction caused by the inflow current.

Release of Pest Fish and other Fish Fauna

The proposed lake may be colonised by pest fish such as tilapia (*Oreochromis mossambicus* and/or *Tilapia mariae*), and by large native predatory fish such as barramundi (*Lates calcarifer).* Where there are screens on the inlet and outlet pipes significant numbers of adult fish are unlikely to leave the lake under normal operating conditions. However in flood conditions, these fish are likely to leave the lake and colonise the surrounding estuaries. The introduction of large numbers of introduced pest fish or large native predatory fish may negatively impact fish and fisheries in the surrounding estuaries via competition for food and habitat, and via disease transfer. Further, some introduced species may also negatively impact habitat and water quality (Greiner & Gregg 2008; GFHSAP 2012). While the estuaries surrounding the proposed lake are relatively small, the overflows from the proposed lake are relatively close to the mouths of the estuaries. This may aid in the dispersal of large numbers of predatory fish such as barramundi, reducing the impact on the estuary. Minimising the use of the proposed lake by predatory fish such as tilapia will assist in reducing this risk (Section 13).

Introduction of native predatory fish such as barramundi to the estuaries may also result in significant increases in catch rates (GFHSAP 2012).

It is recommended that specific fish management plans are developed to mitigate this risk.

14 Further Baseline and Monitoring Requirements

The surveys summarised in this report were designed to provide input into the design of the proposed development, rather than as baseline surveys for a known development. They did not include any seasonal components, the sampling of fish, stygofauna, or macroinvertebrates in the mangrove forests.

Further aquatic ecological studies are recommended prior to development commencing, to describe seasonal changes in aquatic ecosystems that may be affected by the proposed development, and to better describe some of the communities. In addition, it is recommended that baseline data is collected prior to construction commencing. Baseline data should be collected in areas that may be impacted by the proposed development and in nearby reference sites. This data can then be compared to data collected in ongoing monitoring programs to assess potential impacts of the proposed development during and after construction.

Recommended surveys to describe the existing aquatic environment, including seasonal variation, include surveys of:

- water quality
- sediment quality
- estuarine macroinvertebrates in the sediment of the receiving environment
- macroinvertebrates in mangrove ecosystems
- estuarine fish
- freshwater habitat and aquatic plants
- freshwater macroinvertebrate
- freshwater fish, and
- mosquitoes and biting midge larvae.

It has also been recommended the area is surveyed for use by marine turtles (Bunce pers. comm. 2013).

To assess impacts of construction and operation of the proposed development on aquatic ecology, it is recommended that key elements of these surveys are selected for ongoing monitoring.

14.1 Water Quality

There is currently very little data regarding water quality in the three estuaries, and it is consequently difficult to model or otherwise determine likely impacts. Further, the available data indicates that water quality does not currently comply with Preliminary Water Quality Objectives (WQO), in particular for nutrients and turbidity.

Ongoing assessment of water quality is recommended:

- to inform modelling and consequently more detailed design of the proposed development
- to assist in the establishment of local Water Quality Objectives, and
- to assist in the determination of appropriate trigger values.

Water quality should be monitored before, during and after construction of the proposed resort. As outlined in the *Queensland Water Quality Guidelines* (DERM 2009) and the *Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters* (ANZECC & ARMCANZ 2000a) default guideline values may not be appropriate to all regions within Queensland, and the calculation of interim local trigger levels is encouraged. In summary, calculation of local guidelines involves the selection of appropriate reference sites to represent the aquatic habitats found within the survey area, and calculating 20th and 80th percentile values for each water quality parameter, to form the basis of the trigger levels. The 20th and 80th percentile values are used where a range is required (e.g. pH and dissolved oxygen); the 80th percentile value is used where a single trigger value is presented.

To develop local Water Quality Objectives, data needs to be collected from one or two reference sites over at least 12 months, with at least 18 collection times over this period; or a minimum of 12 data points need to be collected over at least 12 months from more than three reference sites (DERM 2009). However, interim trigger levels can be derived from local data after eight data points have been collected from two or more reference sites over a period of 12 months (DERM 2009). Interim objectives are subject to further refinement after more data is collected.

A reference site in estuarine ecosystems is defined as a site where (DERM 2009):

- there are no significant point source wastewater discharges within the estuary or within 20 km upstream. Exceptions can be made for small discharges into large rivers, and

- there is no major urban area (>5000 population) within 20 km upstream. If the urban area is small and the river is large, this can be relaxed.

Where there are insufficient suitable reference sites, the methods described can be applied to more disturbed systems, to provide a realistic expectation of local water quality (DERM 2009).

An aquaculture facility discharges into Richters Creek, upstream of the proposed development. Water discharged from the aquaculture facility may move both down and upstream, depending on the timing of the discharge. It is consequently recommended that a reference site is established upstream of this discharge, on the Barron River upstream of the confluence with Thomatis Creek.

The STP discharges into Half Moon Creek at the upper limit of the estuarine section of the creek. It is consequently not possible to select a reference site upstream of this discharge that is estuarine. It is recommended that water quality is monitored at frc site 8a, and that this data is used as a baseline.

Given the short time period prior to construction (and potential impacts) commencing, it is recommended that water quality data is collected each fortnight from the seven sites on Map130702WQ.

Once construction and operation of the proposed development commences (and local Water Quality Objectives and trigger values are established) water in the receiving environment should be monitored quarterly at a minimum to detect any negative impacts due to potential accidental discharges of contaminants, any impacts due to stormwater run-off and the effects of natural events (e.g. floods and cyclones). Parameters that should be monitored are:

- salinity
- temperature
- pH
- dissolved oxygen
- turbidity
- total suspended solids
- total dissolved solids
- water hardness
- nutrients (total nitrogen, total phosphorus, ammonia, nitrate and nitrite)

- metals and metalloids
- chlorophyll *a*, and
- faecal coliforms.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

Aquis Resort Technical Study: Aquatic Ecology

130702WQ:
Fortnightly water quality monitoring sites

SOURCES

© Copyright Commonwealth of Australia (Geoscience Australia) 2001, 2004
Sourced from http://www.ga.gov.au/meta/ANZCW0703005241.html#distinfo. Australian boundary, roads, locations
© The State of Queensland (Department of Natural Resources and Mines) 2013
Updated data available at http://dds.information.qld.gov.au/dds/. Coastline, Waterways

Document Path: Y:\Projects\2013\130702_EnvNorth_Yorkeys_Knob\Mapping\Workspaces\130702_fortnightly_WQ_13-11-27_CF.mxd

LEGEND

- Water Quality Monitoring Site
- Site Boundary
- Watercourse

N

SCALE

0 0.5 1 2
Kilometres

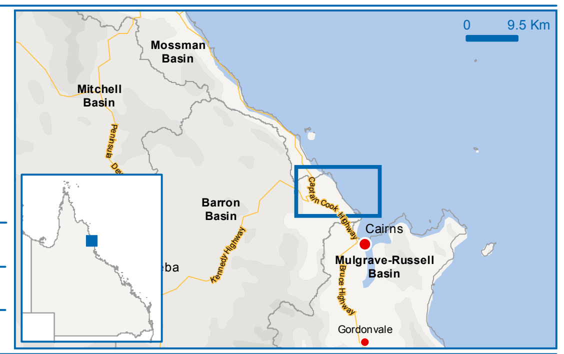
Scale: 1:40,000 @ A3

PROJECTION
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

DATE
2013-11-27

DRAWN BY
CF

VERSION
01



14.2 Sediment Quality

It is recommended that sediment is collected and analysed in the 2013/104 wet season from the same sites as in the October 2013, and from two reference sites in Thomatis / Richters Creek upstream of the aquaculture facility. The full suite of parameters assessed in October 2013 should be assessed in this survey.

14.3 Estuarine Macroinvertebrates in the Sediment of the Receiving Environment

Shallow water benthic invertebrates in estuaries are a key tool for assessing the condition of aquatic ecosystems. Differences 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. Changes in the composition of shallow water estuarine benthic communities may be a key indicator of impacts to the receiving environment from the construction or operation of the proposed development. It is recommended, that as a minimum, the composition of benthic estuarine communities is assessed at the following sites in the 2013/2014 wet season, the 2014 dry season and the 2014 /2015 wet season:

- Thomatis / Richters Creek at sites 3, 4
- Half Moon Creek at sites 5, 6a and 8a
- Yorkeys Creek at site 2, and in
- two nearby reference sites.

Samples for the assessment of water and sediment quality should also be collected at each of these sites.

14.4 Macroinvertebrates in Mangrove Ecosystems

The macroinvertebrates in mangrove ecosystems are closely correlated with mangrove associations and inundation regimes. It is recommended that the distribution of mangrove associations in Thomatis / Richters, Half Moon and Yorkeys Creeks are mapped in the 2013/2014 wet season, and that the macroinvertebrate communities in these associations are then sampled. Sampling sites should include landward associations that are most likely to be impacted by the proposed development, and associations along the creek banks, that provide valuable ecosystems to fisheries. Sites should include at least two analogous sites that are unlikely to be impacted by the proposed development, in each of these associations. It is recommended that sampling of the macro-invertebrates in mangroves includes:

- counts of macroinvertebrates within quadrats
- active searching for macroinvertebrates on trunks and in woody debris, leaves, rocks etc., and
- pitfall traps, and that
- the community structure of the mangroves, sediment and site conditions are described at each site.

14.5 Estuarine Fish

The fish communities in the estuaries surrounding the proposed development may be impacted by physical changes associated with the proposed development including changes to water quality, sedimentation, changes to water velocity and consequent erosion, and by the release of fauna from the lake, particularly during flood events. The mangrove communities in the estuary provide important protective habitat and food for a number of commercially and recreationally important species, particularly in their juvenile phases. It is therefore prudent to establish what fish are currently in the estuary, and in particular fish that are associated with the mangrove habitats within each estuary.

It is recommended that a combination of fyke nets, bait nets and baited traps, combined with creel surveys are used to sample fish communities. Tidal, lunar and seasonal variations in fish populations should be considered in the design of the surveys.

14.6 Freshwater Habitat and Aquatic Plants

It is recommended that the freshwater habitat and aquatic plants in the waterways on site are resurveyed in the 2013/2014 wet season.

14.7 Freshwater Macroinvertebrates

Macroinvertebrate communities are an important part of freshwater aquatic ecosystems and are key components of many aquatic food webs. They also directly influence many aquatic ecological processes such as primary production, sedimentation and the processing of organic matters (e.g. shrimps and crabs).

The composition of macroinvertebrate communities in an aquatic ecosystem varies according to the physical, biological and chemical attributes of the waterbody. The spatial and temporal distribution of macroinvertebrate communities within an aquatic ecosystem is dependent on a variety of factors, such as: the hydrological conditions of the waterway (flow, depth); the composition and structural complexity of the habitat (presence of pools and riffles, snags and water plants, substrate composition); and the chemical and physical components of the water.

Freshwater macroinvertebrates are a key component of aquatic ecological communities, and respond to short-term and long-term changes in the environment.

Freshwater macroinvertebrate communities on site were sampled in October 2013, to account for seasonal variation in these communities it is recommended they are re-surveyed in the 2013/2014 wet season.

14.8 Freshwater Fish

The freshwater dams and dune lakes on the site may hold fish of significance to conservation and /or noxious species. As fish may require salvage, it is important to establish what fish are there, so appropriate methods can be used. Fish communities in the dams, lakes and drainage channels on site are also likely to be indicative of fish communities that colonise the proposed lake.

It is recommended that fish communities in the freshwater water bodies on site are sampled using a boat mounted electrofisher, and other equipment such as fyke nets, baited traps and seines as deemed appropriate by the field team.

14.9 Mosquitos and Midges

Monitoring of mosquitos and biting midge larvae should be conducted after construction to ensure mitigation measures are adequate (Queensland Health 2002). Monthly surveys for mosquitos and biting midge larvae, including detailed identification to species, is recommended to ensure Aquis guests are at minimal risk.

14.10 Marine Turtles

To determine whether turtles are nesting on the beach near the proposed development nocturnal beach patrols / dawn tracking surveys would be required for two weeks, three times during the nesting season. To determine foraging behaviour in the creeks aerial surveys are most effective.

15 References

Adam, P., 1994, 'Saltmarsh and mangroves', In: *Australian Vegetation*, Groves, R. H. (Ed), Cambridge University Press, Cambridge, pp. 395-436.

ALS, 2011a, *Cairns Reginal Council Biological Impact Monitoring Program Historical Data Review 1999-2009*, report prepared for Cairns Regional Council.

ALS, 2011b, *Impact Monitoring Program Historical Data Review 1999-2009*, Prepared for the Cairns Regional Council.

Anon, 2011. *Desalination Plant Intakes Impingement and Entrainment Impacts and Solutions White Paper*. WateReuse Association.

ANZECC & ARMCANZ, 2000a, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

ANZECC & ARMCANZ, 2000b, *Australian Guidelines for Water Quality Monitoring and Reporting*, National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

APVMA, 2010, *The Reconsideration of Registrations of Products Containing MCPA and the Approvals of their Labels. Spray Drift Review. Scope Document*, Australian Government, Australian Pesticides and Veterinary Medicines Authority, Kingston, ACT.

APVMA, 2012, *Diuron*, http://www.apvma.gov.au/products/review/completed/diuron.php, accessed December 2013.

Aquis, 2013. *Initial advice statement: Aquis Resort at the Great Barrier Reef. July 2013. Revision 2*.

Barron, F. & Haynes, D., 2009, *Water Quality Improvement Plan for the Catchments of the Barron River and Trinity Inlet*, Periodical.

Beesley, P.L., Ross, G.J.B. & Glasby, C.J., 2000, *Polychaetes & Allies: The Southern Synthesis*, Fauna of Australia, Volume 4A Polychaetes, Myzosstomida, Pogonophora, Echiura, Sipuncula, CSIRO Publishing, Melbourne xii, pp. 465.

Bellas, J., Beiras, R., Marino-Balsa, J.C. & Fernandez, N., 2005, '*Toxicity of organic compounds to marine invertebrate embyor and larvae: A comparison between the sea urchin embryogenesis bioassay and alternative test species.*', *Ecotoxicology*: 337-353.

Biotropica Australia, 2013, *Aquis Resort at the Great Barrier Reef Terrestrial Ecology September 2013*, report prepared for Environment North.

Birmingham, B.C. & Colman, B., 1977, 'The effect of two organophosphate insecticides on the growth of freshwater algae', *Canadian Journal of Botany* 55: 1453-1456.

Blaber, S., 1980, 'Fish of the Trinity Inlet system of north Queensland with notes on the ecology of fish faunas of tropical Info-Pacific estuaries', *Australian Journal of Marine and Freshwater Research* 31: 137-146.

Blaber, S.J.M., 1997, *Fish and Fisheries of Tropical Estuaries*, Chapman and Hall, London, pp. 363.

Blair, A., 1979, *Control of mosquitoes and non-biting midges in Perth and outer urban areas*, report prepared for Western Australian Department of Conservation and Environment.

BMT WBM, 2013. *AQUIS Resort at Great Barrier Reef Water Quality Assessments report. November 2013*.

Botelho, R.G., Barbosa dos Santos, J., Fernandes, K.M. & Neves, C.A., 2012, 'Effects of atrazine and picloram on grass carp: acute toxicity and histological assessment', *Toxicological and Environmental Chemistry* 94: 121-127.

Boto, K.G. & Wellington, J.T., 1983, 'Phosphorus and nitrogen status in a northern Australian mangrove forest', *Marine Ecology Progress Series* 11: 63-69.

Boys, C., 2010, *Development of Fish Screening Criteria for Water Diversions in the Murray-Darling Basin*, Cotton Catchment Communities CRC.

Boys, C., Baumgartner, L., Rampano, B., Robinson, W., Alexander, T., Reilly, G., Roswell, M., Fowler, T. & Lowry, M., 2012, *Development of Fish Screening Criteria for Water Diversions in the Murray-Darling Basin*, NSW Department of Primary Industries, Port Stephens Fisheries Institute, Nelson Bay, NSW.

Bradford, M., Kroon, F.K. & Russell, D.J., 2011, 'The Biology and management of Tilapia mariae (Pisces : Cichlidae) as a native and invasive species: a review', *Marine and Freshwater Research* 62: 902-917.

Brigitte, H. & Blake, J.A., 2000, 'Long-term analysis of polychaete-dominated benthic infaunal communities in Massachusetts Bay, U.S.A.', *Bulletin of Marine Science* 67: 147-164.

Brinkman, R. & Singh, V.P., 1981 '*Rapid reclamation of brackish water fishponds in acid sulfate soils*', In: Bangkok symposium on acid sulfate soils, Dost, H. & Breemen, N. (Eds.), International Institute for Land and Reclamation and Improvement, Bangkok: 318-330.

Brodie, J., McKergow, L., Prosser, I.P., Furnas, M., O'Hughes, A. & Hunter, H., 2003, *Sources of Sediment and Nutrient Exports to the Great Barrier Reef World Heritage Area*.

Brodie, J., Waterhouse, J., Schaffelke, B., Furnas, M., Maynard, J., Collier, C., Lewis, S., Warne, M., Fabricius, K., Devlin, M., McKenzie, L., Yorkston, H., Randall, L., Bennett, J. & Brando, V., 2013, *2013 Scientific Consensus Statement: Chapter 3 Relative risks to the Great Barrier Reef from degraded water quality*, Reef Water Quality Protection Plan Secretariat, Australia.

Brodie, J.E. & Mitchell, A.W., 2006, 'Nutrients in Australian tropical rivers: changes with agricultural development and implications for receiving environments', *Marine and Freshwater Research* 56: 279-302.

Caldicot, D.G.E., Croser, D., Manolis, C., Webb, G. & Britton, A., 2005, '*Crocodile attack in Australia: an analysis of its incidence and review of the pathology and management of crocodilian attacks in general*', *Wilderness and Environmental Medicine* 16: 14-159.

Cappo, M., Alongi, D.M., Williams, D.M.B. & Duke, N., 1998, *A review and synthesis of Australian fisheries habitat research: Major threats, issues and gaps in knowledge of coastal and marine fisheries habitats-Volume 1: A prospectus of opportunities for the FRDC" Ecosystem Protection Program"*, Australian Institute of Marine Science.

Cardell, M.J., Sarda, R. & Romero, J., 1999, 'Spatial changes in sublittoral soft-bottom polychaete assemblages due to river inputs and sewage discharges', *Oecologica Acta* 20: 343-351.

CCME, 1999, 'Canadian water quality guidelines for the protection of aquatic life: Metribuzin', In: *Canadian environmental quality guidelines 1999*, Canadian Council of Ministers of the Environment (Ed), 1999, Winnipeg.

Chaiyanate, N. & Montani, S., 2001, 'Response of macrobenthic community to seasonal sediment environmental parameter changes in a tidal estuary of the Seto Inland Sea, Japan', *Mer-Tokyo* 39: 167-180.

Chessman, B., 2001, '*Signal 2 A Scoring System for Macro-Invertebrates ('water-bugs')*', In: *Australian Rivers, User Manual Version, 2nd November 2001*.

Chessman, B., 2003. *Signal 2 A Scoring System for Macro-Invertebrates ('water-bugs') in Australian Rivers*. Monitoring River Health Initiative Technical Report Number 31. Commonwealth of Australia, Canberra.

Clough, B.F., 1992, 'Primary productivity and growth of mangrove forests', In: *Tropical Mangrove Ecosystems*, Robertson, A. I. & Along, D. M. (Eds.), American Geophysical Union, Washington DC, pp. 225-249.

Clough, B.F., Boto, K.G. & Attiwill, P.M., 1983, 'Mangroves and sewage: a re-evaluation', In: *Biology and Ecology of Mangroves*, Teas, H. J. (Ed), The Hague, pp. 151-161.

Cogle, A.L., Langord, P.A., Kistle, S.E., Ryan, T.J., McDougall, A.J., Russell, D.J. & Best, E.K., 2000, *Natural Resources of the Barron River Catchment 2 – Water quality, land use and land management interactions*, report prepared for Queensland Department of Primary Industries.

Coleman, P.S.J. & Cook, F.S., 2003. *St Kilda Bay Restoration Options*. Delta Environmental Consulting for the St Kilda Progress Association.

Coles, R.G., Lee Long, W.J., Watson, R.A. & Derbyshire, K.J., 1993, 'Distribution of seagrasses, and their fish and penaeid prawn communities, in Cairns Harbour, a tropical estuary, Northern Queensland, Australia. ', *Australian Jounral of Marine and Freshwater Research* 44: 193-210.

Connolly, N., Doak, N. & Pearson, R., 1996. *Environmental Literature Scan of the Barron River Catchment ACTFR*. 96: 20.

Connolly, R.M., 1986, *Relation of near-shore benthic flora of the Barker Inlet and northern beaches region to pollution sources – with emphasis on Ulva distribution*, Unpublished Student Report to the Department for Environment and Planning.

Connolly, R.M., 1999, 'Saltmarsh as habitat for fish and nektonic crustaceans: Challenges in sampling designs and methods', *Australian Journal of Ecology* 24: 422-30.

Cook, B.D., Unmack, P.J., Huey, J.A. & Hughes, J.M., (in press), 'Do common disjunct populations of freshwater fishes in northern Australia form from the same biogeographic events', *Freshwater Science* in press.

Couchman, D. & Beumer, J., 2002, *Fish habitat management operational policy for the management and protection of marine plants, departmental assessment procedures and policy position*, report prepared for Queensland Department of Primary Industries.

CRC, 2013, *Wastewater Management*, http://www.cairns.qld.gov.au/environment/water-and-waste/wastewater-management, accessed December 2013.

DAFF, 2013, *CHRIS web*, http://chrisweb.dpi.qld.gov.au/chris/, accessed December 2013.

Dafforn, K.A., Kelaher, B.P., Simpson, S.L., Coleman, M.A., Hutchings, P.A., Clark, G.F., Knott, N.A., Doblin, M.A. & Johnston, E.L., 2013, 'Polychaete richness and abundance enhanced in anthropogenically modified estuaries despite high concentrations of toxic contaminants', *PLOS One* 8: e77018.

Danion, M., Le Floch, S., Kanan, R., Lamour, F. & Quentel, C., 2012, 'Effects of in vivo chronic exposure to pendimethalin/Prowl400® on sanitary status and the immune system in rainbow trout (*Oncorhynchus mykiss*)', *Science of the Environment* 424: 143-152.

Day, J.W., Kemp, M., Yanez-Arancibia, A. & Crump, B.C., 2012, *Estuarine Ecology*, John Wiley & Sons.

DEHP, 2013, *Wet Tropics environmental values*, http://www.ehp.qld.gov.au/water/policy/wet-tropics-evs.html, accessed December 2013.

Del-Pilar-Ruso, Y., de-la-Ossa-Carretero, J.A., Casalduero, G. & Sanchez-Lizaso, J.-L., 2010, '*Sewage treatment level and flow rates affect polychaete assemblages*', *Marine Pollution Bulletin* 60: 1930-1938.

Department of State Development Infrastructure and Planning (SDIP), 2013a. *Coastal Protection State Planning Regulatory Provisions. Fact Sheet.*

Department of State Development Infrastructure and Planning (SDIP), 2013b, *State Planning Policy*, http://www.dsdip.qld.gov.au/about-planning/state-planning-policy.html, accessed December 2013.

DERM, 2009. *Queensland Water Quality Guidelines Version 3 September 2009*. Department of Environment and Resource Management, Brisbane

DERM, 2010a, *Monitoring and Sampling Manual 2009, Environmental Protection (Water) Policy 2009, Version 2, September 2010*, Department of Environment and Resource Management, Brisbane.

DERM, 2010b. *Queensland Wetland Definition and Delineation Guideline*. DRAFT Queensland Government, Brisabane.

DERM, 2012, *Water Monitoring Data Portal*, http://watermonitoring.derm.qld.gov.au/host.htm, accessed December 2013.

DEWHA, 2009a, *EPBC Protected Matters Search Tool*, http://www.environment.gov.au/erin/ert/epbc/index.html, accessed December 2013.

DEWHA, 2009b. *Matters of National Environmental Significance*. Department of the Environmental, Water, Heritage and the Arts, Canberra.

DNPRSR, 2013, *Great Barrier Reef Coast Marine Park*, http://www.nprsr.qld.gov.au/marine-parks/gbr_coast_marine_park.html, accessed December 2013.

DNRM, 2001. *Queensland Australian River Assessment System (AUSRIVAS). Sampling and Processing Manual*. Queensland Department of Natural Resources and Mines, Rocklea.

DOE, 2013, *Marine turtles in Australia*, http://www.environment.gov.au/coasts/species/turtles/index.html, accessed December 2013.

Doherty, P.J. & Sheaves, M.J., 1994. *Fish surveys in Half Moon Creek*. Consultancy undertaken by the Australian Institute of Marine Sciences for TNN Cairns Pty.

DSEWPC, 2013a, *Pristis clavata – Dwarf Sawfish, Queensland Sawfish*, http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=68447, accessed December 2013.

DSEWPC, 2013b, *Protected Matters Search Tool*, http://www.environment.gov.au/arcgis-framework/apps/pmst/pmst-coordinate.jsf, accessed December 2013.

Duke, N.C., Lawn, P.T., Roelfsema, C.M., Zahmel, K.N., Pederson, D.K., Harris, C., Steggles, N. & Tack, C., 2003. *Assessing historical change in coastal* *environments: Port Curtis, Fitzroy River Estuary and Moreton Bay*. CRC for Coastal Zone, Estuary and Waterway Management, Brisbane.

Dunstan, D.J., 1990, 'Some early environmental problems and guidelines in New South Wales estuaries', *Wetlands (Australia)* 9: 1-6.

Ebner, B. & Thuesen, P., 2010, 'Discovery of stream-cling-goby assemblages (*Stiphodon* species) in the Australian Wet Tropics', *Australian Journal of Zoology* 58: 331-340.

Edyvane, K., 1996, 'Issues in the South Australian Marine Environment', In: *State of the Marine Environment Report for Australia: State and Territory Issues - Technical Annexe 3*, Zann, L. P. & Sutton, D. (Eds.), Great Barrier Reef Marine Park Authority, Townsville, Queensland.

EHMP, 2007. *Ecosystem Health Monitoring Program 2005-2006, Annual Technical Report*. South East Queensland Healthy Waterways Partnership, Brisbane.

EHP, 2004, *Module 3 Biological Parameters Waterwatch Australia National Technical Manual*, Department of the Environment and Heritage, Australia.

EHP, 2013a, *Barron Drainage Basin Wetland statistics*, http://wetlandinfo.ehp.qld.gov.au/wetlands/facts-maps/basin-barron/, accessed December 2013.

EHP, 2013b. *Cairns Regional Council Saltwater Crocodile Management Plan January 2013*. Department of Enviroment and Heritage Protection.

EHP, 2013c, *Wildlife of Barron drainage basin*, http://wetlandinfo.ehp.qld.gov.au/wetlands/facts-maps/wildlife/?AreaID=basin-barron, accessed December 2013.

EHP, 2013d, *Wildlife Online*, http://www.ehp.qld.gov.au/wildlife/wildlife-online/index.html, accessed December 2013.

Eisler, R., 1990, *Paraquat Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*, U.S. Department of the Interior Fish and Wildlife Service, Washington, DC.

Environment Australia, 2003, *Recovery Plan for Marine Turtles in Australia*, Approvals and Wildlife Division, Environment Australia in consultation with the marine turtle recovery team, Canberra.

Environment North, 2005, *Cairns Harbour Dredging Long-term Disposal Management Plan March 2005*, Environment North in association with Hydrobiology & NIWA Australia for Cairns Port Authority.

EPA, 2010, *Environmental Assessment Guidelines: No. 5 Environmental Assessment Guideline for Protecting Marine Turtles from Light Impacts*, Environmental Protection Agency, Western Australia.

Extoxnet, 1993, *Pendimethalin*, http://pmep.cce.cornell.edu/profiles/extoxnet/metiram-propoxur/pendimethalin-ext.html, accessed December 2013.

Fisheries Research Consultants, 1995, *An assessment of the toxic potential of agrochemical residues within the topsoil, to aquaculture*, report prepared for Environment Science and Services (N.Q.).

Flanagan Consulting Group, 2013a. *Aquis resort at the Great Barrier Reef Revision: Final Environmental Impact Statement Date: 2 December 2013*. Flanagan Consulting Group.

Flanagan Consulting Group, 2013b. *Aquis resort at the Great Barrier Reef, Environmental Impact Statement. Draft September 2013*. Flanagan Consulting Group.

Fortes, R.D., 1979. *Evaluation of tenpounder and tarpon as predators on Java tilapia in brackishwater ponds in the Philippines*. Ph.D. Dissertation, Auburn University, Alabama, USA.

frc environmental, 2002, *Exclusion of Sharks from Emerald Lakes*, report prepared for Nifsan Pty Ltd.

frc environmental, 2006, *Aquatic Flora and Fauna Survey, Skase Channel, Port Douglas*, report prepared for Cardno.

frc environmental, 2007, *Half Moon Bay Masterplan; Coastal Ecology*, report prepared for CLT.

frc environmental, 2013, *Barron River Macroinvertebrate Survey December 2012*, report prepared for Stanwell Corporation Limited.

GBRMPA, 2001, *Bioregions of the Great Barrier Reef World Heritage Area*, Great Barrier Reef Marine Park Authority, GBRMPA Map No. C03051.

GBRMPA, 2009a, *Great Barrier Reef, Townsville, QLD, Australia*, http://www.environment.gov.au/cgi-bin/ahdb/search.pl?mode=place_detail;place_id=105060, accessed December 2013.

GBRMPA, 2009b. *Water Quality Guidelines for the Great Barrier Reef Marine Park*. Great Barrier Reef Marine Park Authority, Townsville.

GFHSAP, 2012, *Gladstone Fish Health Scientific Advisory Panel Final Report*, Gladstone Fish Health Scientific Advisory Panel.

GHD, 2007, *Cairns Regional Council Water and Waste - Mulgrave River Aquifer Feasibility Study Hydrogeological Report May 2007*.

Greiner, R. & Gregg, D., 2008, *Tilapia in north Queensland waterways: Risks and potential economic impacts*, report prepared for Australian Centre for Tropical Freshwater Research, James Cook University.

Gundlach, E.R. & Hayes, M.O., 1978, 'Vulnerability of coastal environments to oil spill impacts', *Marine Technology Society Journal* 12: 18-27.

Harford, A.J., O'Halloran, K. & Wright, P.F.A., 2005, 'The effects of in vitro pesticide exposures on the phagocyctic function of four native Australian freshwater fish', *Aquatic Toxicology* 330-342.

Herbert, B. & Peeters, J., 1995. *Freshwater Fishes of Far North Queensland, Information Series QI95018*. Queensland Department of Primary Industries, Brisbane.

Hicks, W.S., Bowman, G.M. & Fitzpatrick, R.W., 1999, *East Trinity acid sulfate soils. Part 1: Environmental hazards. CSIRO Land and Water Technical Report, 14/99*.

Hill, J.E. & Chichra, C.E., 2005, 'Eradication of a reproducing population of convict cichlids, Cichlasoma nigrofasciatum (Cichlidae), in north-central Florida', *Fla Sci* 68: 65-74.

Holloways, B., 2000, *Environmental Education Centre – Water Quality*, http://www.hollowayseec.eq.edu.au/wq1.htm, accessed December 2013.

Hopkins, T.E. & Cech, J.J.J., 1992, 'Physiological effects of capturing striped bass in gill nets and fyke nets', *Trans Am Fish Soc* 121: 819-822.

Hutchings, P., 1998, 'Biodiversity and functioning of polychaetes in benthic sediments', *Biodiversity and Conservation* 7: 1133-1145.

Hutchings, P.A., Ward, T.J., Waterhouse, J.H. & Walker, L., 1993, 'Fauna of Marine Sediments and Seagrass Beds of upper Spencer Gulf near Port Pirie, South Australia', *Transactions of the Royal Society of South Australia* 117: 1-15.

Jackson, J.B.C., Cubit, J.D., Keller, D.B., Batista, V., Burns, K., Caffey, H.M., Caldwell, R.L., Garrity, S.D., Getter, C.D., Gonzalez, C., Guzman, H.M., Kaufmann, K.W., Knap, A.H., Levings, S.C., Marshall, M.J., Steger, R., Thompson, R.C. & Weil, E., 1989, 'Ecological effects of a major oil spill on Panamanian coastal marine communities', *Science* 243: 37-44.

James, N.P.E. & Bruton, M.N., 1992, 'Alternative life-history traits associated with reproduction in Oreochromis mossambicus (Pisces: Cichlidae) in small water bodies of the eastern Cape, South Africa', *Environ Biol Fishes* 34: 379-392.

Johnson, J.E., Waterhouse, J., Maynard, J.A. & Morris, S., 2010. Reef Rescue Marine Monitoring Program: 2008/2009 Synthesis Report. prepared by the Reef and Rainforest Research Centre Consortium of monitoring providers for the Great Barrier Reef Marine Park Authority. Reef and Rainforest Research Centre Limited, Cairns.

Johnston, R. & Sheaves, M., 2004. *The habitat-related distribution of small fish in tropical estuaries*. Townsville, James Cook University.

Kapitzke, R., 2010, *Culvert Fishway Planning and Design Guidelines: Part B - Fish Migration and Fish Species Movement Behaviour*, James Cook University School of Engineering and Physical Sciences.

Klinbunga, S., Khamnamtong, B., Puanglarp, N., Jarayabhand, P., Yoosukh, W. & Menasveta, P., 2005. *Molecular Taxonomy of Cupped Oysters (Crassostrea, Saccostrea, and Striostrea) in Thailand Based on COI, 16S, and 18S rDNA Polymorphism*. Marine Biotechnology.

Klumpp, D.W. & Kwak, S.N., 2005, 'Composition and abundance of benthic macrofauna of a tropical sea-grass bed in North Queensland, Australia', *Pacific Sciences* 59: 541-560.

Lagler, K.F., 1978, '*Age and Growth*', In: *Methods for assessment of fish production in fresh waters*, Bagenal, T. (Ed), Blackwell Scientific Publications, Oxford, pp. 7-47.

Lam, K. & Morton, B., 2006, 'Morphological and Mitochondrial-DNA Analysis of the Indo-West Pacific Rock Oysters (Ostreidae: Saccostrea Species)', *Journal of Molluscam Studies* 72: 235-245.

Lanyon, J.M., 2003, 'Distribution and abundance of dugongs in Moreton Bay, Queensland, Australia', *Wildlife Research* 30: 397-409.

Lazur, A., Early, S. & Jacobs, J.M., 2006, 'Acute toxicity of 5% rotenone to northern snakeheads', *N Am J Fish Manage* 26: 628-630.

Leadbitter, D., 1993 '*The acid test: basic concerns of the fishing industry about coastal floodplain management in NSW*', In: Proceedings of the National Conference on Acid Sulphate Soils, Bush, R. (Ed.), CSIRO, NSW Agriculture, & Tweed Shire Council, Coolangatta Qld: pp 62-70.

Lee Long, W.J., Mellors, J.E. & Coles, R.G., 1993, 'Seagrass between Cape York and Hervey Bay, Queensland, Australia', *Australian Journal of Marine and Freshwater Research* 44: 19-31.

Levin, L., Boesch, D., Covich, A., Dahm, C., Erséus, C., Ewel, K., Kneib, R., Moldenke, A., Palmer, M. & Snelgrove, P., 2001, 'The function of marine critical transition zones and the importance of sediment biodiversity', *Ecosystems* 4: 430-451.

Limpus, C.J., 2008, 'A biological review of Australian Marine Turtles. 1. Loggerhead Turtle Caretta caretta (Linneaus). Queensland Environment Protection Agency'.

Ling, N., 2003. *Rotenone—a review of its toxicity and use for fisheries management. Science for conservation, vol 211*. Department of Conservation, Wellington.

Liu, J., Kong, L., Yu, H. & Zheng, X., 2011, 'Identifying the true oysters (Bivalvia: Ostreidae) with mitochondrial phylogency and distance-based DNA barcoding', *Molecular Ecology Resources* 11: 820-830.

Lloyd, J., Bean, A., Gwynne, M., Lale, R. & Powell, L., 2011, *Cairns Regional Council Marlin Coast Waste Water Treatment Plant and the Receiving Waters of Avondale Creek and Moon River, Annual Report for Wastewater 2009-10 and Historical Data*, Water & Waste Branch, Cairns Regional Council, Queensland.

López Gappa, J., Tablado, A., Fonalleras, M. & Adami, M., 2001, 'Temporal and spatial patterns of annelid populations in intertidal sediments of the Quequén Grande estuary (Argentina)', *Hydrobiologia* 455: 61-69.

Mack, R.N., Simberloff, D., Lonsdale, M., Evans, H., Clout, M. & Bazzaz, F.A., 2000, 'Biotic invasions: causes, epidemiology, global consequences, and control', *Ecol Appl* 10: 689-710.

Manders, J., 2010. *Acid sulfate soil depositional environments of the Barron River delta*. North Queensland 19th World Congress of Soil Science, Soil Solution for a Changing World.

Martinez-Garcia, E., Sanchez-Jerez, P., Aguado-Giménez, F., Ávila, P.G., Alejandro, Sánchez-Lizaso, J.L., Fernandez-Gonzalez, V., González, N., Gairin, J.I., Carballeira, C., García-García, B., Carreras, J., Macías, J.C., Carballeira, A. & Collado, C., 2013, 'A meta-analysis approach to the effects of fish farming on soft bottom polychaeta assemblages in temperate regions', *Marine Pollution Bulletin* 69: 165-171.

McLaughlin, L., 1987, 'Mangroves and grass swamps: Changes in the shoreline vegetation of the middle Lane Cove River, Sydney', *Wetlands (Australia)* 7: 13-24.

Meksumpun, C. & Meksumpun, S., 1999, 'Polychaete - Sediment Relations in Rayong, Thailand', *Environmental Pollution* 105: 447-456.

Mitchell, A., Brodie, J., Lewis, S., Devlin, M., Bainbridge, Z., Bulsink, D.-J. & Fumas, M., 2008, '*Water Quality Issues in the Barron WQIP Area*'.

Moss, B., 1973, 'The influence of environment factors on the distribution of freshwater algae: an experimental study. II. The role of pH and the carbon dioxide-bicarbonate system', *Journal of Ecology* 61: 157-177.

Murty, A.S., 1986, *Toxicity Of Pesticides To Fish. Vol I.*, CRC Press, Boca Raton, Florida, pp. 178.

NCAMP, 1988. *Chemical Watch Factsheet: Picloram*. NCAMP, Washington, DC.

Neil, K.M., Stafford, H., Rose, C. & Thomas, R., 2003, *Flora and Fauna Survey: Cairns Port Authority Ocean Disposal Site*, CRC Reef Research Centre and Queensland Department of Primary Industries, report to Cairns Port Authority.

Onuf, C.P., Teal, J.M. & Valiela, I., 1977, 'Interactions of nutrients, plant growth and herbivory in a mangrove ecosystems', *Ecology.* 58: 514-526.

Pearson, T.H. & Rosenberg, R., 1978, 'Macrobenthic succession in relation to organic enrichment and pollution of the marine environment', *Oceanography and Marine Biology Annual Review* 16: 229-311.

Pusey, B.J., Kennard, M. & Arthington, A., 2004, *Freshwater Fishes of North-Eastern Australia*, CSIRO Publishing, Collingwood, Victoria, pp. 171.

Queensland Government, 2013, Minor harvest fisheries, http://www.business.qld.gov.au/industry/fisheries/commercial-fishing/commercial-fisheries-profiles/commercial-harvest-fisheries/minor-harvest-fisheries, accessed December 2013.

Queensland Health, 2002. *Guidelines to Minimise Mosquito and Biting Midge Problems in New Development Areas*. Public Health Services, Queensland Health.

Queensland Museum, 2000a, *Wildlife of Tropical North Queensland*, Queensland Museum, Brisbane, Australia.

Queensland Museum, S.B., 2000b, '*Wildlife of tropical north Queensland*'.

Rasheed, M.A., McKenna, S.A. & Tol, S., 2013, *Seagrass Habitat of Cairns Harbour and Trinity Inlet: Annual Monitoring and Updated Baseline Survey – 2012*, Centre for Tropical Water & Aquatic Ecosystem Research, Cairns.

Read, M., Wright, B. & Enoch, C., 2004 '*Crocodiles in Queensland: an overview*', In: 17th Working Meeting of the IUCN-SSC Crocodile Specialist Group, Darwin, Australia, 24-29 May 2004.

Ritter, E.K., 1999. *Fact Sheet: Tiger Sharks*. Shark Info, online.

Robertson, A.I., 1988, 'Abundance, diet and predators of juvenile banana prawns, Penaeus merguiensis, in a tropical mangrove estuary', *Australian Jounral of Marine and Freshwater Research* 39: 467-478.

Robertson, A.I. & Duke, N.C., 1990, 'Mangrove fish-communities in tropical Queensland, Australia: spatial and temporal patterns in densitities, biomass and community structure', *Marine Biology* 104: 369-379.

Rossi, F., 2003, 'Short-term response of deposit-feeders to an increase of the nutritive value of the sediment through seasons in an intertidal mudflat (Western Mediterranean, Italy)', *Journal of Experimental Marine Biology and Ecology* 290: 1-17.

Rossi, F. & Underwood, A.J., 2002, 'Small-scale disturbance and increased nutrients as influences on intertidal macrobenthic assemblages: experimental burial of wrack in different intertidal environments', *Marine Ecology Progress Series* 241: 29-39.

Russell, D.J., McDougall, A.J., Ryan, T.J., Kistle, S.E., Aland, G., Cogle, A.L. & Langford, P.A., 2000. *Natural Resources of the Barron River Catchment 1. Stream Habitat, Fisheries Resources and Biological Indicators*. Information Series QI00032. Department of Primary Industries, Brisbane.

Russell, D.J., Preston, K.M. & Mayer, R.J., 2011, 'Recovery of fish and crustacean communities during remediation of tidal wetlands affected by leachate from acid sulphate soils in north-eastern Australia', *Wetlands Ecology and Management* 19: 89-108.

Sammut, J., Callinan, R.B. & Fraser, G.C., 1993 '*The impact of acidified water on freshwater and estuarine fish populations in acid sulphate soil environments*', In: Proceedings of the National Conference on Acid Sulphate Soils, 1993 June 24, Coolangatta, NSW: 26-40.

Sandström, A. & Karas, P., 2002, 'Effects of eutrophication of Young-of-the-year freshwater fish communities in coastal areas of the Baltic', *Environmental Biology of Fishes* 13: 89-101.

SCA, 2012, *Water Quality HSC Chemistry BOD*, http://hsc.sca.nsw.gov.au/chemistry/investigations/dissolved_oxygen/bod, accessed December 2013.

Schaffelke, B., Carleton, J., Doyle, J., Furnas, M. & I, Z., 2011. Reef Rescue Marine Monitoring Program final report of AIMS activities 2010/2011. Inshore Water Quality Monitoring Report for the Great Barrier Reed Marine Park Authority. Australian Institute of Marine Science Townsville: (83).

Schaffelke, B., Waterhouse, J. & Christie, C., 2001, *A Review of Water Quality Issues Influencing the Habitat Quality in Dugong Protection Areas*, report prepared for Water Quality Unit, Great Barrier Reef Marine Park Authority.

Seagrass Watch, 2013, *Seagrass Watch*, http://www.seagrasswatch.org/, accessed December 2013.

Sigmon, C., 1979, 'Oxygen consumption in lepomis macrochirus exposed to 2, 4-D or 2, 4, 5-T', *Bulletin of Environmental Contamination and Toxicology* 21: 826-829.

Simpson, S.L., Batley, G.E., Chariton, A.A., Stauber, J.L., King, C.K., Chapman, J.C., Hyne, R.V., Gale, S.A., Roach, A.C. & Maher, W.A., 2005, *Handbook for Sediment Quality Assessment*, CSIRO, Lucas Heights, NSW.

Štěpánováa, S., Doleželová, P., Plhalová, L., Prokeš, M., Maršálek, P., Škorič, M. & Svobodová, Z., 2012, 'The effects of metribuzin on early life stages of common carp (*Cyprinus carpio*)', *Pesticide Biochemistry and Physiology* 103: 152-158.

Stevens, J.D., Pillans, R.D. & Salini, J., 2005. *Conservation assessment of Glyphis sp. A (speartooth shark), Glyphis sp. C (northern river shark), Pristis microdon (freshwater sawfish) and Pristis zijsron (green sawfish)*. CSIRO Marine Research.

Swaminathan, S.R. & Vaishnavi, G., 2009. *Raw water intake, screening, and aeration in water supply project*.

Thorburn, D.C., Morgan, D.L., Rowland, A.J. & Gill, H.S., 2007, 'Freshwater sawfish *Pristis microdon* Latham, 1794 (Chondrichthyes: Pristidae) in the Kimberley region of Western Australia', *Zootaxa* 1471: 27-41.

Tilbury, B., R., B. & Young, W., 2001 '*Broad scale mangrove rehabilitation at Luggage Point*', In: Coasts & Ports 2001 Conference, Surfers Paradise, Australia.

Trenerry, M., 1991, *A report on the intertidal fauna of the Daintree, Endeavour and Russell / Mulgrave Rivers*, report prepared for Queensland Parks and Wildlife Service.

TSSC, 2009, *Commonwealth Conservation Advice on Pristis clavata (Dwarf Sawfish)* [Online] Department of the Environment, Water, Heritage and the Arts. Canberra, ACT, http://www.environment.gov.au/biodiversity/threatened/species/pubs/68447-conservation-advice.pdf, accessed December 2013.

Tsutsumi, H., 1990, 'Population Persistence of *Capitella* sp. (Polychaeta: Capitellidae) on a Mudflat Subject to Environmental Disturbance by Organic Enrichment', *Marine Ecology Progress Series* 63: 147-156.

Tsutsumi, H., 1997, 'Population dynamics of Capitella capitata (*Polychaeta; Capitellidae*) in an organically polluted cove', *Marine Ecology Progress Series* 36: 139-149.

USAEPA, 1993, *R.E.D. Facts: Glyphosate*, United States Environmental Protection Agency: Prevention, Pesticides and Toxic Substances.

Worley Parsons, 2010, *Cairns Port Long Term Management Plan 2010*, Worley Parsons.

Wu, 2002, 'Hypoxia: From molecular responses to ecosystem responses', *Marine Pollution Bulletin* 45: 35-45.

16 Database Searches

Table 16.1 Databases searched and coordinates used for the report.

Department	Database	Date Searched	Coordinates
Queensland Department of Environment and Heritage Protection	WetlandSummary	2013-07-30	-16.797125, 145.671748 -16.797125, 145.785388 -16.872376, 145.785045 -16.874348, 145.678271 -16.797782, 145.672778 -16.797125, 145.671748
Commonwealth Department of Sustainability, Environment, Water, Population and Communities	EPBC Act Protected Matters Search	2013-07-30	-16.797125, 145.671748 -16.797125, 145.785388 -16.872376, 145.785045 -16.874348, 145.678271 -16.797782, 145.672778 -16.797125, 145.671748
Commonwealth Department of Sustainability, Environment, Water, Population and Communities	Ramsar wetlands of Australia	2013-08-05	Australia
Queensland Government	Wildlife Online Extract	2013-07-30	-16.797125, 145.671748 -16.797125, 145.785388 -16.872376, 145.785045 -16.874348, 145.678271 -16.797782, 145.672778 -16.797125, 145.671748
Commonwealth Department of Sustainability, Environment, Water, Population and Communities	Australian places on the World Heritage List	2013-07-30	Australia

17 Agency and Community Engagement

Table 17.1 Agency and community engagement.

Agency Contacted	Contact Officer	Date	Issue Discussed
	Paul Aubin (local fisherman)	2013-08-13 2013-10-22	Water quality and fisheries of Thomatis / Richters Creek
Cairns Regional Council	Lynn Powell	2013-08-26	Water quality of the Barron Catchment
Centre for Tropical Water and Aquatic Ecosystem Research James Cook University	Rob Coles Team Leader Seagrass habitats	2013-08-06	Water quality and seagrass
Holloways Beach Environmental Education Centre	Louise Carver	2013-08-14	Water quality on Thomatis / Richters Creek
Department of Agriculture, Fisheries and Forestry	Louise Johns Senior Fisheries Biologist Impact assessment and Management	November 2013	Nomenclature of oysters. Fish species lists.
Department of Environment and Heritage Protection	Andrew Moss Principal Scientist	2013-08-21	Water quality of the Barron Catchment
Department of Environment and Heritage Protection	Justin Meager	2013-08-09	Marine turtles
Department of Environment and Heritage Protection	Ashley Bunce Director Wildlife Management	November 2013	Marine turtles
Department of Environment and Heritage Protection	Mike Trenerry Team Leader Environmental Services and Regulation	November 2013	Fish species lists, marine turtles, fish and mangrove invertebrate assessment programs

Agency Contacted	Contact Officer	Date	Issue Discussed
Department of Science, Information Technology Innovation and the Arts	Neil Tripodi Principal Scientist	November 2013	Water quality trigger values, guidelines and reference sites
Queensland Parks and Wildlife	Kurt Derbyshire Principal Fisheries Resource Officer	November 2013	Nomenclature of *Thenus* and *Ibacus* spp.

Aquis Resort Technical Study: Aquatic Ecology

Addendum: Wet Season Survey

Prepared for:

Flanagan Consulting Group

frc environmental

PO Box 2363, Wellington Point QLD 4160
Telephone: + 61 3286 3850
Facsimile: + 61 3821 7936

frc reference: 130927

freshwater estuarine marine

Document Control Summary

Project No.:	130927
Status:	Final Report
Project Director:	Carol Conacher
Project Manager:	Craig Chargulaf
Title:	Aquis Resort Technical Study: Aquatic Ecology
Project Team:	C. Chargulaf, M. Langridge, C. Conacher, C. Dix, A. Lea
Client:	Flanagan Consulting Group
Client Contact:	David Rivett
Date:	10 April 2014
Edition:	iii
Checked by:	Melissa Langridge
Issued by:	Craig Chargulaf

Distribution Record

Flanagan Consulting Group:	1 pdf; 1 word document
Environment North:	1 pdf; 1 word document

Contents

Tables

Figures

Maps

Summary

Introduction

Aquis Resort at the Great Barrier Reef (the Resort) will be designed to attract international tourists as well as international meetings and conferences. The Resort has been declared a coordinated project under the Queensland *State Development and Public Works Organisation Act 1971* (SDPWO Act).

This report is a supplement to the dry season aquatic ecology report, *Aquis Resort Technical Study: Aquatic Ecology*, prepared by frc environmental and submitted to Flanagan Consulting in December 2013. The report is based on the results of wet season field surveys; results are compared to results of the dry season survey.

A total of 22 sites were surveyed in the wet season assessment from 26 February to 6 March 2014 for:

- water quality (assessed in situ and in a laboratory)
- sediment quality
- benthic macroinvertebrates
- mangrove macroinvertebrates, and
- fish.

Water Quality

Overall, the water quality of creeks surrounding the development area was lower in the wet season than in the dry season. The wet season water quality results collected in situ were similar to the longer-term water quality monitoring results collected by BMT WBM during the wet season. During high wet season flows, the upper estuarine reaches of Thomatis Creek experience substantial freshwater inputs, elevated suspended sediment and nutrient concentrations.

The water quality measured in situ in Thomatis, Richters and Half Moon creeks did not comply with the QWQG for turbidity and percent saturation of dissolved oxygen. The pH was within the QWQG range at all sites, except for the deepest reading at site F6 (Richters Creek) on the incoming tide.

Salinity was highest throughout the water column near the mouth of Richters Creek and in Half Moon Creek. There was a distinct halocline in each of the creeks; at sites further

upstream, the salinity of surface waters in Thomatis and Richters creeks was very low due to input of freshwaters from the Barron River, and less tidal mixing.

There were high concentrations of ammonia, total phosphorous and total nitrogen at most sites in Thomatis and Richters creeks and there were high concentrations of total phosphorous at each site in Half Moon Creek. Discharges from the prawn farm upstream and run-off from the sugar cane farms were likely to have contributed to the high nutrient concentrations.

Water in the dune lake was of poor quality, which may be due to poor mixing and/or run-off from local agricultural land use. The water quality measured in situ at the dune lake did not comply with the QWQG guidelines for pH and the percent saturation of dissolved oxygen.

Sediment Quality

The sediment results were typical of estuarine sediments found in moderately disturbed rivers and creeks of northern Queensland. Significantly higher concentrations of nutrients were found in the sediment during the wet season, compared to the dry season, correlating with an increase in nutrients recorded in wet season water quality samples. There are no guidelines or trigger values for concentrations of nutrients in sediment; however, concentrations of total nitrogen were relatively high in Half Moon Creek and in Thomatis and Richters creeks. Concentrations decreased with distance downstream in each creek indicating increased mixing and flushing at sites closer to the river mouth.

The sediment in all of the creeks was dominated by silt / clay with traces of sand. This high percentage of fine substrates may facilitate an increase in suspended solids and turbidity in periods of high or increased flow.

Estuarine Benthic Invertebrates

The estuarine benthic invertebrate communities of the study area were abundant, and dominated by isopods, tanaids and nereid polychaetes. There were low abundances of bivalves and gastropods throughout the survey area. The communities sampled in the wet season appear to be influenced by nutrients (in the water and sediment), as well as the salinity of the overlying waters. Changes in community structure between the dry and wet season survey were likely to be related to changes in these parameters, due to increases in freshwater flow from the Barron River and increased run-off of nutrient rich waters from agricultural lands.

In Thomatis and Richters creeks, benthic invertebrate abundances decreased with distance downstream. Benthic invertebrate abundances were dominated by crustaceans (i.e. isopods and tanaids) at each site.

The abundance of estuarine benthic invertebrates in the lower reaches of Half Moon Creek were similar to the lower reaches of Richters Creek; however, abundances were dominated by polychaetes.

Mangrove Macroinvertebrates

Mangrove forests provide valuable habitat and food sources for a variety of vertebrate and invertebrate species, and provide productive environments for fisheries. Most of the mangrove communities surveyed were in good health, and displayed a high level of ecological integrity and habitat complexity for aquatic fauna.

Mangrove macroinvertebrate communities were dominated by a variety of crustaceans and molluscs; 28 species of macroinvertebrate were recorded. Mangrove invertebrate communities in *Ceriops* communities were slightly different to those associated with other mangrove communities due to the presence of flatworms several gastropod species that were not recorded at any other site.

Across all sites, the most common species was the crab, *Paracleistostoma wardi*, which was recorded at twelve sites.

The relative abundance and taxonomic richness of macroinvertebrates was typically highest in *Ceriops* mangrove communities, except for one site, located in a *Rhizophora* mangrove community. The lowest abundance and taxonomic richness of macroinvertebrates was in a mixed mangrove community.

The structure of mangrove macroinvertebrate communities correlated most closely with the percent cover of foliage and leaf litter, and the percentage of dead trees at each site, but these correlations were weak, and not statistically significant

Fish

The creeks surrounding the proposed development site provide valuable habitat for a range of estuarine and marine fish species. In particular they are important nursery grounds for a range of commercially and recreationally important species. High proportions of juvenile and intermediate fish were caught in the current survey.

A total of 94 fish, representing 17 species from 16 families, were caught in Thomatis, Richters and Half Moon creeks. All fish caught are commonly known to occur in estuarine reaches of rivers and creeks in northern Queensland.

In Thomatis and Richters creeks, 74 fish were caught with the highest abundance and species richness of fish near the mouth of Richters Creek. The fish communities in Thomatis and Richters Creeks were dominated by juveniles (57% of the catch) and adults of smaller fish species (30% of the catch). All fish caught were in good condition, with no visual defects to signify poor or impaired health (e.g. lesions or parasites).

In Half Moon Creek, a total of 20 fish were caught, representing ten species. The fish communities in Half Moon Creek were dominated by intermediates (60% of the catch) and adults (35% of the catch). All the fish that were caught were in good condition, with no visually apparent defects indicative of poor or impaired health (e.g. lesions or parasites).

Fish recorded in the creel surveys along Thomatis, Richters and Half Moon creeks were typically limited to species of recreational importance. Thirty-three fish families (and at least 40 fish species) were identified as being caught in the area.

In the dune lakes (site F4), a total of 183 fish consisting of three species were caught. The catch was dominated by juvenile eastern rainbowfish. The water quality in the dune lake was poor and unsuitable for many freshwater fish species.

All fish caught in the wet season survey appeared to be healthy.

Potential Impacts and Mitigation Measures

Potential impacts and mitigation measures were assessed in the *Aquis Resort Technical Study: Aquatic Ecology* dry season survey report. No additional impacts were identified from the findings of the wet season survey. Impacts to the aquatic environment associated with the construction and operation of the optional inlet pipeline are discussed in a separate report, *Aquis Resort Proposed Offshore Intake: Aquatic Ecology Assessment*. Design of the lake has not been finalised; therefore, impacts related to the design of the lake will be the subject of a later report. Impacts related to the current lake design are discussed in the *Aquis Resort at the Great Barrier Reef: EPBC Act Issues, March 2014 Version 1*.

Based on the updated development design, other potential impacts that may occur due to construction and operations are direct habitat disturbance in Richters Creek mouth and directly offshore for construction of the inlet pipeline, and noise during construction.

Future Monitoring

Further aquatic ecological studies are recommended prior to development commencing, to describe seasonal changes in aquatic ecosystems that may be affected by the proposed development, and to better describe the aquatic communities. In particular, further surveys of fish and mangrove macroinvertebrates are recommended, as these communities have only been described for the wet season. Surveys of adjacent beaches are also recommended in the turtle nesting and hatching season to determine if marine turtles use these beaches.

1 Introduction

1.1 The Proposed Development

Aquis Resort at the Great Barrier Reef (the Resort) will be designed to attract international tourists as well as international meetings and conferences. It is expected the Resort will assist in the economic growth of North Queensland through government taxes (e.g. gaming taxes once operational) and by increasing job opportunities (approximately 26 700 jobs when fully operational). If approved, the project will begin significant works mid 2014, and completion is set for late 2018. For a description of the proposed development, refer to the draft report *Aquis Resort at the Great Barrier Reef: EPBC Act Issues, March 2014 Version 1* (Environment North 2014).

The Resort has been declared a coordinated project under the Queensland *State Development and Public Works Organisation Act 1971* (SDPWO Act).

1.2 Scope of This Report

This report is a wet season supplement to the dry season aquatic ecology report, *Aquis Resort Technical Study: Aquatic Ecology* (frc environmental 2013), submitted to Flanagan Consulting in December 2013.

The Study Area for the wet season field survey incorporates the proposed development site and the broader area including the Barron River Catchment and delta. In the wet season field survey, the following were assessed:

- water quality (including in situ and samples collected for laboratory analysis)
- sediment quality
- benthic invertebrate communities
- mangrove invertebrate communities, and
- fish communities.

Aquatic flora has been assessed by Biotropica in a separate report and descriptions of mangrove and saltmarsh habitats are described in the following reports:

- *Aquis Resort at the Great Barrier Reef Supplementary EIS Studies* (Biotropica Australia 2013), and

- *Monitoring Mangrove Health on the Aquis at the Great Barrier Reef Development* (Biotropica 2014).

1.3 Constraints and Limitations

The field survey did not sample any groundwater communities (i.e. stygofauna) that may exist on-site. Fishing was limited to methods listed in the Great Barrier Reef Marine Park Authority (GBRMPA) sampling permit issued to frc environmental. The wet season work for the EIS was classified by GBRMPA as 'non-research', and allowed for recreational fishing methods described in the Queensland Department of Employment, Economic Development and Innovation's *Recreational Fishing Rules for Queensland* (2012). Methods used in aquatic surveys were also constrained by safety considerations, including the presence of crocodiles.

Fish communities and catch are likely to vary with environmental factors (e.g. season and moon phase). The results presented are from one wet season survey only and additional surveys would be required to record other species likely to occur in the area.

Due to inclement weather conditions, a survey of the potential inlet pipeline was not conducted. The potential impacts and mitigations measures of the lake inlet pipeline options are addressed in the report, *Aquis Resort Proposed Offshore Intake: Aquatic Ecology Assessment* (frc environmental 2014a).

Surveys of adjacent beaches for turtle nesting and hatching were not commissioned for this report.

2 Survey Design

2.1 Study Approach

The study approach was guided by well recognised indicators of aquatic ecological health that are known to respond to changes in aquatic ecosystems and impacts, such as those that may occur directly or indirectly due to the construction and operations of the resort and associated infrastructure.

The survey design, aquatic ecological indicators and methods used in this study are based on accepted ecological impact monitoring methods, such as those described in the *Australian Guidelines for Water Quality Monitoring and Reporting* (ANZECC & ARMCANZ 2000b) and the Queensland *Monitoring and Sampling Manual 2009* (DERM 2010b). The specific methods used for each indicator are described in each relevant chapter.

2.2 Field Survey

Description of the Survey Area

The Aquis Resort will be located south of Yorkeys Knob, Queensland, approximately 13 km north of Cairns. The proposed development site is between Half Moon Creek and Thomatis and Richters creeks in the Barron River Catchment. Agricultural drains have been constructed over the site and a number of dams have been constructed on Lot 100 and Lot 1. There are a number of natural brackish to freshwater pools on the relic dunes of Lot 100, which are filled following heavy rainfall. The proposed development site also borders two declared Fish Habitat Areas in Half Moon Creek and Yorkeys Creek, which discharge into the Great Barrier Reef Marine Park.

Survey Design

A total of 22 sites were surveyed in the wet season assessment from 26 February to 6 March 2014:

- 10 sites along Thomatis and Richters creeks
- 5 sites along Half Moon Creek
- 4 sites along Yorkeys Creek
- 2 sites along the Barron River, and

- 1 site in the dune lake system adjacent to Yorkeys Creek (Table 2.1 and Map 1).

Sites were selected based on water quality monitoring sites previously determined by WBM BMT, mangrove monitoring sites previously determined by Biotropica and sites selected by frc environmental based on sites surveyed in the dry season and the potential for future impact monitoring, if required. Sites along Richters and Thomatis Creeks were selected to provide baseline data on aquatic ecosystems upstream and downstream of the proposed lake overflow (located near site W4). Additional sites on Half Moon Creek are located downstream of the second lake overflow.

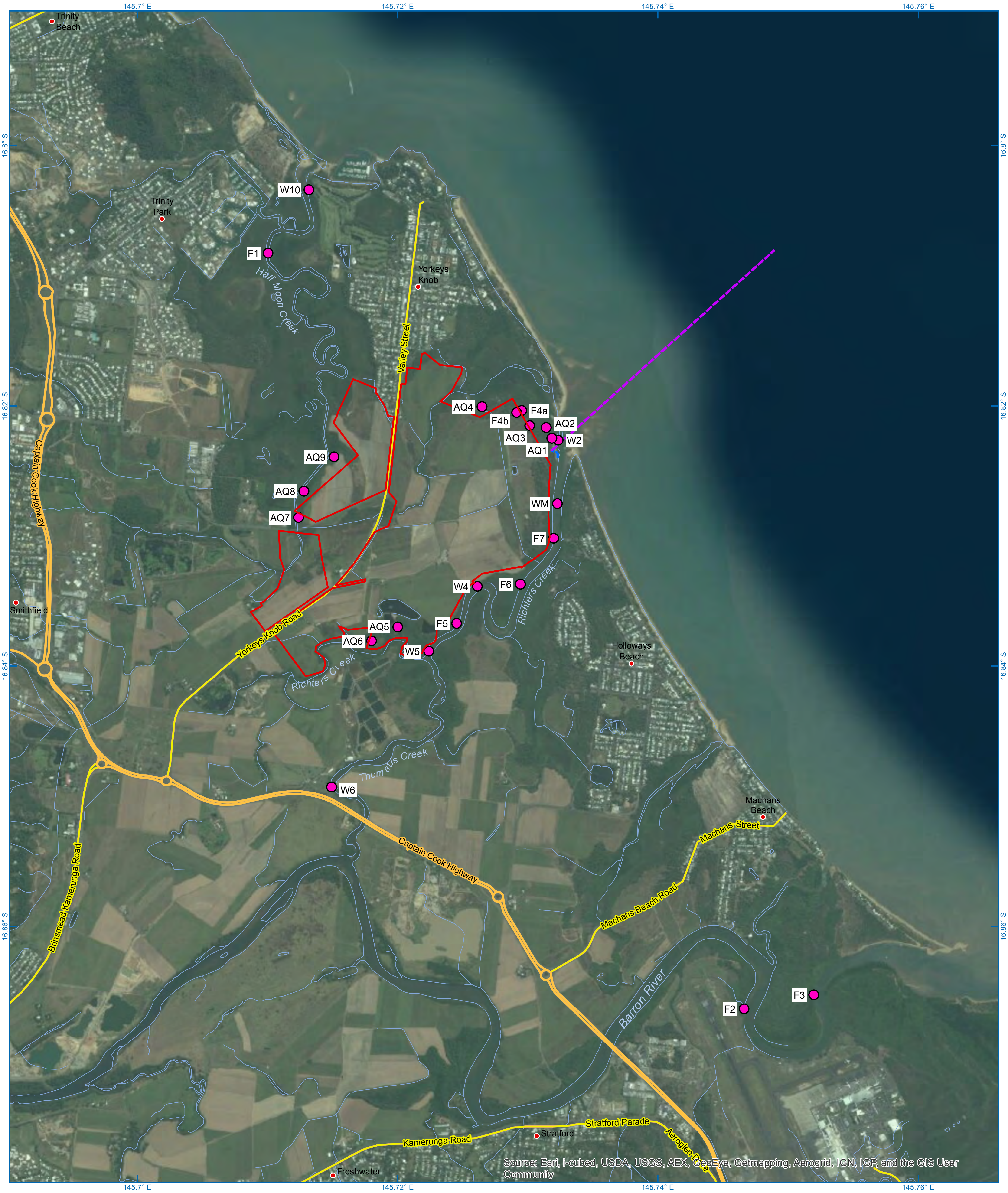
Sites along Thomatis, Richters and Yorkeys creeks were selected as they have the potential to be impacted by the Resort construction and operations. Sites along Half Moon Creek are not expected to be impacted; however, standby water might be sourced from Half Moon Creek as potential alternate for the Resort lake. Sites along the Barron River were selected as comparative sites.

Table 2.1 Survey sites and parameters surveyed in the wet season.

Site	Location	Easting [a]	Northing [a]	Parameters Surveyed				
				Water Quality	Sediment Quality	Benthic Invertebrates	Mangrove Macro-invertebrates	Fish
W2	Richters Creek	364 930	8 139 631	X	X	X		
WM	Richters Creek	364 930	8 139 091	X				X
W4	Richters Creek	364 279	8 138 383	X	X	X		X
W5	Richters Creek	363 884	8 137 828	X				X
W6	Richters Creek	363 096	8 136 668	X	X	X		X
W10	Half Moon Creek	362 911	8 141 612	X	X	X	X	X
F1	Half Moon Creek	362 546	8 141 207	X	X	X		X
F2	Barron River	366 486	8 134 804				X	
F3	Barron River	367 055	8 134 928				X	
F4a	Dune lake	364 631	8 139 881	X				X
F4b	Dune lake	364 591	8 139 863	X				X
F5	Richters Creek	364 111	8 138 069	X			X	
F6	Richters Creek	364 603	8 138 307	X			X	
F7	Richters Creek	364 900	8 138 797	X			X	
AQ1	Yorkeys Creek	364 879	8 139 648				X	
AQ2	Yorkeys Creek	364 834	8 139 738				X	
AQ3	Yorkeys Creek	364 699	8 139 753				X	

				Parameters Surveyed				
Site	**Location**	**Easting** [a]	**Northing** [a]	Water Quality	Sediment Quality	Benthic Invertebrates	Mangrove Macro-invertebrates	Fish
AQ4	Yorkeys Creek	364 302	8 139 888				X	
AQ5	Richters Creek	363 628	8 138 034				X	
AQ6	Richters Creek	363 416	8 137 914				X	
AQ7	Half Moon Creek	362 809	8 138 960				X	
AQ8	Half Moon Creek	362 852	8 139 185				X	
AQ9	Half Moon Creek	363 098	8 139 427				X	

[a] GPS (WGS84, zone 55K)



Aquis Resort Technical Study: Aquatic Ecology

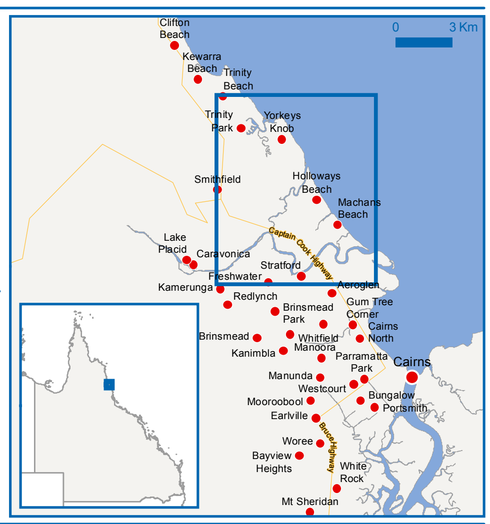
Map 1:
Sites surveyed in the wet season

LEGEND

- Survey Site
- Site Boundary
- Watercourse
- Inlet Pipe
- Outlet Pipe

Road Network

- Highway
- Main Road



frc environmental
AQUATIC ECOLOGISTS
deep thinking.science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

SOURCES

DATE	DRAWN BY	VERSION	PROJECTION
2014-04-04	CF	01	Coordinate System: GCS GDA 1994 Datum: GDA 1994 Units: Degree

Document Path: Y:\Projects\2013\130927_EN_Yorkeys_Knob_wet\Mapping\Workspaces\130927_A_Wet\130927_all_sites_Mar14_14-04-04_AL.mxd

N

SCALE

0 0.5 1

Kilometres

Scale: 1:30,000 @ A3

2.3 Timing

The survey was completed in the wet season from 26 February to 6 March 2014. Rainfall recorded at the Bureau of Meteorology station number 31011 (Cairns Aero) in the months before the survey was below average, except in November 2013 (Figure 2.1). There was rainfall each day of the survey, except on 1 March 2014 (BOM 2014).

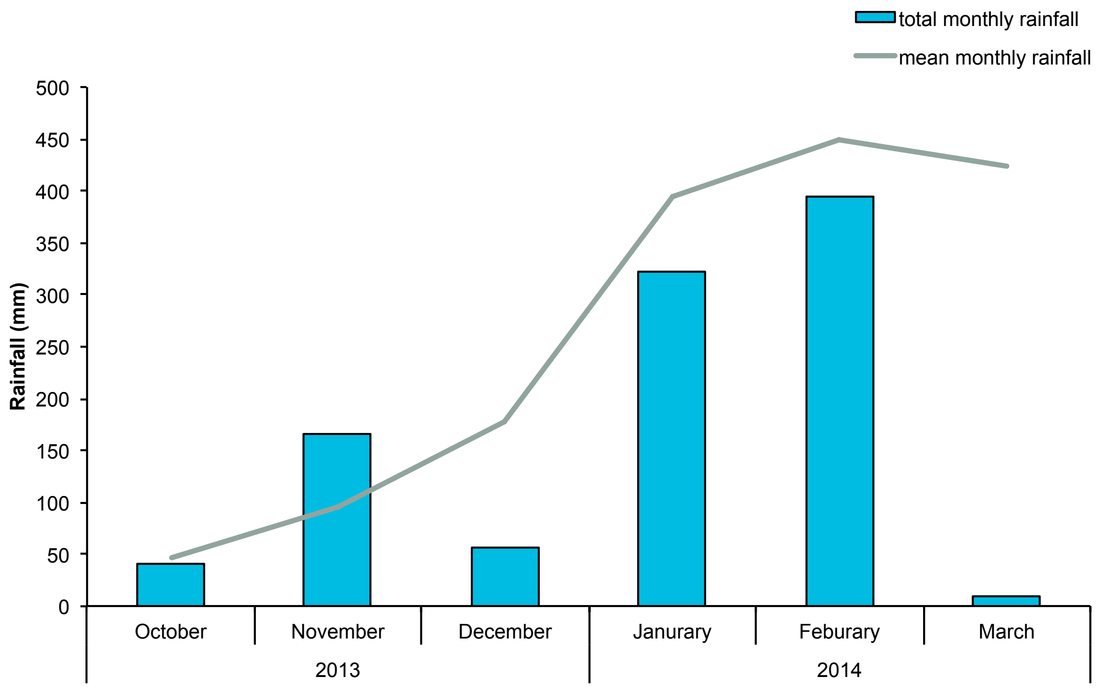


Figure 2.1 Long-term average monthly rainfall and total monthly rainfall from October 2013 to 7 March 2014 at Cairns Aero weather station (station number 13011).

2.4 Aquatic Ecological Indicators

Water and Sediment Quality

Water quality is a key component of aquatic habitat and is a fundamental element of aquatic ecosystem monitoring and assessment. It directly affects aquatic flora and fauna, as different species are adapted to and tolerant of different physical water quality conditions. Changes to water quality may impact aquatic flora and fauna indirectly, where a change in one component leads to changes in other components that then affect fauna and flora.

Sediment quality is also a key component of aquatic habitat, which can have direct and indirect impacts on aquatic flora and flora. Some fauna, such as macroinvertebrates and bottom-dwelling fish, live within the sediment and mangroves set their roots into the sediment.

The proposed development may affect water and sediment quality in a number of ways, including:

- re-suspension of material – clearing works and dredging for the proposed pipeline may cause a re-suspension of material, increasing turbidity, total suspended solids and total dissolved solids as well as having the potential to release toxicants bound to sediment
- water movement – discharges from the proposed development may increase water movement downstream as excess water would be discharged from the site. There may also be changes to dissolved oxygen as a result of the increased water movement
- water and sediment contamination – release of contaminants may occur due to construction and operations that may have an impact on flora and fauna downstream of the Resort, and
- vegetation – changes to the water and sediment quality may affect the growth and condition of aquatic plants. If vegetation is impacted, shading and leaf litter input may decrease, which may lead to increased light penetration, algal growth and a reduction in food for some fauna.

Fauna

Macroinvertebrate communities, both benthic and in mangroves, are an important part of aquatic ecosystems and are key components of many aquatic food webs. They also directly influence many aquatic ecological processes such as primary production, sedimentation and the processing of organic matters (e.g. shrimps and crabs).

The composition of macroinvertebrate communities in an aquatic ecosystem varies according to the physical, biological and chemical attributes of the waterbody. The spatial and temporal distribution of macroinvertebrate communities within an aquatic ecosystem is dependent on a variety of factors, such as: the hydrological conditions of the waterway (flow, depth); the composition and structural complexity of the habitat (type of mangroves, substrate composition); and the chemical and physical components of the water and sediment. To this extent, macroinvertebrates are often used as indicators of the status of an ecosystem (ANZECC & ARMCANZ 2000a; Butler & Bird 2010).

Fish are a key component of aquatic ecological communities, and consequently are a key biological indicator of change in aquatic ecosystems, as they:

- are at the top of the aquatic food web, and feed on a range of prey that respond to disturbance in different ways
- use a range of aquatic habitats and can travel significant distances in a waterway
- are relatively long-lived, and can respond to disturbances over a long period of time, and
- have significant social and economic value.

Differences in fish community composition (i.e. abundance, species richness or life history stage), length-weight relationships and / or relative condition may indicate a response to the influences from the proposed development. Potential impacts to smaller fish species are more likely to occur in a short to medium- timeframe, whereas larger, long-lived fish species, such as barramundi, are expected to take longer to respond as effects are manifested at the molecular and cellular level (Humphrey et al. 2007).

The proposed development may impact on biological indicators due to factors such as:

- increased water movement which may move species out of their preferred habitat, or may favour particular species
- changes to water and sediment quality may have directly toxic effects or make the habitat less suitable, and
- species that compete for the same resources (i.e. are predators or prey) may be influenced differentially, resulting in indirect impacts on other species through changes in the community composition and the food chain dynamics.

3 Water Quality

3.1 Methods

Water quality was measured in situ at 11 sites; eight sites in Thomatis Creek, two sites in Half Moon Creek and one site in one of the dune lakes (Map 2). Water quality was measured in situ at the surface and then at every 0.5 m depth interval to the bottom of the water column on both an incoming and outgoing tide.

A Hydrolab QUANTA multi parameter water quality probe was used in situ to measure:

- water temperature
- pH
- electrical conductivity
- dissolved oxygen
- salinity, and
- turbidity.

Water samples were also collected from the same 11 sites (Map 2), on an outgoing tide. Two samples were collected from two different sites to assess within-site variation and a blank sample (deionized water) was collected from another site to assess field sampling quality control. All samples were analysed by Symbio Alliance (a NATA-accredited laboratory). Samples were analysed for:

- chlorophyll *a*
- biological oxygen demand
- total organic carbon, and
- nutrients (total nitrogen, total phosphorous, ammonia, nitrate and ortho-phosphorous).

The water sample from the dune lake (site F4) was also analysed for salinity.

All sampling was in accordance with the Queensland *Monitoring and Sampling Manual 2009* (DERM 2010a).

Data Analysis

To assess within-site variation, the relative percent difference (RPD)[1] between the two samples collected from the two quality control sites was calculated. A RPD of 50% for field replicated was considered acceptable (DoTE 2009).

Water quality data was compared to the laboratory limits of reporting and the shaded water quality guidelines provided in Table 1.1.

The proposed development site is in the Wet Tropics region. The Queensland government is working with stakeholders to identify environmental values and water quality objectives (WQOs) for fresh, estuarine and coastal waters of this region. The proposed development site is within the Barron Trinity Inlet Water Quality Improvement Plan area. Draft WQOs have been derived for this area (Barron & Haynes 2009), based on the Queensland Water Quality Guidelines (QWQG) for the wet tropics region (DERM 2009) (Table 1.1).

There are also Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2009). However, the Commonwealth and State have agreed that the QWQG will be adopted for all waters inshore of and within the Enclosed Coastal Zone with the exception of pesticides in waters of the Great Barrier Reef Marine Park. All analyses in this study are covered under the QWQG – see Table 1.1.

The QWQG values are for annual medians (DERM 2009), and consequently the comparison of data from only one or a few sampling events should be used with caution.

Any laboratory results less than the laboratory limits of reporting were entered as half the laboratory limit of reporting for graphical and analytical purposes, which is recommended in the *Australian Guidelines for Water Quality Monitoring and Reporting* (ANZECC & ARMCANZ 2000b).

A summary of the results of estuarine water quality monitoring undertaken by BMT WBM is also provided; the results of the wet season survey were compared to these longer-term monitoring results.

---

1 RPD = the difference between two samples divided by the mean x 100

Table 1.1 Water quality guidelines relevant to the study area.

Parameter	Units	QWQG [a]	QWQG [b]	QWQG [c]	ANZECC & ARMCANZ [d]
temperature	°C	–	–	–	–
conductivity	mS/cm	–	–	–	–
pH		6.5–8.4	7.5–8.4	6.0 – 8.0	7–8.5
turbidity	NTU	10	10	2 – 200	1 – 20
dissolved oxygen	% Saturation	80–105	85–105	90 – 120	80–120
salinity	PSS	–	–	–	–
chlorophyll *a*	µg/L	3	2	3	2
BOD	mg/L	–	–	–	NA
total organic carbon	mg/L	–	–	–	NA
total nitrogen	µg/L	250	160	350	250
total phosphorous	µg/L	20	20	10	20
ammonia	µg/L	15	15	10	15
nitrate	µg/L	–	–	–	ID
nitrite	µg/L	–	–	–	NA
ortho-phosphorous	µg/L	–	–	–	NA

Light shaded cells indicate the water quality guidelines used for creeks in this report

Dark shaded cells indicate the water quality guidelines used for the dune lake in this report

a QWQG for mid-estuarine and tidal canals in the Wet Tropics Region (Table 3.3.1a)

b QWQG for enclosed coastal waters

c QWQG for freshwater lakes and reservoirs

d ANZECC & ARMCANZ trigger values for estuarine waters for moderately disturbed systems (Table 3.3.4–3.3.5)

Aquis Resort Technical Study: Aquatic Ecology

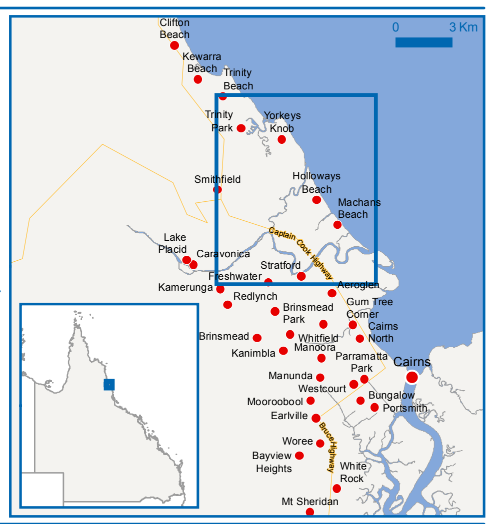
Map 2:
Water quality survey sites

LEGEND

- Water Quality Survey Site
- Site Boundary
- Watercourse
- Inlet Pipe
- Outlet Pipe

Road Network

- Highway
- Main Road



frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

SOURCES

DATE	DRAWN BY	VERSION	PROJECTION
2014-04-04	CF	01	Coordinate System: GCS GDA 1994 Datum: GDA 1994 Units: Degree

Document Path: Y:\Projects\2013\130927_EN_Yorkeys_Knob_wet\Mapping\Workspaces\130927_A_Wet\130927_WQ_Mar14_14-04-04_AL.mxd

N

SCALE

0 0.5 1

Kilometres

Scale: 1:30,000 @ A3

3.2 Results

Water Quality Measured In situ

Thomatis and Richters Creeks

The water quality measured in situ in Thomatis and Richters creeks did not comply with the QWQG for turbidity and percent saturation of dissolved oxygen (Table 3.3 and Table 3.4). The percent saturation of dissolved oxygen was below the guidelines for at least one measurement at all sites on the outgoing tide, and was below the guidelines at the more upstream sites (i.e. sites W4, F5, W5 and W6) on the incoming tide. The percent saturation of dissolved oxygen was typically higher at the surface and at sites towards the mouth of Richters Creek. The high turbidity at all sites was likely to be related to run-off from agricultural land uses in the area and recent rainfall.

The pH was within the QWQG range at all sites, except for the deepest reading at site F6 (mid-Richters Creek) on the incoming tide (Table 3.2).

The temperature was within the natural range expected for north Queensland estuarine creeks in the wet season (Table 3.1).

The salinity data indicates that the waterway is estuarine from the mouth of Richters Creek to the confluence of Thomatis Creek and the Barron River. The salinity of Thomatis and Richters creeks was lower at the surface and further away from the mouth of Richters Creek, which is related to the input of freshwater from the Barron River and less tidal influence further upstream (Table 3.5).

Half Moon Creek

The water quality measured in situ in Half Moon Creek did not comply with the QWQG for turbidity and the percent saturation of dissolved oxygen (Table 3.3 and Table 3.4). The percent saturation of dissolved oxygen was below the QWQG range at the surface at site F1 (Half Moon Creek) and site W10 (Half Moon Creek mouth) on the incoming tide and site F1 (Half Moon Creek) on the outgoing tide. All other measurements of percent saturation of dissolved oxygen were within the QWQG range.

Turbidity was above the QWQG at both sites W10 (Half Moon Creek mouth) and F1 (Half Moon Creek), for all measurements. The high turbidity at both sites was likely to be related to run-off from agricultural lands in the area and recent rainfall.

The temperature and salinity were within natural ranges expected of a north Queensland estuarine creek in the wet season (Table 3.1 and Table 3.5).

Water quality sites in Half Moon Creek were more saline at all depths than sites in Richters and Thomatis creeks; the halocline was also less pronounced, indicating less freshwater influence.

Dune Lake

The water quality measured in situ at the dune lake (site F4a and F4b) did not comply with the QWQG guidelines for pH and the percent saturation of dissolved oxygen (Table 3.6). The pH was below the QWQG range for all measurements except one surface measurement at site F4b, where it was marginally above within the water quality guideline range. The percent saturation of dissolved oxygen was below the guideline range for all measurements, with very low percent saturation of dissolved oxygen at 1 m (Table 3.6).

The salinity was much higher at depth than in surface readings, indicating that saline groundwater may be seeping into the dune lakes.

Table 3.1 Water temperature (°C) measured in situ at each site.

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
Outgoing Tide										
surface	27.63	27.36	27.38	27.10	26.87	26.80	26.66	26.33	28.95	28.65
0.5	27.68	27.37	27.24	27.20	26.85	26.75	26.67	26.39	28.97	28.82
1	27.74	27.77	27.21	27.27	26.97	29.78	26.99	26.28	28.98	28.91
1.5	27.75	27.84	27.40	27.54	27.13	27.30	27.22	28.40	28.94	28.96
2	27.76	–	27.59	27.87	28.08	27.72	28.11	–	28.96	28.92
2.5	27.75	–	27.62	–	27.42	27.87	28.30	–	28.95	28.94
3.0	–	–	27.68	–	28.64	28.66	–	–	28.94	–
3.5	–	–	–	–	28.68	–	–	–	28.93	–
Incoming Tide										
surface	27.61	27.57	27.59	27.39	27.12	27.01	26.93	26.49	27.48	26.81
0.5	28.12	27.94	27.85	27.75	27.83	26.97	27.35	26.48	28.18	28.25
1	27.66	27.96	27.99	27.87	27.83	28.24	27.97	27.36	28.29	28.36
1.5	28.14	28.02	28.01	27.95	27.84	28.39	28.10	27.52	28.33	28.35
2	28.19	28.06	28.04	27.98	27.80	28.26	28.27	29.90	28.35	28.36
2.5	28.13	28.31	28.02	27.99	27.77	28.29	28.37	27.83	28.35	–
3.0	–	–	28.05	27.95	27.74	28.33	28.40	27.84	–	–
3.5	–	–	–	27.99	–	–	28.40	27.81	–	–

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
4.0	–	–	–	28.00	–	–	–	–	–	–

Table 3.2 The pH measured in situ at each site.

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
QWQG = 6.5 to 8.4										
Outgoing Tide										
surface	7.83	7.69	7.61	7.58	7.84	7.57	7.90	8.14	8.08	7.47
0.5	7.87	7.62	7.43	7.48	7.59	7.43	7.66	8.00	8.08	7.79
1	7.91	7.81	7.38	7.50	7.35	7.34	7.27	7.75	8.09	7.95
1.5	7.91	7.85	7.46	7.67	7.31	7.29	7.23	7.14	8.09	8.01
2	7.93	–	7.58	7.84	7.75	7.39	7.65	–	8.08	8.03
2.5	7.93	–	7.66	–	7.82	7.82	7.87	–	8.09	8.01
3.0	–	–	7.71	–	8.00	8.03	–	–	8.09	–
3.5	–	–	–	–	8.07	–	–	–	8.10	–
Incoming Tide										
surface	7.82	7.80	7.85	7.84	7.86	7.06	7.77	8.18	7.17	7.56
0.5	8.01	7.92	7.99	7.96	7.78	7.70	7.53	7.87	7.65	7.89

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
1	7.93	7.92	8.06	8.05	7.93	7.86	7.78	7.37	7.84	7.98
1.5	8.06	8.06	8.08	8.07	8.08	7.87	7.89	7.59	7.93	8.02
2	8.07	8.08	8.09	8.09	8.02	7.92	7.93	7.68	7.97	8.03
2.5	8.06	8.08	8.09	8.09	8.03	7.90	7.87	7.71	8.00	–
3.0	–	–	8.10	8.10	8.05	7.97	7.87	7.72	–	–
3.5	–	–	–	8.37	–	–	7.88	7.69	–	–
4.0	–	–	–	8.81	–	–	–	–	–	–

Shaded cell indicates that the value was not within the QWQG wet tropics regional guideline values for mid estuarine and tidal canals.

Table 3.3 Turbidity (NTU) measured in situ at each site.

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
QWQG = 10										
Outgoing Tide										
surface	29.00	42.30	37.60	43.80	43.70	44.80	51.20	43.70	27.40	15.70
0.5	38.20	39.30	36.70	42.40	42.60	44.30	49.50	43.90	27.40	24.00
1	39.40	42.00	36.70	42.20	39.30	47.00	52.00	44.70	28.00	26.70
1.5	43.50	50.60	32.50	42.20	38.60	43.20	59.20	38.70	26.90	27.50
2	40.60	–	34.00	50.90	35.10	37.00	33.70	–	26.50	28.00

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
2.5	44.10	–	34.40	–	30.30	27.70	33.20	–	34.40	59.90
3.0	–	–	46.00	–	52.80	34.10	–	–	33.30	–
3.5	–	–	–	–	43.30	–	–	–	38.90	–
Incoming Tide										
surface	39.90	15.70	22.70	18.70	13.80	25.30	24.50	30.90	13.40	27.00
0.5	43.60	17.90	26.30	22.80	18.10	25.10	22.60	29.10	47.20	44.40
1	66.90	17.90	32.80	28.90	23.60	28.50	22.80	24.80	61.30	45.30
1.5	88.30	27.70	31.30	30.00	28.00	27.60	22.50	21.40	66.70	41.90
2	89.40	34.20	38.00	31.10	27.70	28.80	25.60	21.30	79.90	42.70
2.5	92.00	33.70	38.30	32.70	29.30	32.70	28.20	26.00	77.20	–
3.0	–	–	43.60	31.00	46.40	46.60	30.80	27.30	–	–
3.5	–	–	–	34.70	–	–	31.00	66.10	–	–
4.0	–	–	–	42.70	–	–	–	–	–	–

Shaded cell indicates that the value was above the QWQG wet tropics regional guideline for mid estuarine and tidal canals.

Table 3.4 Percent saturation of dissolved oxygen (%) measured in situ at each site.

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	**W2a**	**F7**	**F6**	**W4**	**F5**	**W5**	**W6**	**W10**	**F1**
QWQG = 80 – 105										
Outgoing Tide										
surface	83.60	80.40	84.70	79.90	80.50	80.20	81.00	86.20	86.00	76.10
0.5	81.90	78.60	78.00	77.90	78.50	75.10	79.40	81.10	83.00	78.20
1	81.30	77.20	77.90	77.00	76.00	79.00	73.80	81.60	84.10	85.10
1.5	80.50	75.40	72.10	75.90	74.00	70.50	72.10	55.50	83.90	83.00
2	78.50	–	70.50	73.40	70.70	69.20	71.90	–	83.60	82.90
2.5	77.90	–	67.80	–	74.60	73.60	71.40	–	83.70	77.30
3.0	–	–	69.80	–	76.00	52.00	–	–	88.00	–
3.5	–	–	–	–	73.40	–	–	–	85.30	–
Incoming Tide										
surface	89.90	85.50	86.00	87.10	84.40	88.90	80.50	84.60	69.00	65.60
0.5	92.50	87.40	88.00	88.10	79.40	82.90	79.30	82.80	86.60	78.70
1	91.80	87.40	90.60	90.30	81.10	82.80	81.20	77.10	85.00	81.20
1.5	92.60	89.30	94.00	89.90	84.50	78.90	83.00	68.80	83.20	81.10
2	91.10	90.20	88.50	89.20	83.50	79.70	81.70	66.10	85.40	81.50
2.5	90.60	90.90	88.30	89.50	85.70	79.00	79.50	66.10	85.20	–
3.0	–	–	86.80	90.80	86.20	79.90	77.10	65.50	–	–

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
3.5	–	–	–	89.20	–	–	79.10	63.50	–	–
4.0	–	–	–	89.10	–	–	–	–	–	–

Shaded cell indicates that the value was not within the range of the QWQG wet tropics regional guideline values for mid estuarine and tidal canals.

Table 3.5 Salinity (PSS) measured in situ at each site.

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
Outgoing Tide										
surface	17.26	13.78	8.61	10.45	5.61	4.55	2.68	1.11	33.21	30.33
0.5	22.43	15.51	10.65	12.86	6.18	5.10	3.35	1.13	33.28	33.73
1	20.21	23.84	12.01	18.21	11.03	7.04	10.58	1.43	33.58	33.80
1.5	22.99	25.40	23.12	21.87	24.21	12.13	15.77	22.03	33.36	34.05
2	22.71	–	24.69	25.18	25.05	27.77	24.85	–	33.44	34.30
2.5	23.06	–	25.18	–	31.50	32.09	29.52	–	33.88	34.10
3.0	–	–	25.53	–	31.64	32.75	–	–	33.65	–
3.5	–	–	–	–	32.90	–	–	–	33.95	–
Incoming Tide										
surface	17.40	14.51	16.59	11.94	7.80	7.32	6.54	2.16	21.86	27.04
0.5	25.90	23.02	29.06	27.97	24.62	24.12	15.57	2.47	32.65	32.37

Depth (m)	Thomatis and Richters Creeks								Half Moon Creek	
	W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
1	31.70	23.02	31.03	31.03	28.84	28.79	26.54	27.62	32.88	32.89
1.5	31.11	31.99	31.47	31.69	29.06	29.08	28.35	26.61	33.18	32.89
2	33.30	32.21	32.13	32.20	29.49	28.86	28.49	27.24	33.26	32.89
2.5	33.03	32.36	32.21	32.20	29.84	29.22	28.94	27.40	33.33	–
3.0	–	–	32.13	32.20	30.22	29.28	28.93	27.54	–	–
3.5	–	–	–	32.35	–	–	28.86	27.54	–	–
4.0	–	–	–	32.35	–	–	–	–	–	–

Table 3.6 Water quality measured in situ at the dune lake (site F4).

Depth (m)	Temperature (°C)	pH	Turbidity (NTU)	Percent Dissolved Oxygen (%)	Salinity (PSS)
QWQG[a]	–	6.0 – 8.0	2 – 200	90 – 120	–
QWQG[b]	–	6.5 – 8.4	10	80 – 105	–
surface	30.83	5.98	4	58.9	2.27
surface	30.68	5.83	14.6	74	4.69
1	29.35	5.75	34	3.4	18.39
surface	30.21	6.26	4	59.1	2.6

Shaded cell indicates that the value was above the QWQG wet tropics regional guideline value freshwater lakes and reservoirs.

a QWQG for freshwater lakes and reservoirs

b QWQG for mid-estuarine and tidal canals in the Wet Tropics Region (table 3.3.1a)

Water Quality Measured in the Laboratory

The RPD for all parameters was below 50%, except for chlorophyll *a*. This variation was considered in the interpretation of the results.

The concentrations of all parameters in the blank water samples were typically below laboratory limits of reporting. That is, it was unlikely that samples were contaminated during collection and processing.

Thomatis and Richters Creeks

The concentration of chlorophyll *a* was below the water quality guidelines at all sites (Table 1.8). Biological oxygen demand (BOD) was at or below the limit of reporting at all sites (2 mg/L) (Table 3.7). The concentration of total organic carbon was highest at upstream sites W5 (at the confluence of Thomatis and Richters creeks) and W6 (Thomatis Creek) (5.8 mg/L) (Table 3.7).

The concentration of ammonia was above the QWQG at all sites in Thomatis and Richters creeks (Table 3.7). The concentration of total nitrogen was above the QWQG all sites, except sites W2 and W2a near the mouth of Richters Creek. The concentration of total phosphorous was above the guidelines at all sites, except site F6 (mid-Richters Creek) (Table 3.7). There is no QWQG for the concentration of ortho-phosphorous; however, concentrations were low at all sites. High concentrations of nutrients are likely to be associated with run-off from the surrounding agricultural land at all sites, and the prawn farm that discharges into Thomatis Creek downstream of site W6 (but upstream of all other sites). The water quality in Thomatis and Richters creeks was typical of a moderately disturbed aquatic ecosystem.

The water quality measured during this survey is similar to the results observed in the dry season survey (frc environmental 2013). Total nitrogen, ammonia, nitrate and total organic carbon are slightly higher in this survey compared to the dry season survey. This is likely to be due to increased run-off associated with the wet season. All other parameters are similar to those recorded in the dry season.

Half Moon Creek

The concentration of chlorophyll *a* was above the guidelines at both sites (Table 3.7). The biological oxygen demand (BOD) was at the laboratory limit of reporting at both sites (2 mg/L) (Table 3.7). The concentration of total organic carbon was also the same at both sites (3.5 mg/L), and was lower than that recorded in Thomatis and Richters creeks (Table 3.7).

The concentrations of ammonia and total nitrogen were below the guidelines at both sites. The concentration of ammonia and nitrite and ortho-phosphorous was at or below the limit of reporting for one or both sites, and the concentration of nitrate was relatively low compared to sites in Thomatis and Richters Creeks. The concentration of total phosphorous was above the guidelines at both sites.

The water quality in Half Moon Creek is typical of a moderately disturbed aquatic ecosystem. Run-off from the sugar cane farms upstream may be contributing to the chlorophyll *a* and phosphorous concentrations. However, the tidal influences and flow are likely to maintain the relatively good water quality in the lower reaches of the creek.

The water quality measured during this survey is similar to the results from the dry season with all water quality parameters similar to those recorded in the dry season (frc environmental 2013).

Table 3.7 Water quality measured at each site.

Parameter	Units	Limit of Reporting	WQO	Thomatis and Richters Creeks								Half Moon Creek	
				W2	W2a	F7	F6	W4	F5	W5	W6	W10	F1
chlorophyll *a*	µg/L	0.8	3	<0.8	<0.8	2.2	<0.8	<0.8	<0.8	<0.8	<0.8	3.7	4.2
BOD	mg/L	2	–	2	2	2	2	<2	<2	2	2	2	2
total organic carbon	mg/L	0.1	–	4.8	5.6	5.7	5.7	5.7	6	5.8	5.8	3.5	3.5
total nitrogen	µg/L	50	250	180	240	320	290	350	360	360	420	<50	90
total phosphorous	µg/L	10	20	30	40	40	20	40	40	40	40	30	30
ammonia	µg/L	5	15	52	60	76	98	170	69	69	51	<5	5
nitrate	µg/L	5	–	80	73	110	110	130	120	100	120	29	41
nitrite	µg/L	5	–	<5	<5	5	<5	5	6	5	5	<5	<5
ortho-phosphorous	µg/L	5	–	8	8	9	8	8	9	9	9	<5	6

Shaded cell indicates that the value was above the QWQG wet tropics regional guideline value for mid estuarine waters and tidal canals

Dune Lake

The concentration of chlorophyll *a* was high and above the QWQG for freshwater lakes and estuaries (Table 3.8). The concentration of total nitrogen, total phosphorous and ammonia were also above the QWQG (Table 2.1). The salinity was moderately high for a freshwater lake. The concentrations of nutrients are likely to be associated with run-off from the local area or seepage into the lake through the groundwater.

Table 3.8 Water quality at the dune lake (site F4).

Parameter	Units	Limit of Reporting	QWQG[a]	QWQG[b]	Dune Lake
					F4
chlorophyll *a*	µg/L	0.8	3	3	170
BOD	mg/L	2	–	–	4
total organic carbon	mg/L	0.1	–	–	16
total nitrogen	µg/L	50	350	250	650
total phosphorous	µg/L	10	10	20	30
ammonia	µg/L	5	10	15	27
nitrate	µg/L	5	–	–	24
nitrite	µg/L	5	–	–	<0.005
ortho-phosphorous	µg/L	5	–	–	32
salinity	mg/L	–	–	–	1940

Shaded cell indicates that the value was above the QWQG wet tropics regional guideline value for freshwater lakes and reservoirs and also mid-estuarine and tidal canals.

a QWQG for freshwater lakes and reservoirs

b QWQG for mid-estuarine and tidal canals in the wet tropics region (Table 3.3.1a)

3.3 Results from BMT WBM Water Quality Monitoring

BMT WBM have collected monthly baseline water quality data from Richters Creek (5 sites), Thomatis Creek (1 site), Yorkeys Creek (1 site) and Half Moon Creek (1 site) since December 2013. Grab samples were analysed for total nitrogen (including NOx, TKN and ammonia), total phosphorus, reactive phosphorus, total suspended solids and chlorophyll a. Samples from Richters Creek were also analysed for metals (Sb, As, Be, B, Cd, Cr, Co, Cu, Pb, Mn, Ni, Se, Ag, Sn, Zn and Hg). In addition, three water quality sampling loggers have been installed in Richters Creek, and one logger has been installed approximately 1 km offshore of Richters Creek mouth. The loggers recorded temperature, depth, turbidity, conductivity / salinity, dissolved oxygen and pH.

The BMT WBM data collected to date showed that the median turbidity levels peaked towards the mouth and mid-reach of Richters Creek, with high turbidity associated with increased flows from the Barron River. Turbidity was generally above the QWQG during the wet season, but was below the guideline based on historical data collected during the dry season.

Similar to the current survey, BMT WBM recorded a definitive salinity gradient with depth along Richters and Thomatis creeks. During heavy inflows from the Barron River, the upper reaches turned fresh for short periods. The pH of Richters Creek was also influenced by flows from the Barron River, with notable inflow tending to lower the pH. However, the data indicated very little variation in pH, and the median pH data from loggers was within the QWQG range.

Recordings of dissolved oxygen made by BMT WBM during the 2013 / 2014 wet season were lower than those recorded in the current survey. Dissolved oxygen was generally within the QWQG near the river mouth, but was below the QWQG in the upper reaches of Richters Creek. However, dissolved oxygen levels dropped below 30% for short periods in all reaches of Richters and Thomatis creeks during notable inflow from the Barron River. Dissolved oxygen values less than 30% are toxic to some fish species.

Concentrations of nutrients were typically higher in upstream reaches than at the mouth of Richters Creek, and were typically twice the concentration at the mouth during wet weather conditions than during dry weather conditions. Non-compliance with the QWQG values was attributed to heavy rainfall causing runoff from the wider Barron River catchment, especially agricultural areas. Water quality samples from Yorkeys and Half Moon creeks were also above the QWQG for nutrients (total nitrogen, total phosphorus and ammonia) at some sites.

Metal concentrations in Richters and Thomatis creeks were generally below the 95% ANZECC / ARMCANZ (2000a) toxicity trigger values. Manganese was the only metal in

Richters and Thomatis creeks that was consistently above the guideline between December 2013 and February 2014. Copper and zinc were also on occasion above the guidelines. Although there is no guideline limit for boron, it was noted that concentrations of boron were significantly higher in January and February 2014 than in December 2013 (1110–4370 µg/L and 294–786 µg/L in January and February compared to 2.14–4.45 µg/L in December).

3.4 Summary

The wet season water quality results collected in situ were similar to the longer-term water quality monitoring results collected by BMT WBM during the wet season. During high wet season flows, BMT WBM noted that the upper estuarine reaches of Thomatis Creek experience substantial freshwater inputs, elevated suspended sediment and nutrient concentrations. With the exception of nutrients, water quality near the mouth of the creek was typically compliant with the QWQG.

Overall, the water quality of creeks surrounding the development area was lower in the wet season than in the dry season. Similar to the dry season assessment, all creeks surveyed were considered moderately disturbed and typical of waterways affected by agricultural practices.

The pH was similar to that recorded in the dry season, and was within the QWQG range for all sites except one high reading at depth in Richters Creek. This reading was above the QWQG and was also higher than reported by BMT WBM. All other readings were within the range of median values from the BMT WBM data loggers in Richters and Thomatis creeks.

The turbidity was greater than that recorded in the dry season survey, and was above the QWQG at all sites and at all depths. This is most likely due to mobilisation of sediments off the adjacent land into the creek during heavy rainfall. Turbidity was within the range recorded by BMT WBM during their wet season monitoring (BMT WBM 2013).

The percent saturation of dissolved oxygen in Thomatis and Richters creeks was lower than that recorded in the dry season, and was below the QWQG range at most sites, especially those further upstream. The dissolved oxygen was within the QWQG range at sites closer to the mouth of Richters Creek where the waters experience greater tidal mixing. These results were consistent with BMT WBM monitoring results, which indicated that dissolved oxygen was lower in the upper reaches of Thomatis Creek (BMT WBM 2013). However, dissolved oxygen was typically higher than that recorded by BMT WBM during the wet season.

Salinity had a wide range in values, with high salinities throughout the water column near the mouth of Richters Creek and in Half Moon Creek. At sites further upstream, the salinity in surface waters of Thomatis and Richters Creeks was very low due to a pronounced halocline. These results were consistent with BMT WBM, who commented that Richters Creek has a “salt-wedge” with turbid riverine waters overlying clearer oceanic waters. The salt wedge was observed to move upstream on the flooding tide and downstream with the outgoing tide (BMT WBM 2013).

There were high concentrations of ammonia, total phosphorous and total nitrogen at most sites in Thomatis and Richters creeks. Concentrations of chlorophyll a and total phosphorus were also above the QWQG in Half Moon Creek. Concentrations of nutrients were generally within the ranges observed in the wet season by BMT WBM, and were higher than in the dry season.

Water in the dune lake was of poor quality both in the wet and dry seasons, which may be due to poor mixing or run-off from local agricultural land use.

4 Sediment Quality

4.1 Sample Collection

Sediment samples were collected for laboratory analysis. Sediment samples were collected from the wet channel bed at five sites (Table 4.1 and Map 3). At one site, an additional sediment sample was collected to analyse variation within sites. Sediment was collected from the top 0.3 m of sediment using a stainless steel corer, and transferred directly into the sample containers provided by the analytical laboratory.

All sampling was in accordance with the Queensland *Monitoring and Sampling Manual 2009* (DERM 2010b).

Sediment samples were analysed by Symbio Alliance (a NATA-accredited laboratory) for:

- moisture content
- particle size distribution
- total organic carbon
- total nitrogen, and
- total phosphorous.

4.2 Data Analysis

Data was compared to the laboratory limits of reporting and results from the dry season survey. There are no ANZECC & ARMCANZ (2000a) trigger values for sediment for the parameters analysed in this survey.

To assess within-site variation, the RPD between the two samples collected from one site was calculated. A RPD of 50% for field replicates is considered acceptable (DoTE 2009).

To assess laboratory quality, the RPD between samples analysed by the laboratory were also calculated.

Aquis Resort Technical Study: Aquatic Ecology

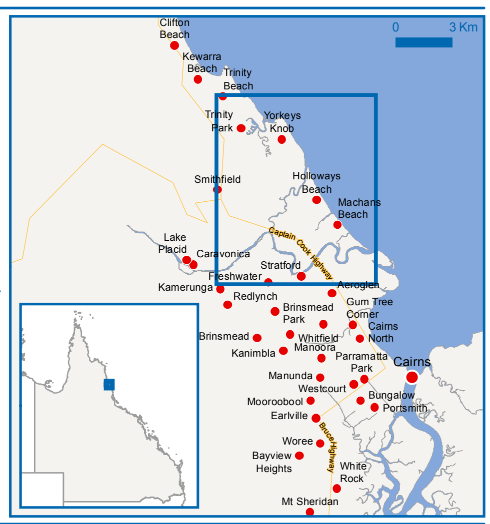
Map 3:
Sediment quality survey sites

LEGEND

- Sediment Quality Survey Site
- Site Boundary
- Watercourse
- Inlet Pipe
- Outlet Pipe

Road Network

- Highway
- Main Road



frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

SOURCES

DATE	DRAWN BY	VERSION	PROJECTION
2014-04-04	CF	01	Coordinate System: GCS GDA 1994 Datum: GDA 1994 Units: Degree

Document Path: Y:\Projects\2013\130927_EN_Yorkeys_Knob_wet\Mapping\Workspaces\130927_A_Wet\130927_sediment_Mar14_14-04-04_AL.mxd

N

SCALE

0 0.5 1

Kilometres

Scale: 1:30,000 @ A3

4.3 Results

The RPD for all parameters for both field and laboratory replicates were below 50% and the results were considered to be accurate.

Thomatis and Richters Creeks

The sediment in Thomatis and Richters creeks was dominated by silt / clay with a low contribution of sand at each site, and traces of gravel at site W6 (Richters Creek) (Table 4.1). A higher percentage of fine substrates may facilitate an increase in suspended solids and turbidity in periods of high or increased flow.

The concentration of nitrogen, phosphorus and organic carbon was lowest at site W2 closest to the mouth and highest at site W6 (Table 4.1). Higher concentrations of nutrients in the upstream reaches of Thomatis Creek were likely to be due to the agricultural use of land on both banks and the minimal tidal flushing compared to the mouth. The concentrations of nitrogen were considerably higher than recorded in the dry season, where all concentrations of nitrogen were below laboratory limits of reporting (note that sediment was analysed at different sites in the dry season) (Table 4.2). Concentrations of phosphorus and total organic carbon were much higher in the wet season survey than during the dry season survey. This was likely to be due to run-off and sedimentation from adjacent banks in the wet season.

Half Moon Creek

The sediment in Half Moon Creek was dominated by silt / clay with some sand at each site. As silt / clay was the most prevalent substrate type in Half Moon Creek, the sediment is likely to be readily transported in periods of high or increased flow. The concentration of nutrients, organic carbon and moisture content were highest at site F1 (Half Moon Creek). The concentration of phosphorus at both sites in Half Moon Creek was within the range of concentrations recorded in Richters Creek; however, the concentrations of nitrogen were higher in Half Moon Creek (Table 4.1). The concentrations of nitrogen were considerably higher than recorded in the dry season, where all concentrations of nitrogen were below laboratory limits of reporting (note that sediment was analysed at different sites in the dry season) (Table 4.2). This was likely to be due to run-off and sedimentation from adjacent banks in the wet season.

Table 4.1 Sediment quality in Thomatis, Richters and Half Moon creeks in February / March 2014.

Parameter	Units	ISQG-low Trigger Value	ISQG-high Trigger Value	Thomatis and Richters Creeks			Half Moon Creek	
				W2	W4	W6	W10	F1
Particle Size Distribution								
gravel	%	–	–	0	0	2.6	0	0
sand	%	–	–	9.1	0.5	11.4	5.9	2.8
silt / clay	%	–	–	90.9	99.5	86	94.1	97.2
Nutrients								
nitrogen	mg/kg	–	–	380	990	1100	1200	1700
phosphorus	mg/kg	–	–	22	130	170	83	140
organic carbon	mg/kg	–	–	13000	26000	27000	47000	48000
moisture content	%	–	–	28.6	37	38.1	53.2	64.4

Table 4.2 Sediment quality in Thomatis, Richters and Half Moon creeks in July / August 2013.

Parameter	Units	ISQG-low Trigger Value	ISQG-high Trigger Value	Thomatis and Richters Creeks		Half Moon Creek		
				3	4	5	6a	8a
Particle Size Distribution								
gravel	%	–	–	0	1	0	6	0
sand	%	–	–	1	6	2	17	2
silt / clay	%	–	–	99	93	98	77	98
Nutrients								
nitrogen	mg/kg	–	–	<0.1	<0.1	<0.1	<0.1	<0.1
phosphorous	mg/kg	–	–	241	128	128	197	651
organic carbon	%	–	–	26.5	22.2	22.2	24.6	36.8
moisture content	%	–	–	70.1	51.7	51.7	70.9	129.8

4.4 Summary

The sediment results were typical of estuarine sediments found in moderately disturbed rivers and creeks of northern Queensland. While more stable than water quality, sediment quality varies with land-use, climate and season. The significantly higher concentrations of nutrients recorded in the sediment during the wet season, compared to the dry season, correlates with the increase in nutrients recorded in water quality samples collected during the wet season.

Higher concentrations of nutrients in sediments can influence the structure of benthic infauna communities; this is discussed in the context of the results of the wet season benthic invertebrate survey in Section 5.

5 Estuarine Benthic Invertebrates

A suite of factors, including nutrient loads, sediment grain size and turbidity, influence the structure of benthic invertebrate communities. Differences 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.

Polychaetes occur in almost all benthic marine and estuarine sediments and are often the dominant component of the macrobenthos in terms of number of species and individuals (Hutchings 1998). Polychaetes play a major role in the functioning of benthic communities in terms of recycling and reworking of benthic sediments, bioturbating sediments and in the burial of organic matter. They are also important component of the food web, with birds, fish, crustaceans and gastropods feeding on them (Hutchings 1998).

Polychaetes of the family Capitellidae are often present in high numbers in organic rich sediments or highly modified systems (Hutchings 1998; Dafforn et al. 2013). A high, abundance of Capitellid polychaetes can indicate organic enrichment of sediments (ANZECC & ARMCANZ 2000a). This can be due to natural causes, such as settlement of wrack (i.e. stranded mats of dead plant material) (Rossi & Underwood 2002), or by the input of nutrients from anthropogenic sources such as sewage treatment plants (Del-Pilar-Ruso et al. 2010) or aquaculture facilities (Martinez-Garcia et al. 2013). Polychaetes have been recognised as useful indicators of environmental quality and are recommended for this purpose, especially for nutrient enriched environments (ANZECC & ARMCANZ 2000a).

5.1 Methods

Sample Collection

Benthic invertebrates were sampled from the shallow subtidal sediments of estuarine waters. Eight cores were collected from the benthos at five estuarine sites (Table 2.1 and Map 3). Cores were collected using a 2 L stainless steel Eyre's corer. Sediment composition was similar at each site, comprising silt and / or clay with traces of sand (results of the particle size distribution analysis are presented in Table 4.1). Cores were sieved in the field through a 1 mm sieve and the benthic fauna, sediment and detritus retained on the sieve were preserved in methylated spirits, and sent to the frc environmental biological laboratory for identification.

Laboratory Analysis

Six samples from each site were stained with Rose Bengal and invertebrates were picked, counted and identified to family level. The taxonomic richness and total abundance of each taxon was recorded for each sample. The two remaining samples are being held in storage, in the event further analysis is required.

Data Analysis

Community differences between sites were displayed visually using non-metric multidimensional scaling plots. 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 six samples from each site) and mean abundance of abundant taxa (i.e. the average number of individuals from each abundant taxa in the six samples from each site) were calculated. Mean abundances were converted to individuals per square metre prior to analysis.

The data was interpreted in the context of the wet season water and sediment quality results. Water and sediment quality parameters were compared with macroinvertebrate community structure using the BIOENV routine, which can allow the identification of variables that may explain the distribution and abundance patterns in benthic invertebrate communities.

Differences in benthic community structure between the wet season and dry season were also noted (though note that benthic invertebrate communities were analysed at different sites in the dry season).

Aquis Resort Technical Study: Aquatic Ecology

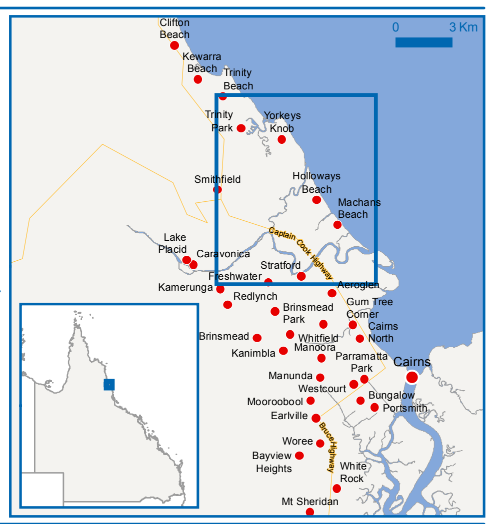
Map 4:
Benthic macroinvertebrate survey sites

LEGEND

- Benthic Macroinvertebrate Survey Site
- Site Boundary
- Watercourse
- Inlet Pipe
- Outlet Pipe

Road Network

- Highway
- Main Road



frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

SOURCES

DATE	DRAWN BY	VERSION	PROJECTION
2014-04-04	CF	01	Coordinate System: GCS GDA 1994 Datum: GDA 1994 Units: Degree

Document Path: Y:\Projects\2013\130927_EN_Yorkeys_Knob_wet\Mapping\Workspaces\130927_A_Wet\130927_benth_invert_Mar14_14-04-04_AL.mxd

N

SCALE

0 0.5 1

Kilometres

Scale: 1:30,000 @ A3

5.2 Results

Community Composition

Estuarine benthic invertebrate communities that were sampled in the wet season were slightly different in Richters and Thomatis creeks than in Half Moon Creek (Figure 5.1). Estuarine benthic invertebrate communities in Thomatis and Richters creeks were dominated by isopods (sub-order Flabellifera), tanaids (order Tanaidacea) and nereid polychaetes (family Nereididae), while benthic invertebrate communities in Half Moon Creek were dominated by polychaetes (families Capitellidae and Magelonidae). There were low abundances of bivalves and gastropods throughout the survey area.

Tanaids were the most common and abundant taxa in the wet season survey. Tanaids are typically benthic animals that burrow in the sediment and feed on detritus and plankton (Jones & Morgan 1994). Isopods are common in intertidal and subtidal marine waters and can thrive on sandy to rocky shores (Jones & Morgan 1994). Nereid polychaetes are common inshore benthic polychaetes that are typically surface deposit feeders and herbivores (Beesley et al. 2000).

Capitellid polychaetes were also commonly recorded and are indicators of organic pollution (Beesley et al. 2000); they may reflect the high concentrations of nutrients in the water and sediment. The densities of capitellid polychaetes in environments with high nutrient and organic loads are typically above 1000 individuals per m^2 (Tsutsumi 1990; Hutchings et al. 1993). Such densities are generally indicative of organic enrichment and are used as the trigger values in the ANZECC & ARMCANZ guidelines. Capitellid populations can also have boom and bust cycles, with very low abundances also typical of nutrient enrichment. Magelonid polychaetes were less common; they burrow in soft sediment and feed on surface sediment deposits (Beesley et al. 2000).

Estuarine benthic invertebrate communities sampled in the dry season were slightly different to those in the wet season (though note that different sites were sampled in each season) (Figure 5.1). In the dry season, benthic invertebrate communities were dominated by Capitellid (family Capitellidae) and Spionid (family Spionidae) polychaetes. Other dominant taxa included ghost crabs (family Ocypodidae), Nereid polychaetes (family Nereidae) and gammarid amphipods (suborder Gammaridae).

Benthic invertebrate communities in the wet season were most closely correlated with salinity and the concentrations of total phosphorus and ortho-phosphorus in the water, and the concentration of total phosphorus in the sediment, but these correlations were not statistically significant (BEST Rho = 0.936, p = 0.29, i.e. a 93.6% correlation).

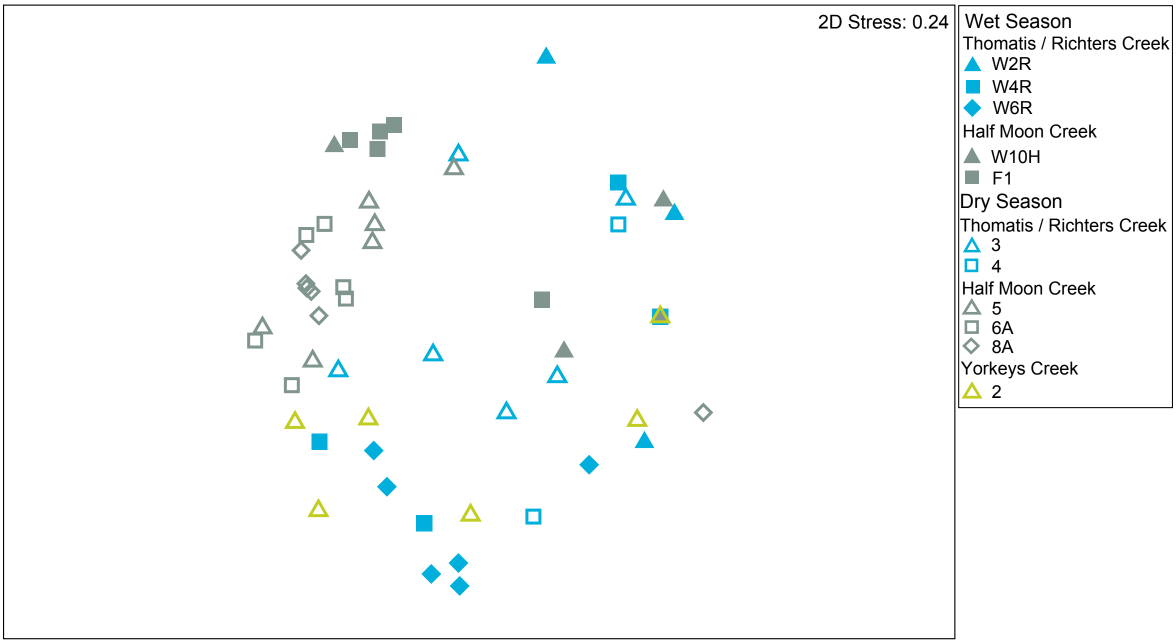


Figure 5.1 Non-metric multidimensional scaling plot of estuarine benthic invertebrate communities in the dry season (July / August 2013) and wet season (February / March 2014).

Thomatis and Richters Creeks

The mean abundance of estuarine benthic invertebrates was highest in the upper reaches of Thomatis Creek (Figure 5.2). Benthic invertebrate abundances were dominated by crustaceans (i.e. isopods and tanaids) at each site, with low abundances of polychaetes (Figure 5.3). Taxonomic richness was relatively low, but highest at upper Thomatis Creek (site W6) (Figure 5.4). Mean abundances were similar to sites surveyed in the dry season survey, with the exception of site W6, which had a much higher mean abundance of invertebrates (though the abundance in each sample was highly variable) (frc environmental 2013). Site W6 was located in the upper reaches of Thomatis Creek, where waters where salinity was lowest (Table 3.5), and had the highest concentration of total nitrogen in (Table 3.7), compared to other sites. Site W6 also had the highest proportion of sand compared to any other site, and was the only site where gravel was recorded. Long-term water quality data collected by BMT WBM also indicates that this site is likely to have the highest turbidity.

The mean taxonomic richness at each site was similar between the wet season and dry season surveys.

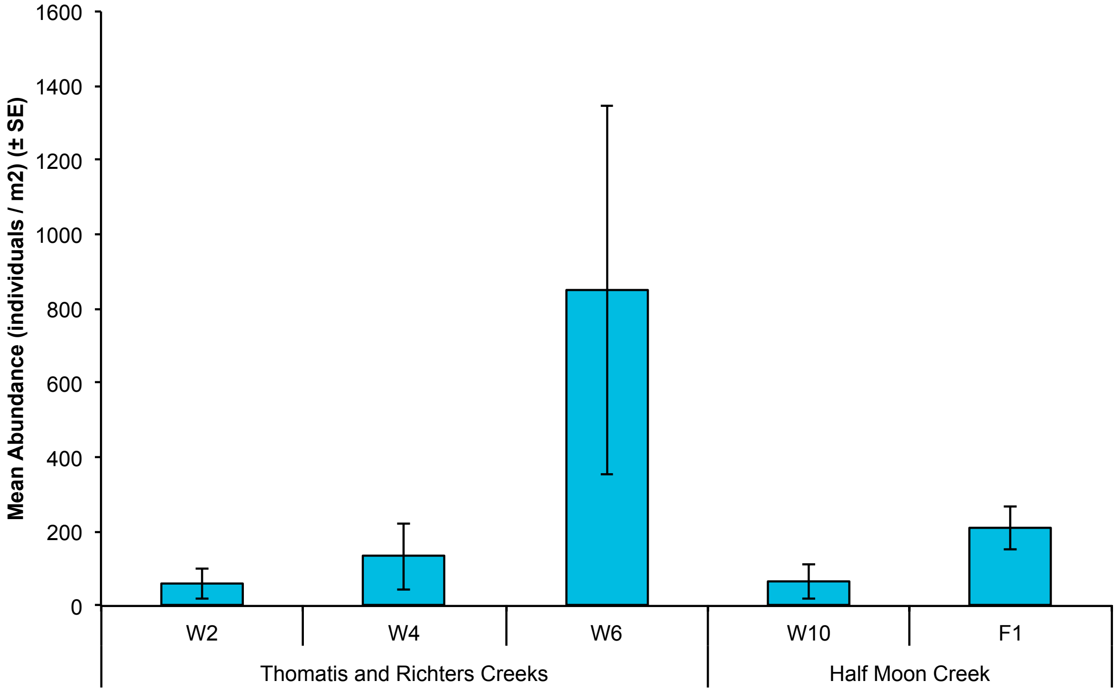


Figure 5.2 Mean abundance (± SE) of estuarine benthic invertebrates at each site.

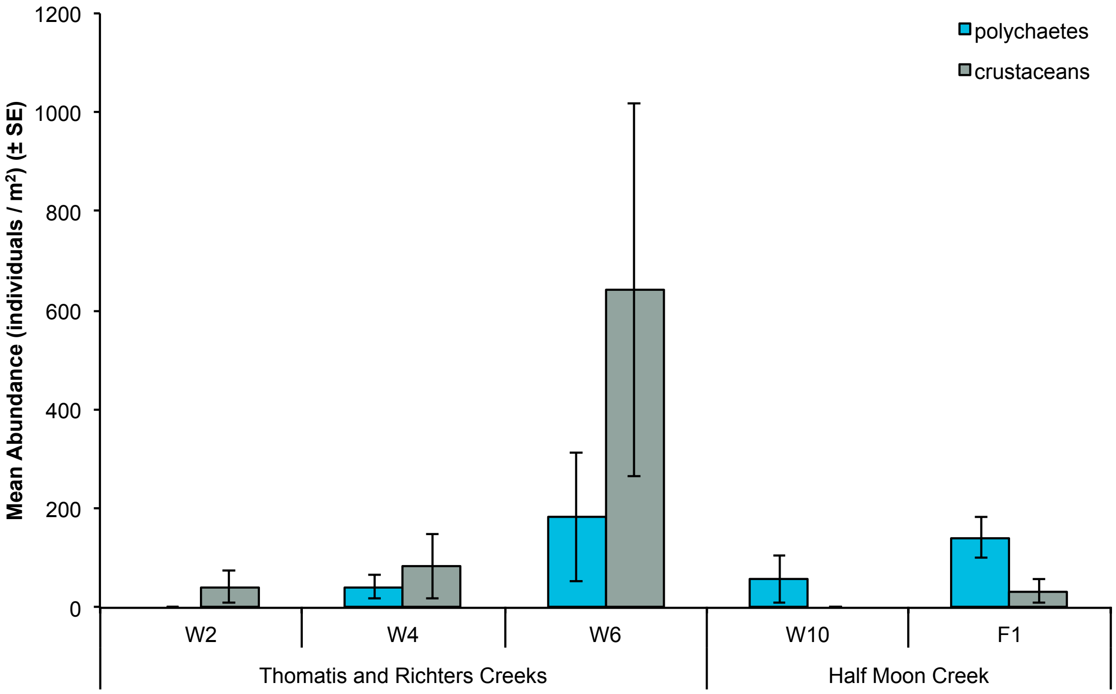


Figure 5.3 Mean abundance of polychaetes and crustaceans (± SE) at each site.

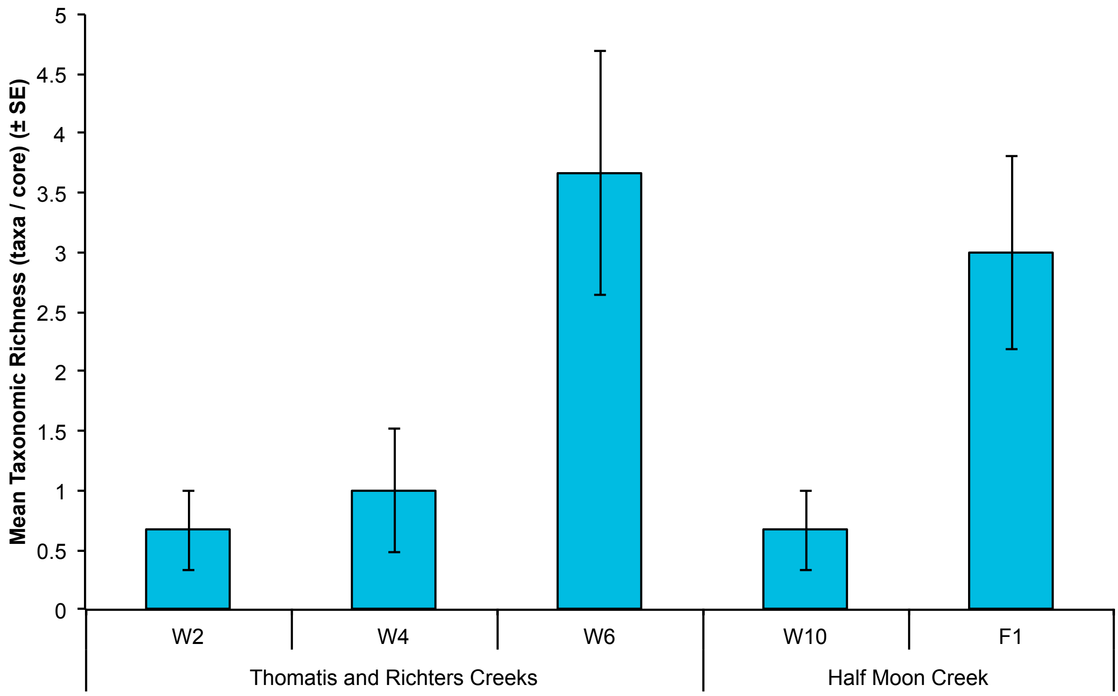


Figure 5.4 Mean taxonomic richness (± SE) of estuarine benthic invertebrates per core at each site.

Half Moon Creek

The abundance of estuarine benthic invertebrates in the lower reaches of Half Moon Creek were similar to the lower reaches of Richters Creek, i.e. in areas of comparable tidal flushing (Figure 5.2). Benthic invertebrates were numerically dominated by polychaetes (Figure 5.3), which also dominated abundances in the dry season survey (frc environmental 2013). Taxonomic richness was also relatively low, but similar to Thomatis and Richters creeks (Figure 5.4). The mean abundance and taxonomic richness of samples collected in the wet season survey was similar to samples collected from a similar location in Half Moon Creek during the dry season survey (site 5, (frc environmental 2013).

Despite spionid polychaetes being recorded from a similar location (with a similar distribution of particle sizes) in Half Moon Creek during the dry season survey, no spionid polychaetes were found in polychaete assemblages in the wet season survey. These sites had the highest concentrations of nutrients, in the sediment, including total nitrogen and organic carbon. It is possible that spionid populations in Half Moon Creek experience boom and bust cycles associated with nutrients or that it was due to natural seasonal variation.

5.3 Summary

The estuarine benthic invertebrate communities of the study area were abundant, and dominated by isopods, tanaids and nereid polychaetes. The communities sampled in the wet season appear to be influenced by nutrients (in the water and sediment), as well as the salinity of the overlying waters. Changes in community structure between the dry and wet season survey were likely to be related to changes in these parameters, due to increases in freshwater flow from the Barron River and increased run-off of nutrient rich waters from agricultural lands. Continued monitoring of estuarine benthic invertebrates is recommended to identify impacts to community structure that may result from the construction and operation of the proposed development.

6 Mangrove Macroinvertebrates

Mangrove macroinvertebrate communities are an important part of estuarine ecosystems and are key components of aquatic food webs. They also directly influence many aquatic ecological processes such as primary production, sedimentation and the processing of organic matters (e.g. shrimps and crabs).

The composition of mangrove macroinvertebrate communities varies according to the mangrove community composition, habitat structure and availability (e.g. dead woody debris and leaf litter), water and sediment quality. Mangrove macroinvertebrate communities may respond to short-term and long-term changes in the environment and their community composition and abundance might be affected by the construction and operation of the proposed development.

6.1 Sample Collection

Mangrove macroinvertebrate communities were surveyed at 15 sites from 26 February to 5 March 2014 (Map 5 and Table 6.1). Mangrove macroinvertebrate communities were surveyed at each site using techniques consistent with previous surveys by Biotropica, including:

- timed searches
- quadrat searches
- crab pots, and
- pitfall traps (Table 6.1).

The design of the baseline mangrove macroinvertebrate survey took into consideration a number of factors. Survey sites were selected to include sites:

- previously sampled by Biotropica in 2013
- on the landward side of the mangrove forests (which may be subject to ‘edge effects’ and / or other disturbances as a result of the proposed development), and on the shoreline side of the mangrove forests (which may be impacted by changes in water quality
- within and downstream of areas of potential impact (i.e. sites directly adjacent to areas of proposed disturbance as well as downstream of the proposed lake overflows), as well as in comparative areas, and

- in a range of different mangrove community associations that had been mapped previously by Biotropica.

Of the 15 survey sites, the floral communities at nine sites (sites AQ1 to AQ9) had been surveyed previously by Biotropica, and five sites had been surveyed for mangrove macroinvertebrates. With the exception of site AQ1, all Biotropica sites were located on the landward side of the mangrove forests. Additional sites selected by frc environmental were located on the shoreline side of the forests:

- site F5 was located upstream of the proposed lake overflow on Richters Creek
- sites F6 and F7 were located downstream of the proposed lake overflow on Richters Creek, and
- sites W10 (Half Moon Creek), and F2 and F3 (Barron River) were unlikely to be impacted by the proposed development.

Macroinvertebrate communities were surveyed within the following mangrove associations:

- sites AQ1 and AQ6 in a mixed community
- sites AQ2 and AQ4 in a *Ceriops australis* community
- site AQ3 in a closed a *Bruguiera gymnorhiza* community
- sites AQ5, AQ9, W10, F3, F5, F6 and F7 in a *Rhizophora stylosa* community
- sites AQ7 and F2 in a *R. stylosa* and *Avicennia marina* community, and
- site AQ8 in an *A. marina* community (Biotropica 2014).

All mangrove macroinvertebrates surveys were conducted under permits issued to frc environmental, which were:

- Queensland Animal Ethics (CA 2012/02/593)
- Queensland Fisheries (153223), and
- Great Barrier Reef Marine Park (G14/36497.1).

Table 6.1 Mangrove macroinvertebrate survey effort and method used at each site.

Site	Method	Date In	Time In	Date Out	Time Out	Effort
AQ1	timed search	04/03/14	0700	04/03/14	0720	20 min
	pitfall traps (5)	04/03/14	0715	05/03/14	0630	116.25 h
	1 x 1 m quadrats (5)	04/03/14	–	–	–	–
AQ2	timed search	04/03/14	0915	04/03/14	0935	20 min
	pitfall traps (5)	04/03/14	0915	05/03/14	0650	107.9 h
	1 x 1 m quadrats (5)	04/03/14	–	–	–	–
AQ3	timed search	04/03/14	0825	04/03/14	0845	20 min
	pitfall traps (5)	04/03/14	0830	05/03/14	0700	112.5 h
	1 x 1 m quadrats (5)	04/03/14	–	–	–	–
AQ4	timed search	04/03/14	0740	04/03/14	0800	20 min
	pitfall traps (5)	04/03/14	0800	05/03/13	0640	113.3 h
	1 x 1 m quadrats (5)	04/03/14	–	–	–	–
AQ5	timed search	28/02/14	1625	28/02/14	1645	20 min
	pitfall traps (5)	28/02/14	1630	04/03/14	0630	430 h
	1 x 1 m quadrats (5)	28/02/14	–	–	–	–

Site	Method	Date In	Time In	Date Out	Time Out	Effort
AQ6	timed search	28/02/14	1550	28/02/14	1610	20 min
	pitfall traps (5)	28/02/14	1600	04/03/14	0640	433.3 h
	1 x 1 m quadrats (5)	28/02/14	–	–	–	–
AQ7	timed search	03/03/14	1530	03/03/14	1550	20 min
	pitfall traps (5)	03/03/14	1530	04/03/14	1530	120 h
	1 x 1 m quadrats (5)	03/03/14	–	–	–	–
AQ8	timed search	03/03/14	1450	03/03/14	1510	20 min
	pitfall traps (5)	03/03/14	1450	04/03/14	1745	134.6 h
	1 x 1 m quadrats (5)	03/03/14	–	–	–	–
AQ9	timed search	03/03/14	1400	03/03/14	1420	20 min
	pitfall traps (5)	03/03/14	1420	04/03/14	1730	135.9 h
	1 x 1 m quadrats (5)	03/03/14	–	–	–	–
W10	timed search	26/02/14	1635	26/02/14	1655	20 min
	pitfall traps (5)	26/02/14	1600	28/02/14	1445	233.8 h
	crab pots (5)	26/02/14	1700	27/02/14	0945	83.8
	1 x 1 m quadrats (5)	26/02/14	–	–	–	–

Site	Method	Date In	Time In	Date Out	Time Out	Effort
F2	timed search	28/02/14	1320	28/02/14	1340	20 min
	pitfall traps (5)	28/02/14	1330	01/03/14	1750	141.7 h
	crab pots (4)	28/02/14	1350	01/03/14	1115	85.7 h
	1 x 1 m quadrats (5)	28/02/14	–	–	–	–
F3	timed search	28/02/14	1215	28/02/14	1235	20 min
	pitfall traps (5)	28/02/14	1240	01/03/14	1740	145 h
	crab pots (4)	28/02/14	1300	01/03/14	1100	88 h
	1 x 1 m quadrats (5)	28/02/14	–	–	–	–
F5	pitfall traps (5)	27/02/14	1335	01/03/14	1525	249.2 h
	crab pots (5)	27/02/14	1330	28/02/14	1015	103.8 h
F6	pitfall traps (5)	27/02/14	1400	01/03/14	1530	247.5 h
	crab pots (5)	27/02/14	1400	28/02/14	1000	100 h
F7	pitfall traps (5)	27/02/14	1430	01/03/14	1545	246.3 h
	crab pots (5)	27/02/14	1430	28/02/14	1030	100 h

Aquis Resort Technical Study: Aquatic Ecology

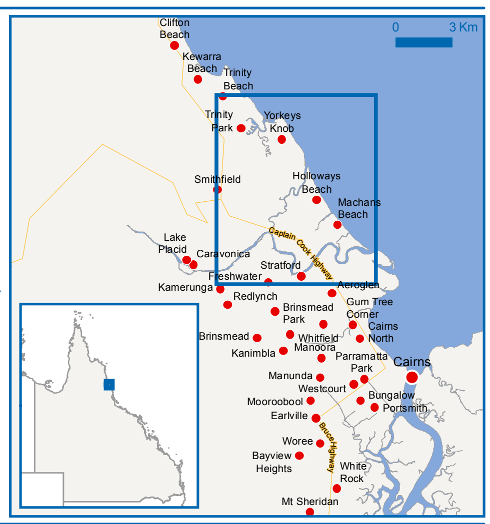
Map 5:
Mangrove macroinvertebrate survey sites

LEGEND

- Mangrove Macroinvertebrate Survey Site
- Site Boundary
- Watercourse
- Inlet Pipe
- Outlet Pipe

Road Network

- Highway
- Main Road



frc environmental
AQUATIC ECOLOGISTS
deep thinking.science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

SOURCES

DATE	DRAWN BY	VERSION	PROJECTION
2014-04-04	CF	01	Coordinate System: GCS GDA 1994 Datum: GDA 1994 Units: Degree

Document Path: Y:\Projects\2013\130927_EN_Yorkeys_Knob_wet\Mapping\Workspaces\130927_A_Wet\130927_mangr_invert_Mar14_14-04-04_AL.mxd

N

SCALE

0 0.5 1

Kilometres

Scale: 1:30,000 @ A3

Timed Searches

At twelve sites, timed searches were conducted to identify and count all mangrove macroinvertebrates possible within 20 minutes. Timed searches were confined to a 10 m x 10 m quadrat and all species visually observed were identified. All substrates including root structures, trunks, logs and other fallen debris and leaves were searched. Photographs were taken and representative specimens of each species were collected for confirmation by the Queensland museum, where required.

Quadrat Searches

At twelve sites, five 1 m x 1 m quadrats were visually assessed within the 10 m x 10 m quadrat. Mangrove macroinvertebrates observed were identified and counted.

Crab Pots

At sites adjacent to the creek or river (six sites), ten crab pots were baited with mullet and set overnight. Crabs caught in the pots were identified, photographed and returned to the environment.

Pitfall Traps

At each site, five pitfall traps made from plastic planting pots (150 mm diameter x 150 mm depth) were set into the sediment (Figure 6.1). Holes were dug out using a stainless steel trowel and traps were lowered in with the dug out sediment used to support the traps and fill in the gaps to make the area as natural as possible. Traps were set for a minimum of 24 hours. All macroinvertebrates trapped in the pitfalls were identified, photographed and returned to the environment.

Figure 6.1

Pitfall trap after one tidal cycle.

Habitat Survey

The following habitat characteristics were recorded within the 10 x 10 m quadrat at each site, to provide context for the results:

- mangrove association type (closed *Rhizophora*, closed *Avicennia*, closed *Avicennia / Rhizophora,* closed *Ceriops,* closed *Bruguiera* or closed mixed community)
- dominant species (in canopy, sub-canopy and ground storey) and height (m)
- canopy tree size (diameter at breast height of five randomly chosen trees)
- foliage cover (0–5%, 5–25%, 50–75% or >75%)
- sediment type (fines / mud, sand, gravel, pebble, cobble, boulder, bed rock)
- abundance of woody debris (rare, occasional, common)
- leaf litter (0–5%, 5–25%, 50–75% or >75%)
- seedling density (very abundant, abundant, common, sparse, absent), and
- overall health (healthy mangroves, unhealthy mangroves, recent mangrove dieback, old mangrove dieback, recent mangrove sinking, old mangrove sinking, small mangrove ponds, mangrove regrowth).

These parameters provided a baseline against which the results could be monitored in the future, and provide information on the structure and composition of the flora communities. The parameters were chosen to be consistent with the attributes described in the report, *Monitoring Mangrove Health on the Aquis at the Great Barrier Reef Development,* *February 2014* (Biotropica 2014). Additional parameters that were quantified within each quadrat were:

- abundance of aerial roots and pneumatophores
- dead trees
- dead branches
- leaf colour
- leaf loss
- leaf size
- insect damage
- adventitious roots
- epicormic shoots
- pheumatophore deformities
- epiphytic algae
- floating algae, and
- benthic microalgae (presence / absence).

6.2 Sample Processing

Any samples required for identification was preserved in methylated spirits and returned to the frc environmental laboratory, where they were identified to the lowest practical taxonomic level and any specimens unable to be identified were sent to Peter Davie at the Queensland Museum for confirmation.

6.3 Data Analysis

Community differences between sites were displayed visually using non-metric multidimensional scaling plots. The relative abundance (i.e. number of individuals visually identified) and taxonomic richness (i.e. number of taxa identified) were calculated. Results are discussed in the context of each mangrove community type, and are compared to the results of the Biotropica macroinvertebrate survey conducted in 2013 (Biotropica 2013). Habitat parameters (i.e. the percent cover of foliage, leaf litter, woody debris, the average number of aerial roots per square metre, and the percentage of dead trees and dead branches in the quadrat) were compared with macroinvertebrate community structure using the BIOENV routine, which can allow the identification of variables that may explain the distribution and abundance patterns in macroinvertebrate communities.

6.4 Results

Mangrove Habitats

Most of the mangrove communities surveyed were in good health, and displayed a high level of ecological integrity and habitat complexity for aquatic fauna. The main differences in habitat value between the different mangrove associations related to differences in tidal inundation and habitat complexity; prop roots and pneumatophores in the *Rhizophora* and *Avicennia* communities increased the habitat available to biota at these sites, and some sites had greater amounts of woody debris. The amount of woody debris was not correlated to any particular mangrove association. Sites that were located on the shoreward side of the mangrove forests (i.e. sites F2, F3, F5–F7 and W10) received greater tidal inundation than sites located on the landward side of the mangrove forests.

With the exception of site AQ1, which was a sandy site near the mouth of Richters Creek, the substrate at all sites was muddy, providing suitable habitat for a range of burrowing fauna such as crabs and bivalves.

The only unhealthy mangroves were at site F2, located near the Cairns airport on the Barron River. Mangroves at these sites had yellowing leaves, with substantial insect damage, and some leaf loss. Sites AQ8 and AQ9, in the upper reaches of Half Moon Creek, also had yellowing leaves with some leaf loss, and rubbish was found throughout the sites.

Detailed descriptions of the mangrove habitats at the Biotropica sites is provided in the report, *Monitoring Mangrove Health on the Aquis at the Great Barrier Reef Development* (Biotropica 2014). The mangrove habitats at new sites surveyed by frc environmental for the wet season survey are detailed in Appendix A.

Community Composition

Mangrove macroinvertebrate communities were dominated by a variety of fauna, including:

- 16 crustacean species

- 11 mollusc species, and
- 1 polycladida (flatworm) species (Table 6.2).

Mangrove invertebrate communities in closed *Ceriops* communities were slightly different to mangrove invertebrate communities associated with other mangrove communities (Figure 6.2 and Table 6.3). This was due to the presence of a flatworm (Figure 6.4) and three gastropod species that were not recorded at any other site (Table 6.3).

Site AQ1 (a closed mixed community near Richters Creek mouth) was also significantly different to all other sites with only one gastropod, *Littoraria luteola* (Figure 6.3), being recorded (this site is not displayed on the MDS plot). Site AQ1 had a different substrate composition to all other sites, being dominated by sand, while all other sites were dominated by finer muds and clays (Biotropica 2014).

Figure 6.2 Non-metric multidimensional scaling plot of mangrove macroinvertebrate communities.

Across all sites, the most common species was the crab, *Paracleistostoma wardi* (Figure 6.6), which was recorded at twelve sites. Other common species were:

- *Cassidula zonata* (Figure 6.7)
- *Neosarmatium fourmanoiri* (Figure 6.8)
- *Nerita melanotragus* (Figure 6.9), and
- *Perisesarma messa* (Figure 6.10).

Two crab species, fiddler crabs (*Uca* Sp.) and mud crabs (*Scylla serrata*), were only found in closed *Rhizophora* and closed *Rhizophora* and *Avicennia* mangroves adjacent to the water's edge.

In the previous survey by Biotropica nine crustacean species and 13 mollusc species were recorded from five mixed mangrove community sites (Table 6.3) (Biotropica 2013). Of the species recorded by Biotropica (2013), two mollusc and three crab species were also recorded in the current survey. Differences in the macroinvertebrate communities recorded in the current survey, and those recorded by Biotropica (2013) are likely due to differences in tidal inundation at each site (Biotropica sites were located on the landward side of mangrove forests while sites in the current study were located in both shoreward and landward mangrove forests) and differences in the type of mangrove habitat available to fauna (Biotropica sites were all mixed mangrove communities, while sites were located in a range of community associations in the current study). Over one hundred species of macroinvertebrates have been recorded in mangrove habitats of the Wet Tropics (frc environmental 2013 and references therein).

Mangrove macroinvertebrate communities in the current study correlated most closely with the percent cover of foliage and leaf litter, and the percentage of dead trees at each site, but these correlations were weak and not statistically significant (BEST Rho = 0.447, p = 0.43).

Figure 6.3

The periwinkle *Littoraria luteola* was commonly recorded on the leaves and trunks of mangroves.

Figure 6.4

The flatworm was only recorded on the substrate in closed *Ceriops* mangrove communities.

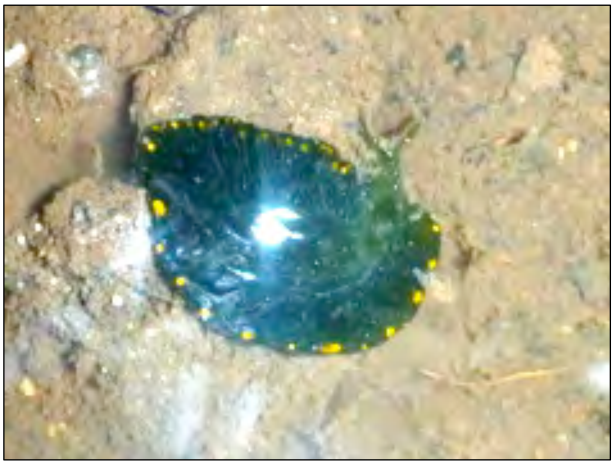


Figure 6.5

The gastropod *Telescopium telescopium* was only recorded on the substrate in closed *Ceriops* mangrove communities.

Figure 6.6

The crab *Paracleistostoma wardi* was commonly recorded on the substrate and mangroves pneumatophores.

Figure 6.7

The gastropod *Cassidula zonata* was common on mangrove trunks.

Figure 6.8

The crab *Neosarmatium fourmanoiri* was commonly recorded on the substrate around mangrove trunks.

Figure 6.9

The gastropod *Nerita melanotragus* was commonly found on mangrove trunks and on the substrate.

Figure 6.10

The crab *Perisesarma messa* was commonly found on the substrate and mangrove pneumatophores.

Table 6.2 Mangrove macroinvertebrates identified at each site.

Family	Species	Closed Mixed		Closed *Ceriops*		Closed *Bruguiera*	Closed *Rhizophora*							Closed *Rhizophora* and *Avicennia*		Closed *Avicennia*
		AQ1	AQ6	AQ2	AQ4	AQ3	AQ5	AQ9	W10	F3	F5 [a]	F6 [a]	F7 [a]	AQ7	F2	AQ8
Crustaceans																
Camptandriidae	*Paracleistostoma wardi*	–	18	6	19	26	23	1	4	6	–	–	3	10	39	9
Macrophthalmidae	*Australoplax tridentata*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Macrophthalmidae	*Ilyograpsus paludicola*	–	–	–	–	–	–	1	3	1	–	1	–	–	–	–
Ocypodidae	*Ocypode* sp.	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–
Ocypodidae	*Uca* spp.	–	–	–	–	–	–	–	6	3	–	–	1	–	5	–
Palaemonidae	unknown	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Portunidae	*Scylla serata*	–	–	–	–	–	–	–	–	–	2	–	–	–	2	–
Sesarmidae	*Metagrapsus frontalis*	–	–	–	–	–	–	–	–	–	–	–	–	23	–	–
Sesarmidae	*Neosarmatium fourmanoiri*	–	–	11	19	6	8	16	–	–	–	–	–	–	–	39
Sesarmidae	*Neosarmatium trispinosum*	–	–	1	10	–	–	8	–	–	–	–	–	1	–	1
Sesarmidae	*Parasesarma erythrodactyla*	–	8	–	–	2	–	1	–	–	–	–	–	3	–	12
Sesarmidae	*Perisesarma lividum*	–	–	1	–	–	–	–	2	–	–	–	–	–	–	–
Sesarmidae	*Perisesarma messa*	–	22	–	31	2	20	2	21	23	–	1	–	1	9	1
Xanthidae	unidentified species	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
unknown	unidentified species 1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
unknown	unidentified species 4	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–
Mollusca																
Batillariidae	*Batillaria* sp.	–		–	–	–	–	–	37	–	–	–	–	–	–	–
Cerithiidae	*Cerithium* sp.	–	–	34	8	–	–	–	–	2	–	–	–	–	1	–
Cirripedia	unknown	–	–	–	–	–	–	–	12	–	–	–	–	–	–	–
Cyrenidae	*Polymesoda erosa*	–	1	3	1	1	1	–	–	–	–	–	–	1	–	–
Diogenidae	unknown	–	–	–	–	–	–	–	5	–	–	–	–	–	–	–
Ellobiodea	*Cassidula zonata*	–	4	3	2	2	–	1	1	–	–	–	–	5	–	15
Littorinidae	*Littoraria luteola*	1	1	–	–	–	–	–	15	7	–	–	–	–	5	–

Family	Species	Closed Mixed		Closed *Ceriops*		Closed *Bruguiera*	Closed *Rhizophora*							Closed *Rhizophora* and *Avicennia*		Closed *Avicennia*
		AQ1	**AQ6**	**AQ2**	**AQ4**	**AQ3**	**AQ5**	**AQ9**	**W10**	**F3**	**F5** [a]	**F6** [a]	**F7** [a]	**AQ7**	**F2**	**AQ8**
Neritidae	*Nerita melanotragus*	–	–	1	–	3	–	–	30	10	–	–	–	4	17	2
Neritidae	*Nerita* sp.	–	–	–	–	–	–	–	5	–	–	–	–	–	–	–
Potamididae	*Telescopium telescopoium*	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
unknown	unidentified species 1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Polycladida																
unknown	unknown	–	–	46	44	–	–	–	–	–	–	–	–	–	–	–

– none observed

[a] data from pitfall traps and crab pots only

Table 6.3 Mangrove macroinvertebrates identified in each mangrove community association in the wet season and dry season.

Family	Species	Wet Season [a]						Dry Season [b]
		Mixed	***Ceriops***	***Bruguiera***	***Rhizophora***	***Rhizophora / Avicennia***	***Avicennia***	**Mixed**
Crustacea								
Camptandriidae	*Paracleistostoma wardi*	X	X	X	X	X	X	–
Diogenidae	unknown	–	–	–	–	–	–	X
Macrophthalmidae	*Australoplax tridentata*	–	–	–	–	–	X	–
Macrophthalmidae	*Ilyograpsus paludicola*	–	–	–	X	–	–	–
Ocypodidae	*Ocypode* sp.	–	–	–	X	–	–	–
Ocypodidae	*Uca coarctata*	–	–	–	–	–	–	X
Ocypodidae	*Uca* spp.	–	–	–	X	X	–	X
Palaemonidae	unknown	–	–	–	X	–	–	–
Pilumnidae	*Pilumnus semilanatus*	–	–	–	–	–	–	X
Portunidae	*Scylla serrata*	–	–	–	X	X	–	–
Sesarmidae	*Metopograpsus frontalis*	–	–	–	–	X	–	–
Sesarmidae	*Metopograpsus* sp.	–	–	–	–	–	–	X
Sesarmidae	*Neosarmatium fourmanoiri*	–	X	X	X	–	X	–

Family	Species	Wet Season [a]						Dry Season [b]
		Mixed	*Ceriops*	*Bruguiera*	*Rhizophora*	*Rhizophora / Avicennia*	*Avicennia*	Mixed
Sesarmidae	*Neosarmatium trispinosum*	–	X	–	X	X	X	–
Sesarmidae	*Parasesarma erythrodactyla*	X	–	X	X	X	X	X
Sesarmidae	*Perisesarma lividum*	–	X	–	X	–	–	–
Sesarmidae	*Perisesarma messa*	X	X	X	X	X	X	X
Sesarmidae	*Pseudohelice subquadrata*	–	–	–	–	–	–	X
Sesarmidae	unidentified species	–	–	–	–	–	–	X
Xanthidae	unidentified species	–	–	–	X	–	–	–
unknown	unidentified species 1	–	X	–	–	–	–	–
unknown	unidentified species 4	–	X	–	–	–	–	–
Mollusca								
Batillariidae	*Batillaria* sp.	–	–	–	X	–	–	–
Batillariidae	*Pyrazus ebeninus*	–	–	–	–	–	–	X
Camaenidae	unknown	–	–	–	–	–	–	X
Cerithiidae	*Cerithium* sp.	–	X	–	X	X	–	–

Family	Species	Wet Season [a]						Dry Season [b]
		Mixed	*Ceriops*	*Bruguiera*	*Rhizophora*	*Rhizophora / Avicennia*	*Avicennia*	Mixed
Cirripedia	unknown	–	–	–	X	–	–	–
Corbiculidae	*Polymesoda erosa*	–	–	–	–	–	–	X
Cyrenidae	*Polymesoda erosa*	X	X	X	X	X	–	–
Diogenidae	unknown	–	–	–	X	–	–	–
Ellobiodea	*Cassidula zonata*	X	X	X	X	X	X	X
Littorinidae	*Littoraria luteola*	X	–	–	X	X	–	–
Nassariidae	unknown	–	–	–	–	–	–	X
Neritidae	*Nerita melanotragus*	–	X	X	X	X	X	–
Neritidae	*Nerita* sp.	–	–	–	X	–	–	X
Potamididae	*Telescopium telescopoium*	–	X	–	–	–	–	X
unknown	unidentified species 1	–	X	–	–	–	–	–
unknown	unidentified species 2	–	–	–	–	–	–	X
unknown	unidentified species 3	–	–	–	–	–	–	X
unknown	unidentified species 4	–	–	–	–	–	–	X
unknown	unidentified species 5	–	–	–	–	–	–	X

Family	Species	Wet Season [a]						Dry Season [b]
		Mixed	*Ceriops*	*Bruguiera*	*Rhizophora*	*Rhizophora / Avicennia*	*Avicennia*	Mixed
unknown	unidentified species 6	–	–	–	–	–	–	X
unknown	unidentified species 7	–	–	–	–	–	–	X
Polycladida								
unknown	unknown	–	X	–	–	–	–	–

X observed

– none observed

[a] data from current study

[b] data from Biotropica 2013

Relative Abundance and Taxonomic Richness

Closed Mixed Mangrove Communities

The relative abundance of mangrove macroinvertebrates in closed mixed communities was the lowest at site AQ1, which was likely to be related to the substrate as this site was dominated by a sandy substrate while all other sites were dominated by mud (Figure 6.11 and Table 6.2). The macroinvertebrate community at site AQ6 was dominated by crabs and was similar to the relative abundance at most other mangrove communities except for closed *Ceriops* communities and site W10 in a closed *Rhizophora* mangrove community.

Similar to relative abundance, the taxonomic richness of mangrove macroinvertebrates was lowest at site AQ1, with only one taxa being recorded; however, taxonomic richness at site AQ6 was similar to all other sites, except for sites in closed *Ceriops* mangrove communities and site W10 in a closed *Rhizophora* mangrove community (Figure 6.12).

Closed Ceriops Communities

The relative abundance of mangrove macroinvertebrates was high at sites AQ2 and AQ4 in closed *Ceriops*-dominated mangrove communities (Figure 6.11 and Table 6.2). The relative abundances at these sites were high due to the abundance of flatworms on the substrate in pools at low tide. Closed *Ceriops* communities also had the highest taxonomic diversity of macroinvertebrates compared to other mangrove communities (with the exception of one closed *Rhizophora* site) (Figure 6.12). This was due to the occurrence of the flatworm and two gastropods (one unidentified species and *Telescopium telescopium*), which were not recorded at any other site.

Closed Bruguiera Communities

The relative abundance of mangrove macroinvertebrates was lower in the *Bruguiera* community than most other sites (Figure 6.11 and Table 6.2); the crab, *Paracleistostoma wardi*, was the most abundant species at the site. The taxonomic richness of mangrove macroinvertebrates in closed *Bruguiera* communities was similar to the taxonomic richness recorded at most sites in other mangrove communities (Figure 6.12).

Closed Rhizophora Communities

The relative abundance of mangrove macroinvertebrates was highest at site W10 due to a high abundance of molluscs on mangroves (Figure 6.11 and Table 6.2). However, the relative abundance of mangrove macroinvertebrates at all other closed *Rhizophora* sites was similar to the relative abundance of mangrove macroinvertebrates in other mangrove communities (except closed *Ceriops*, which had the highest abundance).

The taxonomic richness of mangrove macroinvertebrate communities was highest at site W10 (Figure 6.12), which was the only closed *Rhizophora* site located at Half Moon Creek. Some crab species (e.g. *Uca* sp.) and prawns were caught at this site, but not at any other site (Table 6.2). The taxonomic richness at site AQ5 was relatively low compared to other sites, which was due to a low richness of mollusc species.

Closed Rhizophora and Avicennia Communities

The relative abundance of mangrove macroinvertebrates in closed *Rhizophora* and *Avicennia* communities was dominated by the crab *Metagrapsus frontalis* at site AQ7 and by the crab *Neosarmatium fourmanoiri* at site F2 (Table 6.2). The relative abundance of mangrove macroinvertebrates in closed *Rhizophora* and *Avicennia* communities was similar to the relative abundance of mangrove macroinvertebrates in other mangrove communities, except closed *Ceriops* (Figure 6.11).

The taxonomic richness of mangrove macroinvertebrates in closed *Rhizophora* and *Avicennia* communities was similar to the taxonomic richness recorded at sites in other mangrove communities, except for the closed *Ceriops* communities (Figure 6.12).

Closed Avicennia Communities

The relative abundance of mangrove macroinvertebrates in closed *Avicennia* communities was dominated by the crab *Neosarmatium fourmanoiri* (Table 6.2). The relative abundance of mangrove macroinvertebrates in closed *Avicennia* communities was similar to the relative abundance of mangrove macroinvertebrates in other mangrove communities, except the closed *Ceriops* communities (Figure 6.11).

The taxonomic richness of mangrove macroinvertebrates in closed *Avicennia* communities was also similar to the taxonomic richness recorded at sites in other mangrove communities, except for the closed *Ceriops* communities (Figure 6.12).

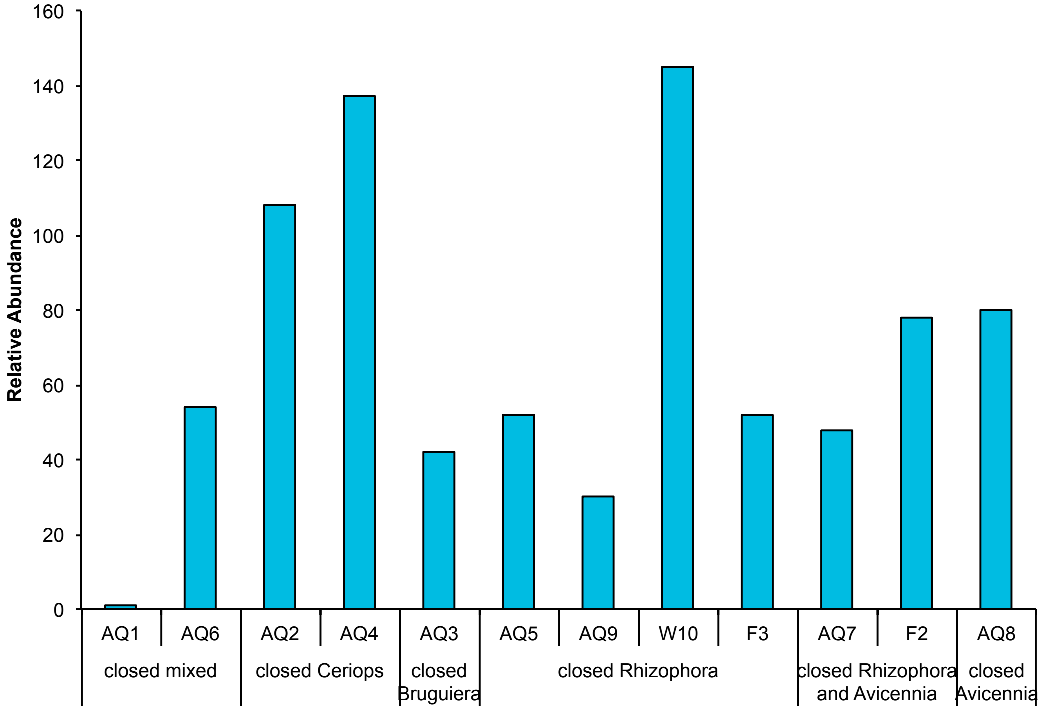


Figure 6.11 Relative abundance of mangrove macroinvertebrates at each site.

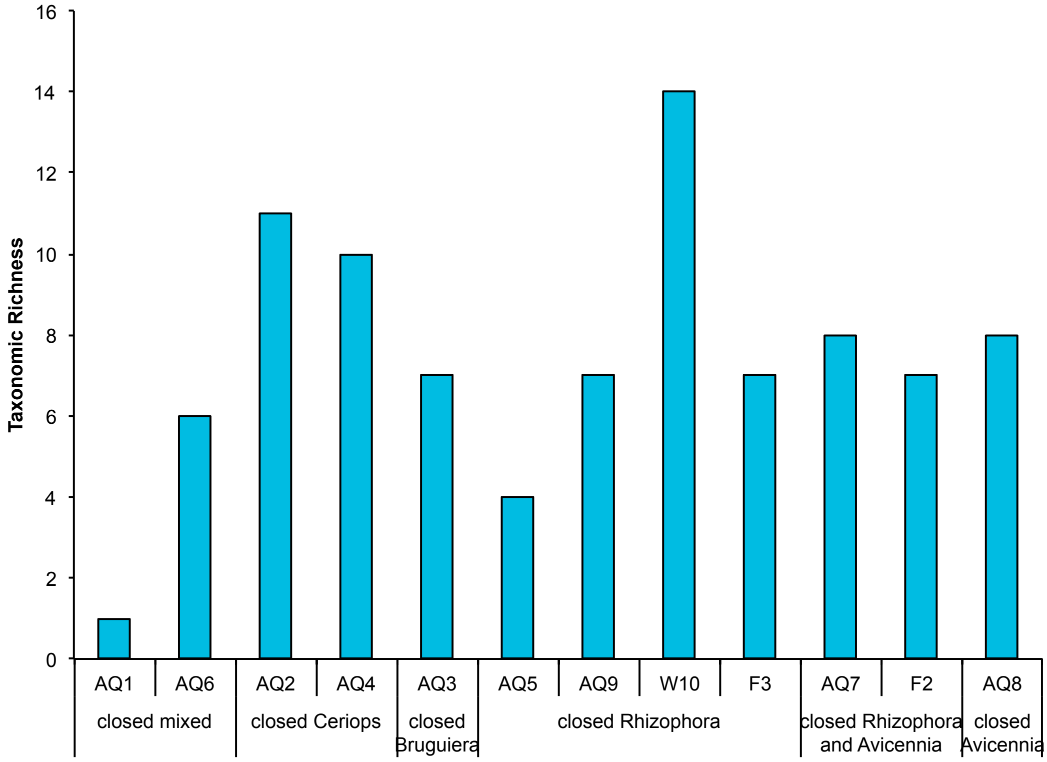


Figure 6.12 Taxonomic richness of mangrove macroinvertebrates at each site.

6.5 Conclusion

Mangrove forests provide valuable habitat and food sources for a variety of vertebrate and invertebrate species, and provide productive environments for fisheries (Quinn 1992). 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. Previous studies indicate that healthy mangroves support a higher diversity of invertebrates than degraded ones (Schrijvers et al. 1995; Stromberg et al. 1998). Thus impacts to mangrove communities, particularly those associated with water and sediment quality, are likely to affect the macroinvertebrate communities that inhabit the mangrove forests.

The mangrove lined reaches of Thomatis Creek, Richters Creek, Half Moon Creek and the Barron River provide habitat for abundant and diverse invertebrate assemblages that play an important role in the local food web. The abundance and diversity of macroinvertebrate communities was slightly different in different mangrove associations, and at sites with more sandy sediments. The cover of foliage and leaf litter, along with the number of dead trees at each site, may also influence the abundance and diversity of macroinvertebrate communities found in different mangrove associations.

Decomposing mangrove material provides both soluble nutrients and detrital fragments that are eaten by crustacea such as those recorded in the current survey. Increased litter fall increases the amount of carbon available for mangrove macroinvertebrates and fish (Lee 1995). Litter fall from *Avicennia marina* trees is typically much greater during wet summer months than in the remainder of the year (Mackey & Smail 1995). However, increases in leaf fall can also be associated with declining mangrove health, which can be linked to changes in water and sediment quality.

Previous studies have found that salinity, dissolved oxygen levels, organic matter content and sulfide concentrations can govern the distribution and diversity of macroinvertebrate communities (Kumar & Khan 2013). Collection of additional water and sediment quality data from the mangrove macroinvertebrate survey sites would provide valuable data that could be used to determine whether changes in sediment and water quality are influencing mangrove macroinvertebrate communities.

7 Fish

7.1 Methods

Fish communities were surveyed at seven sites:

- two in Half Moon Creek
- four in Thomatis and Richters creeks, and
- in one of the dune lakes near Yorkeys Creek (Map 6).

Fish communities were surveyed using a variety of techniques:

- cast netting
- small baited box traps, and
- baited opera traps.

The fishing methods and effort at each site are presented in Table 7.1. All fishing was conducted under permits issued to frc environmental, which were:

- Queensland Animal Ethics (CA 2012/02/593)
- Queensland Fisheries (153223), and
- Great Barrier Reef Marine Park (G14/36497.1).

Other fishing methods, such as seine and fyke nets, were not used due to permit constraints and health and safety issues due to the potential for estuarine crocodiles in the creeks.

Creel surveys were also conducted during the survey. People fishing along the banks, at boat ramps and boating in the creeks were approached and interviewed to identify fish they typically catch and methods used. Creel surveys were also conducted at local bait and tackle shops to identify any other species that are commonly caught in the creeks.

Aquis Resort Technical Study: Aquatic Ecology

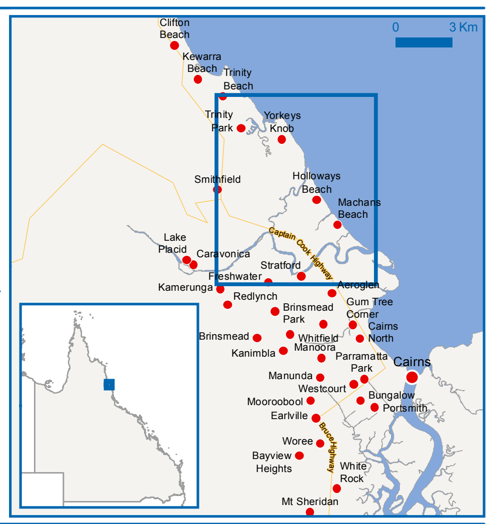
Map 6:
Fish survey sites

LEGEND

- Fish Survey Site
- Site Boundary
- Watercourse
- Inlet Pipe
- Outlet Pipe

Road Network

- Highway
- Main Road



frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

SOURCES

DATE	DRAWN BY	VERSION	PROJECTION
2014-04-04	CF	01	Coordinate System: GCS GDA 1994 Datum: GDA 1994 Units: Degree

Document Path: Y:\Projects\2013\130927_EN_Yorkeys_Knob_wet\Mapping\Workspaces\130927_A_Wet\130927_fish_Mar14_14-04-04_AL.mxd

N

SCALE

0 0.5 1
Kilometres

Scale: 1:30,000 @ A3

Table 7.1 Fish survey effort and method used at each reach.

Site	Method	Habitat	Date In	Time In	Date Out	Time Out	Effort
W2a	opera traps (5)	Glide	28/02/14	1045	01/03/14	1545	145 h
	small bait traps (5)		01/03/14	1620	02/03/14	1545	117.1 h
	opera traps (5)		27/02/14	1600	28/02/14	1545	118.75 h
	small bait traps (5)		27/02/14	1600	28/02/14	1600	120 h
	cast net		02/03/04	–	–	–	40 casts
W4	opera traps (5)	Glide	28/02/14	1030	01/03/14	1640	150.85 h
	small bait traps (5)		01/03/14	1640	02/03/14	1530	114.15 h
	opera traps (5)		27/02/14	1645	28/02/14	1535	114.15 h
	small bait traps (5)		27/02/14	1545	28/02/14	1600	121.25 h
	cast net		02/03/14	–	–	–	40 casts
W5	opera traps (10)	Glide	28/02/14	1350	01/03/14	1630	266.7 h
	small bait traps (10)		02/03/14	1350	03/03/14	1630	266.7 h
	cast net		01/03/14	–	–	–	40 casts
W6	opera traps (10)	Glide	01/03/14	1310	02/03/14	1310	240 h
	small bait traps (10)		01/03/14	1310	02/03/14	1310	240 h
	cast net		01/03/14	–	–	–	40 casts

Site	Method	Habitat	Date In	Time In	Date Out	Time Out	Effort
W10	opera traps (5)	Glide	26/02/14	1330	28/02/14	1300	237.5 h
	small bait traps (5)		26/02/14	1330	28/02/14	1300	237.5 h
	opera traps (5)		04/03/14	1700	05/03/14	0830	77.5 h
	small bait traps (5)		04/03/14	1700	05/03/14	0830	77.5 h
	cast net		26/02/14	–	–	–	40 casts
F1	opera traps (5)	Glide	26/02/14	1300	28/02/14	1300	240 h
	small bait traps (5)		26/02/14	1300	28/02/14	1300	240 h
	cast net		26/02/14	–	–	–	20 casts
	cast net		27/02/14	–	–	–	10 casts
	opera traps (5)		04/03/14	1700	05/03/14	0815	76.25 h
	small bait traps (5)		04/03/14	1700	05/03/14	0815	76.25 h
	cast net		05/03/14	–	–	–	10 casts
F4	seine net	Pool	04/03/14	–	–	–	3 hauls
	opera traps (10)		03/03/14	1700	04/03/14	0730	145 h
	small bait traps (8)		05/03/14	1700	06/03/14	0730	116 h

h hours

7.2 Data Analysis

The following was recorded for each site:

- fish abundance
- fish species richness
- life-history stage, and
- apparent health of individuals.

The data was discussed in the context of the wet season water quality results from the current survey and in the context of longer-term water quality monitoring data provided by BMT WBM.

7.3 Results

A total of 94 fish, representing 18 species from 16 families, were caught in Thomatis, Richters and Half Moon creeks (Table 7.2). Fish caught in creeks around the proposed development were:

- pikey bream (*Acanthopargus berda*) (Figure 7.1)
- shadow goby (*Acentrogobius nebulosus*) (Figure 7.2)
- long-spined glass perchlet (*Ambassis interruptus*) (Figure 7.3)
- chacunda gizzard shad (*Andodontostoma chacunda*) (Figure 7.4)
- duckbill sleeper (*Butis butis*) (Figure 7.5)
- milk-spotted toadfish (*Chelonodon patoca*) (Figure 7.6)
- estuary cod (*Ephinephelus coioides*) (Figure 7.7)
- Castelnau's herring (*Herklostichthys castelnaui*) (Figure 7.8)
- barramundi (*Lates calcarifer*) (Figure 7.9)
- common ponyfish (*Leiognathus equulus*) (Figure 7.10)
- Russel's snapper (*Lutjanus russelli*) (Figure 7.11)
- sea mullet (*Mugil cephalus*) (Figure 7.12)
- mangrove cardinalfish (*Ostorhinchus hyalosoma*) (Figure 7.13)
- mudskippers (*Periopthalmus* Spp.) (Figure 7.14)

- javelin grunter (*Pomadasys kaakan*) (Figure 7.15)
- striped scat (*Selenotoca multifasciata*) (Figure 7.16)
- rabbitfish (*Siganus* Sp.) (Figure 7.17), and
- Hamilton's thryssa (*Thryssa hamiltonii*) (Figure 7.18).

Table 7.2 Fish species recorded in Thomatis, Richters and Half Moon creeks.

Species	Family	Common Name	Thomatis and Richters Creeks			Half Moon Creek		
			W2a	W4	W5	W6	W10	F1
Acanthopargus berda	Sparidae	pikey bream	3	1	0	0	7	0
Acentrogobius nebulosus	Gobiidae	shadow goby	0	0	0	0	1	0
Ambassis interruptus	Ambassidae	long-spined glass perchlet	3	13	4	2	1	3
Anodontostoma chacunda	Clupeidae	chacunda gizzard shad	9	0	0	0	0	0
Butis butis	Eleotridae	duckbill sleeper	0	2	4	1	0	0
Chelonodon patoca	Tetradontidae	milk-spotted toadfish	2	0	0	0	0	0
Ephinephelus coioides	Serranidae	estuary cod	0	0	0	0	1	0
Herklotsichthys castelnaui	Clupeidae	Castelnau's herring	0	0	0	0	0	2
Lates calcarifer	Latidae	barramundi	0	0	0	0	1	0
Leiognathus equulus	Leiognathidae	common ponyfish	0	0	2	0	0	0
Lutjanus russelli	Lutjanidae	Russel's snapper	3	7	1	1	0	0
Mugil cephalus	Mugilidae	sea mullet	0	0	0	0	1	0
Ostorhinchus hyalosoma	Apogonidae	mangrove cardinalfish	6	0	0	0	0	0

Species	Family	Common Name	Thomatis and Richters Creeks			Half Moon Creek		
			W2a	**W4**	**W5**	**W6**	**W10**	**F1**
Pomadasys kaakan	Haemulidae	javelin grunter	2	0	0	0	1	0
Selenotoca multifasciata	Scatophagidae	striped scat	0	2	0	0	0	0
Siganus Sp.	Signaidae	rabbitfish	1	1	3	0	0	1
Thryssa hamiltonii	Engraulidae	Hamilton's thryssa	0	0	0	0	1	0
unknown	unknown	unidentifiable juvenile	0	0	0	1	0	0
Total			**29**	**26**	**14**	**5**	**12**	**8**

Figure 7.1

Pikey bream.

Figure 7.2

Shadow goby.

Figure 7.3

Long-spined glass perchlet.

Figure 7.4

Chacunda gizzard shad.

Figure 7.5

Duckbill sleeper.

Figure 7.6

Milk-spotted toadfish.

Figure 7.7

Estuary cod.

Figure 7.8

Castelnau's herring.

Figure 7.9

Barramundi.

Figure 7.10

Common ponyfish.

Figure 7.11

Russel’s snapper.

Figure 7.12

Sea mullet.

Figure 7.13

Mangrove cardinalfish.

Figure 7.14

Mudskipper.

Figure 7.15

Javelin grunter.

Figure 7.16

Striped scat.

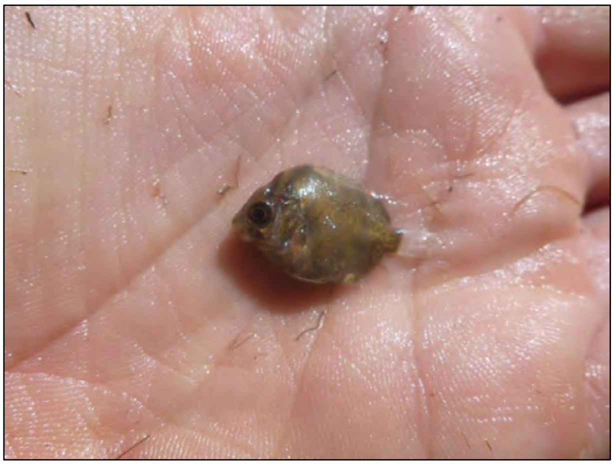


Figure 7.17

Rabbitfish.

Figure 7.18

Hamilton's thryssa.

Thomatis and Richters Creek

In Thomatis and Richters creeks, 74 fish were caught with the highest abundance and species richness of fish near the mouth (site W2a). Several mudskippers (*Periopthalmus* Spp.) were also observed on the banks throughout the creeks, but were not caught. The abundance and species richness of fish decreased with distance upstream, which was likely to be due to the greater freshwater influence from the Barron River, and associated decreases in dissolved oxygen and pH (BMT WBM 2014).

Most fish species caught were catadromous (fish born in saltwater that migrate to freshwater as juveniles before migrating back to the ocean as adults) (e.g. barramundi, mullet and herring) and it would be unlikely to find large adults of these species upstream in the freshwater reaches. All fish caught, are commonly known to occur in estuarine reaches of rivers and creeks. All species caught in Thomatis and Richters creeks were identified as likely to occur in estuaries in the wet tropics region (frc environmental 2013).

The fish communities in Thomatis and Richters creeks were dominated by juveniles (57% of the catch) and adults of smaller fish species (e.g. long-spined glassfish) (30% of the catch). All fish caught were in good condition, with no visual defects to signify poor or impaired health (e.g. lesions or parasites).

Half Moon Creek

In Half Moon Creek, a total of 20 fish were caught representing ten species (Table 7.2). Several mudskippers (*Periopthalmus* Spp.) were also observed on the banks throughout the creek, but were not caught. There were several species that were caught in Half Moon Creek that were not caught in Thomatis and Richters creek, including:

- barramundi
- estuary cod
- Hamilton's thryssa
- sea mullet
- shadow goby, and
- Castelnau's herring.

Despite not being caught in Thomatis and Richters creeks in the current survey, it is highly likely that these species are also found in Thomatis and Richter creeks, due to the proximity and connectivity of the creek systems around the proposed Aquis development.

Of the species recorded in Half Moon Creek, estuary cod and shadow goby have not been recorded in previous surveys of creeks and rivers in the wet tropics (Blaber 1980; Robertson & Duke 1990; Russell et al. 2011; EHP 2014). However, estuary cod are common in tropical waters and they are highly likely to occur in other estuaries along the Queensland coast. The shadow goby is a small cryptic species and is unlikely to be caught by most traditional fishing methods used in other surveys. This species is fairly common and likely to occur in other mangroves and estuaries along the north Queensland coast.

The fish communities in Half Moon Creek were dominated by intermediates (60% of the catch) and adults (35% of the catch). All fish caught were in good condition, with no visual defects to signify poor or impaired health (e.g. lesions or parasites).

Creel Surveys

Fish recorded in the creel surveys along Thomatis, Richters and Half Moon Creeks were typically limited to species of recreational importance. Thirty-three fish families were identified as being caught in the area (Table 7.3). The fisherman that were surveyed typically used baited line fishing or cast netting methods. Of the fish recorded, one species, tilapia, is a declared noxious pest under the Queensland Fisheries Regulation 2008. Three families caught in the current field survey were not identified in the creel surveys; Apogonidae, Engraulidae and Leiognathidae. These families are not of high commercial value nor are they typically used as bait fish, and are consequently not likely to be recorded in creel surveys. Several families identified by recreational fishers were not caught in the current survey:

- Anguillidae
- Ariidae
- Carangidae
- Carcharhinidae
- Chanidae
- Cichlidae
- Dasyatidae
- Hemiramphidae
- Kuhliidae
- Megalopidae

- Muraenidae
- Muraenescocidae
- Platycephalidae
- Polynemidae
- Sciaenidae
- Sillaginidae
- Sphyraenidae
- Terapontidae, and
- Toxotidae.

Species from these families were most likely not caught due to the limited fishing techniques and short duration of the survey. Nonetheless, the creeks are likely to support a diverse range of fish and the presence of many species is likely to be seasonal or dependant on the tidal cycle.

Table 7.3 Fish identified from creel surveys.

Family	**Species**	**Common Name**
Ambassidae	*Ambassis* spp.	perchlets
Anguillidae	*Anguilla* spp.	eels
Ariidae	–	catfish
Carangidae	*Scomberoides* spp.	queenfish
Carangidae	*Caranx ignobilis*	giant trevally
Carangidae	*Gnathanodon speciosus*	golden trevally
Carcharhinidae	*Carcharhinus leucas*	bull shark
Chanidae	*Chanos chanos*	milkfish
Cichlidae	*Oreochromis* spp.	tilapia
Clupeidae	–	herring
Dasyatidae	*Dasyatis fluviorum*	estuary stingray
Eleotridae	–	gudgeons
Gobiidae	*Periophthalmus* spp.	mudskipper
Haemulidae	*Pomadasys kaakan*	javelin grunter
Haemulidae	*Plectorhinchus* spp.	sweetlips

Family	Species	Common Name
Hemiramphidae	–	garfish
Kuhliidae	*Kuhlia rupestris*	jungle perch
Latidae	*Lates calcarifer*	barramundi
Lutjanidae	*Lutjanus johnii*	fingermark
Lutjanidae	*Lutjanus argentimaculatus*	mangrove jack
Megalopidae	*Megalops cyprinoides*	tarpon
Mugilidae	–	mullet
Muraenidae	–	moray eel
Muraenescocidae	*Muraenesox* sp.	pike eel
Platycephalidae	*Platycephalus indicus*	bartail flathead
Platycephalidae	*Platycephalus fuscus*	dusky flathead
Polynemidae	*Eleutheronema tetradactylum*	blue salmon
Polynemidae	*Polydactylus macrochir*	threadfin salmon
Scatophagidae	*Scatophagus argus*	scat
Sciaenidae	–	jewfish
Serranidae	*Epinephelus coioides*	estuary cod
Siganidae	*Siganus* spp.	rabbitfish
Sillaginidae	*Silago* spp.	whiting
Sparidae	*Acanthopagrus berda*	pikey bream
Sparidae	*Acanthopagrus australis*	yellowfin bream
Sphyraenidae	*Sphyraena* sp.	barracuda
Terapontidae	*Terapon jarbua*	crescent perch
Terapontidae	*Bidyanus bidyanus*	sooty grunter
Tetradontidae	–	pufferfish and toadfish
Toxotidae	*Toxotes chatareus*	archerfish

– genus and / or species unknown as only common names were given by recreational fishers and no specimens were observed or sampled

Dune Lakes

In the dune lakes (site F4), a total of 183 fish consisting of three species were caught:

- silverbiddy (*Gerres* sp.) (Figure 7.19)
- eastern rainbowfish (*Melanotaenia splendida splendida*) (Figure 7.20), and
- empire gudgeon (*Hypseleotris compressa*).

The catch was dominated by juvenile eastern rainbowfish, with only one juvenile silverbiddy and one adult empire gudgeon. The dune lakes are ephemeral and fish populations would fluctuate with changes in water levels; however, the eastern rainbowfish and empire gudgeon are known to thrive in impounded habitats (Pusey et al. 2004). These two species are also known to occur in the Barron River catchment (Table 7.4). The silverbiddy is usually an estuarine and marine species and this specimen was likely in the dune lake due to connectivity with the nearby estuarine Yorkeys Creek and associated mangrove forests.

The eastern rainbowfish and empire gudgeon tolerate a wide range of environmental conditions. Despite this, the electrical conductivity and dissolved oxygen levels recorded in the dune lake were at the limit of physiological tolerance for each of these species (Table 7.5). In general, the water quality recorded at the dune lake was poor and unsuitable for many other freshwater fish species, particularly due to the high electrical conductivity at depth, and the low concentration of dissolved oxygen (Section 3).

Dune lakes are rare aquatic ecosystems that do occur along north-eastern Queensland coasts (Cook et al. 2011). There are no fish species endemic to north Queensland dune lake ecosystems; however, common species of northern dune lakes not caught in the current survey were:

- McCullochs rainbowfish (*Melanotaenia maccullochi*)
- spotted blue eyes (*Pseudomugil gertudae*), and
- pennyfish (*Denariusa bandata*) (Cook pers. com. 2014).

The endangered Lake Eacham rainbowfish (*Melanotaenia eachamensis*) has been reported as occurring in the region (DoTE 2014; EHP 2014); however, this species was not caught in the dune lake nor is the habitat likely to be suitable (i.e. low elevation and water too conductive) for this species (Pusey et al. 2004). All fish caught were in good condition, with no visual defects to signify poor or impaired health (e.g. lesions or parasites).

Figure 7.19

Silverbiddy.

Figure 7.20

Eastern rainbowfish.

Table 7.4 Freshwater fish known to occur in lowland areas of the wet tropics and fish caught in the current survey.

Family / Scientific Name	Common Name	Barron River	Trinity Inlet and Cairns Creeks	Current Survey
Ambassidae				
Ambassis agassizii	Agassiz's glassfish	X	–	–
Ambassis agrammus	sailfin glassfish	X	–	–
Ambassis gymnocephalus	bald glass perchlet	X	X	–
Ambassis interruptus	long-spined glassfish	X	–	–
Ambassis miops	flag-tailed glassfish	X	–	–
Ambassis vachellii	Vachelli's glassfish	X	–	–
Denariusa australis	pennyfish	X	–	–
Anguillidae				
Anguilla obscura	pacific short-finned eel	X	–	–
Anguilla reinhardtii	long-finned eel	X	–	–
Apogonidae				
Glossamia aprion	mouth almighty	X	–	–
Atherinidae				
Craterocephalus stercusmuscarum	fly-specked hardyhead	X	–	–
Cichlidae				
Astronotus ocellatus	oscar	X	–	–
Hemichromis bimaculatus	jewel cichlid	–	X	–
Oreochromis mossambicus	tilapia	X	X	–
Tilapia mariae	black mangrove cichlid	X	X	–
Clupeidae				
Nematalosa erebi	bony bream	X	–	–
Eleotridae				
Bunaka gyrinoides	greenback gauvina	X	–	–

Family / Scientific Name	Common Name	Barron River	Trinity Inlet and Cairns Creeks	Current Survey
Butis butis	duckbill sleeper	X	X	–
Eleotris fusca	brown gudgeon	X	–	–
Eleotris melanosoma	ebony gudgeon	X	–	–
Giurus margaritacea	snakehead gudgeon	X	–	–
Hypseleotris compressa	empire gudgeon	X	–	X
Hypseletoris spp.	common carp gudgeon	X	–	–
Mogunda adspersa	purple-spotted gudgeon	X	–	–
Ophiocara porocephala	spangled gudgeon	X	X	–
Oxyeleotris lineolatus	sleepy cod	X	–	–
Gerreidae				
Gerres sp.	common silverbiddy	–	–	X
Gobiidae				
Awaous acritosus	Roman nose goby	X	–	–
Chlamydogobius ranunculus	tadpole goby	X	X	–
Glossogobius bicirrhosis	bearded goby	X	–	–
Glossogobius circumspectus	circumspect goby	X	–	–
Glossogobius giuris	flathead goby	X	X	–
Glossogobius sp. 1	false celebes goby	X	–	–
Psammogobius biocellatus	mangrove goby	X	X	–
Redigobius bikolanus	specked goby	X	–	–
Schismatogobius sp.	scaleless goby	X	–	–
Sicyopterus lagocephalus	rabbithead cling-goby	X	–	–
Stenogobius psilosinionus	unknown	X	–	–
Hemiramphidae				
Arramphus sclerolepis	snub-nosed garfish	X	X	–

Family / Scientific Name	Common Name	Barron River	Trinity Inlet and Cairns Creeks	Current Survey
Kuhliidae				
Kuhlia rupestris	jungle perch	X	–	–
Latidae				
Lates calcarifer	barramundi	X	X	–
Megalopidae				
Megalops cyprinoides	tarpon	X	X	–
Melanotaeniidae				
Melanotaenia maccullochi [1]	McCulloch's rainbowfish	X	–	–
Melanotaenia splendida splendida	eastern rainbowfish	X	X	X
Mugilidae				
Mugil cephalus	sea mullet	X	X	–
Plotosidae				
Neosilurus ater	narrow-fronted catfish	X	–	–
Neosilurus hyrtlii	Hyrtl's tandan	X	–	–
Porochilus rendahli [2]	Rendahl's catfish	X	–	–
Tandanus tandanus	eel-tailed catfish	X	–	–
Poeciliidae				
Gambusia holbrooki	mosquitofish	X	X	–
Poecilia reticulata	guppy	X	X	–
Xiphophorus helleri	swordtail	X	X	–
Xiphophorus maculatus	platy	X	X	–
Pseudomugilidae				
Pseudomugil gertrudae [3]	spotted blue-eye	X	–	–
Pseudomugil signifer	Pacific blue-eye	X	X	–
Scorpaenidae				
Notesthes robusta	bullrout	X	–	–

Family / Scientific Name	Common Name	Barron River	Trinity Inlet and Cairns Creeks	Current Survey
Synbranchidae				
Ophisternon gutturale	swamp eel	X	X	–
Synbranchidae spp.	unidentified swamp eel	X	–	–
Terapontidae				
Amniataba percoides	barred grunter	X	–	–
Hephaestus fuliginosus	sooty grunter	X	–	–
Hephaestus tulliensis	khaki grunter	X	–	–
Leiopotherapon unicolor	spangled perch	X	–	–
Toxotidae				
Toxotes chatereus	seven-spot archerfish	X	X	–
Toxotes jaculatrix	banded archerfish	X	–	–

Source: Pusey et al. 2004; Cook pers. com. 2013.

– not recorded

X recorded

[1] While McCulloch's rainbowfish was described from a specimen form the lower Barron it is likely to be locally extinct in this area.

[2] Rendahl's catfish has a patchy distribution, and may or may not occur in the Barron.

[3] Spotted blue eye is a known wetland species from the region and was more widely spread throughout the region before systematic development / loss of wetlands for agriculture / urban development. It is known to co-occur with McCulloch's rainbow fish, and given that the McCulloch's rainbow fish is known to used to have been in the Barron, it is likely this species is (or has been) in the catchment in suitable habitat.

Table 7.5 Fish species caught in the dune lake and the range of water quality conditions in which they are known to occur, and water quality measured in situ in the dune lake.

Family *Latin Name*	**Common name**	**Water Temp. (ºC)**	**Dissolved Oxygen (mg/L)**	**pH**	**Conductivity (µS/cm)**	**Turbidity (NTU)**
Eleotridae						
Hypseleotris compressa	empire gudgeon	17.5–27.3	5.33–8.81	4.5–7.9	6–65.6	0.3–22.1
Gerreidae						
Gerres Sp.	silverbiddy	–	–	–	–	–
Melanotaeniidae						
Melanotaenia splendida splendida	eastern rainbowfish	17.1–29.7	4.91–11.6	5.13–8.38	6–65.6	0.25–12.19
Dune Lake Water Quality						
Surface		30.83	4.33	5.98	4250	4
1 m deep		29.25	0.36	5.75	29600	34

Source: Pusey et al. 2004
– data not available
NTU Nephelometric Turbidity Unit

7.4 Summary

The creeks surrounding the proposed development site provide valuable habitat for a range of estuarine and marine fish species. In particular they are important nursery grounds for a range of commercially and recreationally important species. High proportions of juvenile and intermediate fish were caught in the current survey, and this is likely to be common during the summer months (Doherty & Sheaves 1994). Most fish species caught were catadromous, and able to tolerate a range of salinity. Despite being adapted to a range of water quality conditions, fish caught in the current survey are likely to be affected by dramatic changes to water quality (either directly, for example through reduced dissolved oxygen, or indirectly where changes in water quality leads to changes in other components of the estuarine food web, such as declines in the abundance of invertebrate food sources).

Being mobile, most fish species are able to move away from areas with unfavourable conditions to avoid direct impacts. For example, fish are likely to move seaward during periods of high freshwater flow, when concentrations of dissolved oxygen can drop to toxic levels (<30% saturation). Despite high concentrations of various metals (magnesium, boron and on occasion, copper and zinc), and nutrients recorded in Thomatis and Richters creeks by BMT WBM, all fish caught during the wet season survey appeared to be healthy.

8 Potential Impacts and Mitigation Measures

Potential impacts and mitigation measures were assessed in the *Aquis Resort Technical Study: Aquatic Ecology* dry season survey report (frc environmental 2013). The impacts identified in the dry season survey report are still current, and no additional impacts were identified from the findings of the wet season survey. Impacts to the aquatic environment associated with the construction and operation of the optional inlet pipeline are discussed in detail in the report, *Aquis Resort Proposed Offshore Intake: Aquatic Ecology Assessment* (frc environmental 2014b), and are summarised below. Design of the lake has not been finalised; therefore, impacts to aquatic ecology related to the design of the lake will be the subject of a later report. Impacts related to the current design are discussed in the *Aquis Resort at the Great Barrier Reef: EPBC Act Issues, March 2014 Version 1*.

The design of the Aquis development has changed since the initial assessment, and more detail regarding some aspects is available: consequently the assessment of potential impacts requires updating. Potential impacts as described for the dry season that are still of concern are:

- loss of onsite waterbodies (i.e. existing farm dams)
- changes to water quality of the surrounding environment (including nutrient enrichment and changes to salinity)
- increased turbidity, sediment suspension and smothering
- spills of hydrocarbons and other contaminants
- disturbance of acid sulfate or potential acid sulfate soils
- alteration of local hydrology
- proliferation of pest species
- changed light regime, and
- waste and litter.

Based on the updated development design, additional potential impacts that may occur due to construction and operations are:

- direct habitat disturbance in Richters Creek mouth and directly offshore for construction of the inlet pipeline, and
- noise during construction.

These impacts were not previously addressed in the dry season report, and are discussed in the sections following.

8.1 Direct Habitat Disturbance

There are currently two options proposed to source water to fill and maintain lake water levels, which are:

- Option 1: an inlet pipe in Richters Creek with standby water from Half Moon Bay, and
- Option 2: an inlet pipe from offshore in the Coral Sea with no standby.

Option 2 is currently favoured as it can be relied upon to deliver good quality salt water free from local fresh conditions and any effects of a partial closure of Richters Creek. However, either option would require an inlet pipeline to be installed, which would involve dredging of sediment to lay the pipe. Results of a recent habitat survey along the offshore pipeline footprint for Option 2 showed that no notable habitats (e.g. seagrass beds or coral / rocky reefs) were present (frc environmental 2014b).

The dredging works will have the potential to increase sedimentation and turbidity, and release contaminants from the sediments to be dredged (including nutrients, which were recorded in high concentrations in Richters Creek during the wet season survey). Mitigation measures that can reduce the potential impacts from the dredging works, include:

- scheduling the works to be undertaken during the dry season
- using perimeter silt curtains, bunds or similar technologies around the site to contain sediments / materials that become suspended during construction
- testing the sediments proposed to be disturbed during construction of the inlet and outlet pipelines for contaminants prior to disturbance, and implementing appropriate management measures according to the results
- implementing an Acid Sulfate Soils Management Plan (ASSMP) during excavation and backfilling of the site
- using coarse-grained sediments during backfilling to prevent siltation (where sediment testing indicates a high proportion of fines are present in the sediments to be dredged)

- undertaking water quality monitoring during the construction period, including the use of 'trigger levels' to effectively control suspended solids concentrations in adjoining waters
- rehabilitating areas where mangroves have been removed for construction of the pipeline route
- employment marina fauna spotters during dredging operations, and
- fitting the dredging equipment with turtle exclusion devices (including ticker chains), where possible.

8.2 Noise During Construction

Dredging works have the potential to increase noise underwater, which may impact on marine fauna. Noise may cause negative effects with differing magnitudes, according to the characteristics of the noise emissions, and may affect species differently depending on their age, sex and prior noise experience (ACCOBAMS 2013). Behavioural changes in response to increased noise are likely (e.g. avoidance of the area). However, this is likely to be a short-term response, and fauna are likely to return once construction is completed.

Impacts to marine fauna as a result of noise can be reduced where a marine fauna exclusion zone (nominally 500 m from the noise source) is established prior to the commencement of a noise-intensive activity (e.g. dredging). Impacts to marine fauna can be reduced if noise intensive activities are suspended when listed threatened species (e.g. marine turtles) are sighted within the exclusion zone (until 30 minutes of observations have passed until the last sighting).

Where these measures are implemented, the risk of impact to marine fauna due to increased noise is low.

9 Further Monitoring

Further aquatic ecological studies are recommended prior to development commencing, to describe seasonal changes in aquatic ecosystems that may be affected by the proposed development, and to better describe some of the communities. Particularly surveys of fish and mangrove macroinvertebrates, which have only been described for the wet season.

At the time of writing, technical staff from the Queensland Government were not aware of the results of any surveys of marine turtles nesting in the vicinity of the proposed development. However, it is likely that there is some sparse nesting of marine turtles on the beaches in the vicinity of the proposed development (Bunce pers. comm. 2013, Trenerry 2013 pers. comm.). It is recommended that the beaches be surveyed during the peak nesting season (nominally between November and January) for use by marine turtles (frc environmental 2013).

To assess impacts of construction and operation of the proposed development on aquatic ecology, it is recommended that key elements of the dry and wet season surveys be selected for ongoing monitoring. The key elements recommended for monitoring are:

- water quality
- sediment quality
- estuarine macroinvertebrates in the sediment of the receiving environment
- macroinvertebrates in mangrove ecosystems, and
- fish communities.

10 References

ACCOBAMS, 2013. *Fifth Meeting of the Parties to ACCOBAMS Tangier, 5-8 November 2013*. ACCOBAMS-MOP5/2013/Doc24.

ANZECC & ARMCANZ, 2000a, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

ANZECC & ARMCANZ, 2000b, *Australian Guidelines for Water Quality Monitoring and Reporting*, National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

Barron, F. & Haynes, D., 2009, *Water Quality Improvement Plan for the Catchments of the Barron River and Trinity Inlet*, Periodical.

Beesley, P.L., Ross, G.J.B. & Glasby, C.J., 2000, *Polychaetes & Allies: The Southern Synthesis*, Fauna of Australia, Volume 4A Polychaetes, Myzosstomida, Pogonophora, Echiura, Sipuncula, CSIRO Publishing, Melbourne xii, pp. 465.

Biotropica, 2013, *Aquis Resort at the Great Barrier Reef Supplementary EIS Studies, October 2013*, report prepared for Environment North.

Biotropica, 2014, *Monitoring Mangrove Health on the Aquis at the Great Barrier Reef Development*, report prepared for Environment North.

Biotropica Australia, 2013, *Aquis Resort at the Great Barrier Reef Terrestrial Ecology September 2013*, report prepared for Environment North.

Blaber, S., 1980, 'Fish of the Trinity Inlet system of north Queensland with notes on the ecology of fish faunas of tropical Info-Pacific estuaries', *Australian Journal of Marine and Freshwater Research* 31: 137-146.

BMT WBM, 2013. *AQUIS Resort at Great Barrier Reef Water Quality Assessments report. November 2013*.

BMT WBM, 2014, *Aquis Resort at Great Barrier Reef Water Quality Assessments Report to Support EIS*, report prepared for Flanagan Consulting Group on behalf of Aquis Resort.

BOM, 2014, *Cairns Aero Daily Rainfall*, http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=2014&p_c=-192340552&p_stn_num=031011, accessed April 2014.

Butler, S. & Bird, F., 2010, *Monitoring the macroinvertebrates and soft sediments in the Marine National Parks in Western Port. Parks Victoria Technical Series No. 60*, Parks, Victoria, Melbourne.

Cook, B., Kennard, M., Ward, D. & Pusey, B., 2011, *The Hydroecological Natural Heritage Story of Cape York Peninsula*, Report to the Queensland Government Department of Environment and Resource Management. Available at: http://www.derm.qld.gov.au/cape_york/pdf/cyp-hydroecology.pdf.

Dafforn, K.A., Kelaher, B.P., Simpson, S.L., Coleman, M.A., Hutchings, P.A., Clark, G.F., Knott, N.A., Doblin, M.A. & Johnston, E.L., 2013, 'Polychaete richness and abundance enhanced in anthropogenically modified estuaries despite high concentrations of toxic contaminants', *PLOS One* 8: e77018.

DEEDI, 2012, *Recreational fishing rules for Queensland*, DEEDI.

Del-Pilar-Ruso, Y., de-la-Ossa-Carretero, J.A., Casalduero, G. & Sanchez-Lizaso, J.-L., 2010, '*Sewage treatment level and flow rates affect polychaete assemblages*', *Marine Pollution Bulletin* 60: 1930-1938.

DERM, 2009. *Queensland Water Quality Guidelines Version 3 September 2009*. Department of Environment and Resource Management, Brisbane

DERM, 2010a, *Monitoring and Sampling Manual 2009 Environmental Protection (Water) Policy 2009 Version 2 September 2010 (July 2013 format edits)*, report prepared for Department of Environment and Heritage Protection, Brisbane.

DERM, 2010b, *Monitoring and Sampling Manual 2009, Environmental Protection (Water) Policy 2009, Version 2, September 2010*, Department of Environment and Resource Management, Brisbane.

Doherty, P.J. & Sheaves, M.J., 1994. *Fish surveys in Half Moon Creek*. Consultancy undertaken by the Australian Institute of Marine Sciences for TNN Cairns Pty.

DoTE, 2009. *Matters of National Environmental Significance*. Department of the Environmental, Water, Heritage and the Arts, Canberra.

DoTE, 2014, Protected Matters Search Tool, http://www.environment.gov.au/arcgis-framework/apps/pmst/pmst-coordinate.jsf, accessed April 2014.

EHP, 2014, *Ray-finned fishes of Barron drainage basin, WetlandInfo*, http://wetlandinfo.ehp.qld.gov.au/wetlands/facts-maps/wildlife/?AreaID=basin-barron&Kingdom=animals&Class=ray-finned fishes, accessed April 2014.

Environment North, 2014. *Aquis Resort at the Great Barrier Reef: EPBC Act Issues* March 2014 Version 1, draft for internal use.

frc environmental, 2013, *Aquis Resort Technical Study: Aquatic Ecology Stage 1 and 2 Reports: Existing Situation, Preliminary Impact Assessment and Mitigation*, report prepared for Flanagan Consulting Group.

frc environmental, 2014a, *Aquis Resort Technical Study: Aquatic Ecology Addendum: Wet Season Survey*, report prepared for Flanagan Consulting Group.

frc environmental, 2014b, *Aquis Resort Technical Study: Inlet Pipeline Report*.

GBRMPA, 2009. *Water Quality Guidelines for the Great Barrier Reef Marine Park*. Great Barrier Reef Marine Park Authority, Townsville.

Humphrey, C.A., King, S.C. & Klump, D.W., 2007, 'A multibiomarker approach in barramundi (Lates calcarifer) to measure exposure to contaminants in estuaries of tropical North Queensland', *Marine Pollution Bulletin* 54: 1569-1581.

Hutchings, P., 1998, 'Biodiversity and functioning of polychaetes in benthic sediments', *Biodiversity and Conservation* 7: 1133-1145.

Hutchings, P.A., Ward, T.J., Waterhouse, J.H. & Walker, L., 1993, 'Fauna of Marine Sediments and Seagrass Beds of upper Spencer Gulf near Port Pirie, South Australia', *Transactions of the Royal Society of South Australia* 117: 1-15.

Jones, D.S. & Morgan, G.J., 1994, *A Field Guide to Crustaceans of Australian Waters*, Reed, Chatswood.

Kumar, P.S. & Khan, A.B., 2013, 'The distribution and diversity of benthic macroinvertebrate fauna in Pondicherry mangroves, India', *Aquatic Biosystems* 9: 15.

Lee, D.P., 1995 'Non-native fish issues and management in California', In: American Fisheries Society Symposium, volume 15, abstract only.

Mackey, A.P. & Smail, G., 1995, 'Spatial and temporal variation in litter fall of Avicennia marina (Forssk.) in the Brisbane River, Queensland', *Aquatic Botany* 52: 133-142.

Martinez-Garcia, E., Sanchez-Jerez, P., Aguado-Giménez, F., Ávila, P.G., Alejandro, Sánchez-Lizaso, J.L., Fernandez-Gonzalez, V., González, N., Gairin, J.I., Carballeira, C., García-García, B., Carreras, J., Macías, J.C., Carballeira, A. & Collado, C., 2013, 'A meta-analysis approach to the effects of fish farming on soft bottom polychaeta assemblages in temperate regions', *Marine Pollution Bulletin* 69: 165-171.

Pusey, B.J., Kennard, M. & Arthington, A., 2004, *Freshwater Fishes of North-Eastern Australia*, CSIRO Publishing, Collingwood, Victoria, pp. 171.

Quinn, R.H., 1992, *Fisheries Resources of the Moreton Bay Region*, report prepared for Queensland Fish Management Authority (QFMA).

Robertson, A.I. & Duke, N.C., 1990, 'Mangrove fish-communities in tropical Queensland, Australia: spatial and temporal patterns in densitities, biomass and community structure', *Marine Biology* 104: 369-379.

Rossi, F. & Underwood, A.J., 2002, 'Small-scale disturbance and increased nutrients as influences on intertidal macrobenthic assemblages: experimental burial of wrack in different intertidal environments', *Marine Ecology Progress Series* 241: 29-39.

Russell, D.J., Preston, K.M. & Mayer, R.J., 2011, 'Recovery of fish and crustacean communities during remediation of tidal wetlands affected by leachate from acid sulphate soils in north-eastern Australia', *Wetlands Ecology and Management* 19: 89-108.

Schrijvers, J., Vangansbeke, D. & Vincx, M., 1995, 'Macrobenthic infauna of mangroves and surrounding beaches at Gazi Bay, Kenya', *Hydrobiologia* 306: 53-66.

Stromberg, H., Patterson, C. & Johnson, R., 1998, 'Spatial variations in benthic macrofauna and nutrient dynamics in a mangrove forest subject to intense deforestation: Zanzibar, Tanzania', *Ambio* 27: 734-739.

Tsutsumi, H., 1990, 'Population Persistence of *Capitella* sp. (Polychaeta: Capitellidae) on a Mudflat Subject to Environmental Disturbance by Organic Enrichment', *Marine Ecology Progress Series* 63: 147-156.