AQUIS RESORT AT THE GREAT BARRIER REEF PTY LTD

ENVIRONMENTAL IMPACT STATEMENT

VOLUME 2

CHAPTER 11

WATER QUALITY

11. WATER QUALITY

11.1 EXISTING SITUATION

11.1.1 Overview

There is an unavoidable overlap in the issues required to be addressed under Flooding (**Chapter 9**), Water Resources (**Chapter 10**), and Water Quality (this chapter) and judgment has been used in where these are discussed. In particular, it has been decided to detail the following matters as described:

- flooding (**Chapter 9**):
  - Barron River flood history
  - flooding of the Aquis Resort site
  - modelling of design flows
  - impacts of flooding on Aquis Resort and the impact of Aquis Resort mitigation on surrounding areas
- water resources (**Chapter 10**):
  - surface water hydrology and hydraulics
  - groundwater hydrology, hydraulics, and quality
  - use of surface water
  - use of groundwater
  - surface water / groundwater interaction
- water quality (**this chapter**):
  - quality of surface water
  - stormwater drainage
  - detailed operation of lake, including numerical modelling of lake operation and interaction with the receiving environment and hydrodynamic impacts of sea water extraction and discharge.

Cross references between the three chapters are provided where appropriate.

11.1.2 Catchment Details

As discussed in detail in **Chapter 10** (Water Resources), the site is situated at the seaward limit of the delta of the Barron River (catchment 217 500 ha) and is within several hundred metres of the Coral Sea. At a local level, the site lies partly within the sub-catchments of:

- Richters Creek (catchment 449 ha)
- Yorkeys Creek (catchment 267 ha)
- Half Moon Creek (catchment 3,797 ha).

Of these, Richters Creek is the largest of the waterways, being a distributary of the Barron River due to its connection via Thomatis Creek. Refer to **Figure 11-1** and **Figure 11-2**.

FLANAGAN CONSULTING GROUP

AQUIS GREAT BARRIER REEF RESORT

Figure 11-1 Barron River catchment.

Source: Appendix M (Figure 2-1).

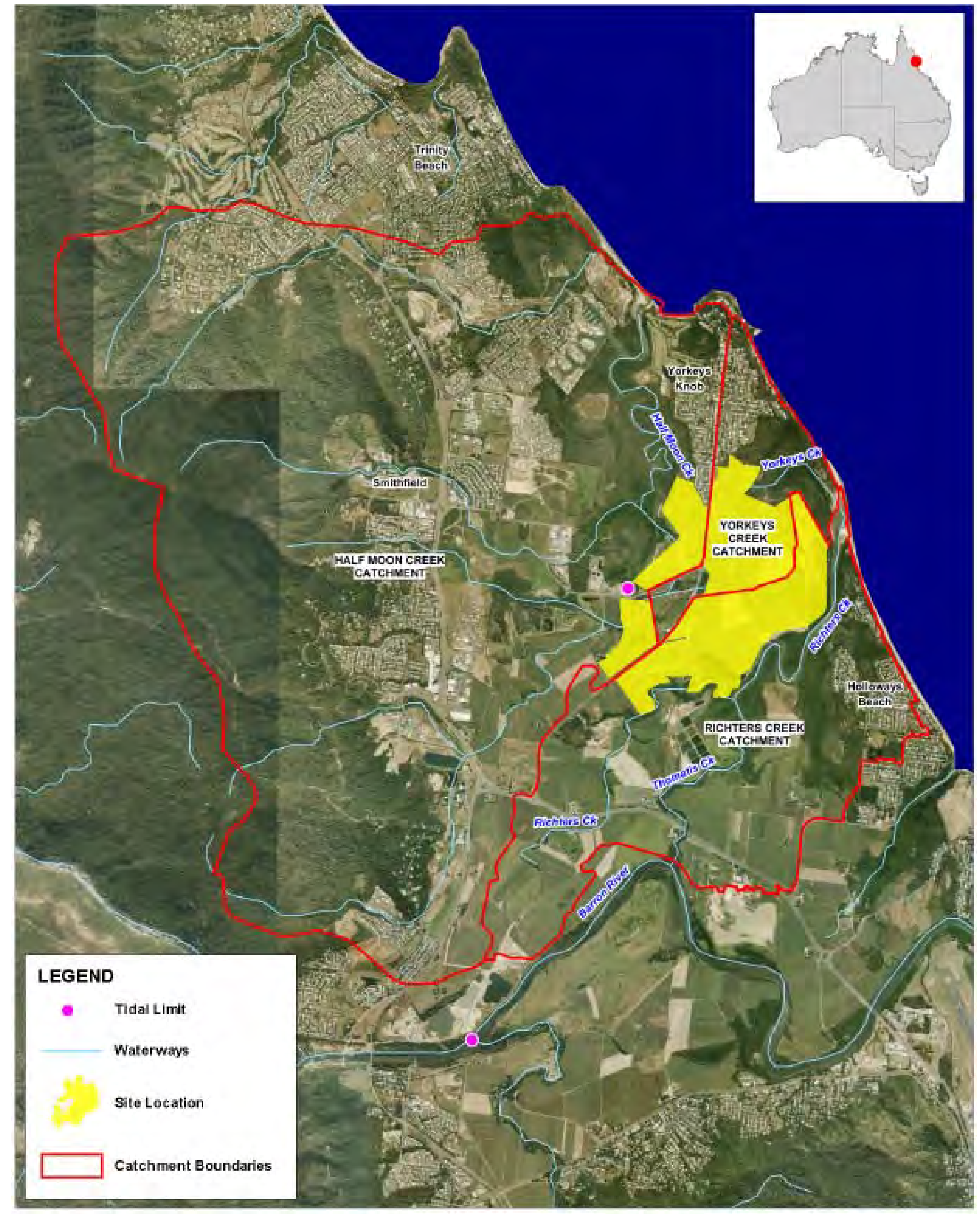

Figure 11-2 Catchment overview (Richters Creek, Yorkeys Creek, Half Moon Creek).

Source: Appendix M (Figure 2-2).

11.1.3 Description of Environmental Values

Table 11-1 provides a summary of the relevant environmental values (EVs) of the Thomatis / Richters, Yorkeys, and Half Moon Creek estuaries, and associated water quality guidelines (WQGs). Trigger values defined by relevant WQGs are in turn provided in **Table 11-2**. The EVs and WQGs presented are used to assist in the evaluation of existing (baseline) water quality conditions in these estuaries.

With reference to the trigger values summarised in **Table 11-2**, the Queensland Water Quality Guidelines (QWQG) provide the quantitative measure of performance for the EVs where applicable followed by the WQGGBRMP (Great Barrier Reef Marine Park Authority 2010) and the ANZECC / ARMCANZ (2000) in order of precedence. Compliance with the most stringent aquatic ecosystem values will ensure achievement of all EV outcomes for Thomatis / Richters, Yorkeys Creek and Half Moon Creek estuaries.

It is noted that the QWQG values are annual medians, i.e. the annual median from monitoring data should be compared to these values for assessing compliance and impact. In contrast, the ANZECC / ARMCANZ (2000) toxicity trigger values for metals / metalloids are for instantaneous comparison of data.

TABLE 11-1 ENVIRONMENTAL VALUES OF THOMATIS / RICHTERS, YORKEYS AND HALF MOON CREEKS AND ADJACENT NEAR-SHORE WATERS

Water		Aquatic Ecosystem	Human Consumer	Primary Recreation	Secondary Recreation	Visual Recreation	Cultural Heritage	Industrial Use	Aquaculture	Drinking Water	Irrigation	Stock Water	Oystering	Seagrass	Corals
Enclosed Coastal/Lower Estuary		✓	✓	✓	✓	✓	✓		✓					✓	✓
Richters, Yorkeys & Half Moon Creek (mid-estuarine)		✓	✓	✓	✓	✓	✓	✓	✓						
Applicable Water Quality Guideline	QWQG (2009)[a]	✓													
	ANZECC (2000)[b]		✓	✓	✓	✓									

a. Queensland Water Quality Guidelines 2009, prepared by the Environmental Protection Agency, Queensland Government.

b. Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000, prepared by the Australian and New Zealand Environmental and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ).

Source: Appendix M (Table 1-1). For ringed EVs the National Health and Medical Research Council (NHMRC) guidelines should also be used.

The various environmental studies undertaken for this EIS suggest that relevant EVs of the receiving waters are:

- aquatic ecosystem (slightly to moderately disturbed)
- secondary recreation
- visual recreation
- aquaculture
- seagrass (not present)
- corals (not present).

TABLE 11-2 WATER QUALITY GUIDELINE VALUES

Physico-Chemical Indicator	Wet Tropics		Applicable Guideline
	Mid Estuary (Thomatis/Richters, Yorkeys Half Moon Creek)	Enclosed Coastal	
Dissolved Oxygen (% Saturation)	Lower 80% / Upper 105%	Lower 85% / Upper 105%	QWQG (2009)[a] (Annual Median Values)
pH	Lower 6.5 / Upper 8.4	Lower 7.5 / Upper 8.4	
Turbidity (NTU)	10	10	
Temperature (°C)	Upper & lower limits to be determined locally		
Conductivity (µS/cm)	n/a	n/a	
Ammonia (µg/L)	15	15	
Organic Nitrogen (µg/L)	200	135	
Oxidised Nitrogen (µg/L)	30	10	
Total Nitrogen (µg/L)	250	160	
Total Phosphorus (µg/L)	20	20	
Filterable Reactive Phosphorus (µg/L)	5	5	
Suspended Solids (mg/L)	nd	nd	
Secchi (m)	1.0	1.0	
Chlorophyll a (µg/L)	3	2	
Sedimentation	max. avg./yr = 3mg/cm²/day daily max = 15mg/cm²/day		WQGGBRMP (2010)[b]
Arsenic ASIII & AsV (µg/L)	2.3/4.5		ANZECC/ARMCANZ (2000)[c] (toxicity trigger values for 95 % level of protection)
Antimony	-		
Barium (µg/L)	1000*		
Cadmium (µg/L)	0.7		
Chromium Cr VI (µg/L)	4.4		
Cobalt (µg/L)	1		
Copper (µg/L)	1.3		
Lead (µg/L)	4.4		
Manganese	80		
Mercury (inorganic) (µg/L)	0.1		
Molybdenum	-		
Nickel (µg/L)	7		
Silver (µg/L)	1.4		
Vanadium (µg/L)	100		
Zinc (µg/L)	15		
Ammonia (µg/L) [d]	460		ANZECC/ARMCANZ (2000)[c] (Toxicity values for 95 % level of protection)
NO_x (mg/L)	7.5		

Notes: (*) based on more stringent NHMRC Rec Water Guidelines value

a. Queensland Water Quality Guidelines 2009, prepared by the Department of Environment & Heritage Protection, Queensland Government.

b. Water Quality Guidelines for the Great Barrier Reef Marine Park 2010, prepared by the Great Barrier Reef Marine Park Authority, Townsville

c. Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000, prepared by the Australian and New Zealand Environmental and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ).

d. Ammonia trigger value is dependent on pH. The default ammonia trigger value presented here is for a pH of 8; however ANZECC/ARMCANZ (2000) provides ammonia trigger values for other pH values.

Source: Appendix M (Table 1-2).

11.1.4 Available Water Quality Data

Thomatis / Richters Creek has been the subject of several studies over the past 20-30 years. These were principally undertaken for the once-proposed canal development on the site and also as part of an on-going community-based Holloways Beach Environmental Education Centre (HBEEC) program in the area.

Existing information varies considerably in type, extent, time period, and quality of the data. Given that a significant volume of the available information was collected over 20 years ago, additional water quality monitoring is required to further characterise the existing water quality.

Available baseline data has been extracted from a number of sources at the locations shown on the **Figure 11-3**. **Table 11-3** provides an overview of the data available prior to the commencement of the current program (**Section a)**) and the extent to which it is fit for purpose. Reference is made in the following table to the QWQG (DERM 2009).

TABLE 11-3 SUMMARY OF BASELINE DATA

SOURCE	DETAILS / PERIOD	LOCATION OF EXTRACTED DATA	ASSESSMENT
(former) Department of Environment and Heritage	In-situ and laboratory analyses encompassed a five year period between 1983 and 1988 and occurred at those sites shown on **Figure 11-3**.	For the purposes of this study, data at station Numbers 1, 2 and 3 (Adopted Middle Thread Distance 0.0 km, 2.6 km and 4.5 km) have been extracted, and are presented in Appendix B of **Appendix M**. These sites correlate with Sites 1, 2 and 3 of the four WBM sites.	This data, while now over 30 years old, provides reliable detailed water quality monitoring data for Richters Creek.
WBM	In-situ and laboratory analyses from three field surveys in Richters Creek in late 1990 to early 1991. Four sites shown on **Figure 11-3** were visited during the survey at approximately two hourly intervals.	**Appendix M** (Chapter 3 and relevant appendices)	The WBM data while now over 20 years old provides reliable detailed water quality monitoring data particularly focussed on a dry and wet period for Richters Creek. Ideally the monitoring data would cover at least two seasons however it does provide an insight to the variability of Richters Creek.
Holloways Beach Environmental Education Centre	The results available for inspection indicate sampling occurred from 2000 to 2003 on a monthly basis. The survey data provides relatively recent results and will be particularly useful for comparative purposes to older data sets.	**Appendix M** (Chapter 3 and relevant appendices)	The use of average data set rather than the raw data limits the overall use of the data for establishing baseline percentile for comparison purposes to DERM (2009).

(Continued over)

SOURCE	DETAILS / PERIOD	LOCATION OF EXTRACTED DATA	ASSESSMENT
Natural Resources of the Barron River Catchment - Water Quality, Land Use & Land Management Interactions	Physical and chemical data up to June 2000.	**Appendix M** (Chapter 3 and relevant appendices)	Useful for establishing context for the more local data.
Frc environmental (current investigation)	Water quality data was collected in July 2013 for **Appendix F** in the Thomatis / Richters Creek area, Yorkeys Creek and Half Moon Creek for this project.	**Appendix F** **Appendix M** (Chapter 3 and relevant appendices)	While providing valuable and up to date data, its worth is limited in defining the true baseline of the receiving water as it is only a single grab sample rather than a two year monthly water monitoring program as described by DERM (2009).
WBM (2014 wet season investigation)	Wet season water quality data was collected between December 2013 and February (on-going) for **Appendix M** in the Thomatis / Richters Creek area, Yorkeys Creek and Half Moon Creek for this project.	**Appendix M** (Chapter 3 and relevant appendices)	This work is the beginning of a 12 month (minimum) monitoring program designed to determine site specific WQOs. See below.

Source: Study team compilation.

a) Historical Water Quality Data

A detailed analysis of historical monitoring data is provided in **Appendix M** for the Barron River and each of Richters, Yorkeys, and Half Moon Creeks on a creek-by-creek basis. While some of the historic data is over 30 years old, it is still considered to provide reliable detailed water quality monitoring data for Richters Creek. The quality and scope of data varies for the creeks, with Richters Creek data being the most extensive. Data exists for the following physico-chemical and in some cases, biological indicators:

- turbidity, total suspended solids and Secchi depth
- conductivity / salinity
- nutrients
- dissolved oxygen
- pH
- temperature
- chlorophyll a
- metals.

Findings are summarised in **Section 11.1.4d).**

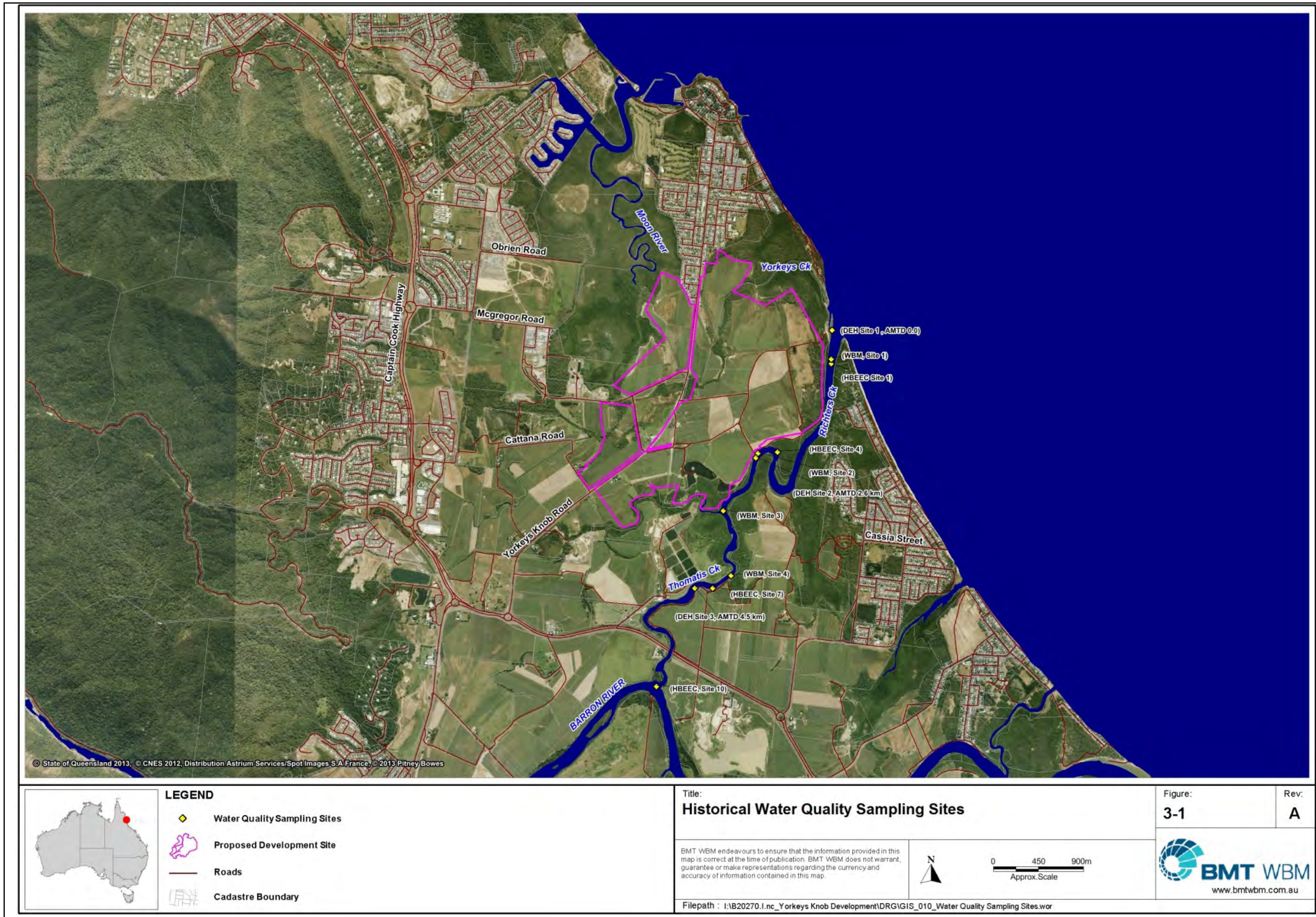

Figure 11-3
Historic water quality sampling sites (all sources).

Source: Appendix M (Figure 3-1).

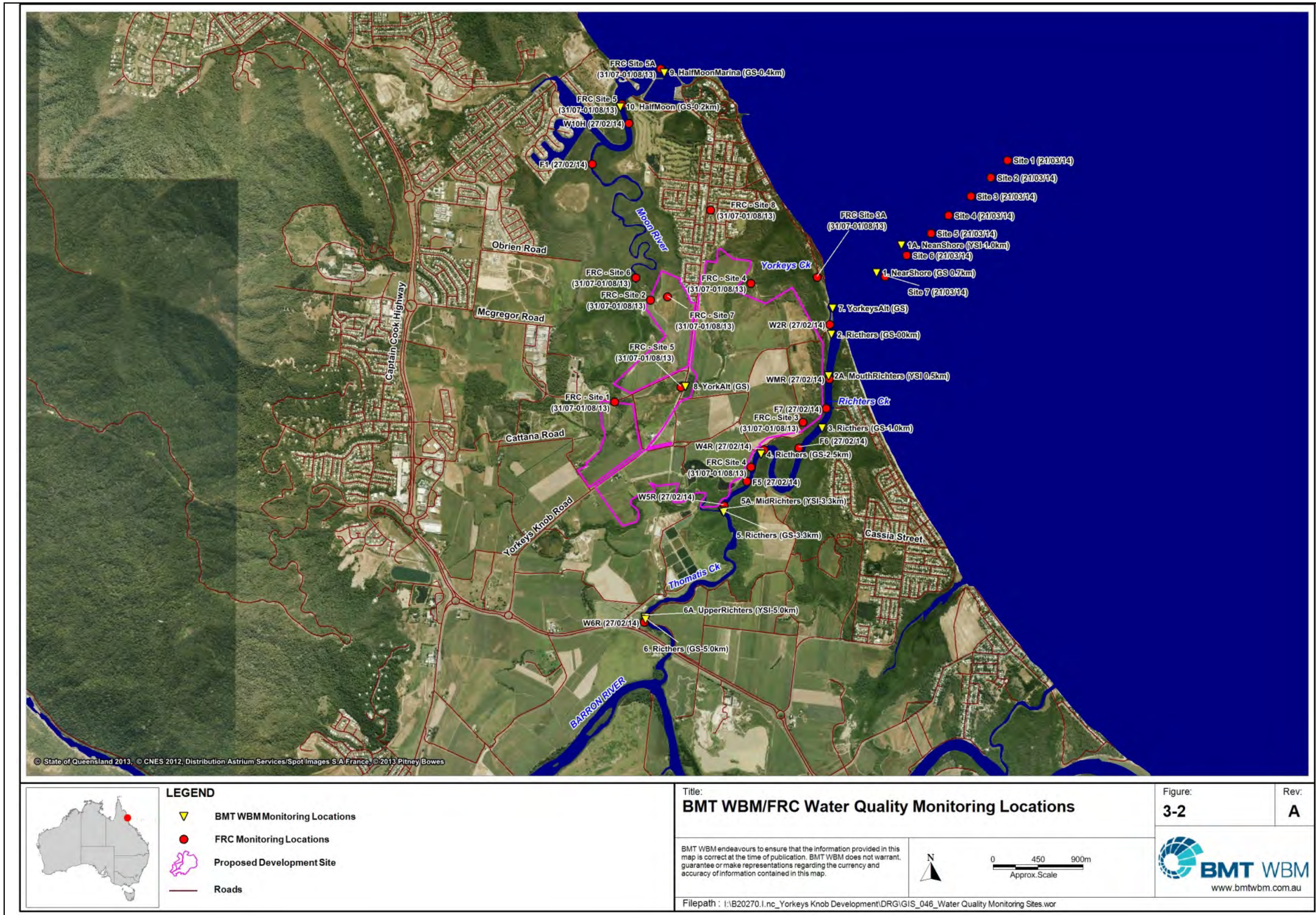

Figure 11-4 Water quality monitoring sites (current program).

Source: Appendix M (Figure 3-2).

b) *Present Water Quality Monitoring Program*

Water quality monitoring data is currently being collected by BMT WBM to provide a present baseline assessment of Richters Creek, Yorkeys Creek and Half Moon Bay. The water quality data collected has also been used to calibrate and verify the numerical TUFLOW-FV hydrodynamic water quality model of the site (refer to **Section 11.3.1a)**) to determine the potential impacts the development may have upon the receiving environment. The water quality monitoring program commenced in December 2013 and results up to and including February 2014 are summarised below. This data has been collected using three continuous water sampling loggers into Richters Creek and one into the near-shore area of Richters Creek (refer to **Figure 11-5**). The loggers are used to record and determine the following physico-chemical indicators:

- turbidity
- depth
- conductivity / salinity
- temperature
- dissolved oxygen
- pH.

Grab samples have also been collected on a monthly basis in Richters Creek (including the near-shore area), Yorkeys Creek and Half Moon Creek for laboratory analysis of the following water quality parameter suite:

- total N (TN) incl. NOx, TKN and ammonia
- total P (TP) and reactive P
- total suspended solids (TSS)
- Chlorophyll a.

An assessment of metals in Richters Creek was also included for the following: Sb, As, Be, B, Cd, Cr, Co, Cu, Pb, Mn, Mo, Ni, Se, Ag, Sn, Zn and Hg.

c) *Inlet Pipeline Survey*

The project concept includes lake water exchange that draws water from an inlet located 2.2 km north-east of the site via a buried pipeline. The route of the pipeline is shown on **Figure 11-5** and was the subject of a detailed aquatic ecology assessment (**Appendix H**).

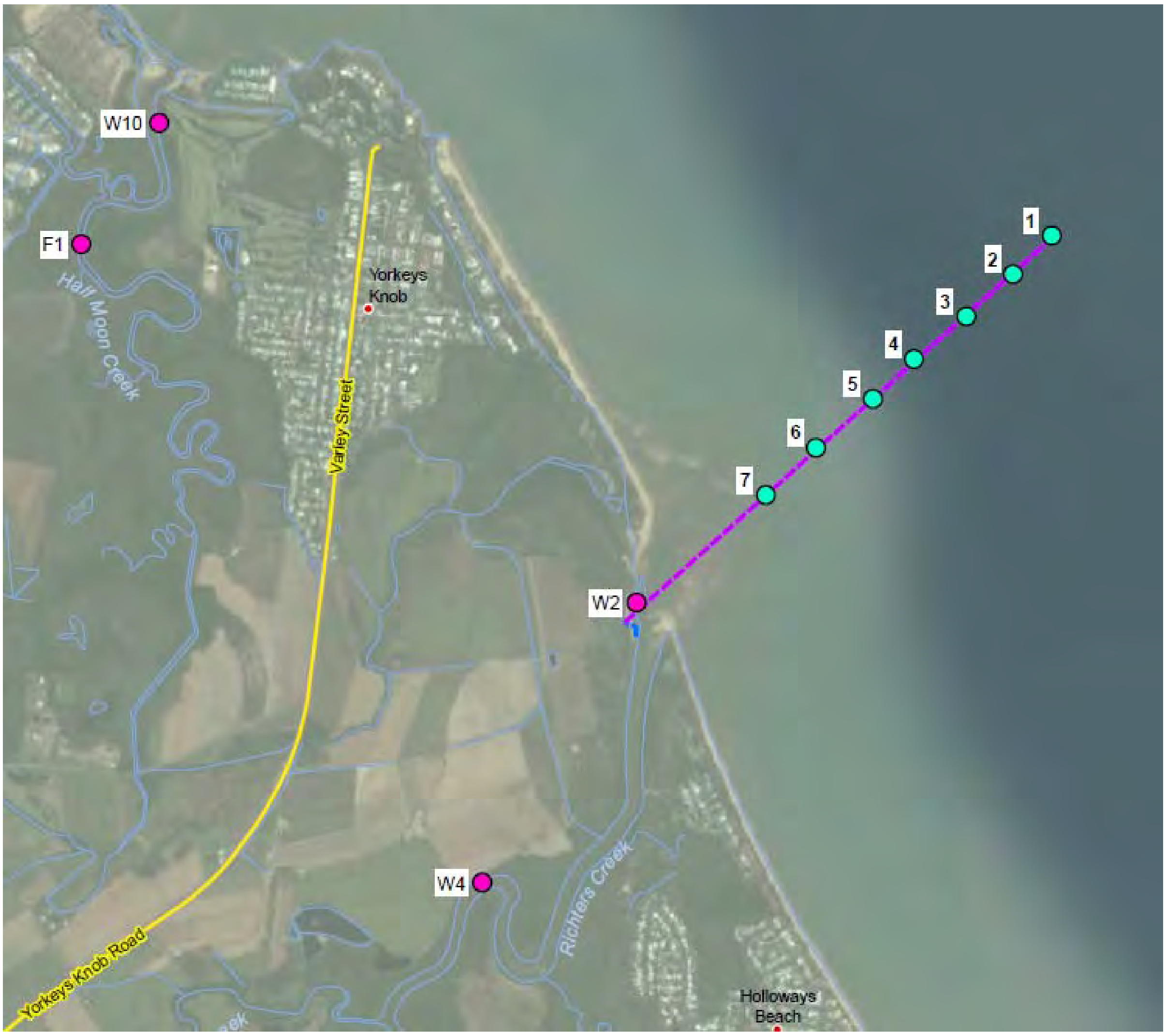

Figure 11-5 Inlet pipeline corridor.

Source: Appendix H (Map 5 extract). Sites marked are those from which water quality and sediment samples described below were taken. Site 1 is the proposed inlet.

At the time of the survey (March 2014) approximately half of the pipeline alignment was within turbid surface water plumes coming from both Richters Creek and the Barron River. These plumes were caused by heavy rainfall in the days preceding the survey. There was a 5 mm to 10 mm layer of fine red-brown sediment over the surface of the mud, which was likely due to fine sediment settling from these freshwater plumes.

During the survey, the turbid freshwater surface plume shifted extent by hundreds of metres based on the prevailing conditions, being blown further in-shore by increasing wind and wave action from the south-east. Salinity and pH were likely to have been affected by this recent rainfall.

The following plots (**Figure 11-6**) are example water quality profiles for temperature, pH, salinity, dissolved oxygen and turbidity at site 1 (furthest site off-shore) and site 7 (furthest site inshore). Site 1 is at the site of the lake inlet and WQ2 at that of the lake outlet.

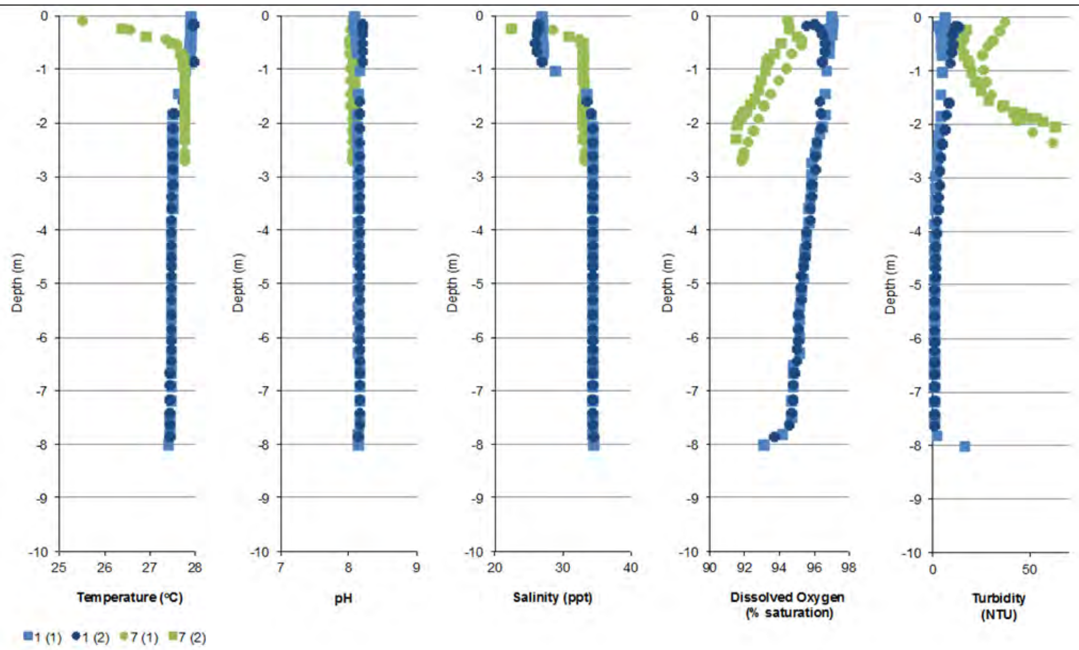

Figure 11-6 Example water quality profiles at site 1 (furthest site off-shore) and site 7 (furthest site inshore).

Source: Appendix H (Figure 4-2). Squares represent profile replicate number one; circles represent profile replicate number 2.

The following general comments apply to water quality findings (field probe and laboratory results):

- The pH of surface waters was slightly below (i.e. do not comply) the *Wet Tropics draft surface water quality guideline for open coastal waters in the Barron Basin* – draft WQG (EHP 2013a) at all sites, except site 1 and site 3. Frequent rainfall throughout the survey and subsequent freshwater flows from Richters Creek and the Barron River are likely to have lowered the pH of surface water. The salinity of surface waters was lower than expected at all sites (salinity of seawater is approximately 35 mg/L). Despite low salinity in surface waters, salinity was at normal levels in deeper water (for example, 34.4 mg/L at ~2 m depth at site 1) (**Figure 11-6**). The low surface levels are indicative of a freshwater plume in surface waters, likely due to rainfall and freshwater flows from Richters Creek and the Barron River.
- Turbidity and Secchi values of surface waters were well above the draft WQG at all sites (i.e. do not comply). Turbidity was lowest at site 1, which was the greatest distance from the mouth of Richters Creek (**Figure 11-6**). Poor water clarity is likely to be associated with runoff from the local area. Dissolved oxygen was within the draft WQG for surface waters; however, dissolved oxygen was below the draft WQG in deeper waters both near the mouth of Richters Creek (e.g. site 7) below ~0.7 m depth, and in open water (e.g. site 1) below ~6.5 m depth (**Figure 11-6**). The depth of water where the concentration of dissolved oxygen was below the draft WQG increased with distance off-shore.
- Water quality at site 1 (i.e. the proposed entrance to the intake pipeline) at depth (approx. 7.5 m) was similar to that at the surface, except for salinity, which at depth was close to the expected range of seawater. Water quality parameters were within the WQG, where available.

The results of the pipeline survey are generally consistent with results from previous surveys of the region. Surface water quality was poor at the time of survey but improves with depth. Testing confirms that the expected benefits in adopting a deep water inlet for lake exchange water will be realised. Referring to **Table 11-11**, the inlet water, when compared with that at the outlet has:

- 5% better DO (and complies with the QWQG)
- a more desirable pH (and complies with the QWQG)
- a more desirable salinity (approximately that of seawater)
- a similar temperature
- a significantly lower turbidity (and complies with the QWQG).

d) Summary

A summary of the historic and recent results has assisted in characterising and determining the baseline water quality primarily in Thomatis and Richters Creeks, but also Half Moon, Yorkeys Creek and near-shore conditions. Of the available data only the DEH data provides a dataset that is of significant length (i.e. approximately four years) to be appropriately compared to the QWQG long-term median concentrations.

An assessment of compliance of the physico-chemical indicators with the QWQG is provided in **Table 11-4** below.

TABLE 11-4 DEH MONITORING DATA & COMPLIANCE WITH QWQG

PHYSICO-CHEMICAL INDICATOR	RICHTERS CREEK (COMPLIANCE WITH QWQG MEDIAN VALUES)						
	DEHP SITES (east to west) See Figure 11-3			BMT WBM YSI SITES (east to west) See Figure 11-4			
	Site 1 (Mouth of Richters Creek)	Site 2 (Bend in Richters Creek)	Site 3 (Confluence of Richters Creek and Thomatis Creek	1A. Near-shore (YSI-1.0 km)	2A. Mouth Richters (YSI-0.5 km)	5A. Mid Richters (YSI-3.3 km)	6A. Near-shore (YSI-5.0 km)
Dissolved Oxygen	✓	✓	✓	✓	✓	×	×
pH	✓	✓	✓	✓	✓	✓	✓
Turbidity	✓	✓	✓	×	×	×	×
Ammonia	×	×	×	-	-	-	-
Organic Nitrogen	×	×	×	-	-	-	-
Oxidised Nitrogen	✓	×	×	-	-	-	-
Total Nitrogen	×	×	×	-	-	-	-
Total Phosphorus	✓	✓	×	-	-	-	-
Secchi	×	×	×	-	-	-	-

Source: Appendix M (Table 3-50). In this table:

✓ indicates compliance with QWQG, × indicates non-compliance, - indicates no data or not applicable.

Evaluation of the above data indicates that monitoring sites closest to the mouth of the Richters Creek and the near-shore area provides the best compliance to the QWQG and are compliant except for:

- nutrients
- turbidity / Secchi.

Further water quality data for the BMT WBM current monitoring program is required to determine median water quality values for nutrients to allow an appropriate comparison to QWQG (2009). However, general conclusions drawn from perusal of available monitoring data are given below.

Thomatis / Richters Creek

- Nutrient levels in Richters Creek during high wet season flows are typically twice those recorded during the dry season. This trend is also consistent with current water quality monitoring data.
- Nutrient levels at times of lower wet season flows (i.e. Barron River base-flows) are equivalent to dry season values.
- Estuarine water clarity during high wet season flows is considerably less than that both during the dry season and at times of lower wet season flows. Current monitoring indicates turbidity increase with notable inflows from the Barron River.
- Richters Creek exhibits a freshwater flow related 'salt-wedge' phenomenon for the majority of field surveys presented. During the high flow survey (refer to BMT WBM monitoring) this salt wedge was distinct, with turbid riverine waters overlying clearer oceanic waters. This salt wedge was observed to move upstream with the flooding tide, and downstream with the ebbing tide, with an overall net movement upstream.
- From historical data, occasional dissolved oxygen super-saturation was observed in the upper reaches of the estuary. Current and continuous monitoring indicates DO saturation is low in the upper reach of Richters Creek and only just above toxic levels for some fish.
- Metal concentrations are generally below the ANZECC/ARMCANZ (2000) toxicity trigger values for 95% level of protection. Manganese and particularly Boron typically exceed guideline values.
- During high wet season flows, upper estuarine reaches experience purely freshwater conditions and elevated suspended sediment and nutrient concentrations.
- Water quality at the mouth is strongly influenced by oceanic influences. Mean salinity is higher than the other sites, similarly pH. Mean water clarity is marginally lower than other sites, reflecting the influence of near-shore sediments resuspended by wave action.

Yorkeys Creek

- Nutrient levels of TN and TP recorded from single grab samples were above the QWQG recommended levels.
- The concentration of all other nutrients (i.e. ammonia, nitrate/nitrite, ortho-P, chlorophyll *a*, organic carbon, BOD) were below the QWQG.

Half Moon Creek

- The concentration of TN and ammonia were above the QWQG except at the site at the mouth of the creek.
- Concentrations at the mouth of Half Moon creek were the lowest of all sites due to mixing from the oceanic currents.

<u>Near-shore</u>

- Historical median concentrations of all nutrients are compliant with the QWQG.
- High levels of nutrient are possible within the near-shore area with the 80th percentile generally exceeding median QWQG values.
- Similar to the historical data, current monitoring indicates that nutrients are generally compliant with QWQG, however during notable inflows from the Barron River concentrations generally exceed the guideline values.

e) Implications

With respect to the proposed development and key baseline data the following observations can be made:

- Richters Creek mouth and the near-shore area typically have QWQG-compliant water. The quality of water – particularly in the near-shore area during the dry season and periods of low catchment inflows area – is considered to be of acceptable quality for use in the lake. Location of the intake 2.2 km from the mouth of Richters Creek (i.e. still within the near-shore area) will further provide improved water quality conditions that will be less impacted by Barron River and Richters Creek flows.
- Generally, more turbid waters will be expected near the mouth and inner near-shore area of Richters Creek where the wind regime and ensuring waves and swell may influence re-suspension of sediments. Location of the inlet 2.2 km from the mouth of Richters Creek will likely improve turbidity conditions. This many not necessarily be beneficial as low turbidity within the lake will allow growth of benthic flora due to increased light levels.
- During periods of high wet weather flows, Richters Creek has elevated levels of nutrients and suspended sediments due to catchment runoff. The proposed near-shore inlet (i.e. 2.2 km from Richters Creek mouth) will assist in ensuring that water supplies for lake exchange are of an appropriate standard.
- Discharge of lake water to Richters Creek mouth will need to be maintained to a reasonable standard as to not impact on the receiving environment. However it should be noted the receiving water quality generally exceeds the QWQG (2009) in Richters Creek in the mid to upper reaches and would be considered one of a moderately disturbed ecosystem. The lake would most likely improve the receiving water quality in this area because the inlet water derived from the near-shore inlet is of a higher quality and modelling shows that this is not markedly diminished by the flushing process.

11.2 STORMWATER DRAINAGE DESIGN AND PERFORMANCE

11.2.1 Impacts

Analysis of site conditions and those of the surrounding environment reveals the following key surface water (non-flooding) features of the site:

- As shown on **Figure 3-4**, the site is adjacent to protected areas where water quality is important. These are:
  - the GBRWHA (and GBRMP (Commonwealth) further off-shore)
  - the GBR Coast Marine Park (Queensland)
  - the Yorkeys Creek and Half Moon Creek FHAs.
- The maintenance of high water quality in these areas is essential to their ongoing ecological function and protection of recognised conservation values.

- Current water quality in the catchment of the proposed development is generally good, although the waters do not meet the QWQG for various nutrients and turbidity. It appears that water quality is adversely affected by agricultural runoff from the surrounding land (predominantly cane farming in the overall catchment and the prawn farm on Richters Creek) and the Marlin Coast WWTP on Half Moon Creek.

Land development typically poses threats to water quality through the construction process (e.g. soil and water runoff associated with earthmoving activities, mobilisation of soil contaminants, ASS / PASS conditions) and during operation (e.g. stormwater drainage, chemical and fuel spills, overflows and other losses from sewerage systems).

Avoidance and minimisation of impacts on the values of the receiving waters involves:

- construction management initiatives (and associated monitoring)
- development of a stormwater drainage system that improves all site runoff, including treated effluent to be imported as a substitute for part of the project's water demand.

a) Stormwater Drainage Design

<u>Overall Approach</u>

The overall approach to conceptual stormwater drainage design involved the following process:

- The undeveloped (cane farm) and developed (Aquis Resort) sites were broken up into sub-catchments, with the developed case being based on a preliminary site grading (**Figure 11-9**).
- The development of the catchment plan adopted the following principles:
  - As a general rule, all stormwater drainage will adopt Water Sensitive Urban Design (WSUD) principles to limit the export of sediments and nutrients. This will include appropriate stormwater quality improvement devices (SQIDs) and other techniques as outlined below.
  - The catchment of the lake was limited as far as possible to restrict the inflow of possibly contaminated runoff, which would then present a water quality challenge within the lake. This will be achieved by placing a levee around the perimeter of the lake to exclude inflows from outside the lake limits for non-flood flows.
  - Land in the vicinity of built structures south of the lake was designed to drain to SQIDs located the eastern part of the site before discharging to Richters Creek.
  - Land on Lot 2 RP745120 was graded so that runoff would to drain to SQIDs located the western part of the site before discharging to Half Moon Creek.
  - The golf course follows the natural surface which will, in general, not be altered. This currently drains to the edges of the site and runoff will be intercepted by retained existing natural and the additional plantings included in the Concept Master Plan.
- A conceptual stormwater drainage strategy was developed. This is proposed to designed to involve a 'beyond best practice' regime consisting of:
  - rainwater harvesting and re-use
  - in-line treatment to achieve the desired pollutant load reductions, generally through proprietary devices with other methods to be investigated later
  - management of inputs (e.g. fertilisers, pesticides, herbicides, irrigation water)
  - vegetated buffer areas (existing natural vegetation to remain plus restored areas)
  - an education program to encourage the required management regime (aimed at both guests and staff).
- A Model for Urban Stormwater Improvement Conceptualisation (MUSIC) was established for the site. MUSIC is an industry-standard tool for modelling stormwater runoff using actual rainfall data and a range of user-defined catchment and treatment parameters.

- For the purpose of assessing the impact of discharges, three cases were assumed:
  - existing land use (i.e. cane farm with no runoff treatment) – see **Figure 11-7**
  - developed site with no runoff treatment (investigated purely for comparative purposes)
  - developed site with runoff treatment in accordance with the stormwater drainage strategy (and including re-use of treated effluent) – see **Figure 11-8**.
- Outflows were calculated as per the broad strategy outlined above, namely:
  - all treated flows within the Hotel Complex Precinct (approximately 40 ha) were considered as inputs to the lake, together with rainfall landing directly on the 330 ha lake surface
  - all treated flows not within the lake catchment (approximately 268 ha excluding Yorkeys Knob Road) were assumed to discharge directly into Richters Creek, Half Moon Creek and Yorkeys Creek catchments, generally as per the catchment plan shown on **Figure 11-9**.

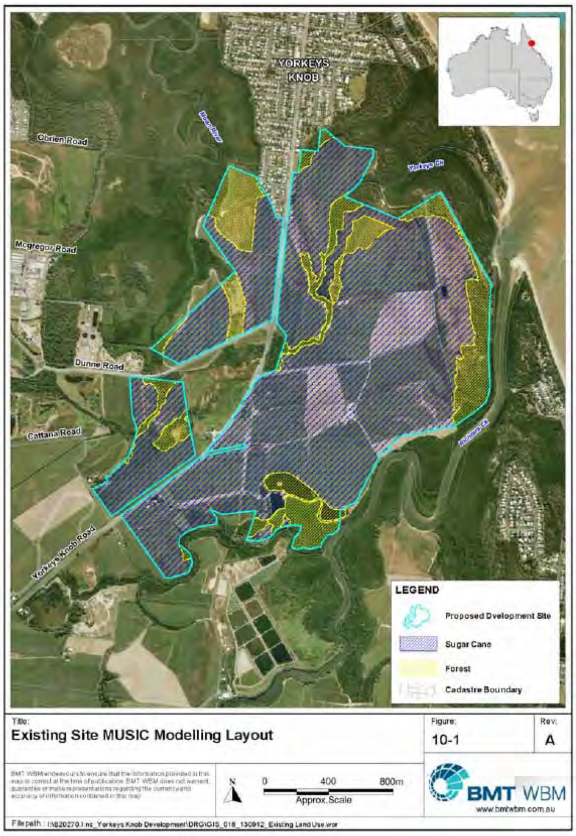

Figure 11-7 Existing land use.

Source: Appendix M (Figure 10-1).

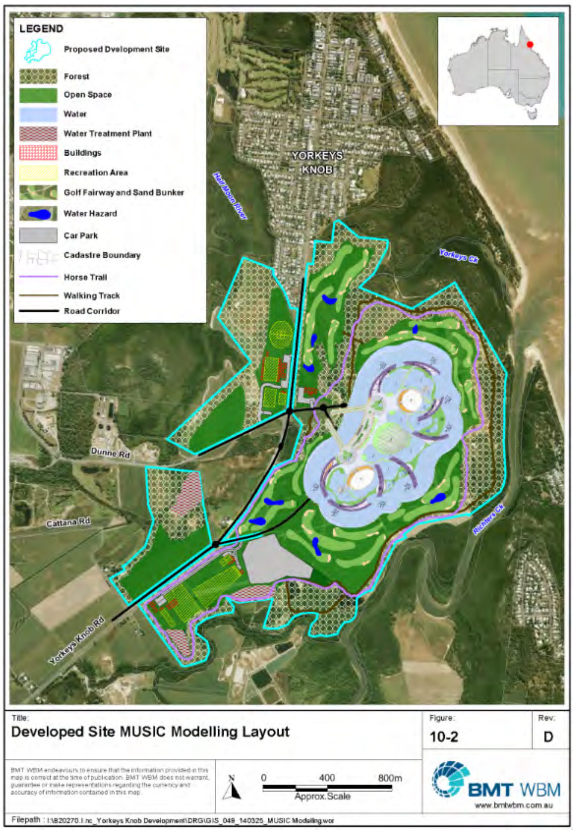

Figure 11-8 Proposed land use.

Source: Appendix M (Figure 10-2).

Conceptual Stormwater Drainage Strategy

The conceptual stormwater drainage strategy for the overall site is shown schematically on **Figure 11-10**. Elements of the strategy are:

- designation of appropriate sub-catchments (**Figure 11-9**)
- determination of load reduction targets for sediments and nutrients
- selection of SQIDs to achieve these targets
- consideration of effluent re-use and implications for stormwater drainage
- specification of a suite of management initiatives to complement the physical infrastructure.

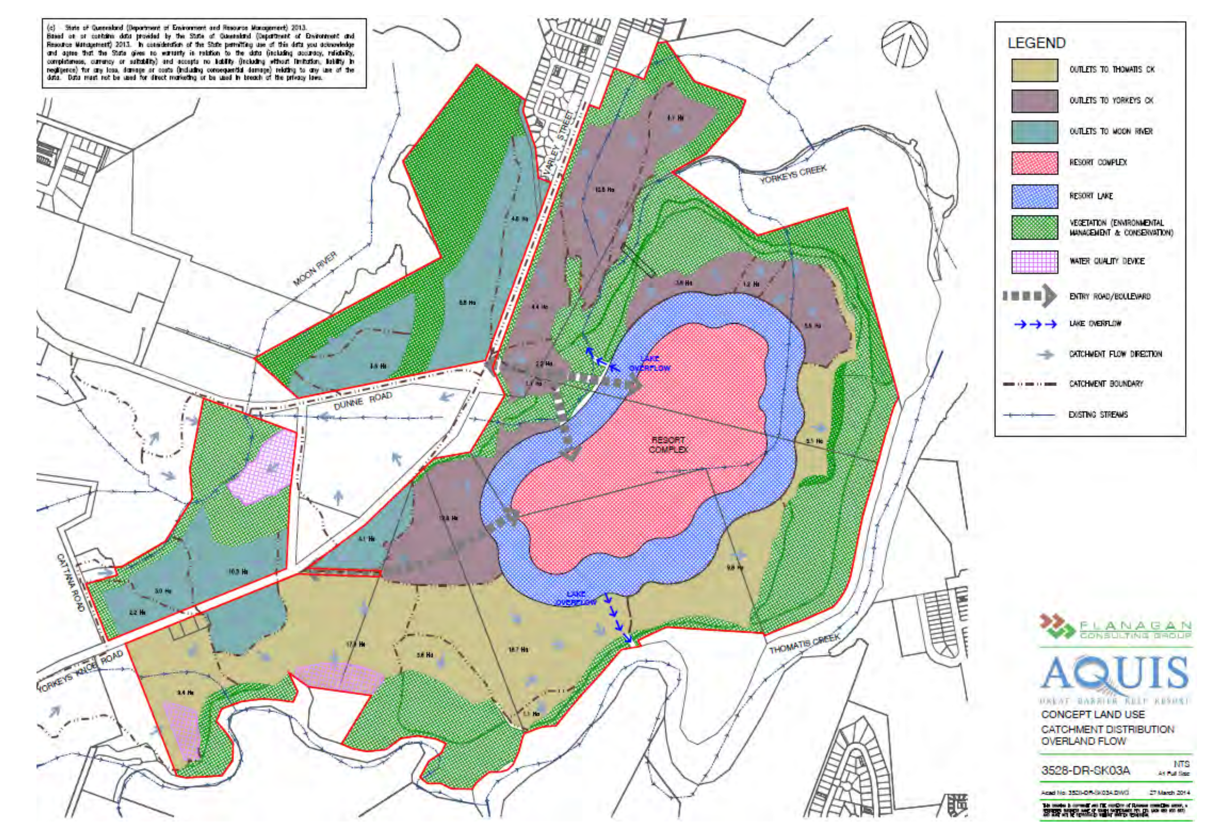

Figure 11-9 Conceptual catchment plan showing the target catchments of the developed site.

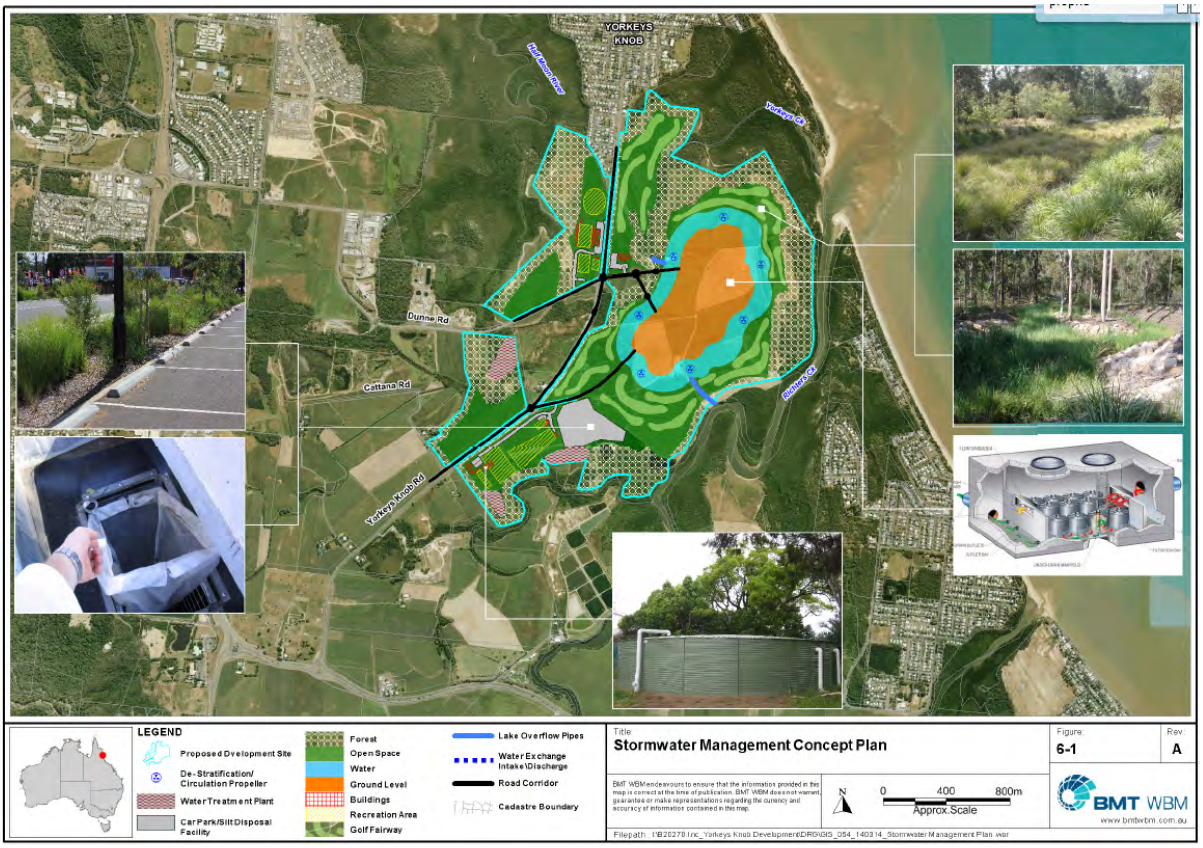

Figure 11-10 Stormwater drainage strategy.

Source: **Appendix M** (Figure 6-1)

Performance Objectives – Load Reduction

Desired load reduction targets for WSUD are based on the following state standards as a minimum:

- State Planning Policy (SPP) 2013 under *Planning for environment and heritage (Water)* and Appendix 2 Table B (this supersedes former SPP 4/10 *Healthy Waters* (Department of Environment and Resource Management 2010b) but uses the same data).
- Urban Stormwater Quality Planning Guidelines 2010 (Department of Environment and Resource Management 2010d).

These targets are as follows.

TABLE 11-5 LOAD REDUCTION TARGETS (MINIMUM)

POLLUTANT	TARGET	NOTES
Total Suspended Solids	80% reduction	Generally readily achievable.
Total Phosphorus	60% reduction	Generally readily achievable.
Total Nitrogen	40% reduction	Higher reduction proposed for golf course and other non-lake sub-catchments. Much of the nitrogen input to the lake catchment is dissolved in rainwater.
Gross Pollutants (5 mm or larger)	90% reduction	Generally readily achievable.

Source: SPP 2013 Appendix 2 Table B. See also **Appendix M** (Table 6-1).

The proposed measures for the Aquis Resort development will be designed to achieve the performance criterion outlined above, while also implementing contemporary stormwater water re-cycling / harvesting measures.

<u>Stormwater Quality Improvement Devices and Management</u>

The following is a summary of the stormwater drainage strategy for each of the identified sub-catchments. This includes SQIDs and management initiatives to complement the physical infrastructure as currently conceived.

TABLE 11-6 STORMWATER QUALITY IMPROVEMENT DEVICES

SUB-CATCHMENT	TREATMENT	NOTES
Lake	Rainwater collection from clean surfaces, storage, and re-use Bio-retention basins (tbc) Proprietary devices Education	Assumed no discharge of clean water Evaluation of effectiveness required EnviroPod or similar (especially for carparks for all staff and guests)
Golf course	Fertiliser and herbicide/pesticide management Irrigation management to limit runoff Reduced turf cover Constructed wetlands if needed (tbc)	Soil testing, application rate monitoring, in situ testing Soil moisture sensors and 'smart' sprinklers Lower standards at edges of fairways If restoration areas not sufficient
Sports and recreation facilities etc.	Rainwater collection from clean surfaces, storage, and re-use Proprietary devices Bio-retention basins (tbc) SQIDs Education	Assumed no discharge of clean water EnviroPod or similar (especially for carparks) Evaluation of effectiveness required As allowed for in Concept Land Use Plan For all staff and guests

Source: Study team compilation. The feasibility of bio-retention devices and constructed wetlands for Aquis Resort conditions will be confirmed during detailed design.

As noted above, the feasibility of bio-retention devices and constructed wetlands for Aquis Resort conditions will be confirmed during detailed design. Some typical examples are shown on the following images.

Figure 11-11 Bio-retention devices.

Source: Appendix M (Figure 8-2).

Nutrient Capture using Treated Effluent

When fully developed, the Aquis Resort is estimated to export a total of 1800 ML/a of sewage effluent to the Marlin Coast Wastewater Treatment Plant (WWTP). After treatment to the licensed standard, this effluent would normally be discharged to Half Moon Creek where it would eventually make its way to the Coral Sea / GBR lagoon. Re-use of recycled water from the Marlin Coast WWTP and / or the Northern WWTP is proposed to substitute part of the development's potable water demand for both potable water substitution and irrigation. A conceptual recycled water strategy is shown on **Figure 11-12**.

This strategy involves piping untreated wastewater from the development to the Marlin Coast WWTP for treatment. Recycled water is then piped back to a storage tank within the development. Linked to the storage tank, a distribution network will transport the recycled water to the dedicated reticulation system for non-potable uses and throughout the open space areas of the development for irrigation. Irrigation demand on the distribution network will be controlled by an automated system utilising soil moisture sensors to ensure the most efficient use of the recycled water.

The volume of irrigation required for the open space areas will vary depending on the type of open space (golf course, landscaped areas) and the seasonal conditions (wet or dry season). The use of soil moisture sensors within these areas will enable the most efficient use of the recycled water and more importantly, prevent runoff.

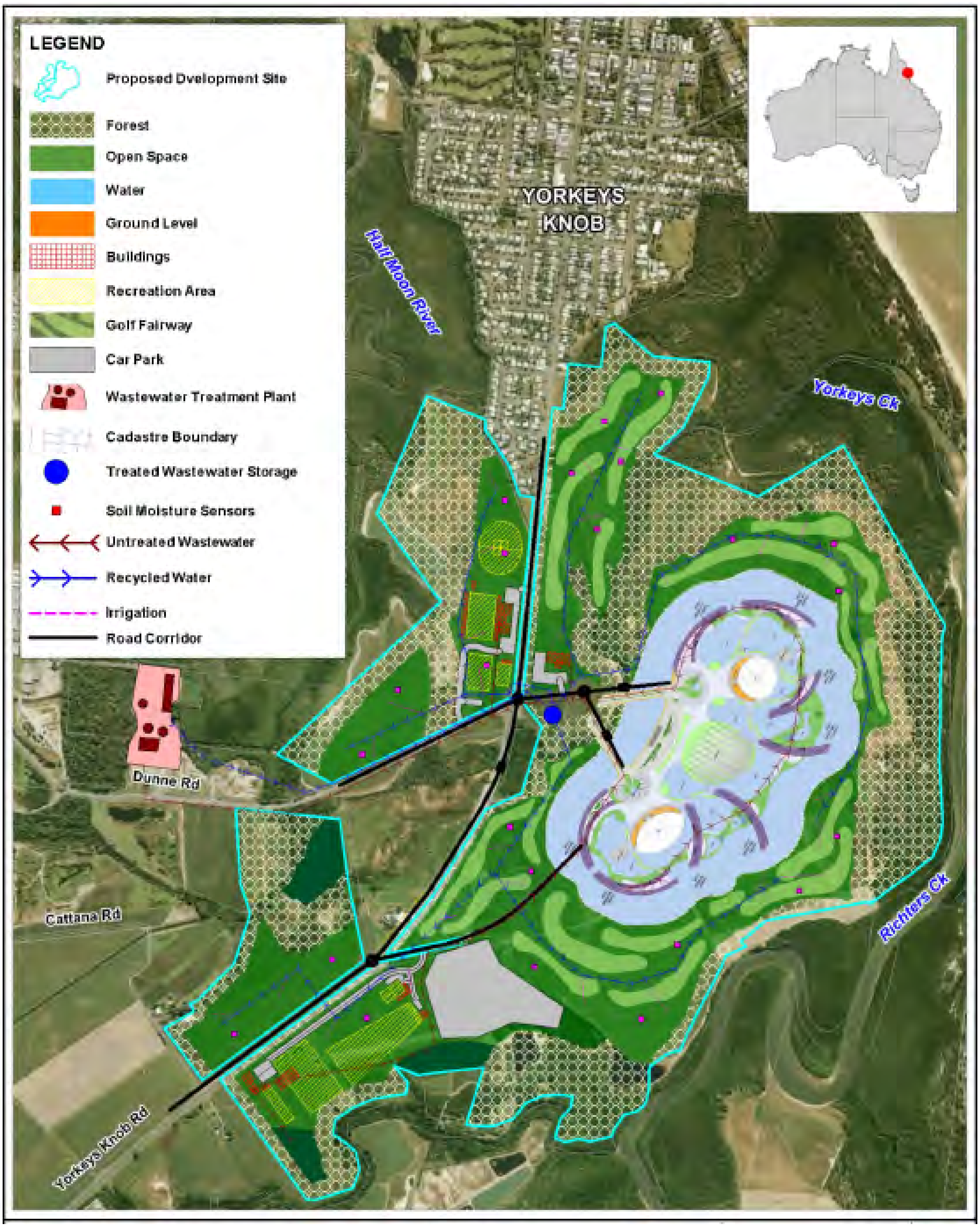

Figure 11-12 Recycled water strategy.

Source: Appendix M (Figure 8-3).

In addition to reducing the reliance on potable water, this allows the suspended solids and nutrient loads included in this water to be used on-site rather than exported to the Coral Sea. The effect on annual export of pollutants depends on the amount of sewage generated and the amount of treated effluent returned to the site. This varies over time depending on the status of construction and operation works as shown in **Table 11-7** below.

TABLE 11-7 SEWAGE GENERATED AND EFFLUENT REUSED BY STAGE

STAGE	SEWAGE (ML/annum)	RE-USE (ML/annum)	DIFFERENCE (ML/annum)
Stage 1 construction	37	200	163
Stage 1 operation	980	1,380	400
Stage 2 construction and Stage 1 operation	1,015	1,580	565
Long term (Stage 2 operation)	1,800	1,430	-370

Source: Study team compilation.

It can be seen that effluent re-use exceeds sewage production until the end of Stage 2 construction. Even though there is a small net export at that time, there are still benefits in the re-use of treated effluent. This worst-case scenario is examined in the calculation of net exports of sediments and nutrients in the following discussion.

Evaluating Performance

The MUSIC model was used in the design and assessment of the stormwater drainage system as described above and also as an input to the lake / receiving water assessment as described later. In order to evaluate the performance of the stormwater drainage system, MUSIC was used to estimate unmitigated and mitigated stormwater pollutant export from the overall site. Ten years of daily discharges were calculated using actual historical rainfall and potential evapotranspiration data for the period 1 January 1992 to 31 December 2001 as per the guidelines. This modelling produces estimates of annual pollutant load and is useful for comparing the relative export of pollutants of the Aquis Resort and the existing cane farm.

Modelled Cases

For the purposes of estimating overall pollutant discharges attributable to the project, two sets of calculations were undertaken as follows:

- Case 1: discharge from stormwater drainage to the lake and non-lake catchments, as per MUSIC modelling, and using WSUD features.
- Case 2: as above:
  - plus discharge from the Aquis Resort sewage after treatment at the Marlin Coast WWTP – this is the (adverse) contribution that the operation of the resort would make to the export of pollutants via its sewage production, after treatment at the Marlin Coast WWTP
  - minus re-use of the designated volume of Marlin Coast WWTP effluent (this is the contribution (beneficial) of treated effluent imported to the site for use as a potable water substitute).

For Case 2, by re-using treated effluent to offset sewage production, a reduction in total export can be achieved as quantified in **Table 11-7**. It is conservatively assumed that there is negligible volume loss through the WWTP.

Case 1 – Load Calculations

The annual load of pollutants carried in stormwater drainage (after treatment in the various WSUD elements) was calculated using the MUSIC modelling package. Results are summarised below for the following cases (annual totals for a full ten year simulation using the MUSIC model):

- existing land use (i.e. cane farm with no runoff treatment)
- developed site with no runoff treatment (this case was included as the base case for subsequent load reductions)
- developed site with runoff treatment in accordance with the stormwater drainage strategy.

The following data is from a model run using a six minute time step from 1 January 1992 to 31 December 2001. The results are annual average figures and can be used for long term load calculations.

TABLE 11-8 MUSIC MODEL LOAD ANNUAL RESULTS

CREEK CATCHMENT	TSS (kg/a)	TP (kg/a)	TN (kg/a)
Yorkeys Creek			
Existing	117,000	354	2,430
Developed site with no treatment	195,000	229	1,540
Developed Site with treatment	57,900	97	1,040
Richters Creek			
Existing	130,000	390	2,700
Non-lake – developed site with no treatment	249,000	312	1,860
Non-Lake – developed site with treatment	64,800	123	1,220
Resort – developed site with no treatment	50,500	134	1,410
Resort – developed site with treatment	10,100	50	984
Half Moon Creek			
Existing	35,000	97	680
Developed site with no treatment	77,500	112	753
Developed Site with treatment	23,200	46	498
Total Development Site			
A: Existing	285,000	845	5'834
B: Developed site with no treatment	572,000	787	5,563
C: Developed site with treatment	156,000	315	3,742
% Removal (B-C)/B	73%	60%	33%
Target (**Table 11-5**)	80%	60%	40%
% Change (A-C)/A	45%	63%	36%

Source: Based on **Appendix M** (Table 11-2).

It should be noted that the catchment areas of both Yorkeys Creek and Richters Creek are different for the existing and developed cases. For this reason, it is more useful to compare the loads from the entire site in its undeveloped and developed condition.

The table shows that:

- Load reduction targets (**Table 11-5**) for the developed site are nearly met (73%, 60%, 33% predicted VS 80%, 60% and 40% target for TSS, TP and TN respectively). It is expected that the modelled performance will be able to be improved on during detailed design. It should be noted that the load reductions are not as great as they will be in reality because the Environmental Management and Conservation Precinct was included in the area of the development but no treatment was assumed. In fact, natural filtration and biological uptake can be expected in these areas.
- Based on achieving the prescribed operational performance objectives through incorporation of sufficient mitigation devices and strategies, and subject to suitable detailed design, modelled pollutant loads can be reduced to levels below existing/current conditions for all pollutants modelled. In particular, when comparing the developed site with treatment and the undeveloped cane farm, the development will:
  - reduce export of TSS by 129.0 t/a (45%)
  - reduce export of TP by 0.5 t/a (63%)
  - reduce export of TN by 2.1 t/a (36%)
  - reduce export of the three pollutants by 131.6 t/a (45%).

Case 2 – Net Export of Pollutants

These figures are for the calculated reduction in pollutant loads achieved by the application of WSUD principles. They point to a substantial net reduction in export of suspended sediments and nutrients to the GBR lagoon as a result of the development when compared with the cane farm.

As previously described, re-use of recycled water from the Marlin Coast WWTP and / or the Northern WWTP is proposed to reduce the development's potable water demand for both potable water and irrigation. The effect on annual export of pollutants depends on the amount of sewage generated and the amount of treated effluent returned to the site as shown in **Table 11-7**.

Assuming that the proposed stormwater drainage strategy is successful in managing irrigation water such that it does not result in any pollutant runoff (and that is certainly the aim of the strategy), all of the pollutant load contained in the imported treated effluent will be captured on-site. It is also assumed that the treated effluent is delivered to the site at the average concentration achieved by the plant for the past year (based on figures provided by CRC).

It can be seen from **Table 11-7** that effluent re-use exceeds sewage production until the end of Stage 2 construction. Even though there is a net export at that time, there are still benefits in the re-use of treated effluent. This worst case scenario is shown below.

TABLE 11-9 NET ANNUAL POLLUTANT LOAD – STORMWATER AND NET EFFLUENT

PARAMETER	WWTP Conc'n	ANNUAL LOAD (t/a)				
		WWTP load (for -370 ML/a net)	Aquis stormwater	Aquis stormwater less WWTP	Farm stormwater	Aquis stormwater less net WWTP less Farm stormwater
TSS	5.1 m g/L	-1.89	156.00	157.89	290.00	-132.11
TP	0.8 m g/L	-0.30	0.32	0.61	0.85	-0.24
TN	3.7 m g/L	-1.36	3.74	5.10	5.80	-0.70

Source: Study team compilation based on WWTP records and **Appendix M**.

This simple calculation shows that the effect of re-using most of the sewage produced by the resort is such that, when subtracted from the MUSIC modelled pollutants from the treated Aquis Resort site, will result in the following net changes to the existing (cane farm) use:

- TSS: 132.1 t/a decrease (46%)
- TP: 0.24 t/a decrease (28%)
- TN: 0.7 t/a decrease (12%).

Overall, the export will drop by 133 t (45%). This is the worst case (i.e. after all construction has finished and only 80% of the sewage produced can be re-used). A comparison the pollutant exports of the existing cane farm and the treated development are shown graphically on **Figure 11-31** below.

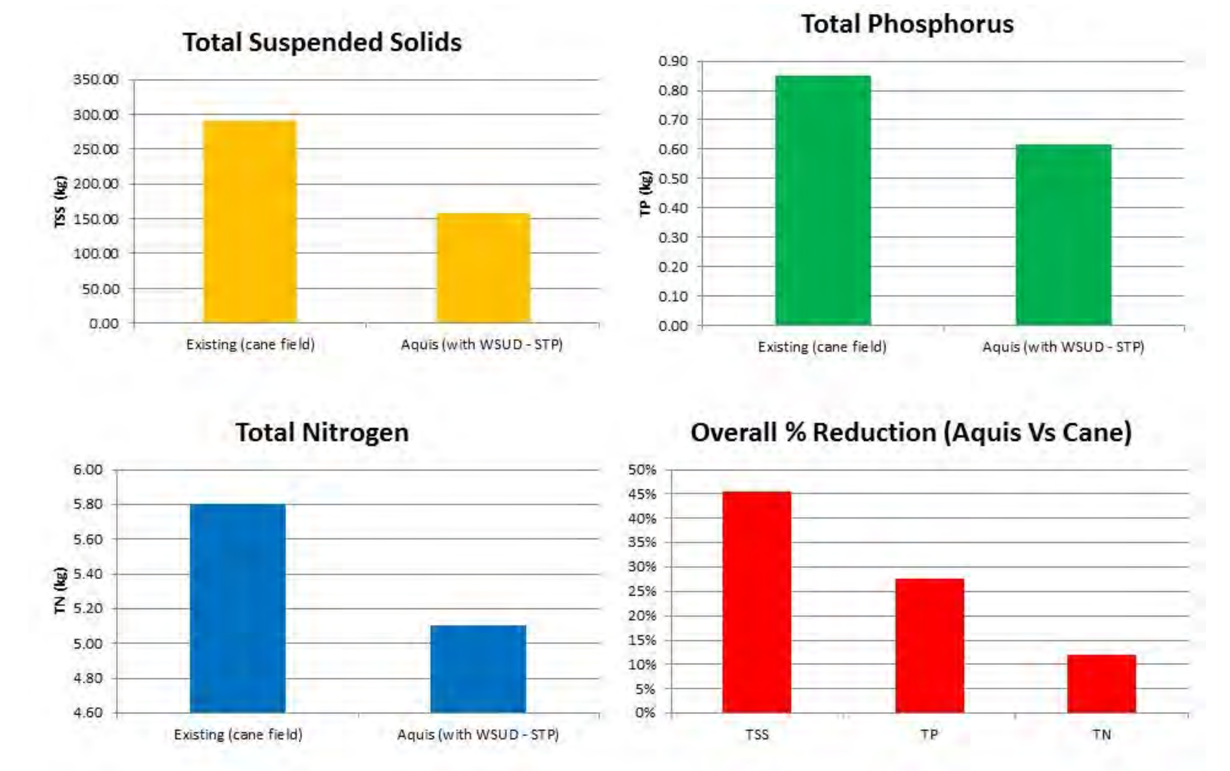

Figure 11-13 Summary of results of application of stormwater drainage strategy.

Based on data contained in **Table 11-8**.

In the above charts, the Aquis Resort figures are for the net export of the pollutants allowing for re-use of as much as possible of resort sewage effluent after treatment at the WWTP and stormwater drainage flows after on-site treatment.

Summary and Conclusions

In summary, the combined stormwater drainage strategy and effluent re-use allows for:

- the on-site use of as much as possible of the Aquis Resort sewage production as treated effluent for potable water substitution (this is greater than the production during the early years and levels out at about 80% after construction of Stage 2 is completed)
- broad compliance with industry-standard load reduction targets and the subsequent removal of most of the loads carried by stormwater.

The net effect is a reduction of 133 t/a compared with the cane farm.

There are two aspects to the consideration of the impact of stormwater drainage on the receiving environment:

- Flux (i.e. the overall load of sediments and nutrients that enters the receiving waters, expressed as a solid mass per year).
- Concentration (i.e. the instantaneous quality of water as measured by various physical and chemical/ biological properties such as salinity, dissolved oxygen, and chlorophyll *a*).

In this discussion, flux is dealt with in this section and applies to the whole site (i.e. not just the lake catchment). Concentration is dealt with in the context of lake discharge in **Section 11.3.1a)** for the lake catchment only.

Flux

Modelling shows that the developed site (and this includes the lake catchment) will export a total of 160 t/a of pollutants contained in stormwater drainage, made up of:

- 156 t/a TSS
- 0.315 t/a TP
- 3.742 t/a TN.

As noted above, further load reductions can be expected to take place in the Environmental Management and Conservation Precinct but these were not modelled.

The current cane farm exports 285 t/a, which is over 80% more than the Aquis Resort export. The project concept includes two measures to achieve this reduction and, in addition, reduce any further export arising from the site's operation (e.g. sewage production):

- WSUD initiatives incorporated into the design dramatically reduce sediment and nutrient generation from the project's operation.
- Most (over 80%) of the project's sewage will be imported back to the site as treated effluent following treatment by CRC's Marlin Coast WWTP, and used to reduce water demand for both potable water and irrigation. In so doing, nutrients from the sewage that would otherwise be exported from the treatment plant will be used on-site.

Modelling shows that the effect of these two initiatives will result in the following net changes to the existing (cane farm) use:

- TSS: 132.1 t/a decrease (46%)
- TP: 0.24 t/a decrease (28%)
- TN: 0.7 t/a decrease (12%).

Overall, the export will drop by 133 t (45%). This is the worst case (i.e. after all construction has finished and only 80% of the sewage produced is able to be re-used, based on current calculations).

Threats to the Receiving Environment

Sediments

Construction of the Aquis Resort has the potential to contribute sediment to the waters of Half Moon, Yorkeys, Thomatis and 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.

Excavation of sediments during construction of the seawater inlet and outlet pipes will also temporarily increase turbidity and sediment suspension in estuarine areas at Richters Creek mouth, and in marine areas off-shore.

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 invertebrate communities leading to a reduction in abundance and biodiversity
- traumatisation of fish gill tissues affecting growth and survival
- burying of aquatic plants (including roots and mangrove pneumatophores) and invertebrate communities (burrowing polychaetes and crustaceans)
- reduced algal and coral diversity and reductions in epifaunal densities in coral communities (however, note that the nearest coral community is >10 km from the mouth of Richters Creek).

The effect of increased suspended solid concentrations and sediment deposition on marine vertebrate communities is likely to be minimal, primarily because mobile organisms tend to avoid unfavourable environments. Further, the likely absence of seagrass in the area makes it unlikely habitat for listed threatened, migratory or marine species such as dugongs (*Dugong dugon)*, green turtles (*Chelonia mydas*) and syngnathids (seahorses and sea dragons). While some marine vertebrates will avoid areas of high turbidity, these waters may attract a range of fishes, particularly juveniles, as it confers a greater degree of protection from predators (Blaber & Blaber 1980).

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

Management measures to mitigate these impacts are available and are a commitment of the project (refer to **Chapter 23**).

Nutrients

Without appropriate management, construction and operation of the proposed development may mobilise various nutrients (and other chemicals) in on-site or estuarine soils and result in an increase in nutrients to the estuaries and downstream coastal waters via a number of processes including:

- disturbance and excavation of soil and sediment
- release of treated effluent.

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 include:

- aquatic plants:
  - changes to community composition and distribution of the mangrove and saltmarsh communities
  - an initial increase in biomass of mangroves followed by longer-term degeneration of mangrove communities as nutrient saturation levels are reached, and as species composition changes.
  - increased uptake of other toxic chemicals as a consequence of enhanced growth due to increased nutrient supply
  - increased biomass of algae such as *Ulva* and *Enteromorpha* within the mangrove habitats, blocking drainage lines and preventing / retarding the establishment and growth of young seedlings
- benthic invertebrates:
  - a reduction in community diversity and species richness
  - trophic shifts toward deposit feeding taxa and the dominance of polychaetes in soft sediment communities
- marine vertebrates:
  - reduced habitat availability due to the deterioration of mangrove communities
  - reduction in the species diversity and production of crustaceans and molluscs can affect fish populations that are important prey for many vertebrate species (e.g. dolphins).

Management measures to mitigate these impacts are available and are a commitment of the project (refer to **Chapter 23**).

GBR Perspective

The threats assessment contained in the strategic assessment of the GBR (GBRMPA 2013) considers that the key impacts in relation to water quality in the Region are nutrients, sediments and pesticides in catchment run-off (p 6-74). In response, the *Reef Water Quality Protection Plan 2013* (Reef Plan) sets a target of '50% improvement by 2018'. At 45% improvement, the Aquis Resort is close to achieving the Reef Plan target and it is expected that additional improvements will be able to be achieved as a result of the detailed design process.

The net export figures quoted allow for the re-use of a minimum of 80% of the sewage generated by the report at full operation (higher percentages of re-use apply at intermediate stages). The benefit of this re-use is not limited to the overall mass of pollutants removes from the GBR – by re-directing treated effluent to the Aquis Resort site the local impacts of discharge of treated effluent to the Half Moon Creek system will be avoided.

<u>Overall Assessment</u>

Overall, with appropriate management, the impacts of the Aquis Resort with respect to stormwater drainage are expected to be beneficial.

11.2.2 Mitigation and Management

a) Construction Phase

Key aspects of the management of soils-related construction activities that could impact on water quality are described elsewhere, namely:

- soils (**Chapter 15**)
- contaminated land (**Chapter 15**)
- ASS / PASS (**Chapter 15**).

As described in more detail in **Section 11.3.2a)**, the construction methodology requires that the lake will be excavated and constructed over approximately a four year period. During this time, wherever permitted by topography, temporary bunds will be built and drains cut to ensure that as great an area as possible of the disturbed areas of the site drains back to the lake which will act as a sediment basin.

Management of soil and water during construction involves well-known techniques and all necessary construction management actions will be integrated into the comprehensive EMP (Construction) as detailed in **Section 23.4.4**.

b) Operation Phase

Mitigation of stormwater drainage impacts during the operation phase is inherent in the design of the system. Referring to **Table 11-6**, measures include:

- education (guests and staff)
- fertiliser and herbicide/pesticide management
- irrigation management to limit runoff using soil moisture sensors and 'smart' sprinklers
- soil testing, application rate monitoring, in situ testing
- maintenance.

These and other measures will be developed and managed under the Integrated Water Management Strategy (IWMS) for the Aquis Resort. This will be guided by a series of principles aimed at directing subsequent planning stages to better facilitate the IWMS/WSUD planning and design processes. These principles will apply throughout the lifecycle of the development including the planning/design, construction, establishment and operational phases. These principles (many of which are based on those of National Water Commission's (2013) WSUD principles) include the following:

Principle 1: Minimise the impact on existing natural features and ecological processes

Principle 2: Minimise impact on natural hydrologic behaviour of catchments

Principle 3: Protect water quality of surface and ground waters

Principle 4: Minimise demand on the reticulated water supply system

Principle 5: Improve the quality of, and minimise polluted water discharges to the natural environment

Principle 6: Incorporate collection treatment and/or reuse of runoff, including roof water and other stormwater

Principle 7: Reduce run-off and peak flows from development

Principle 8: If possible, re-use treated effluent and minimise wastewater generation

Principle 9: Increase social amenity through multi-purpose green space, landscaping and integration of water into the landscape to enhance visual, social, cultural and ecological values

Principle 10: Add value while minimising development costs

Principle 11: Account for the nexus between water use and wider social and resource issues

Principle 12: Design to reduce the urban heat island effect and warming of waterways

Principle 13: Monitor the efficacy of solutions as well as the response in receiving ecosystems

Principle 14: Adaptively manage the development so that it continually maintains the adopted IWMS principles and best practice standards as they evolve

The development of an IWMS involves well-known techniques and will be integrated into the comprehensive EMP (Operation & Maintenance) as detailed in **Section 23.4.5**.

11.2.3 Residual Impacts

Based on the proposed design and management measures described above, it is considered that the residual impact of stormwater drainage will be a small net improvement. Net flux is expected to be reduced by 45% compared with the current land use and this is expected to be able to be increased to meet the '50% improvement by 2018' target of the *Reef Water Quality Protection Plan 2013* (Reef Plan). It is expected that additional improvements will be able to be achieved for Aquis Resort as a result of the detailed design process.

In addition to being part of the flux reduction, the re-use of treated effluent will also reduce local impacts of the discharge of 1430 ML/a of effluent from the Marlin Coast WWTP into Half Moon Creek.

The above export of sediments and nutrients via stormwater drainage needs to be put in the context of the overall loads exported to the receiving environment of Richters Creek. As part of the Barron River delta, Richters Creek receives sediment and nutrient loads from the total catchment including the agricultural lands of the Atherton Tableland. The following table shows the theoretical site pollutant loads based on MUSIC modelling for the existing and developed site, compared to the Queensland Government predicted long-term average loads into the Barron River Delta which discharges to Trinity Bay.

TABLE 11-10 LONG TERM EXPORT LOAD

ITEM	TSS (t/a)	TP (kg/a)	TN (kg/a)	TOTAL (t/a)
Barron River (Long Term Average)	115,287	85	585	115,957
Aquis Existing Conditions	285	0.85	5.83	292
% of total Load	0.25%	1.00%	1.00%	0.25%
Aquis Developed with Treatment	156	0.32	3.74	160
% of total Load	0.14%	0.37%	0.64%	0.14%

Source: Appendix M.

It can be seen that the Aquis Resort will contribute a very small proportion (0.14%) of the total load to the receiving environment. Even if the proposed pollutant load reduction strategies for the site were to fail for whatever reason, the risk of the development having a significant and adverse impact on the water quality of the receiving environment is extremely low.

11.3 LAKE ENVIRONMENT AND WATER EXCHANGE

11.3.1 Impacts

In addition to stormwater drainage, the other design-related constraint to water quality is the lake, which is required to be constructed on the eastern lots as a flood mitigation solution (**Chapter 9** – Flooding). This lake is designed to hold water at all times and this creates challenges for water quality during all conceivable conditions, such as dry season, wet season, and during times of Barron River flooding. This applies to both the construction and operation phases.

- Avoidance and minimisation of impacts on the values of the receiving waters involves:
- construction management initiatives (and associated monitoring)
- environmental design of the lake for all conceivable conditions
- lake operation management initiatives aimed at meeting discharge acceptance criteria (and associated monitoring).

a) Lake Design

<u>Overview of Lake and Lake Operation</u>

The project concept includes a 33 ha lake designed as a flood mitigation measure, as detailed in **Chapter 9** (Flooding). The need for flood conveyance and floodplain storage was a major factor in setting the dimensions of the lake, although other considerations were also relevant, as outlined below. The management of this waterbody in all foreseeable circumstances is the major focus of both the flooding report (**Appendix K**) and the water quality report (**Appendix M)**.

The following is a summary of the lake design and operation as currently envisaged.

- The lake occupies an area of 33 ha, with plan dimensions and shape determined by flooding considerations. A bund around the lake at a level of 2.0 m AHD (approximately 50% AEP level) is proposed in order to exclude lesser floods from the lake.
- The lake will be quarantined from groundwater by either lining or barrier solutions as described in **Chapter 10** (Water Resources).
- Bed level (a matter for possible optimisation during detailed design) is set at -2.5 m AHD. Additional depth over that required for flood and water quality performance may be provided to allow for sediment build-up resulting from a flood and normal lake operations, although calculations (**Chapter 9** – Flooding) suggest that this additional volume (if required) is relatively small.
- Normal top water level will be +1.5 m AHD. Under ‘normal’ conditions the lake volume is approximately 1.3 GL. There is an additional volume of 0.17 GL between normal water level and the top of the surrounding bunds. This provides temporary storage capacity (an additional 13%) for rainwater, floods, and an emergency volume for storing water that cannot be discharged for any reason.
- Lake water quality will be maintained by flushing with seawater sourced from 2.2 km off-shore from the mouth of Richters Creek. Water exchange is currently designed to create a 14 day residence time (subject to optimisation) to be achieved by continuously pumping from the inlet and discharging on the ebb tide only at a point near the mouth of Richters Creek. Provision exists for this residence time to be reduced to seven days by 24 hour pumping (in and out). **Figure 11-14** shows details of the lake inlet and outlet infrastructure.
- Salinity in the lake will be essentially identical to that of Richters Creek (i.e. that of seawater), although it will vary seasonally due to incident rainfall, stormwater runoff, and flooding. By selecting an off-shore intake, the effects of freshwater runoff in Richters Creek on inlet water quality will be limited.

- Internal mixing to avoid salinity and temperature stratification will be achieved primarily by the flushing flow, augmented to a small extent by propeller pumps, aerators, and most likely fountains. These devices will also help general mixing and flushing.
- To release water stored above the normal top water level (e.g. following heavy rainfall or floods), two high level lake outlets are provided:
  - one discharging to Richters Creek near the south-east corner of the lake at a location where there is a natural clearing and where the creek bank is eroded (erosion protection integrated with the outlet structure is proposed – see **Figure 11-14** below)
  - the other discharging to Yorkeys Creek at the north-west corner of the lake where the creek runs through the Aquis Resort site.
- Under flood conditions when the Barron River breaks its banks and floodwaters enter the site, the lake will first fill and then surcharge, leaving the built form of the Hotel Complex well above the expected flood levels. At this time, most of the rest of the site and the adjacent Yorkeys Knob area will be inundated and flow through the lake will join the general overland flood flow and exit the site via the existing creek system. As the flood falls, the lake level will be gradually lowered by the two lake overflows (until the level falls below their inverts) and by pumping to the lake outlet.
- An allowance has been made for a small over-dredge margin to allow for silt deposited in a flood or during normal lake operations. A preliminary maintenance regime has been developed to deal with any silt and sediment deposition.
- Finally, it is recognised that there is a risk that the existing abandoned aquaculture ponds could adversely affect water quality in a flood. It is likely that floodwaters could flush these ponds and mix sediments and organic matter with the lake to the detriment of water quality. Accordingly, it is currently proposed that these ponds be drained and filled as part of the project development.

The construction of the lake, its performance during site construction works, and its transformation to the final operational state is described in **Section 11.3.2a)**.

Inlet Water quality

The decision to extract lake flushing water from the off-shore location was made after the water quality monitoring program commenced and therefore little data currently exists. The site was selected based on a desktop review of bathymetry and historic aerial photographs that show that inlet is always clear of the turbid inshore plume that is evident during the wet season.

The pipeline survey (**Appendix H**) was undertaken during March 2014 when there was heavy rain and strong winds. Water quality monitoring undertaken at that time provides the only current information and should be considered as a snap-shot only. However, the data is illuminating as the following table shows. In this table, Site W2 is near the proposed lake discharge point in the mount of Richters Creek (at the surface) and Site 1 is 0.5 m from the bottom at the site of the inlet. Also included are the QWQG values.

TABLE 11-11 WATER QUALITY AT INLET AND OUTLET (MARCH 2014)

PARAMETER	UNITS	WQG	SITE 1 (INLET)	SITE W2 (OUTLET)
Dissolved oxygen	% sat.	95 – 105	95	90
pH	–	8.15 – 8.4	8.16	7.82
Salinity	mg/L	–	34.4	17.4
Temperature	°C	–	27.5	27.6
Turbidity	NTU	1	1	40

Source: Appendix H (extracts from Tables 4.1 and 4.2). Shaded cell indicates that measured value is outside the QWQG vale range.

This table demonstrates that the inlet water, when compared with the outlet has:

- 5% better DO (and complies with the QWQG)
- a more desirable pH (and complies with the QWQG)
- a more desirable salinity (approximately that of seawater)
- a similar temperature
- a significantly lower turbidity (and complies with the QWQG).

More monitoring is required to confirm the quality at the inlet but this snapshot certainly shows that water quality at the inlet is superior to that at the outlet during wet and windy conditions. This gives the lake a comparative advantage in meeting its water quality objectives when these are to be matched to water quality of the receiving environment.

Infrastructure Details

Overall Plan

See **Figure 11-14** below.

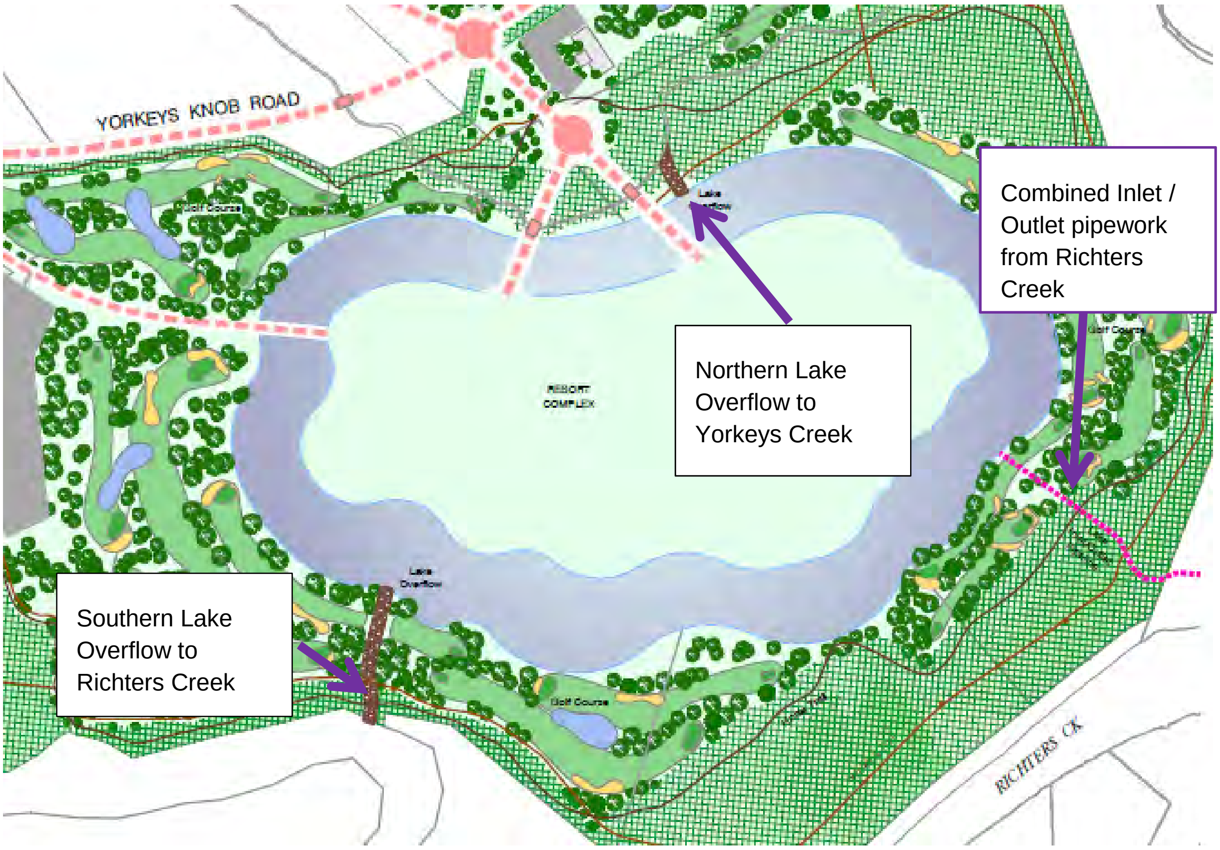

Figure 11-14 Lake concept plan showing inlet, outlet, and overflows.

Inlet and Outlet

Operation

The lake inlet and lake outlet structures will be designed to achieve both engineering and aquatic ecology objectives. The pump system will be adequate to enable a 14 day lake turnover (requiring an inlet and outlet flow of 2.16 m^3). An alternative emergency turnover water supply arrangement is also proposed using 24 hours a day pumping. This will allow the lake's volume to be turned over within seven days.

Exchange water will be delivered to the lake under a combined gravity / pumping system from the inlet sump located some 2.2 km seaward of the Yorkeys Knob beach via a 1.8 m diameter pipe. This arrangement was selected in preference to an inlet within Richters Creek as it can be relied upon to deliver good quality salt water free from local fresh water conditions and any effects of a partial closure of Richters Creek. The off-shore intake is proposed to be mounted on the bed with a horizontal intake screen approximately one metre above the bed (approximately -8.1 m AHD).

Water will be drawn by gravity to a pump well located on land adjacent to the creek. From here it will be pumped to the lake and be discharged under water. This will establish a head difference in the lake that will drive flushing.

Once the tide in Richters Creek starts falling, water will be pumped from the lake via the second pipeline and delivered to the diffuser outlet arrangement near the mouth of Richters Creek. The diffuser is designed to dissipate energy at the outlet and to maximise 'blending' of the lake water with the ambient water in Richters Creek.

Structures

Figure 11-15 and **Figure 11-16** provide details of the proposed location, orientation, and level of the inlet and outlet structures relative to the local tidal datum. It is noted that some works may be required in the bed of Richters Creek to achieve the depths required relative to lowest astronomical tide (LAT). Where necessary, a concrete-lined well will be constructed around the outlet at a sufficient depth to allow discharge under LAT conditions.

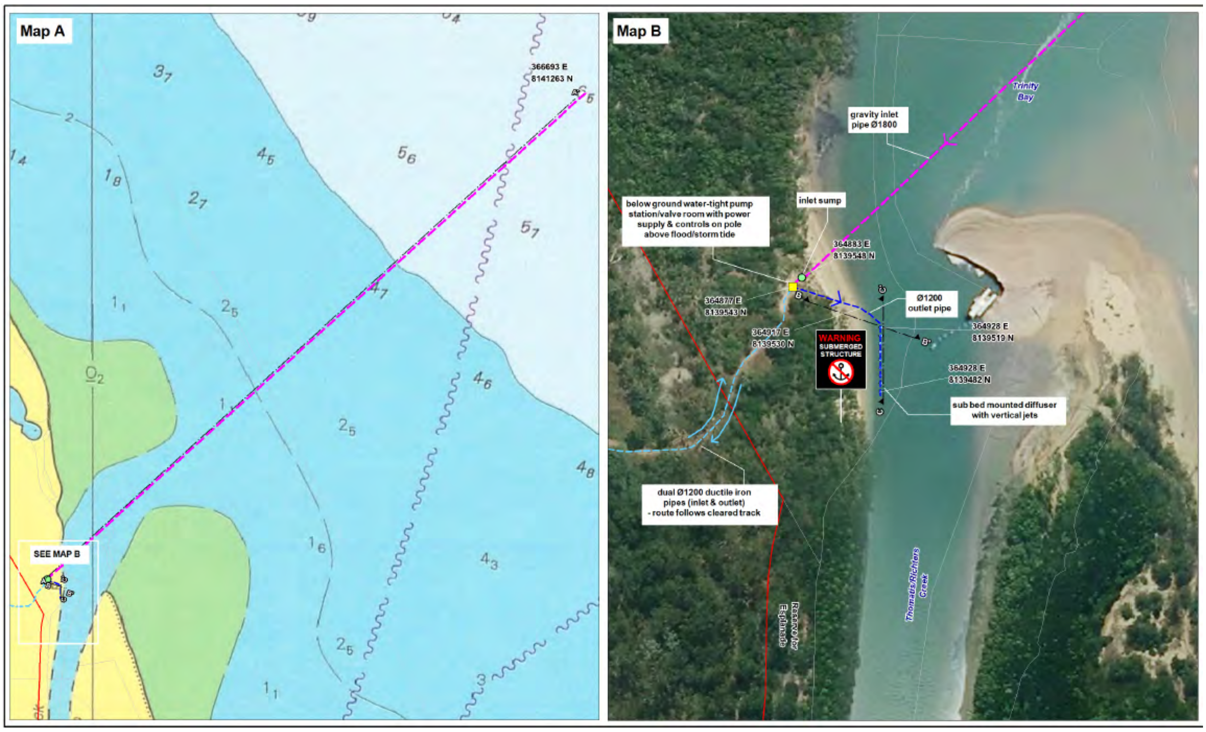

Figure 11-15 Plan view of lake inlet and outlet pipework.

Source: Appendix M (Figure 8-2). Navigation markers will be provided for boating safety.

The outlet will consist of a diffuser located parallel to the bank (refer to **Figure 11-15**) with sufficient jets to adequately mix the discharge. The initial mixing zone will be designed to be within 2 m of the jet so there will be no discernible effect on the natural tidal velocities within 5 m of the outlet (assessment of these velocities and appropriate design responses will be addressed during detailed design).

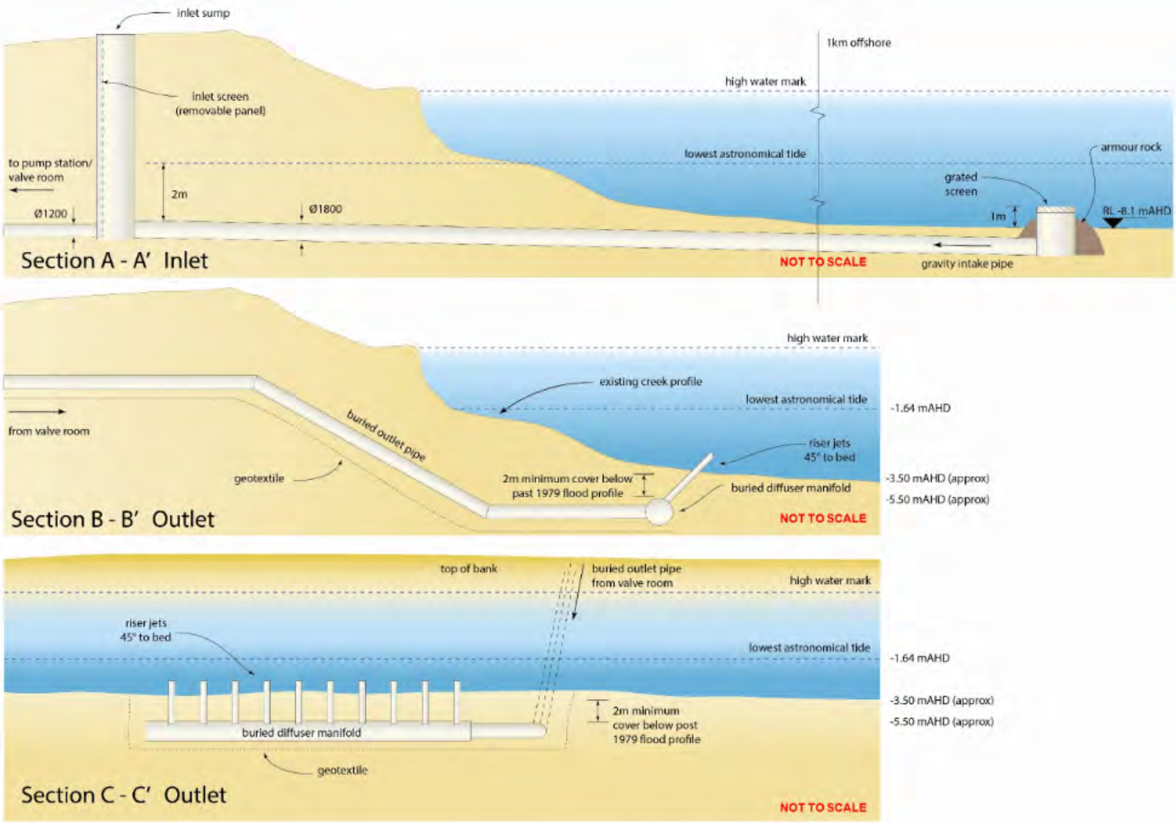

Figure 11-16 Cross sections (location as per **Figure 11-15**).

Source: Appendix M (Figure 7-3).

Lake Overflows

Southern (Richters Creek) Lake Overflow

The two lake overflows are designed to allow water to discharge to Richters Creek and Yorkeys Creek when the lake level is well above its design level of 1.5 m AHD. This will occur after heavy rain or a major flood. The design is still conceptual but it is envisaged that these overflows will take the form of open channels approximately 20 m wide with a slight fall towards the creeks. **Photo 10-7** below shows the approximate location of the Richters Creek overflow and preliminary details are shown on **Figure 11-17**.

By incorporation of flood flaps to the overflow weirs, flood flow back into the lake up to 2 m AHD will be prevented. The weirs will also include the use of drop boards, to allow it to be lowered temporarily to 1.0 m AHD, such that gravity drainage can continue. Once the lake and flood level drops below 2 m AHD, the outlet pumps will also start operation again.

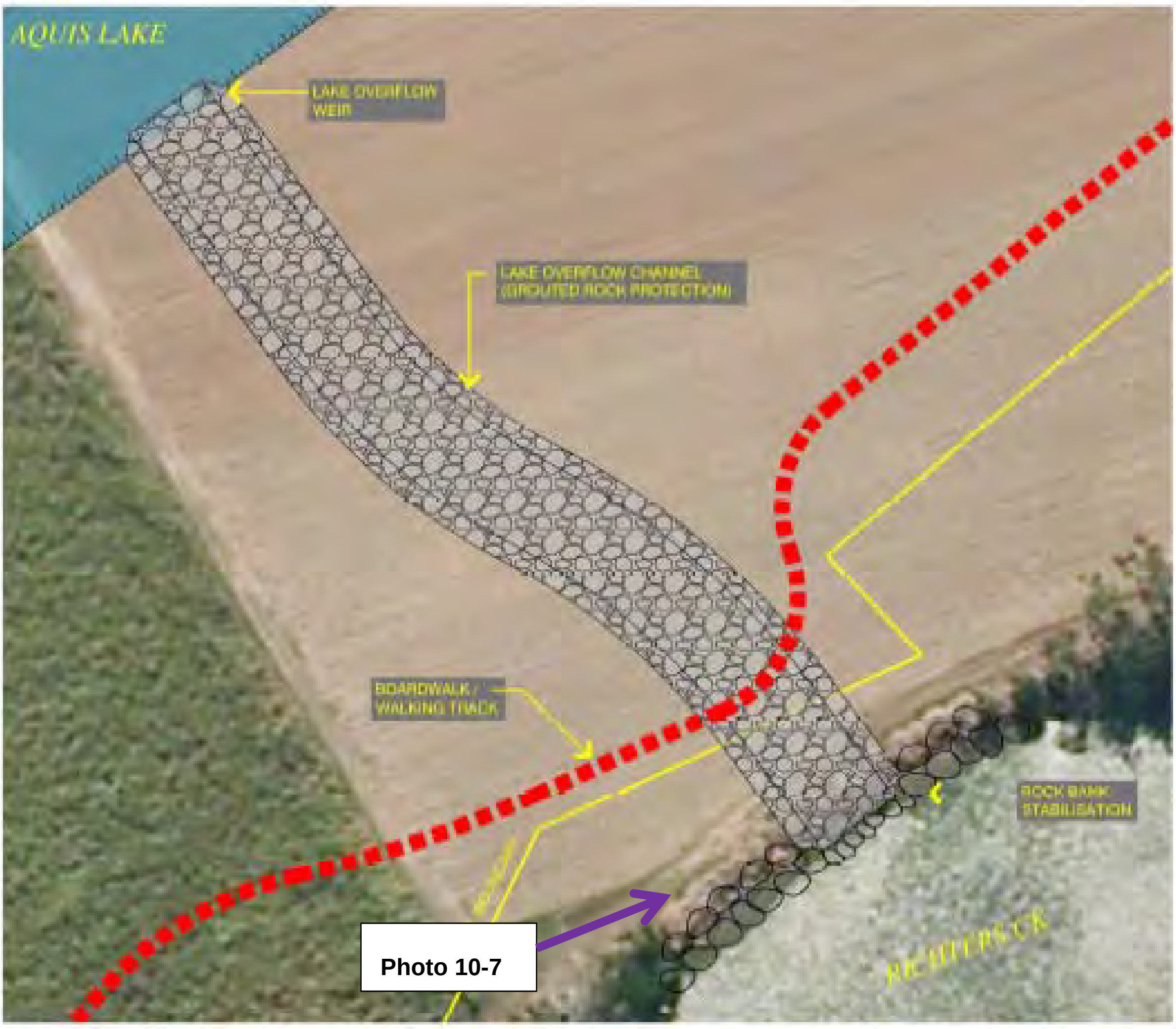

Figure 11-17 Conceptual design for Richters Creek Lake overflow.

The works will include protection of the eroded bank of Richters Creek at this location (see also Chapter 8 – Coastal Processes).

Photo 11-1 Richters Creek looking downstream from Lot 2 RP800898.

This is one of a very few areas on Richters Creek where riparian vegetation is absent and thus the proposed location of the southern lake overflow.

Northern (Yorkeys Creek) Lake Overflow

The Yorkeys Creek overflow will be similar, with the design intent to lead floodwaters to the creek at the best location and angle to suit local conditions. The preliminary location selected for this overflow is in the vicinity of where flood flows currently drain to Yorkeys Creek. This location is clearly shown the digital elevation model (see **Figure 10-6**). An extract of this is provided below as **Figure 11-18**.

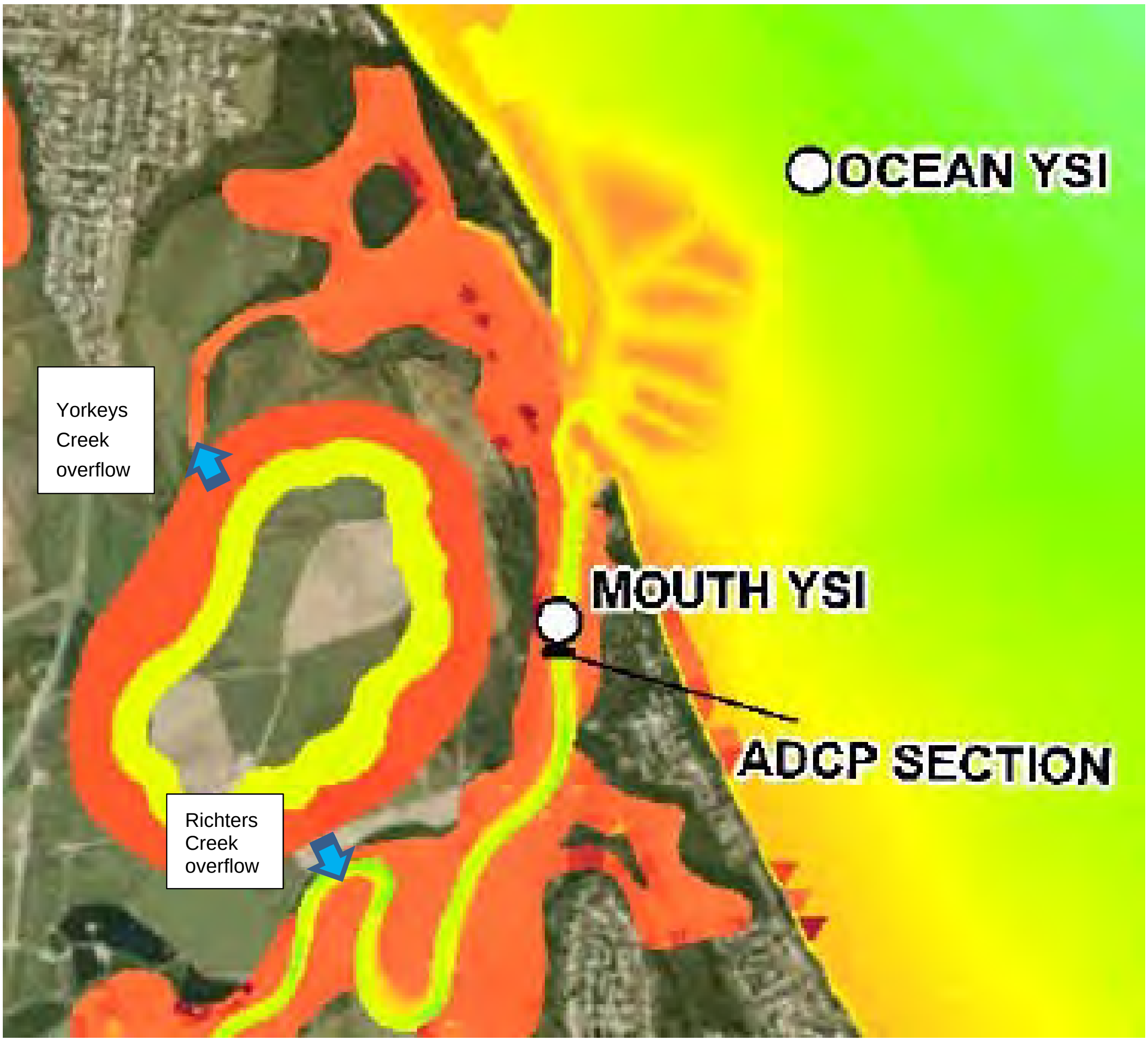

Figure 11-18 Location of Yorkeys Creek and Richters Creek overflows.

This is an extract from **Figure 10-6.**

Design and Construction of Inlet and Outlet Infrastructure

Construction of the Inlet Structure and Pipeline

The construction of the inlet pipeline will be a ‘cut and cover’ operation with excavation being undertaken by a long reach excavator mounted on a spud pile barge. Silt curtains will be deployed around the excavation and work zone. If necessary, a no-fines gravel backfill will be used which could be dumped from a second barge.

Another barge will be used to allow the construction team to make the pipe joints and progressively lower the pipe into the trench.

The trench is expected to be about 2 m deep and the disturbance about 4 m wide, over the 2.2 km length.

Construction of the Outlet Structure

The outlet will consist of a diffuser located parallel to the bank (refer to **Figure 11-19**) with sufficient jets to adequately mix the discharge. The initial mixing zone will be designed to be within 2 m of the jet so there would be no discernible effect on the natural tidal velocities within 5 m of the outlet.

Figure 11-19 Outlet structure and shore-based works.

This is an enlargement of **Figure 11-15** (Map B).

This structure is proposed to be constructed 'in the dry' using a sheet pile coffer dam from which water is pumped out. Following de-watering, the trench will be excavated to the necessary levels. Given the location of the site and the potential for ASS / PASS, the excavated material will be stockpiled in a contained area, if necessary, the material neutralised with lime in accordance with the ASSMP, which will be in place at the time of construction.

Sediments will be contained by the use of a silt curtain installed around the work area.

Temporary and permanent navigational structures (markers / signage) will be installed in accordance with the requirements of Maritime Safety Queensland (MSQ).

Rehabilitation of the Site

Although the pipeline route has been selected to make use of an existing clearing, some natural vegetation will be unavoidably damaged / removed during construction. Necessary approvals for the removal of mangroves etc. will be in place prior to the commencement of works and the disturbed area will be rehabilitated with the existing species following completion of construction.

Waterway Safety / Navigational Requirements

MSQ has been contacted regarding the navigational requirements associated with construction of hazards within Richters Creek. Preliminary advice suggests that bollards adjacent to the ends of the outlet structure (with appropriate signage on the bollards) would satisfy requirements. The height and diameter of the bollards, along with the size and wording on the signage, will be designed to meet MSQ requirements.

Provision for Aquatic Organisms

The lake inlet has the potential to entrain fish by capturing them in the flow of the incoming water. Screening the mouth of the inlet pipe can physically prevent fish impingement and entrainment, and even more beneficially, keep them at a distance where velocities are such that they are able to avoid entrainment. The inlet structure is located within open waters at a depth of -8.1 m AHD where velocities are expected to be quite low.

The incorporation of specifically designed fish diversion screening will further reduce the likelihood of entrainment. A well-designed fish screen will also minimise stress and injury should fish impact the screen or be subjected to changes in water speed and direction caused by the inflow current. Flow velocity in the inlet pipe will be approximately 0.6 m/s and it is proposed to provide approximately 6 m^2 of inlet screen / bellmouth to limit adjacent velocities to 0.4 m/s as recommended.

While 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
- an approach velocity of 0.4 m per second is likely to avoid entrainment of most fish.

The actual mesh size also involves consideration of the need to exclude pest fish and sharks. Overall, fish diversion screening at the off-shore intake and within the pump will be designed to prevent the entrainment of fishes larger than approximately 75 mm in length (including sharks) and crabs. The predicted inlet velocity of approximately 0.4 m/s is sufficiently low to enable effective avoidance of entrapment and entrainment by most fishes (with the notable exception of planktonic eggs and larvae).

Screening at the entrance of the lake outlet pipe is also proposed to prevent the entrainment of fishes and crabs.

Performance Objectives and Management

Broadly, the water quality performance objectives of the lake are:

- discharge of lake water under specified conditions (dry season, wet season, flood) must meet specific compliance standards to protect the environmental values of the receiving waters
- the lake environment must be sustainable under all conditions – this involves aesthetic and habitat considerations and to a large extent is a necessary pre-condition to achieving the discharge criteria.

The adopted performance objectives are based upon the QWQG (20009) and ANZECC (2000) guidelines and are discussed in further detail in **Appendix M**. Details are provided below in terms of draft compliance criteria that will eventually be derived from a long term data set currently being collected. At this stage, it is envisaged that measured stream flows in the Barron River at Myola will be used to determine the applicable operating conditions (i.e. dry season, wet season, flood) and therefore the appropriate discharge criteria.

Dry Weather ('Normal') Operation

Under dry weather conditions, the 'normal' lake operations are proposed, i.e. the constant inflow from the off-shore inlet and the ebb tide discharge. The inflow will need to be regulated to maintain the design water level and accommodate evaporation and dry season rainfall.

Objectives

Performance objectives and associated management actions for maintaining acceptable water quality for the 'normal' dry weather operational regime are provided below.

TABLE 11-12 DRY WEATHER 'NORMAL' LAKE OPERATION PERFORMANCE OBJECTIVES

LAKE MANAGEMENT ITEMS	PERFORMANCE OBJECTIVE
Lake water quality	As per the discharge criteria – to be determined during detailed design based on trigger values derived from water quality monitoring and approval conditions.
Intake from off-shore inlet to lake	Physico-Chemical Indicators: within the 20^{th} percentile to 80^{th} percentile (or ± 1 standard deviation) limits.

Source: Appendix M (Table 7-1).

Lake discharge during dry weather is proposed to be managed such that it meets the following discharge performance objectives.

TABLE 11-13 DRY WEATHER 'NORMAL' DISCHARGE PERFORMANCE OBJECTIVES

LAKE MANAGEMENT ITEMS	PERFORMANCE OBJECTIVE
Medium to long term (chronic)	**Physico-Chemical Stressor** A trigger for further investigation will be deemed necessary when the median discharge concentration exceeds the 80th percentile of the same indicator at a suitably chosen reference site and / or QWQG (2009) guideline value. **Toxicants** Default guideline values: 'It is recommended that action is triggered if the instantaneous discharge exceeds the default trigger value.' Derived default trigger value: 'For those months, seasons or flow periods that constitute logical time intervals or events background data will be derived. The 80th percentile of background data (from a minimum of 10 observations) will be compared with the default guideline value. The 80th percentile value will be used if the new trigger value for this period exceeds the default guideline value provided in ANZECC (2000). If the baseline 80th percentile exceeds even the 80% species protection level, then the trigger value adopted will be applied as a stressor rather than a toxicant (i.e. long-term median based limit instead of an instantaneous maximum)
Short-term (pulse)	**Physico-Chemical Stressor** Non-compliance and trigger for further investigation if discharge concentrations are clearly in excess of the 95th percentile of the same indicator at a suitably chosen reference site in Richters Creek. **Toxicants** 95% of the discharge concentrations are within the default guideline value (i.e. ANZECC guidelines).

Source: Appendix M (Table 7-2).

Lake discharge is proposed to only occur when it meets the discharge compliance limits shown in **Table 11-14**.

TABLE 11-14 DRY WEATHER 'NORMAL' COMPLIANCE LIMITS

PHYSICO-CHEMICAL INDICATOR	MEDIAN BASELINE WATER DATA*	COMPLIANCE TRIGGERS		
		Medium- to Long-term		Short-term (Pulse)
		80th Percentile*	QWQG	95th Percentile*
Dissolved Oxygen (% Saturation)	n/a	Lower 79 / Upper 92.3%	Lower 80% / Upper 105%	n/a (adopt 80% to 105%)
pH	n/a	7.6 to 8.1	Lower 6.5 / Upper 8.4	Lower 6.5 / Upper 8.4
Turbidity (NTU)	6.4-10	14-16	10	nd
Conductivity (µS/cm)	nd	nd	n/a	nd
Ammonia (µ g/L)	20	34	15	48.5
Organic Nitrogen (µ g/L)	300	500	200	600
Oxidised Nitrogen (µ g/L)	30	58	30	70
Total Nitrogen (µ g/L)	300	480	250	694
Total Phosphorus (µ g/L)	20	50	20	194
Filterable Reactive Phosphorus (µ g/L)	nd	nd	5	nd
Suspended Solids (m g/L)	nd	nd	nd	nd
Secchi (m)	0.6	1.4	1.0	
Chlorophyll a (µ g/L)	nd	nd	3	nd

Source: **Appendix M** (Table 7-3).

Note * Refer to **Appendix M** Section 3.4 baseline water quality data analysis. Shaded cells indicate baseline conditions currently exceed QWQG. 'nd' indicates that no data is currently available.

The compliance assessment is based upon the ANZECC (2000) default compliance protocols of a slightly to moderate disturbed receiving water, as presented in Appendix D of QWQG. Monitoring of the performance objectives will be undertaken in accordance with the Operational Lake Water Quality Management Plan as outlined below (**Section 11.3.2b)**). In particular, the above compliance limits are draft only and will be substituted by site-specific limits derived from the water quality monitoring program that is currently underway. This work will be done well in advance of any actual discharge.

Management

Operational management to achieve these outcomes involves a number of procedures introduced, namely:

- Pre-treatment of stormwater drainage.
- Flushing. Flushing of the lake using seawater from 2.2 km off-shore of the site in the waters of the Coral Sea will occur through mechanical means as described. This is designed to reduce algal blooms, excess nutrients, and organic matter including providing a supply of well-oxygenated water with suitable pH and salinity.
- Lake water level / groundwater separation. The lake water will be quarantined from groundwater to avoid any risk of interaction.

- De-stratification: Artificial mixing is proposed to assist in preventing the potential for stratification (i.e. temperature and salinity) through a combination of de-stratification propellers and aerators. The de-stratification propellers will cycle the lake's water before being discharged to Richters Creek.
- Water fountains and / or water bubblers: Fountains typically pump bottom waters to the surface causing aeration of the water and an aesthetically pleasing amenity. Bubblers are able to improve the water quality by reducing the potential for stratification while adding dissolved oxygen to the water. Well-oxygenated water will also accelerate the process of organic matter breakdown and prevent anoxic conditions.
- Management. A conceptual *Lake Sedimentation and Maintenance Dredging Strategy* is included in **Appendix M** and will be integrated into the project's EMP (Planning) – it has been re-branded as the *Lake Management Strategy*. Details are provided in **Chapter 23**.

Wet Weather Operation

Under wet weather conditions, the dry season water exchange operations described above are proposed to continue. However, under these conditions there will be:

- additional inflow to the lake from higher wet season rainfall the Resort Complex Precinct
- additional inflow to the lake from higher wet season rainfall
- possibly poorer quality inlet water (although the off-shore inlet was chosen to limit this effect)
- poor quality in the receiving waters (Richters Creek and the broader environment).

Objectives

Performance objectives designed to appropriately manage lake water quality throughout the wet weather operational cycle are provided below.

TABLE 11-15 WET WEATHER LAKE OPERATION PERFORMANCE OBJECTIVES

LAKE MANAGEMENT ITEMS	PERFORMANCE OBJECTIVE
Runoff into the lake	Pre-treatment of stormwater drainage.
Intake from off-shore inlet to lake	Physico-Chemical Indicators: within the 20th percentile to 80th percentile (or ± 1 standard deviation) limits of inlet. These limits may be amended based on additional wet season baseline monitoring.

Source: Appendix M (Table 7-4).

Lake discharge during the wet season is proposed to only occur when it meets the discharge compliance limits shown in **Table 11-16**.

TABLE 11-16 WET WEATHER DISCHARGE PERFORMANCE OBJECTIVES

LAKE MANAGEMENT ITEMS	PERFORMANCE OBJECTIVE
Medium to long-term (chronic)	**Physico-Chemical Stressor** A trigger for further investigation will be deemed necessary when the median discharge concentration exceeds the 80th percentile of the same indicator at a suitably chosen reference site in Richters Creek during the wet season (i.e. January, February and March). Toxicants *Default guideline values*: 'It is recommended that action is triggered if the instantaneous discharge exceeds the default trigger value.' *Derived default trigger value*: 'For those months, seasons or flow periods that constitute logical time intervals or events background data will be derived. The 80th percentile of background data (from a minimum of 10 observations) will be compared with the default guideline value. The 80th percentile value will be used if the new trigger value for this period exceeds the default guideline value provided in Section 3.4.3 of ANZECC (2000). If the baseline 80th percentile exceeds even the 80% species protection level, then the trigger value adopted will be applied as a stressor rather than a toxicant (i.e. long-term median based limit instead of an instantaneous maximum)
Short-term (pulse)	**Physico-Chemical Stressor** Non-compliance and trigger for further investigation if discharge concentrations are clearly in excess of the 95th percentile of the same indicator at a suitably chosen reference site in Richters Creek during the wet season (i.e. January, February and March). Toxicants 95% of the discharge concentrations are within the default guideline value (i.e. ANZECC guidelines).

Source: Appendix M (Table 8-5).

Lake discharge is proposed to only occur when it meets the following discharge compliance limits.

TABLE 11-17 WET WEATHER COMPLIANCE LIMITS

PHYSICO-CHEMICAL INDICATOR	MEDIAN BASELINE WATER DATA *	COMPLIANCE TRIGGERS	
		Medium-term	Short-term (Pulse)
		80th Percentile*	95th Percentile*
Dissolved Oxygen (% Saturation)	n/a	Lower 79 / Upper 92.3%	n/a (adopt 80% to 105%)
pH	n/a	7.6 to 8.1	5.5 <pH<9.0 (QWQG)
Turbidity (NTU)	47	56	63.7
Conductivity (µS/cm)	nd	nd	nd
Ammonia (µ g/L)	40	58	67
Organic Nitrogen (µ g/L)	340	400	442
Oxidised Nitrogen (µ g/L)	90	110	116
Total Nitrogen (µ g/L)	395	492	552
Total Phosphorus (µ g/L)	80	100	100
Filterable Reactive Phosphorus (µ g/L)	nd	nd	nd
Suspended Solids (m g/L)	nd	nd	nd
Secchi (m)	0.2	0.2	-
Chlorophyll a (µ g/L)	nd	nd	nd

Source: Appendix M (Table 8-6).

Note * Refer to **Appendix M** Section 3.4 baseline water quality data analysis.

As for the dry season case, the above compliance limits are draft only and will be substituted by site-specific limits derived from the water quality monitoring program that is currently underway. This work will be done well in advance of any actual discharge.

Management

Management to achieve these outcomes involves the following operations:

- All dry weather mitigation measures described above as appropriate. It is expected that the inlet quality will be significantly superior to that of the discharge point in Richters Creek. The limited testing to date reveals that this is the case (see **Table 11-11**).
- Wet season management as described above.

Flood Operation

Objectives

Site specific performance objectives for lake discharge will be required to be determined for Richters Creek, which, during the wet season, will regularly encounter episodic pulsed high turbidity and sedimentation events. Therefore, if the lake were to become inundated from river / creek flooding in the Barron River delta, discharge of the lake water should be permitted to continue, provided that the in situ water quality is within the range of natural flood variability. This is the basis of a methodology developed by McArthur et al. (2002) (see **Appendix M**) which notes that marine species regularly encounter (and survive) episodic pulsed turbidity and sedimentation events; therefore, if water quality is maintained within the range of natural variability, then marine species and communities will be maintained.

Flood performance objectives are provided below, based on the ‘no change’ limit methodology during periods of flood for individual locations, where the assessment is referenced with regard to the historical exceedance profile and duration of each location.

TABLE 11-18 FLOOD OPERATION PERFORMANCE OBJECTIVES

LAKE MANAGEMENT ITEMS	PERFORMANCE OBJECTIVE
Runoff into the lake	Site-specific trigger levels (see Appendix M s6.2.2) and brief discussion below. Essentially, it is recognised that marine species regularly encounter episodic pulsed turbidity and sedimentation events; therefore, if water quality is maintained within the range of natural variability, then marine species and communities will be maintained. This methodology can be used to determine impacts to receiving environments, and involves analysis of site-specific baseline data to establish a ‘no change’ limit. Thus, during periods of flood for individual locations, the assessment is referenced with regard to the historical exceedance profile and duration of each location.

Source: Study team compilation based on **Appendix M** (Appendix E).

Lake discharge during a flood is proposed to only occur when it meets the following discharge compliance limits.

TABLE 11-19 FLOOD COMPLIANCE PROTOCOLS FOR DISCHARGE

DISCHARGE LIMIT	PERFORMANCE OBJECTIVE
Short Term (Pulse)	Physico-chemical Indicators McArthur et al. (2002) Trigger Levels & retained sediment load to be disposed off-site. Toxicants 95% of the discharge concentrations are within the default guideline value (i.e. ANZECC guidelines) or 80th percentile background trigger if this trigger exceeds the 95th percentile ANZECC guideline.
Trigger Value	95% Level of Protection
Arsenic ASIII & AsV (µ g/L)	2.3/4.5
Antimony	-
Barium (µ g/L)	1,000*
Cadmium (µ g/L)	0.7
Chromium Cr VI (µ g/L)	4.4
Cobalt (µ g/L)	1
Copper (µ g/L)	1.3
Lead (µ g/L)	4.4
Manganese	80
Mercury (inorganic) (µ g/L)	0.1
Molybdenum	-
Nickel (µ g/L)	7
Silver (µ g/L)	1.4
Vanadium (µ g/L)	100
Zinc (µ g/L)	15
Ammonia (µ g/L) [d]	460
NO_x (m g/L)	7.5

Source: Appendix M (Table 7-7).

Monitoring of the performance objective will also be undertaken in accordance with 'Operational Lake Water Quality Management Plan'.

Management

The lake will have a 'bank full' volume (i.e. at the 2 m AHD bunded level) of approximately 1.5 GL that will require discharging and cleaning to a standard suitable for re-commencement of dry weather typical discharge to Richters Creek. As previously noted, the water exchange system lake will have a discharge capacity of approximately 3.25 m^3/s or 0.29 GL/day assuming a full 24 hour operation (i.e. 22% per day of total volume) that can be used to pass the flood waters received back to Richters Creek once it has drained below the perimeter bund level. Ultimately, five to seven days of continuous pumping following a flood would be required to fully exchange the lake.

The proposed management measures to treat the flood waters from the lake are discussed in **Section 11.3.2b)**.

Construction

Refer to **Section 11.3.2a).**

b) Evaluating Performance

Evaluating Performance – Numerical Modelling

The previous discussion describes the proposed operation of the lake, the stormwater drainage strategy, the use of treated effluent, and lake discharge criteria for various weather conditions. For the purposes of conceptual design and subsequent impact assessment of the lake, numerical modelling has been undertaken as outlined below. In summary, this includes using historic flow and meteorological data to simulate:

- stormwater drainage inputs to the lake from the Hotel Complex Precinct and direct rainfall effects, simulated as inflow resulting from a selected modelling period using historic rainfall and runoff data
- lake performance based on this inflow, direct rainfall, and flushing with sea water over the selected modelling period

This data was also used to model the impact of lake discharge on the receiving environment over the selected modelling period.

Numerical Models

Two numerical (mathematical) models commonly used in design and impact assessment of waterbodies were established and linked. These are MUSIC and TUFLOW-FV as described below. Also used was a regional catchment model supplied by DSITIA. See also **Figure 11-20**.

- MUSIC. As previously described, the MUSIC model was used in the design and assessment of the stormwater drainage system. For this first task it was used to estimate annual loads of sediment and nutrients. It was then used in the analysis described below as an input to the lake / receiving water assessment. In this second case, the MUSIC model was run using actual weather data from a 12 month period between 1 September 2012 and 31 August 2013 (see **Figure 11-23**) to capture dry, wet, and flood conditions and to input modelled flows to the lake on a daily basis.
- TUFLOW FV The performance of the lake was evaluated using a calibrated numerical model called TUFLOW FV. The TUFLOW model is a fully three-dimensional finite volume hydraulic advection / dispersion model[4]. The model was used to simulate a range of relevant biophysical processes and effects in the lake, such as lake stratification and lake flushing time. The model also has full water quality simulation capabilities that can predict distributions of, for example, dissolved oxygen, nutrients, and chlorophyll *a*. In the following discussion, both features of the model are referred to:
    - dilution / concentration results of a 'conservative tracer' (see footnote) – a conservative approach wherein the model's advection dispersion (AD) mode was used to predict relative water quality change (essentially mixing) and the resulting dilution
    - full water quality simulation – this feature requires detailed calibration as described below.

[4] Transport processes in the environment may be divided into two categories: *advection* and *dispersion*. Advection refers to transport with the mean fluid flow. For example, if a bag of dye is emptied into the centre of a river, advection will carry the resulting spot of dye downstream. In contrast, *dispersion* refers to the transport of compounds through the action of *random* motions. *Dispersion* works to eliminate sharp discontinuities in concentration and results in smoother, flatter concentration profiles. Advective and dispersive processes can usually be considered independently. In the example of a spot of dye in a river, while advection moves the centre of mass of the dye downstream, dispersion spreads out the concentrated spot of dye to a larger, less concentrated region. The tracking of a theoretical 'tracer dye' is one way to model how any water quality parameter will be transported and diluted in the receiving waters, ignoring biological or chemical decay. It therefore represents a conservative approach with respect to resultant concentrations.

- Regional Catchment Spreadsheet Model. Data included in DSITIA (2014) was used to determine catchment loads/concentrations received into the Barron River. This data was used to develop a spreadsheet model based upon data sourced from the Myola gauge 110001D (refer to http://watermonitoring.derm.qld.gov.au) and used to inform the TUFLOW-FV boundary inflows and water quality components of the model. The model was also used to compare typical catchment wide annual pollutant loads to that of the proposed development.

TUFLOW was then coupled with the regional water quality model (RWQM) to simulate the effect of lake discharge on the receiving environment (Richters Creek and the near-shore part of the Coral Sea). See **Figure 11-20** below. This is described in the discussion of impacts (**Section 11.3.10**).

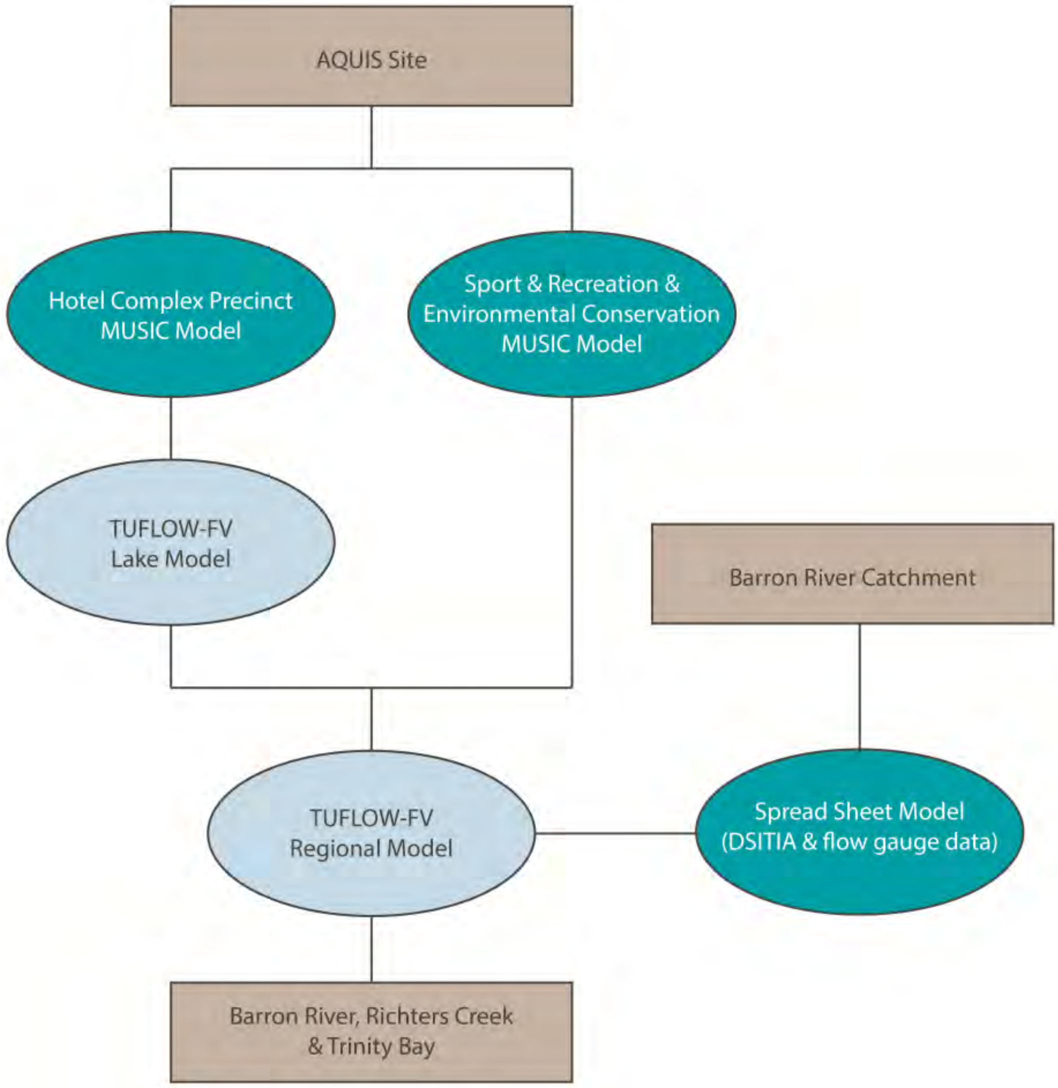

Figure 11-20 Integrated modelling conceptual diagram.

Source: Appendix M (Figure 10-1).

TUFLOW FV Model Extent

The following figure shows the model 'mesh' which is a suite of points at which various modelled parameters can be determined. These are identified in **Figure 11-21**.

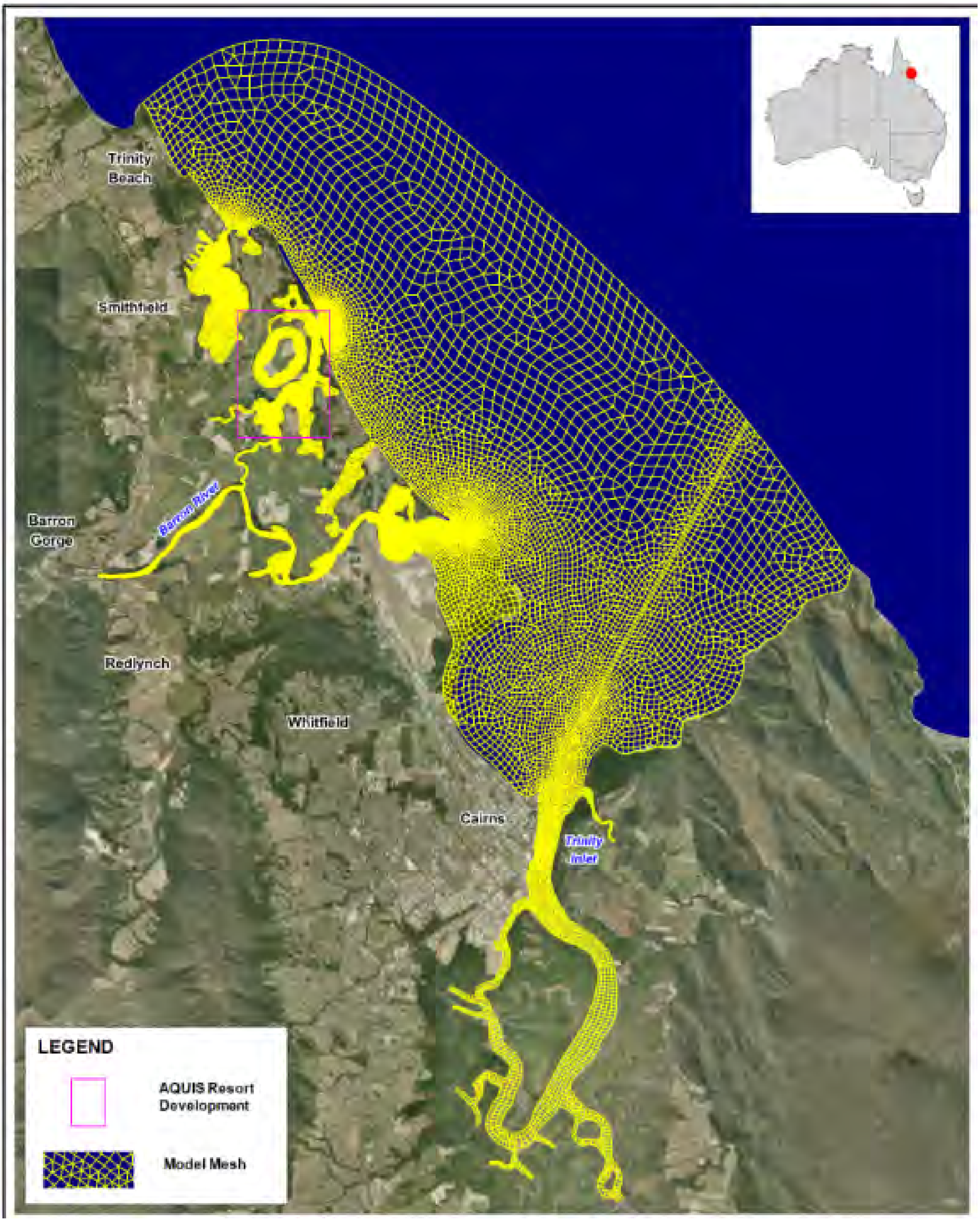

Figure 11-21 TUFLOW coarse model mesh (regional model plus lake model).

Source: Appendix M (Figure 10-3).

The bathymetry of Thomatis / Richters Creek was quantified by the specific boat-based survey investigations for this study using echo sounder transects subsequently corrected for tidal water level variations.

The results of these surveys were then used to create a bathymetric digital elevation model (DEM) of Thomatis / Richters Creek as a shown on **Figure 10-6**, with this DEM informing the TUFLOW water quality model mesh development.

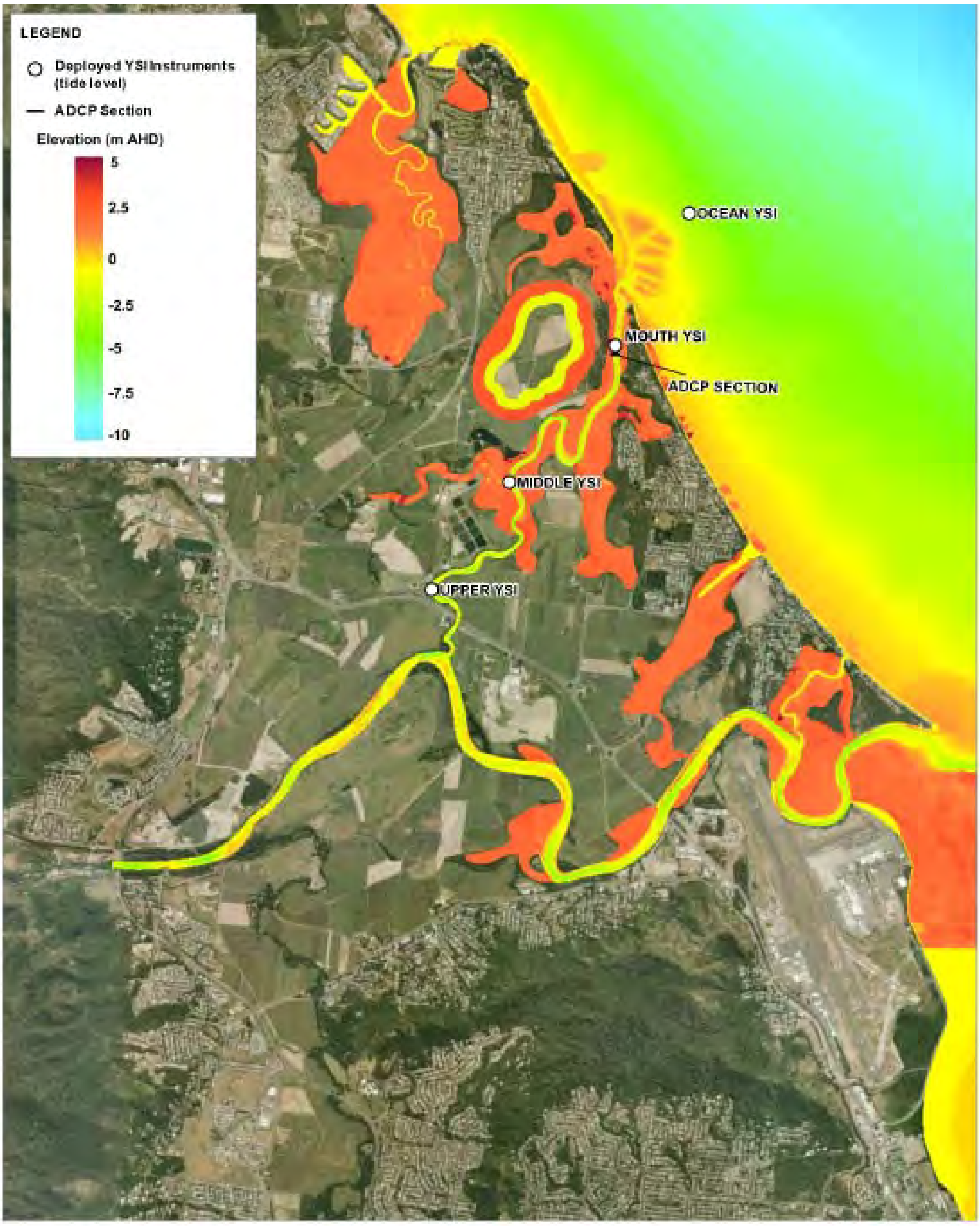

Figure 11-22 Digital elevation model.

Source: Appendix M (Figure 10-4).

Inputs

The TUFLOW FV model was configured with Barron River flow and meteorological data to enable a simulation of a recent 12 month period (August 2012 to July 2013). The modelling period encompassed ‘dry’ and ‘wet’ periods as follows:

- Dry: October to December 2012 (i.e. daily flows are generally at or below the 20th percentile)
- Wet: January to March 2013 (i.e. peak daily flows during events generally exceed 90th percentile)
- Flood (Australia Day 2013): 20 January 2013 to 14 February.

The rainfall associated with the Australia Day 2013 flood event was 238 mm, with 109 mm falling on 23 January 2013. The peak flood flow reached 1028 m^3/s which is between a 50% AEP and a 20% AEP flood event. This would theoretically have overtopped the lake edge bund (approximately 50% AEP) and resulted in overland flow. The RWQM as currently configured does not model such overland flow and in the modelling, this flood was forced to flow through the lake and discharge pipework. It is proposed of fully integrate the flooding and water quality aspects of the lake and RWQM as a design tool during detailed design and accommodate the analysis of such events.

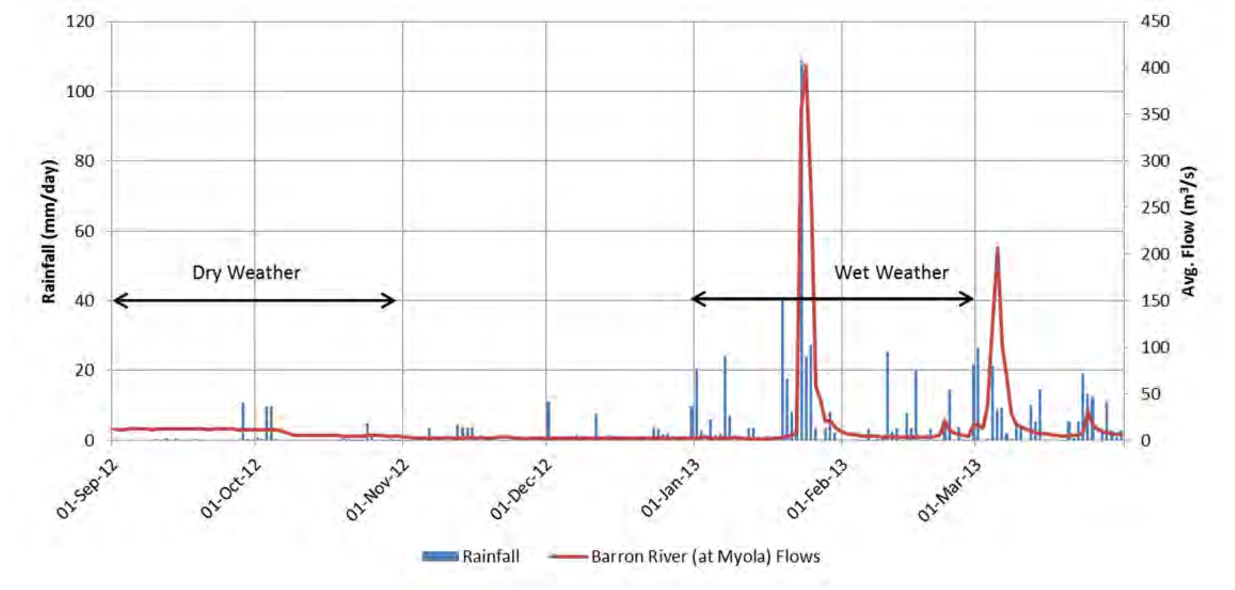

Figure 11-23 Model simulation period for dry & wet weather conditions.

Source: Appendix M (Figure 11-1). This is a sub-set of the annual data period described above.

The average daily flows and median daily flows for the Barron River at Myola for the simulation period are shown on **Figure 11-24** and **Figure 11-25** respectively. In addition to this flow data, measured load information (sediments and nutrients) was used as an input to the regional water quality model to simulate real conditions in the receiving environment as much as possible.

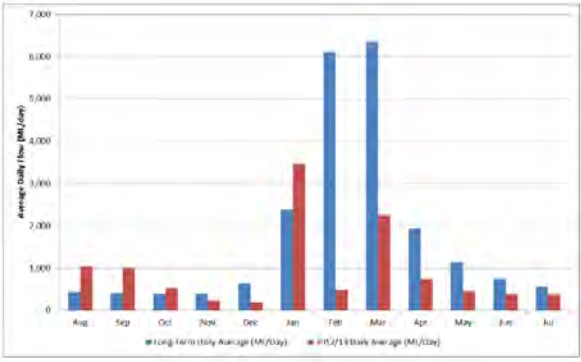

Figure 11-24 Average daily flow in Barron River for 12 month simulation period.

Source: Appendix M (Figure 11-2).

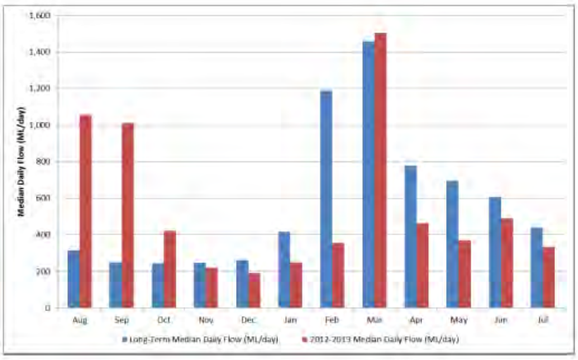

Figure 11-25 Median daily flow in Barron River for 12 month simulation period.

Source: Appendix M (Figure 11-2).

During the August 2012 to July 2013 period (see **Figure 11-23** which is a subset of this annual data) a significant flood occurred on the Australia Day long weekend. The peak flood flow reached a maximum of 1028 m^3/s which is between a 50% AEP and 20% AEP flood event for the Barron River. Ultimately, the model will be simulated over a multi-year period to capture a range of dry, wet and typical years.

The lake was forced with the following key datasets and coefficients:

- local wind speed and direction data, expressed as spatially gridded time series data across the model surfaces
- inflow/outflow time series of the proposed lake pumping/flushing regime
- relevant lake, creek and near-shore bathymetry data
- Relevant meteorological data in the form of rainfall, temperature, relative humidity etc. were also used to support and inform model temperature simulations and, in particular, how these model results and earlier mentioned wind speed and direction data will control lake stratification behaviour.
- Runoff from the Resort Complex Precinct (with best practice stormwater treatment) based on the MUSIC model of the lake catchment and also rainfall falling directly onto the lake surface.

The flushing behaviour was forced with the following key attributes:

- Intake flow rate at a constant near average rate of 1.09 m^3/s, varying ±50% (i.e. 0.54 m^3/s to 1.63m^3/s) as required to control lake levels from the impacts of rainfall and evaporation.
- Discharge on the ebb tide (i.e. between high tide and low tide) at an average rate of 2.15 m^3/s whilst varying flow rates ±50% (1.09 m^3/s to 3.25 m^3/s) to limit impacts during neap tides and maximise pumping during spring tides
- Intake salinity was as predicted from the proposed off-shore intake - a near constant rate of 35 g/L was applied, but sourced from the RWQM.

Calibration

The TUFLOW FV model was configured to conform to the following:

- Tidal boundary conditions (water levels) were taken from the RWQM described previously. This is a well-calibrated, large-scale TUFLOW FV model of the entire Great Barrier Reef lagoon developed previously by BMT WBM.
- Inflow time series flow data at the tidal limit of the Barron River was obtained from data collected in this location by Queensland Government departments.

The calibration process required to make use of the full water quality modelling capabilities of TUFLOW depends of high quality site data. At the time of writing (May 2014), four months of water quality data is available and processed and has been used to calibrate the model. In addition, bathymetric surveys have been undertaken as described above and the model has been calibrated hydraulically for a spring and neap tide. See below.

The TUFLOW-FV RWQM was calibrated / verified based on data sets collected during the December 2013 to March 2014 monitoring campaign. The calibration and validation process is described below.

- The hydraulic (i.e. water level, velocity and flow) elements of the Richters Creek model were calibrated to a period of spring tides on the 27 February 2014 and validation undertaken using a period of neap tides on the 4 April 2014 using an acoustic Doppler current profiler (ADCP[5])flow dataset. This calibration and validation process followed conventional industry practice of mesh refinement and model friction / resistance representation adjustment (within acceptable bounds) until such time as model results and recorded data agree.
- The water quality element of the Richters Creek / RWQM was calibrated initially to the physical parameters (i.e. advection / dispersion) and subsequently to relevant water quality parameters. The model will need to be continually updated, particularly for the chemical parameters as monitoring data becomes available. At present, the advection/dispersion and water quality elements have been calibrated to a three month period between 16 December 2013 and 20 February 2014. This period has consisted of prevailing dry and wet weather conditions. Similar to the hydraulic calibration, the process followed conventional industry practice of refining model water quality process rates and coefficients (within acceptable bounds) until model results and recorded data agree.

Key calibration and validation data sets used by the study are summarised below:

- Tidal water level data were collected at a number of locations along Richters Creek over a three month period from December 2013 to March 2014.
- Tidal flow data were collected at a location near to the development during a spring tidal cycle on 27 February 2014 and a neap tide on 4 April 2014 using a boat mounted ADCP.
- Ambient water quality data in Richters Creek, using the three month dataset collected between December 2013 and March 2014 for this study.

Monitoring has continued since the calibration was completed and is set to continue at least until 2015. Further calibration will take place over this time based on new data and the model refined for design and compliance purposes.

---

5 An Acoustic Doppler Current Profiler (ADCP) is a hydroacoustic current meter similar to a sonar, device and is used to measure velocities over a depth range using the Doppler effect of sound waves scattered back from particles within the water column.

Modelled Parameters

The following physical parameters of the lake were modelled and the model interrogated at each of the four points shown on **Figure 11-26** below, at the top and bottom of the lake, and as a vertically-averaged figure:

- lake salinity
- lake temperature
- dissolved oxygen
- total suspended solids
- total nitrogen
- total phosphorus
- chlorophyll *a*.

In addition, flushing time was estimated as explained later.

Conservative Approach

In considering lake performance, the TUFLOW model currently ignores a number of proposed water quality mitigation measures selected to achieve suitable exchange and turnover rates, as well as containment and recovery arrangements, namely:

- vertical and horizontal lake mixing and aeration devices (these serve to prevent temperature or salinity stratification and improve dissolved oxygen)
- use of chemical flocculants
- possible use of the swimming lagoon filtration and treatment system for emergency lake treatment.

Mixing and aeration devices are routinely used in managing the water quality of bodies such as the Aquis Resort lake and there is a well-established body of knowledge regarding their use and effectiveness. It is stressed that these mixers would not be relied upon to create the flushing flows (which would arise from the pumping regime) but rather at a fine scale to mix the lake both horizontally and vertically.

Although there is a need for further development of the lake design, the models as established are sufficient for conceptual design and impact assessment. In particular, they have been set up and tested to ensure that they are robust and producing expected behaviours, and have been informed and forced by relevant external boundary conditions and internal parameter sets (e.g. model, dispersion coefficients, and friction factors) and adequate calibration for the purpose.

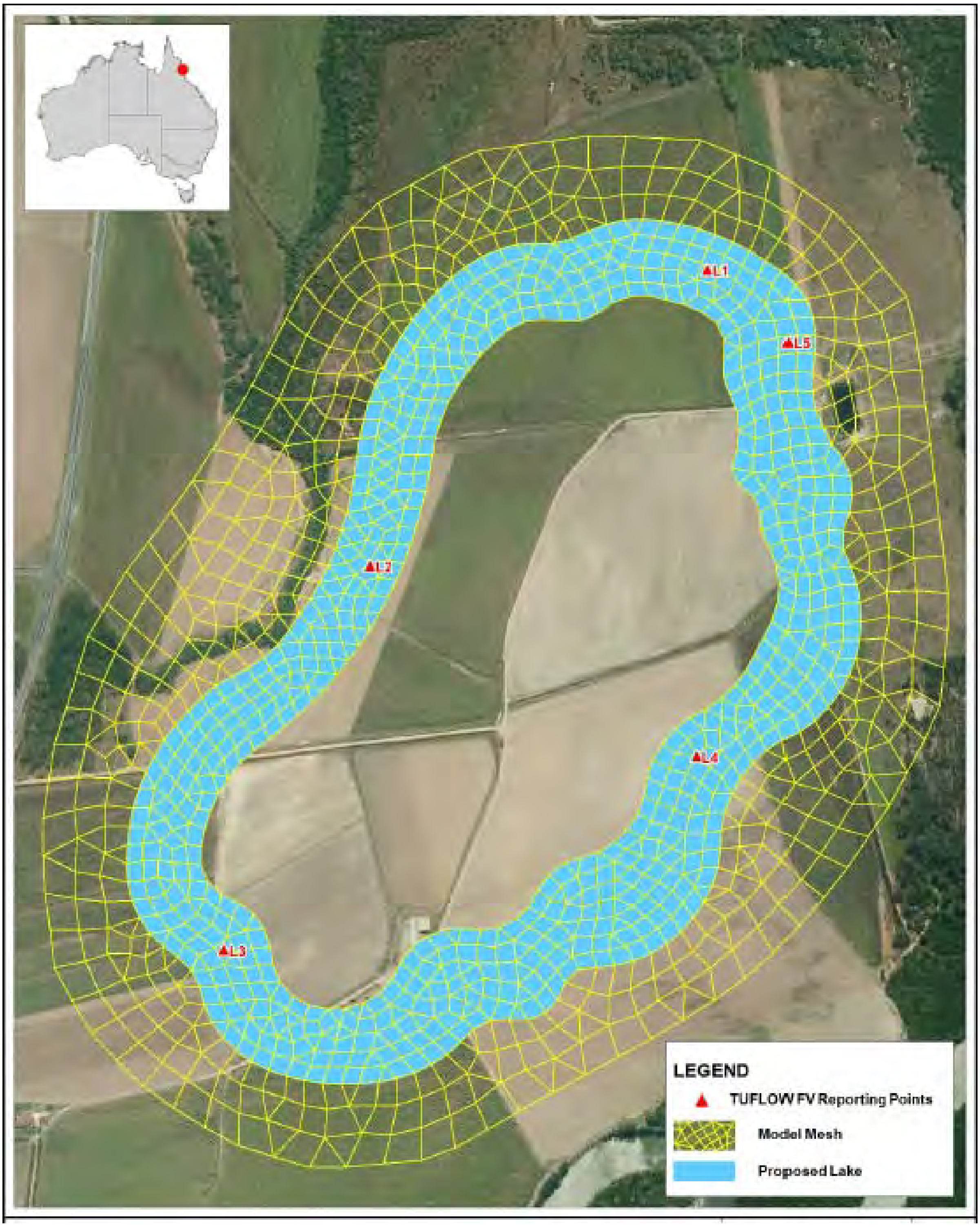

Figure 11-26 Location of four reporting sites within the lake model.

Source: Appendix M (Figure 11-5).

Evaluating Performance – Numerical Modelling Results

Summarising the above discussion, comprehensive modelling work was undertaken to investigate the performance of the lake:

- over the 12 month modelled period between September 2012 and August 2013
- at four selected points within the lake
- at the surface and bottom at each of these points, and a vertically-averaged result
- for a the following parameters:
  - salinity
  - temperature
  - total suspended solids
  - dissolved oxygen
  - total nitrogen
  - total phosphorus
  - chlorophyll *a*

Overall flushing as also investigated.

Physical and Chemical Properties

The following is a summary of the findings of the analysis of the above physical and chemical properties (detailed tables and graphs are included in **Appendix M**).

- Salinity. The lake will remain saline through most years, with salinities varying from 30 g/L up to 36 g/L. Median salinities throughout the lake are generally about 35 g/L and may typically vary between 33 g/L and 35 g/L. For the relatively dry period from October 2012 to December 2012, the salinity in the lake is not predicted to become hypersaline, due to the regular flushing with seawater drawn from the off-shore inlet and the a 14 day turnover cycle. For the 'wet' period between January 2013 and February 2013, the lake is influenced by stormwater drainage from the Resort Complex Precinct and direct rainfall upon the lake. In contrast to the dry conditions, during significant periods of rainfall (i.e. January 2013 and March 2013) the lake will show a limited propensity to stratify by up to 3.0 g/L, but then return to well-mixed conditions after the event. Any stratification predicted by the model is conservative (i.e. likely to be greater than expected) because the effects of submersed mixers have not been included in the simulations. These mixers will assist in dismantling any stratification that develops.
- Temperature. Temperatures in the lake will typically vary between 22.9^{o}C and 34.7^{o}C. Modelling shows that there is potential for temperatures in the lake to induce some vertical stratification, particularly during the warmer months from November to April when a 4.0^{o}C top to bottom difference in temperature is predicted. This temperature difference is caused by solar heating of the lake and the incoming cooler ocean water from the off-shore inlet. No particular dry or wet period modelled would appear to induce thermal stratification. Submersible mixing devices have not been modelled and are expected to reduce temperature-induced stratification.
- Total suspended solids. The TSS values in the lake results largely reflect those of the inlet water (approximately 10 m g/L). In the lake, TSS concentrations will be reduced due to the diluting effect of incident rainfall on the water surface and increased due to stormwater drainage inputs from the Resort Complex Precinct. The varying nature of the TSS (and resulting turbidity) is a consequence of the atmospheric conditions (i.e. predominately wind) and the effect of the lake flushing regime (inlet / discharge and spring / neap cycle) that combine to cause periods of settling and re-suspension.

- Dissolved oxygen. The lake is well-oxygenated, particularly in the upper layers, with DO levels typically ranging from 6.2 m g/L to 7.1 m g/L. DO concentrations at the bottom of the lake can reduce to as low as 2.7 m g/L on occasions in the south-eastern part of the lake, while in the area where the lake inlet water discharges the minimum DO level are between 3.4 m g/L to 3.7 m g/L. The varying nature of DO in the bottom of the lake is a result of the aeration at the surface, combined with the sediment oxygen demand and vertical mixing. Submersible mixing devices have not been modelled and are expected to improve DO levels throughout the lake.
- Total nitrogen. TN levels are generally consistent with off-shore inlet conditions (0.3 m g/L) and variations associated with local cycling of nutrients within the lake. Concentrations of TN range from 0.25 m g/L to 0.38 m g/L. An increase in TN occurs at the bottom of the lake due to the sediment flux and settling of sediment. TN levels at the surface vary up to 0.35 m g/L as a response to the Australia Day 2013 flood whereby TN loads from stormwater drainage from the Resort Complex Precinct would occur, despite the proposed SQIDs. There are not significant periods of elevated TN levels when compared to incoming background conditions of 0.3 m g/L. It is relevant to note that during peak flood TN levels in Richters Creek can be in excess of 1.0 m g/L.
- Total phosphorous. Similar to TN, TP values are generally consistent with the off-shore inlet conditions (0.05 m g/L) and variations are associated with local cycling of nutrients within the lake. TP levels are shown to vary between 0.038 m g/L and 0.055 m g/L. There are no significant periods of elevated TP levels when compared to incoming background conditions of 0.05 m g/L or Richters Creek. Unlike TN, TP levels do not exhibit a notable response to the Australia Day 2013 flood.
- Chlorophyll *a*. Chlorophyll *a* levels in the lake are a result of internal growth with the lake system, rather than levels contained within inlet water (1 µ g/L). The lake shows a propensity for elevated Chlorophyll *a* during the warmer month (January to April) indicating potential for phytoplankton growth. Chlorophyll *a* levels range from 0.0 µ g/L to 16 µ g/L. These levels are consistent with background conditions predicted in Richters Creek and do not exhibit a notable response to the Australia Day 2013 flood. Submersible mixing devices have not been modelled and are expected to result in a notable reduction in Chlorophyll *a* levels, particular during the warmer months.

With the possible exception of DO, the above results are indicative of a healthy environment likely to sustain marine life. The addition of mixing devices (not modelled) is expected to have a beneficial effect on certain modelled parameters, in particular:

- The propensity for stratification induced by salinity and temperature gradients will be reduced.
- Localised low levels of DO will not occur due to the combined effect of aeration and mixing.
- High chlorophyll a levels will be reduced by better mixing that will reduce high temperatures at the surface. In addition, these devices can be used to deliberately re-suspend settled sediments and increase turbidity – this is desirable to reduce water clarity and hence control chlorophyll a levels. Lake management will need to involve steps to ensure that turbidity is not so low as to encourage the growth of algae and other marine vegetation. That is, water clarity should not be too good.

Lake Flushing

A key performance metric for long-term lake water quality is flushing or residence time. In order to determine how the lake will flush, the lake was ‘dosed’ with a conservative tracer (i.e. 100%) at the beginning of the ‘dry’ period (noting that flushing times under dry weather conditions will be the most extreme (i.e. largest) as there are no catchment or direct rainfall inflows which would increase lake flushing rates – or reduce lake flushing times) and the response of the numerical tracer to pumped inflow and outflows was simulated.

The flushing time at the designated lake locations was determined by using the ‘e folding’ method: that is, determining when the concentration of a tracer reduces to a value of 1/e, or 37%, of its initial value.

This is a standard technique in describing the behaviour of a system exhibiting exponential decay of certain parameters as is the case for the Aquis Resort lake.

Results are presented in a seven day time-series plan view snapshot on **Figure 11-27** and a time-series graph at the four key reporting points (refer to **Figure 11-26**). The plan view and graphs shows that flushing times are very good and as presented in **Table 11-20** are just over two weeks. For most water quality parameters in a lacustrine system, a flushing time of this order typically indicates that water quality levels will be comparable with the source water supply, in this case water sourced via the ocean intake.

TABLE 11-20 LAKE FLUSHING TIMES – DRY CONDITIONS

SITE LOCATION	DEPTH LOCATION	E FOLDING FLUSHING TIME (DAYS)
L1 - North (discharge point of inlet pipe)	Top	<1
	Avg.	<1
	Bottom	<0.5
L2 - West	Top	9
	Avg.	9
	Bottom	3.5
L3 - East	Top	14
	Avg.	14
	Bottom	14
L4 – North-east (discharge)	Top	16
	Avg.	16
	Bottom	16

Source: Appendix M (Table 11-8).

The above table shows that ‘e folding’ flushing times vary between the top and bottom layer at the discharge point of the lake inlet (Point L1) and western portion of the lake (L2), before becoming predominately mixed on the eastern side of the lake (L3) and towards the discharge point (L4). The bed-mounted submersible mixing devices proposed to be installed at key locations in the lake will promote exchange, mixing, and flushing and will reduce residence times further. The precise location and operational regimes of these devices will be determined during detailed design.

The flowing schematic (**Figure 11-27**) shows the change over time of the composition of water within the lake, based purely on hydrodynamic criteria (i.e. no biological processes).

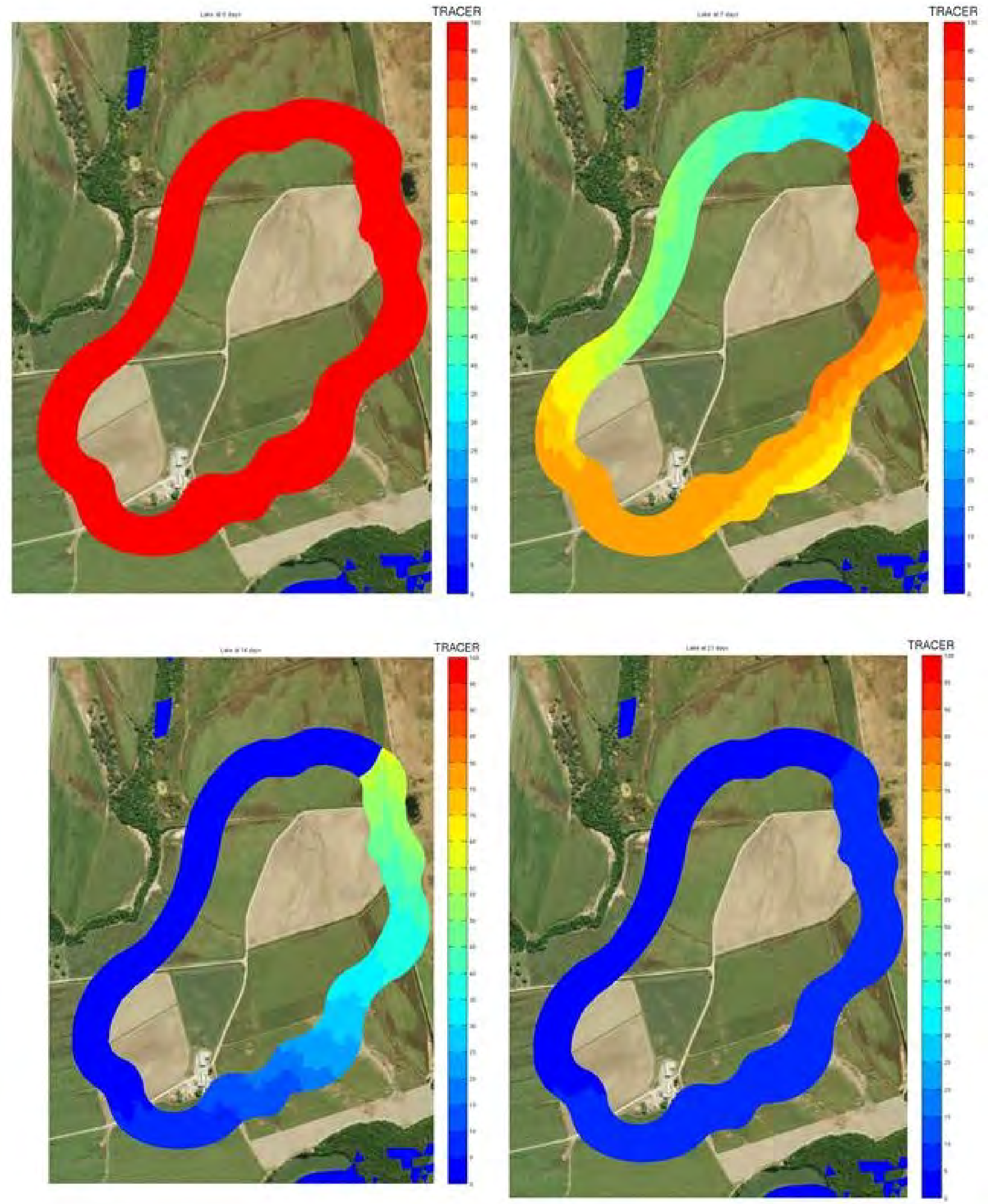

Figure 11-27 Lake flushing.

Source: Appendix M (Figure 11-15).

These results can be shown numerically (**Figure 11-28**).

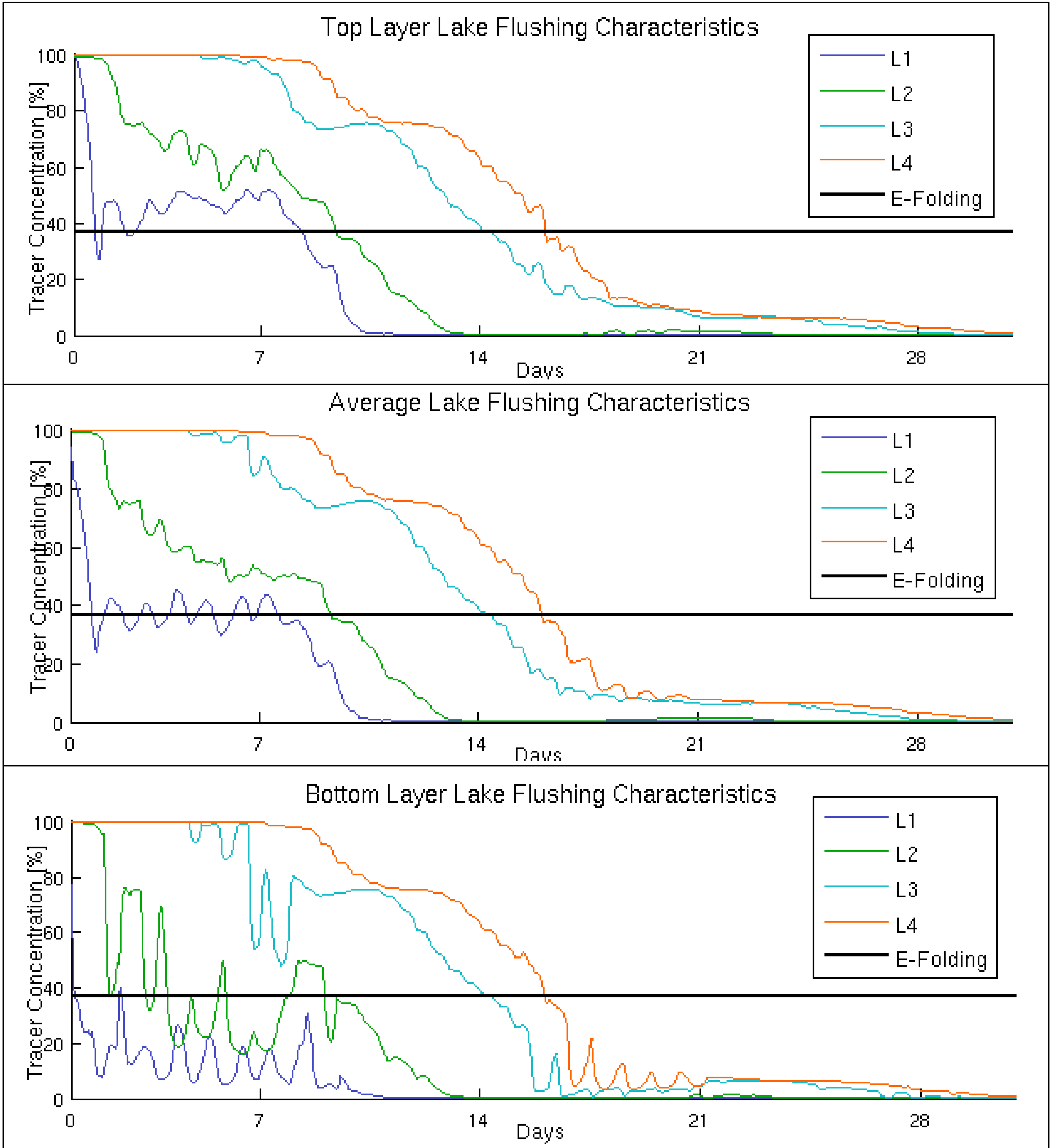

Figure 11-28 Lake flushing (dry season) in the top, average, and bottom layer.

Source: Appendix M (Figure 11-16).

This set of figures shows quantitatively that the desired e-folding point is reached between three and 12 days. With the proposed mixing equipment (not modelled), the whole lake can be expected to be flushed well within the 14 days allowed for. Wet season results are very similar, with flushing occurring within the two week period.

In general, and within the limitations of the modelling undertaken to date, the following observations can be made regarding the Aquis Resort lake:

- It is well flushed even under adverse dry and wet conditions, as occurred on the Australia Day flood (25 January 2013), and will be more so when submerged mixer devices are included in the configuration.
- Overall the lake water quality it expected to be adequately controlled through the use of a pumped system from the proposed off-shore intake.

Summary

- Lake salinity. Although the lake shows a slight propensity to develop salinity stratification with rainfall, salinity recovery occurs relatively quickly. This will be improved by the proposed mixing devices.
- Temperature. There is some propensity for the lake to develop thermal stratification where the inlet pipeline discharges into the lake and in the western portion. This is induced by a combination of solar heating of the top surface and the introduction of cool water derived from close to the sea floor at the off-shore inlet at the bottom of the lake. The model shows that this stratification disappears quickly and will improve with submerged mixer devices. During detailed design attention will be given to optimising the manner by which the inlet water is introduced to the lake and using this to maximise local mixing.
- Total suspended solids. The TSS results largely reflect consistent ocean inlet conditions of approximately 10 m g/L but will also be impacted on by direct rainfall onto the lake (dilution) and the Hotel Complex Precinct as a source of sediment. The varying nature of the turbidity and TSS is reflective of the atmospheric conditions (i.e. predominately wind) and the flushing pumping regime (intake/discharge and spring/neap cycle) that together causes periods of settling and re-suspension.
- Dissolved oxygen level in the bottom of the lake show a propensity to reduce to a level at or near the limit that could be toxic to some fish species. Circulation via mechanical mixers and aerators will significantly improve mixing.
- Nutrient levels are largely consistent with background levels, indicating that the lake provides a system that is well buffered and resilient to local inflows. Furthermore, relative changes to in-situ discharge concentrations would indicate compliance with proposed discharge compliance protocols.
- Chlorophyll *a* levels show a propensity for productivity due to elevated temperatures during the warmer months of January to April. The Chlorophyll *a levels* are system-derived and similar to background levels in Richters Creek, indicating that the management of:
  - nutrients from the lake catchment is an important function to reduce the potential for phytoplankton growth
  - water circulation (horizontally and vertically) within the lake via mechanical mixers and aerators will be an important function to reduce surface temperatures and limit growth.
- the lake is well flushed even under adverse dry and wet conditions and will be more so when submerged mixer devices are included in the configuration.

Overall the lake water quality it expected to be adequately controlled through the use of a pumped system from the proposed off-shore intake.

Lake Discharge

The previous section has described the design of the lake and its performance in terms of internal water quality parameters and flushing. This is based on the designated flushing regime whereby, under normal conditions, lake water is discharged to the mouth of Richters Creek every ebb tide. The following section describes potential and likely impacts of this discharge in terms of water quality and hydraulic criteria.

Evaluating Impacts – Numerical Modelling

As described above, the TUFLOW model was used to simulate the performance of the lake. For that assessment, the lake model was coupled with the TUFLOW 'existing conditions' RWQM to simulate:

- the inlet input from the RWQM to the lake
- the lake outlet to the RWQM.

The model simulates both the internal conditions in the lake (as reported above) and the effect on the receiving environment (the subject of the following discussion). The simulation period described below is as already mentioned, i.e. the period extending from 1 September 2012 to 31 March 2013 and refer to the designated 'dry' and 'wet' periods previously described. Operational assumptions (e.g. pumping rates) are as previously described.

Existing conditions were derived from the model using existing (pre-development) data for the modelled period for:

- tidal flow
- salinity
- temperature.

It is relevant to note that measured and modelled salinity profiles confirm that Richters Creek generally exists with a pronounced salt-wedge stratification, which has a significant influence on system water circulation dynamics. Freshwater outflows have a tendency to be concentrated near the surface (with a corresponding net-downstream average flow). In contrast, the near-bed flows in a salt-wedge system will have a net-upstream average flow. This vertically stratified circulation pattern has significance for the discharge of lake water (with approximately seawater characteristics) into the mouth of Richters Creek. This is further discussed below.

Figure 11-29shows the location of the points within the RWQM where modelled parameters have been reported. These points are referred to in the ensuing discussion.

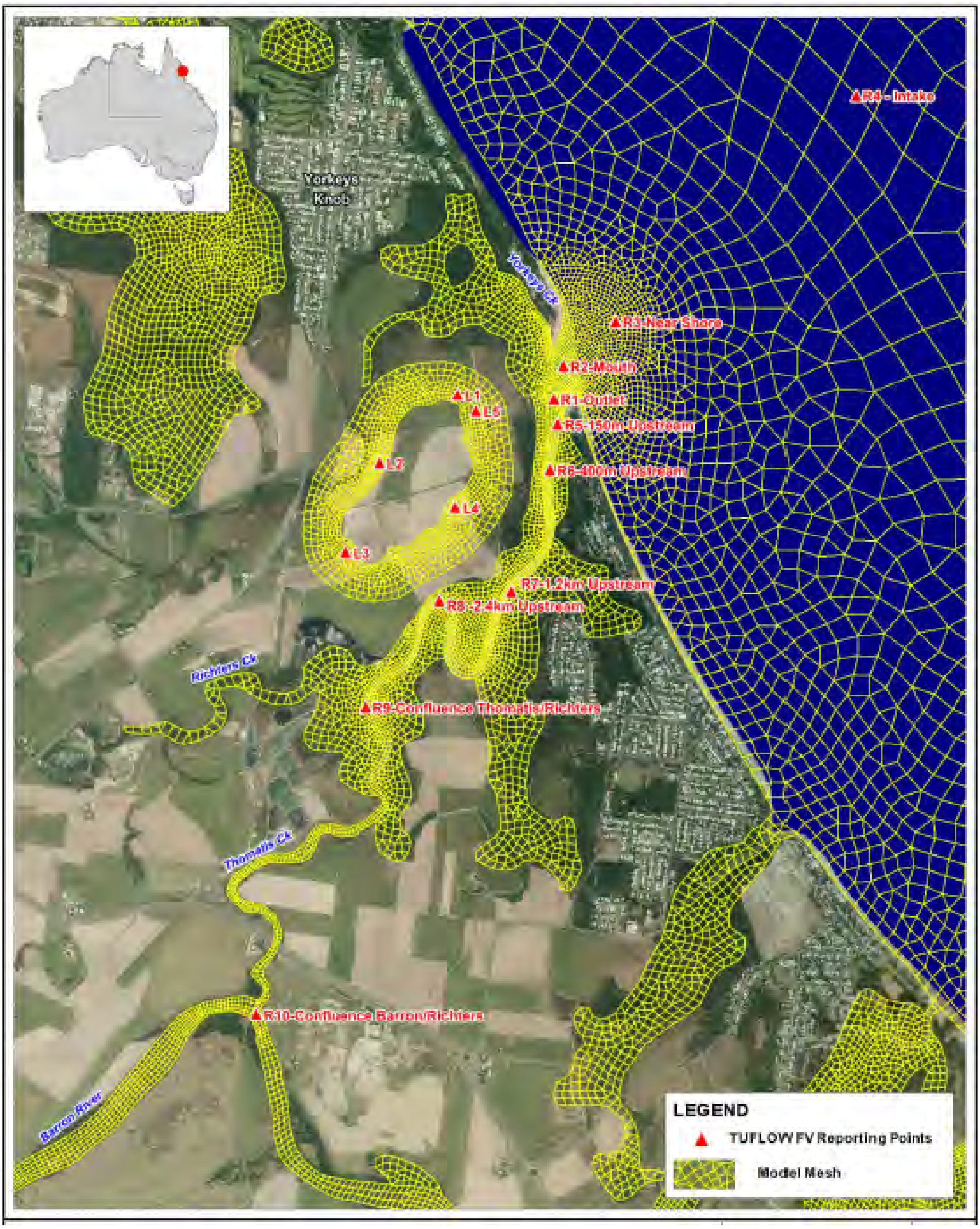

Figure 11-29 TUFLOW FV mesh and reporting points.

Source: Appendix M (Figure 11-17).

Labelled points shown are those at which water quality parameters are reported on below.

Operational assumptions were:

- intake at a constant near constant rate of 1.09 m^3/s, while varying ±50% (i.e. 0.54 m^3/s to 1.63 m^3/s) as required to control lake levels from rainfall and evaporation
- discharge on the ebb tide (i.e. 1hr before slack tide and 1hr before flood tide) at a near constant rate of 2.15 m^3/s while varying flow rates ±50% (1.09 m^3/s to 3.25 m^3/s) to limit impact during neap tides and allowing for rainfall events
- salinity was as predicted from the proposed off-shore intake a near constant rate of 35 g/L (monitoring confirms that this figure is appropriate)
- tracer concentration was conservatively applied at 100% to enable full dilution rates to be calculated.

Evaluating Impacts – Numerical Modelling Results

Tidal Prism

The tidal prism represents the total volume of water moving past a fixed cross section of Richters Creek during each flood and ebb tide (i.e. slack water to slack water). The following table shows the results of tidal prism calculations at the Richters Creek mouth from the tide volume for one typical spring-neap cycle (07/09/2012 to 23/09/2012).

TABLE 11-21 TIDAL PRISM AT RICHTERS CREEK

TIDE	TIDAL VOLUME (ML)	LAKE DISCHARGE (ML)	% OF TIDAL VOLUME
Neap	225	46 (down to 23)*	20% (10%)
Spring	625	46 (typically 73)*	7% (12%)

***** average discharge rate, but variable discharge used for neap and spring tides as required to limit impacts, maintain turnover, rainfall impacts and lake level.

From the above table is can be seen that the proposed lake discharge rate is between 7% and 20% of the Richters Creek tidal prism. While the total volume of the tidal prism is significantly greater than that being discharged by the lake, it should be noted that this does not necessarily give an indication of how well the discharge is dispersed throughout the receiving waters. See below.

Velocity and Bed Shear Stress Impacts

The regional TUFLOW-FV model was interrogated at the lake outlet location and at the mouth of Richters Creek for velocity and bed shear stress to ascertain if scour is likely to result from the proposed pumping regime. Modelling shows that the velocity change at the outlet and Richters Creek mouth is minimal with changes in the order of 0.005 m/s to 0.02 m/s throughout the full year. Bed shear stresses are also notably small in the order of 0.1 N/m^2 to 0.4 N/m^2 including the change in bed shear stress.

These results indicate the increase in tidal prism volume will not cause any notable increase in scour potential along Richters Creek.

Salinity

The analysis allows the following conclusions to be drawn:

- There is negligible change in salinity (10^{th} to 90^{th} percentile change = 0 g/L) to the off-shore environment, with a slight near-shore change in salinity of up to 1 g/L (90^{th} percentile change 0.4 g/L).
- At the mouth and outlet, peak changes in salinity are typically in the order of 2 g/L to 3 g/L with up to 4 g/L change during the Australia Day 2013 Flood. Median changes in salinity are in the order of 0.5 g/L to 0.7 g/L.
- Salinity changes are typically reduced in the upstream portions of Richter Creek with peak salinity changes limited to approximately 1 g/L at the Thomatis / Richters Creek confluence. Median changes in salinity are in the order of 0.5 g/L to 0.7 g/L.
- There is minimal change in salinity to the Barron River at the confluence with Thomatis Creek.

Overall, there is limited to negligible change in salinity concentrations in Richters Creek and the near-shore region due to the tidal exchange system. This reflects the relatively low discharge volume compared with the tidal prism volume.

Dissolved Oxygen

Modelling shows that there are no notable changes in DO levels.

Nutrients

Nutrient levels are generally expected to be reduced within Richters Creek as a result of the development due to the increased quantity of high quality seawater entering the system through the lake discharge and due to the decreased development site nutrient loads (as predicted by the MUSIC modelling). Modelling allows the following specific conclusions to be drawn:

- There is negligible decrease in TN and TP (10^{th} to 90^{th} percentile change of 0 µg/L to 1 µg/L) to the off-shore inlet conditions, with a near-shore median decrease in TN of up to 8 µg/L and no change for TP median concentrations.
- In the near-shore region, TN concentrations are decreased from the 10^{th} percentile through to the 90^{th} percentile range in the order of 7 µg/L to 17 µg/L. The results indicate that Richters Creek is typically conveying nutrients higher than the lake discharge – therefore the lake will provide a dilution effect.
- Conversely to TN, TP concentrations in the near-shore region vary from a decrease in concentration in the 10^{th} percentile range of 1 µg/L, whilst for the 90^{th} percentile concentration an increase by up to 11 µg/L is predicted. The results typically indicate that during normal dry weather conditions, TP concentrations remain unchanged, whilst during notable rainfall events the development will increase TP concentrations in Richters Creek.
- At the mouth and lake outlet, TN concentrations are decreased in the order of 6 µg/L to 20 µg/L across the percentiles calculated. TP concentrations are decreased marginally for the lower percentiles (i.e. 10^{th} to 20^{th} percentile), whilst an increase is noted by up to 20 µg/L in the 90^{th} percentile range with a minor median increase of 1 µg/L.
- TN and TP levels in the upstream portions of Richters Creek are consistent with that of the mouth and near-shore area with a decrease in TN concentrations and an increase in TP concentrations. However the change in concentrations is progressively reduced.
- Concentrations of TN and TP at the confluence with Thomatis Creek (i.e. near the Ponderosa Prawn Farm) results in a decrease in TN concentration in the range of 4 µg/L to 12 µg/L whilst there is negligible increase in TP of up to 1 µg/L.

Overall there is limited change in nutrient concentrations in Richters Creek and the near-shore region due to the proposed resort. With WSUD measures proposed within the site, the Aquis project will see the release of less nutrients than the existing cane farm.

Chlorophyll a

Modelling of chlorophyll a along Richters Creek and the near-shore / off-shore region reveals:

- There is no change in chlorophyll *a* at the off-shore locations, with a slight near-shore median change of up to 1 µg/L.
- At the mouth and outlet/intake, chlorophyll *a* increases are typically less than 1 µ/L with generally no change.
- No notable change to chlorophyll *a* is predicted in the upstream reaches of Richter Creek with a general decrease limited to approximately 1 µg/L.

Overall there is limited to no change in chlorophyll *a* concentrations in Richters Creek and the near-shore region due to the development.

Dilution/Concentration

An important aspect of impact assessment is the dilution of lake discharge in the receiving waters at the point of discharge (actually outside the 2 m to 5 m local mixing zone) and then the dispersion of this mixed water throughout the Richters Creek / Trinity Bay system.

Table 11-22 shows the annual dilution / concentration figures for the dry component of the modelled period (1 September 2012 to 31 March 2013). Values of 100 and 0 correspond to pure lake water and pure estuarine water, respectively. Intermediate values represent various dilutions with, for example, a value of 60 representing 60 parts lake water and 40 parts estuarine water.

TABLE 11-22 DILUTION/CONCENTRATION – LONG TERM CONDITIONS

Site Location	Vertical Location	10th Percentile (%)	20th Percentile (%)	Median (%)	80th Percentile (%)	90th Percentile (%)
R1 - Outlet	Top	0.4	1.3	3.9	6.0	7.3
	Avg.	0.7	1.7	7.7	19.1	26.5
	Bottom	0.6	0.6	14.8	58.6	76.7
R2 - Mouth	Top	0.2	0.5	3.9	7.4	9.1
	Avg.	0.2	0.5	4.6	15.1	19.5
	Bottom	0.2	0.2	4.8	23.1	30.1
R3 - Near-shore (330m)	Top	0.3	1.1	4.0	6.5	7.9
	Avg.	0.3	0.9	7.7	17.0	20.5
	Bottom	0.3	0.3	9.5	32.5	42.1
R4 - Off-shore (intake)	Top	0.0	0.0	0.1	0.1	0.1
	Avg.	0.0	0.0	0.1	0.1	0.1
	Bottom	0.0	0.0	0.1	0.1	0.1
R5 - 150m Upstream	Top	0.4	1.4	4.0	6.2	7.4
	Avg.	0.4	1.2	5.1	14.0	20.8
	Bottom	0.4	0.4	5.8	40.3	62.5

Site Location	Vertical Location	10th Percentile	20th Percentile	Median	80th Percentile	90th Percentile
		(%)	(%)	(%)	(%)	(%)
R6 - 400m Upstream	Top	0.5	1.8	4.1	6.3	7.5
	Avg.	0.5	1.4	4.4	11.5	17.8
	Bottom	0.4	0.4	3.9	30.2	53.4
R7 - 1.2 km Upstream	Top	1.5	2.5	4.3	6.5	7.7
	Avg.	1.6	2.7	5.0	8.6	11.2
	Bottom	0.8	0.8	4.1	10.2	17.0
R8 - 2.4 km Upstream	Top	1.6	2.3	3.9	6.2	7.8
	Avg.	3.5	4.4	6.2	8.4	9.9
	Bottom	3.2	3.2	6.6	9.3	11.5
R9 - Thomatis / Richters	Top	1.2	1.9	3.4	5.3	6.4
	Avg.	3.6	4.5	6.0	8.1	9.4
	Bottom	4.3	4.3	7.6	10.5	12.4
R10 - Barron/Richters	Top	0.4	0.7	2.0	3.4	3.9
	Avg.	2.3	2.8	4.0	5.4	6.2
	Bottom	4.4	4.4	6.9	9.2	11.0
GBRMP Boundary	Top	0.0	0.0	0.1	0.1	0.1
	Avg.	0.0	0.0	0.1	0.1	0.1
	Bottom	0.0	0.0	0.1	0.1	0.1

Source: Appendix M (Table 12-5).

Modelling shows that typical dilutions are high (i.e. low tracer concentrations), including in the immediate vicinity of the lake water discharge point. The spring-neap tidal cycle is clearly evident, with neap tidal conditions resulting in generally lower dilutions. The opposite is true for spring tides.

Dilution rates during a dry period will represent ‘worst case’ conditions where dilution is largely reliant on the tidal exchange only, while during wet periods upstream flows will assist in advection of lake waters into the bay.

Progressive six hourly plots shown on each of the figures from **Figure 11-30** to **Figure 11-32** show the advective and diffusive nature of the receiving environment and notably the limited spatial extent of any impact. Tracer concentrations from the lake (i.e. at 100%) are rapidly diluted close to background conditions (i.e. 0%) in the immediate near-shore environment. As previously noted, provided the Aquis lake has similar or better water quality than that of Richters Creek (i.e. as opposed to the conservative tracer plots provided) then no notable receiving water quality impacts will be evident.

From the tabulated and plan view results presented (and time series plots included in **Appendix M**), dilutions are generally high (i.e. low tracer concentrations), including in the immediate vicinity of the lake water discharge point. Bottom tracer concentrations are generally higher than depth average and surface tracer concentrations which reflect the salinity stratification that occurs in Richters Creek and the saline resort discharge that occur at the bottom of Richters Creek (i.e. albeit via diffusers).

The spring-neap tidal cycle is clearly evident in the figures, with neap tidal conditions resulting in generally lower tracer concentrations, the opposite is true for spring tides. The following conclusions can be drawn from the results presented:

- There is negligible change in water quality concentrations off-shore with 90th percentile changes indicating over 99.9% dilution.
- Median tracer concentrations at the mouth and near-shore of Richters Creek are of the order of 3.9% to 9.5% indicating relatively high dilution rates from the discharge. It is also noted that the 90th percentile dilution is of the order of 9% to 20% at the surface and depth average indicating that 90% of the data results in dilutions greater than this. Dilutions within the bed of the channel are notably less and tracer concentrations are of the order of 30% to 42%, indicating the effect of stratification in this area.
- Dilution rates upstream of the outlet are also generally high with median tracer concentration in the order of 1% to 7%. Similar to the mouth and near-shore regions, the 90th percentile data indicates dilution rates are notably lower in the bottom half of the water column and are in the order of 10% to 62% indicating that the discharge from the proposed lake is largely concentrated in this region.

Progressive six hourly plots are shown on figures **Figure 11-30** to **Figure 11-32** below.

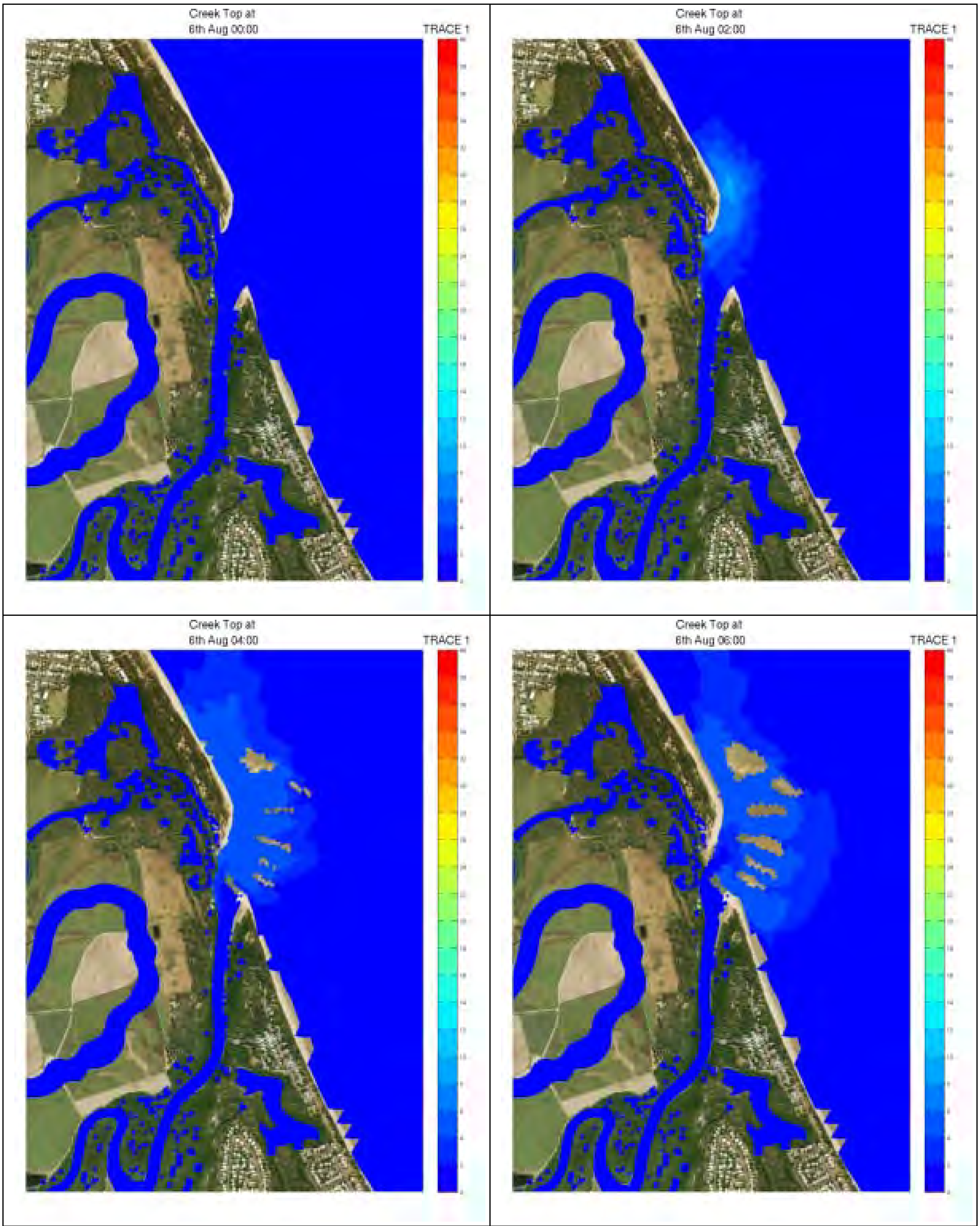

Figure 11-30 Richters Creek Dilution (Top) – 6 hr Series.

Source: Appendix M (Figure 11-22).

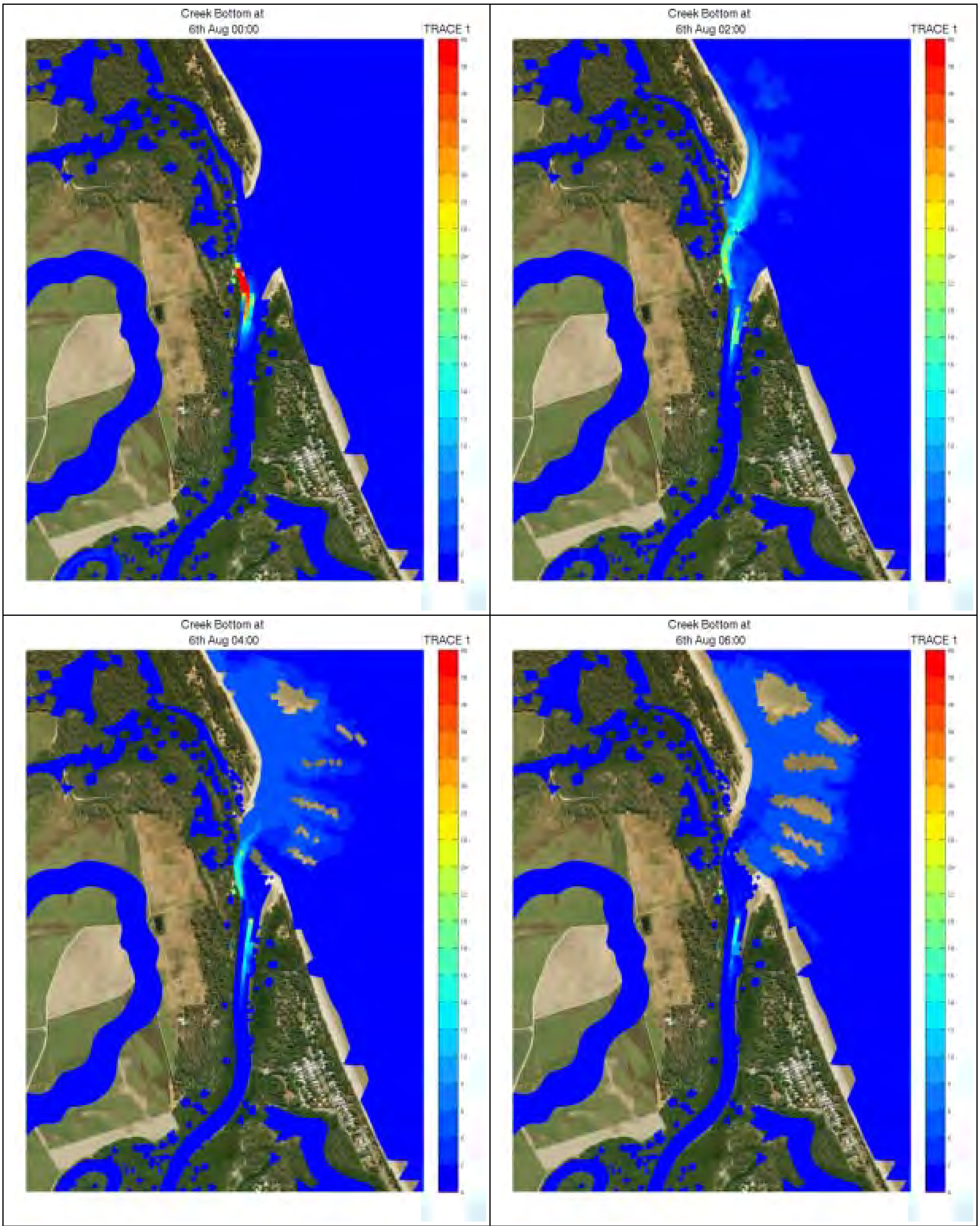

Figure 11-31 Richters Creek Dilution (Bottom) – 6 hr Series.

Source: Appendix M (Figure 11-23).

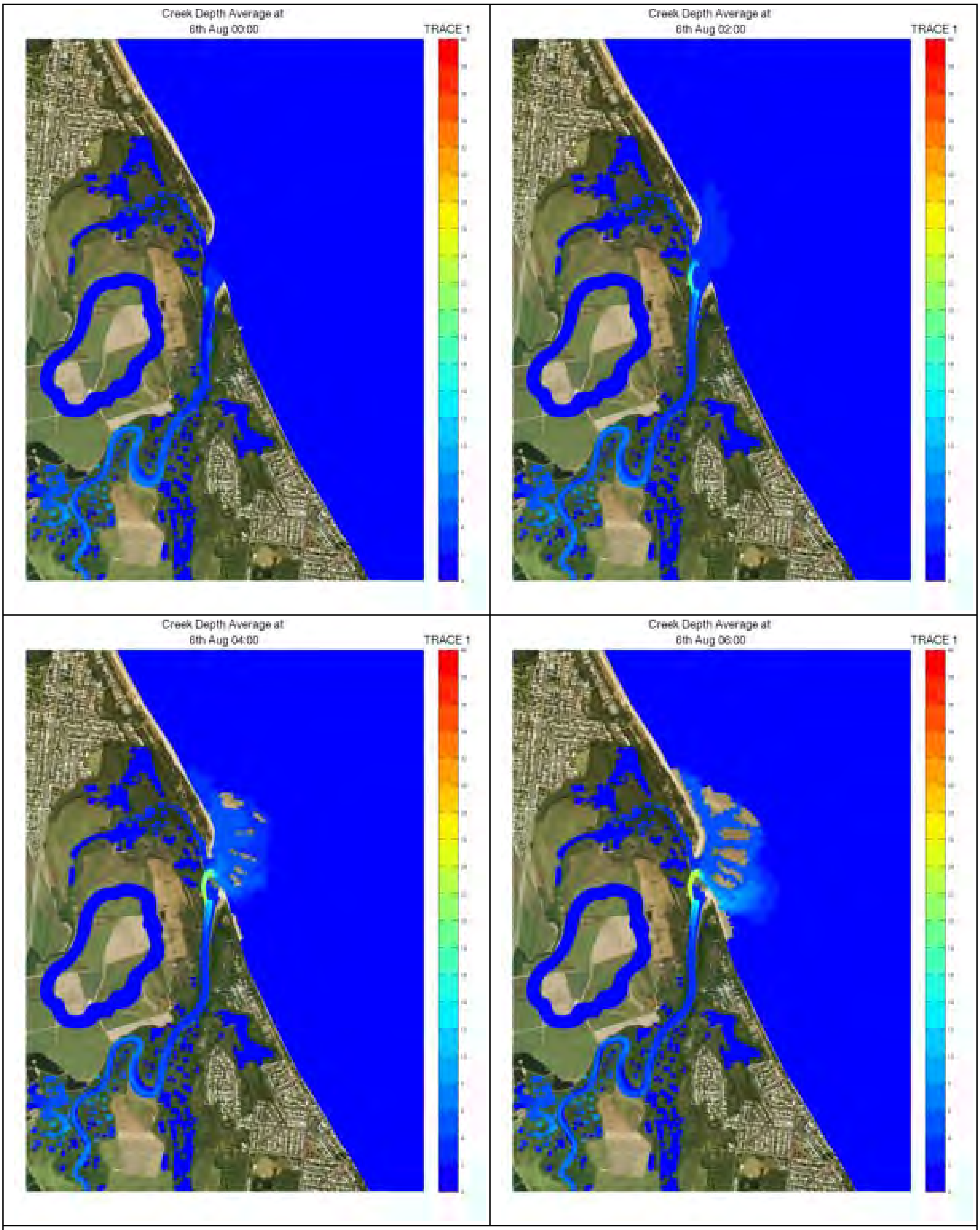

Figure 11-32 Richters Creek Dilution (Average) – 6 hr Series.

Source: Appendix M (Figure 11-24).

Initial Comparison with Discharge Compliance Limits

It is useful to compare modelled discharge with draft compliance limits set out in **Table 11-14** and **Table 11-17** for TN and TP (to date these are the only parameters examined to this level of detail). It should be noted that the comparison is to 'potential changes to ambient concentrations', rather than explicit values, and notwithstanding the limited historical data available to date for comparison purposes.

- TN:
  - Median lake concentrations are consistent with the off-shore intake, indicating annual median compliance would be achieved provided the off-shore concentrations are at or better than Richters Creek. This is expected to be the case and the limited testing to date suggests that this is true.
  - 80th percentile lake concentration increases are typically only +0.01 mg/L higher than median levels (maximum concentrations are only +0.08 mg/L), indicating that this is well below the natural TN fluctuation of Richters Creek of up to +0.18 mg/L for dry weather and +0.192 mg/L for wet weather (based on the 80th percentile medium to long-term trigger for compliance assessment).
  - 90th percentile and maximum concentration changes of up to +0.08 mg/L are again well below the 95th percentile short-term pulse compliance trigger.
- TP:
  - Median lake concentrations are typically lower than the off-shore intake quality indicating annual median compliance provided off-shore concentrations are at or better than Richters Creek (as expected).
  - 80th percentile lake concentration increases are typically only 0.004 mg/L higher than median levels (maximum concentrations are only +0.01 mg/L) indicating that this is well below the natural TP fluctuation of Richters Creek of up to +0.03 mg/L for dry weather and +0.08 mg/L for wet weather (based on the 80th percentile medium to long-term trigger for compliance assessment).
  - 90th percentile and max concentration changes in the lake of up to +0.01 mg/L are again well below the 95th percentile short-term pulse compliance trigger (i.e. natural increase of 0.174 mg/L for 95th percentile historical data).

Summary of Lake Performance and Receiving Water Effects

In general, and within the limitations of the data collation, model calibration, verification and impact assessments undertaken to date, the following observations can be made for the numerical water quality modelling assessment of Richters Creek and the near/off-shore environment in regard to likely water quality changes post development:

- Limited to negligible change in salinity concentrations in Richters Creek and the near-shore region.
- No notable change in DO levels throughout Richters Creek and the near-shore region.
- Limited to negligible change in nutrient concentrations in Richters Creek and the near-shore region.
- Limited to no change in chlorophyll *a* concentrations in Richters Creek and the near-shore region.

The following observations can be made for the conservative tracer impact assessment to Richters Creek and the near/off-shore environment:

- Ninetieth (90^{th}) percentile changes (i.e. 90% of all modelled observations) in water quality off-shore were less than 0.1%.
- Median tracer concentrations at the mouth and near/off-shore of Richters Creek is in the order of 3.9% to 9.5%. Dilutions within the bed of the channel are notably less and tracer concentrations are in the order of 30% to 42% for 90^{th} percentile concentrations indicating the effect of salt-wedge stratification in this region.
- Dilution rates upstream of the outlet are also generally high with median tracer concentrations in the order of 1% to 7%. Dilution rates are notably less near the bed of the channel and tracer concentrations are in the order of 10% to 62% for the 90^{th} percentile.

It should also be noted that detailed near-field mixing of the discharged lake water has not been assessed in the regional model and additional detailed modelling assessments will be required and are recommended to estimate the degree of near-field dilution associated with the outlet diffuser operation.

The influence of the proposed Aquis lake discharge is expected to have only a small influence on the receiving environment of Richters Creek including the near-shore environment. Furthermore, and as demonstrated above, if lake water quality is maintained in a similar or better condition to Richters Creek, then no discernible reduction in water quality is expected. This is a reasonable expectation as the lake model indicates that water quality is likely to be better than that of Richters Creek, particularly during increased flows from the Barron River.

Impact on Nearby Aquaculture Operations

The Ponderosa Prawn Farm operated by Cairns Fresh Seafood is located on Lot 2 RP894172 which lies south of the site as shown on the following figure.

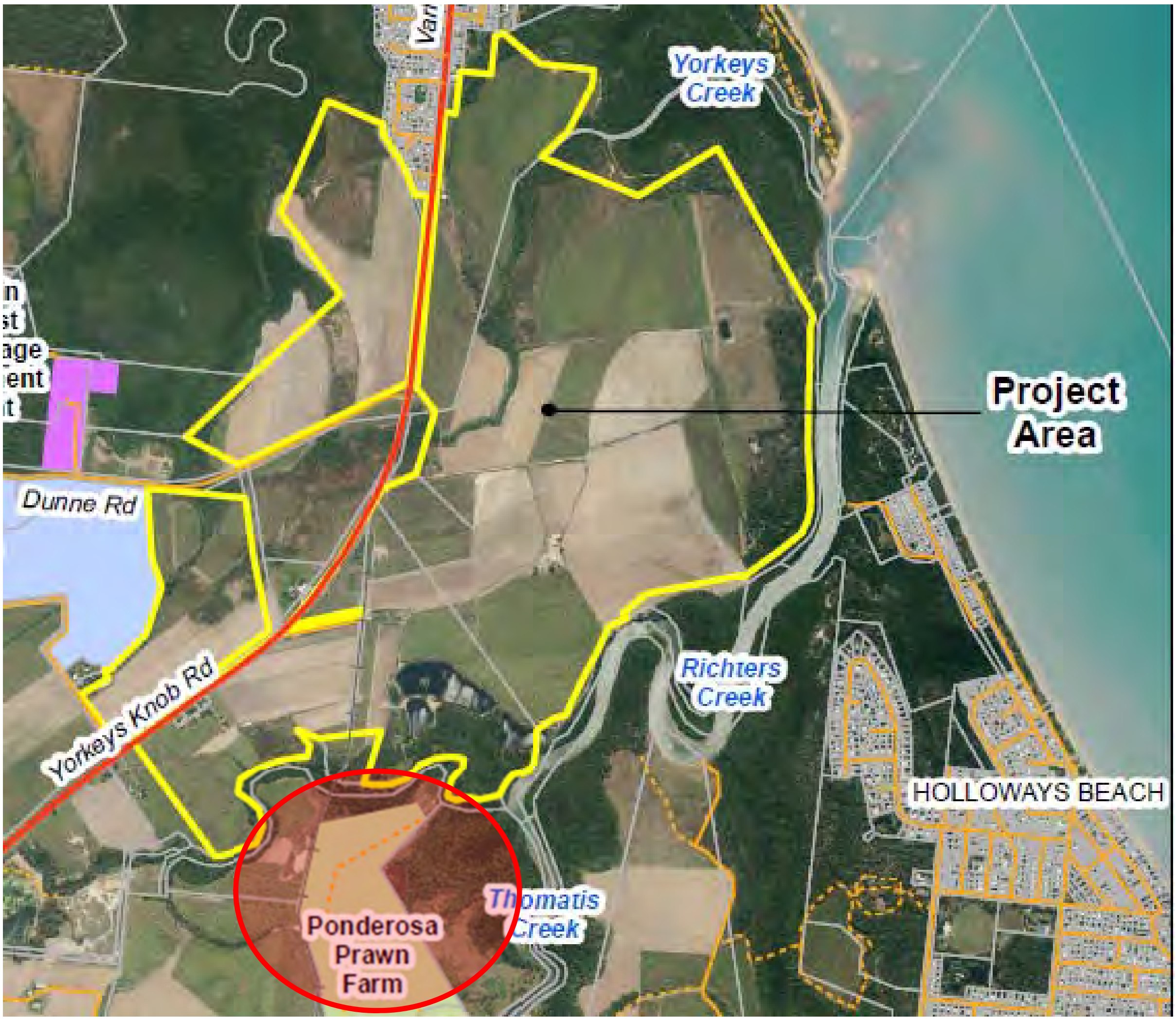

Figure 11-33 Site and Ponderosa Prawn Farm (circled).

This farm has been in operation since 1995 and prior to that the land was used for growing sugar cane. In a submission to the Coordinator-General, the operator listed a number of potential impacts, most of which related to water quality. The aquaculture facility relies on tidal recycling of water equivalent to 10% of pond water volume per day, and this is sourced from Richters Creek. Water quality concerns are:

- previous contaminated land and groundwater – mobilisation of metals and contaminants in waterways
- potential and actual acid sulfate soils – mobilisation of sulfuric acid and metals into waterways
- suspended solids and nutrients increase in waterway
- salinity – increase in total dissolved salts in waterways
- faecal coliforms discharged to waterways from overflows or burst sewers
- flooding – changes to hydrological regime of existing catchment.

The submitter was relying on information in the IAS which was provided without the benefit of detailed work since completed, and in particular any mitigation. The following is a summary of the assessment of likely impacts based on available information. It should be noted the water quality and sediment baseline program currently being designed includes reference sites upstream and downstream of the facility on Richters Creek, selected specifically to allow long-term monitoring to be undertaken as part of the lake management regime.

Contaminated Land and Groundwater

The EIS for the Ponderosa Prawn Farm (Environment Science & Services (NQ) 1995) included an extensive desktop and laboratory study of chemicals then used on the site. This work, in addition to a review of the agrichemical usage history of the site, found all chemicals used on both sites are common chemicals used in association with sugar cane farming. It was found that, although at high concentrations all then-used chemicals can impact aquatic flora and fauna, residual concentrations of organophosphate pesticides and metals and metalloids were unlikely to result in an adverse effect on crustaceans and fish (Fisheries Resource Consultants 1995). It is instructive to note even direct contact with soils containing chemicals by prawns in ponds excavated into such soils, has not been found to be an issue for Ponderosa.

The contaminated land assessment documented in **Chapter 15** (Geology and Soils) identified only Lot 2 on RP800898 was listed on the EMR for petroleum product and oil storage. A site inspection confirmed the presence of fuel and oil containers and tanks and farm chemicals and minor spills. More detailed investigations and possible remediation of contaminated areas will need to occur to enable a Site Suitability Statement to be issued for the proposed development. This can be a condition of development approval.

Residual concentrations of herbicides and pesticides in cultivation areas are not expected to represent a risk to human health and represent a relatively low risk to aquatic ecosystems. However, sediment and erosion control measures should be adopted during construction works to prevent sediment discharges as a precautionary measure.

The management of contaminated land is a component of the proposed EMP (Construction).

Potential and Actual Acid Sulfate Soils

The ASS / PASS assessment documented in **Chapter 15** (Geology and Soils) concluded that although the mobilisation of acid sulfate soils has the potential to create water quality problems that could affect marine organisms, the required management actions are well known and will be a commitment of the Aquis Resort project. The management of acid sulfate soils is a component of the proposed EMP (Construction).

Suspended Solids and Nutrients

The stormwater drainage strategy will result in a substantial net decrease in the export of suspended solids and nutrients from the site when compared with the existing cane farm. This will apply to all of the subject site’s creeks but most particularly for Richters Creek by virtue of biological uptake within the lake. Modelling results for TN and TP are shown below.

TABLE 11-23 CHANGE IN ANNUAL TN AND TP DISTRIBUTION DUE TO LAKE DISCHARGE

Site Location	Vertical Location	10th Percentile (µg/L)	20th Percentile (µg/L)	Median (µg/L)	80th Percentile (µg/L)	90th Percentile (µg/L)
R9 - Thomatis / Richters (TN)	Top	-6	-5	-4	-8	-4
	Avg.	-8	-7	-5	-12	-10
	Bottom	-7	-6	-5	-10	-8
R9 - Thomatis / Richters (TP)	Top	-1	-1	1	-1	0
	Avg.	-1	0	1	0	0
	Bottom	-1	-1	1	-1	0

Source: Appendix M (extract from Table 11-17 and 10-18).

This table shows that concentrations of TN and TP at the confluence of Richters Creek with Thomatis Creek (i.e. near the Ponderosa Prawn Farm) results in a decrease in TN concentration in the range of 4 µg/L to 12 µg/L and a negligible change in TP (between a 1 µg/L increase and decrease).

The impact of these changes is negligible to slightly beneficial.

Dissolved Oxygen

Modelling results for dissolved oxygen are shown below.

TABLE 11-24 CHANGE IN ANNUAL DISSOLVED OXYGEN DISTRIBUTION DUE TO LAKE DISCHARGE

Site Location	Vertical Location	10th Percentile (µg/L)	20th Percentile (µg/L)	Median (µg/L)	80th Percentile (µg/L)	90th Percentile (µg/L)
R9 - Thomatis / Richters	Top	0.0	0.0	0.0	0.0	0.0
	Avg.	0.1	0.1	0.0	0.0	0.0
	Bottom	0.1	0.0	0.0	0.0	0.0

Source: Appendix M (extract from Table 11-16).

This table shows that dissolved oxygen will increase very slightly. The impact of this change is slightly beneficial. As previously noted, current and continuous monitoring indicates that DO saturation is low in the upper reach of Richters Creek and only just above toxic levels for some fish. Any slight improvement in this area would be beneficial.

Salinity

Discharge from the lake will be at essentially the same salinity as that of the receiving waters of Richters Creek during both dry and wet conditions. Under wet season conditions, the salinity in the vicinity of the prawn farm is expected to vary by 0.6% (**Appendix M** Table 12-3). This is insignificant.

TABLE 11-25 CHANGE IN ANNUAL SALINITY DISTRIBUTION DUE TO LAKE DISCHARGE

Site Location	Vertical Location	10th Percentile	20th Percentile	Median	80th Percentile	90th Percentile
		(g/L)	(g/L)	(g/L)	(g/L)	(g/L)
R9 - Thomatis / Richters	Top	0.3	0.4	0.4	0.5	0.7
	Avg.	0.7	0.5	0.4	0.5	0.6
	Bottom	0.4	0.4	0.3	0.1	0.2

Source: Appendix M (extract from Table 11-15).

This table shows that there will be minimal increase in salinity adjacent to the prawn farm. This is expected to be slightly beneficial as it will bring the salinity of the prawn farm's inlet water slightly closer to that of sea water.

Faecal Coliforms

There is a risk that failure of sewerage infrastructure could result in unplanned discharges of untreated sewage. This is a matter that needs attention in the EMP (Operation & Maintenance) as discussed in **Section 23.4.5**.

Flooding

During flood conditions any material mobilised from the site will flow downstream, away from the Ponderosa facility. At such time any Aquis Resort runoff will join the huge Barron River floodwaters where it will receive significant dilution. The Ponderosa facility will also be flood-affected and it is unlikely that Aquis Resort will contribute to any impacts under these circumstances.

Management of Impacts

The management of lake water quality will ensure that any impacts on the prawn farm will be minimal. The current monitoring program (**Section 23.6**) includes sites in Richters Creek upstream and downstream of the prawn farm and these will be used to monitor changes in water quality. These locations will allow for changes in water quality attributable to the prawn farm discharge itself to be isolated.

<u>Construction Phase Impacts</u>
Potential (i.e. unmitigated) construction phase impacts of the Aquis Resort are summarised below.

TABLE 11-26 IMPACTS OF PROJECT CONSTRUCTION

PROJECT FEATURE	CONSTRUCTION ASPECT	POTENTIAL IMPACTS TO WATER QUALITY
Lake and Resort Complex Precinct	Mechanical excavation and dredging to form the lake.	Increased turbidity and reduced light penetration from overflow or runoff to Richters Creek or Yorkeys Creek and ultimately Trinity Bay. Uncontrolled release of turbid water during periods of Barron River flooding. Potential mobilisation of contaminants from the sub-surface land material. Smothering of aquatic biota through uncontrolled sediment release. Disturbance of acid sulphate soils and/or the potential release of acid water.
	Placement of dredged material to dredged spoil zone	Increase turbidity and potential mobilisation of contaminants to Richters Creek. Siltation into the Richters Creek dense wetland area (refer to Ecological report) causing health and bio-diversity issues for aquatic life.
	Construction of revetments to protect the lake from erosion	Increased turbidity and reduced light penetration from overflow or runoff to Richters Creek or Yorkeys Creek. Disturbance of acid sulphate soils and/or the potential release of acid water.
	Tailwater discharge from the lake platform areas	Increased turbidity and reduced light penetration from tailwater discharge to Richters Creek or Yorkeys Creek.
	Lake overflow and rock armouring	Increased turbidity and reduced light penetration from tailwater discharge to Richters Creek or Yorkeys Creek.
Sport and Recreation Precinct & Environmental Management and Conservation Precinct	Clearing and re-profiling ground surfaces to desired levels	Loss of topsoil and/or sediment to Half Moon Creek and Yorkeys Creek. Health and biodiversity issues for aquatic life due to increased turbidity and reduce light penetration. Siltation into the Half Moon Creek dense wetland areas causing health and biodiversity issues for aquatic life.
Yorkeys Road Upgrade	Construction of waterway culvert crossings	Increased turbidity to waterway.
	Construction of emban kment foundation for road raising	Loss of topsoil and/or sediment to Half Moon Creek and Yorkeys Creek.

Source: Study team compilation based on **Appendix M**.

The principal potential impacts on water quality during construction are expected to be:

- impacts arising from disturbance of soils (broadscale erosion and sedimentation, release of soil contaminants from isolated areas, and acid sulfate soil issues)
- the consequences of flooding when the site is in a vulnerable condition.

11.3.2 Mitigation and Management

a) Construction Phase

Construction methodology Issues

Section 11.2.2a) documents construction phase impacts from the perspective of stormwater drainage. These also apply to the construction of the lake as it is part of the site earthworks. As noted, all necessary construction management actions will be integrated into the comprehensive EMP (Construction) as detailed in **Section 23.4.4.**

The construction methodology requires that the lake will be excavated and constructed over approximately a four year period and will act as a detention basis during this time. Following rainfall, the lake will periodically pond freshwater, and during significant flood events, will overtop and fill with floodwaters.

The management of water in this construction–phase lake will be the same for the post-flood operation phase for overtopping flood events. For local runoff events that result in significant ponded water in the lake, the intent is to maintain a significant active buffer in the lake to contain up to the 10% AEP flood event. Pumped discharge to Richters Creek will occur after water quality testing and as necessary with neutralisation and flocculation. This requires that lake exchange infrastructure and construction phase power is available early in the construction period.

Other water quality aspects of construction staging require:

- completion of the groundwater quarantining works prior to excavating the lake below the groundwater level (this will be required in any event as part of the dewatering strategy for the Resort Complex Precinct basement construction)
- management of the site to ensure that works and plant are protected when there is a risk of flood (this may involve temporary bunds – and associated flood mitigation works where required – and drains) or cessation of high risk activities during the wet season.

The presence of the abandoned aquaculture ponds (to be drained and filled) provides an opportunity during construction as they are large ponds with high bunds that may be suitable for a range of soil and water management activities.

Detailed construction staging and methodology for the lake will be planned and detailed to prevent adverse impacts.

Performance Objectives and Management

The typical approach to operational water quality compliance is to assess the discharge quality against the QWQG guideline values. This method allows a direct comparison of the likely compliance with established guidelines to ensure protection and / or enhancement of environmental values for the waters of concern. As noted in the QWQG guidelines, the ANZECC (2000) guidelines provide a default approach to assessing the long-term chronic (i.e. sustained) compliance and this approach has been taken for the ‘normal’ dry season and situations.

However, the ANZECC (2000) default approach (i.e. chronic compliance method) is not appropriate for assessing medium- and short-term compliance that will be relevant for periods during construction and during storm and flood conditions. For medium and short-term compliance, ANZECC (2000) recommends that new guidelines should be derived based on background data. For the Aquis Resort project, long-term, medium-term, and short-term water quality compliance will be measured through an in situ water quality program using physico-chemical and biological indicators within the lake, Richters Creek and other receiving waters. A detailed monitoring program to establish local discharge / acceptance criteria commenced in December 2013 and will continue for at least 12 months.

Construction

Construction will require several years of continuous, seasonal, and short-term construction tasks. Compliance protocols will correspondingly require short, medium, and long-term periods to ensure that temporary construction impacting activities are acceptable and within the natural variability of the receiving environment. In general, however, the construction activity has a limited life, and water quality over relatively short time frames cannot always be appropriately compared to the long-term QWQG where annual median water quality figures are used. As a result, site-specific trigger values for water quality values have been developed to assess the potential impacts to the receiving environment and ecologically sensitive areas. The approach used above for flooding compliance (trigger analysis) is appropriate for construction. As noted previously, this approach requires quality baseline data and relies on the assumption that marine species regularly encounter (and survive) episodic pulsed turbidity and sedimentation events.

This methodology can be used to determine impacts to receiving environments, and involves the following process using data collected from a single site (i.e. the assessment is undertaken on a site-by-site basis):

- Based on long-term monitoring data, the 95th (threshold concentration) and the 99th (intensity) percentile total suspended solid (TSS) concentration are calculated.
- The data set is then analysed to determine the duration of all events (exposure times) during which the threshold value is exceeded. The 95th percentile longest event is calculated as the duration guideline value.
- The data-set is again analysed to develop ‘frequency’ guideline values. To develop frequency guidelines, all events exceeding the threshold value are grouped into classes by duration. A nominal timeframe is adopted, and the 95th confidence limit is then selected as the total allowable frequency.

This approach essentially establishes a ‘no change’ limit for individual locations, where the assessment is referenced with regard to the historical exceedance profile of each location. The concentration limits are calculated based on the baseline conditions.

As the long-term data is particularly distinct for wet and dry periods that show large variability in TSS, site-specific thresholds are deemed more appropriate than a ‘one size fits all’ approach, particularly during wet or flooding periods. The thresholds will need to be refined for specific areas using background data of suitable quality and quantity. Thus, the continual collection of water quality data from a range of receptor sites adjacent to the Aquis Resort site will further support the robustness of the recommended approach and setting performance objective, particularly during times of flood.

b) Operation Phase – Water Quality Management

<u>Overview</u>

As noted throughout this chapter, there has been a strong emphasis on avoidance and minimisation of water quality impacts by design. Key aspects are summarised below:

- Lake and Resort Complex Precinct:
  - 14 day lake turnover using water from 2.2 km off-shore where near-shore water quality problems are largely absent.
  - Strict receiving waters discharge criteria with discharge only allowable when suitable standards are achieved and only on ebb tide.
  - Where discharge criteria cannot be achieved, alternative (i.e. emergency) seven day turnover of lake water using the normal inlet and outlet pipework, but pumping for 24 hours a day.
  - Suitable lake bathymetry design and mechanical mixing (vertical and horizontal) to minimise adverse water quality impacts, e.g. stratification, benthic growth.

- Best practice stormwater management measures for the Resort Complex Precinct development to reduce pollutant loads into the lake.
- Best practice stormwater harvesting for re-use throughout the development.
- Re-use of treated effluent from sewage produced on-site to reduce the overall export of pollutants to the GBR lagoon.
- On-going and comprehensive reactive water quality monitoring regime.

- Balance of Site:
  - Best practice stormwater management measures for the development area to reduce pollutant loads into the receiving creeks.
  - Best practice stormwater harvesting for re-use throughout the development.
  - Best practice measures for golf course design and operation.
  - Use of Class A treated effluent from the Marlin Coast / Northern Cairns STP as a potable water substitute and the opportunity to remove all residual pollutants on-site, to the benefit of the receiving waters.

<u>Lake Management</u>

In addition to these design-related factors (essentially all related to improving the quality of stormwater drainage inflows and internal flushing) are a number of management actions, including:

- Treatment of lake water in-place before discharge during adverse water quality conditions, including emergency event filtration using the lagoon treatment system.
- Lake management and maintenance measures including clean-up after floods, de-silting through periodic dredging, and aquatic plant harvesting

These are proposed to be included in the Lake Water Quality Management Plan and Sedimentation and Maintenance Dredging Plan outlined below.

Management of aquatic ecology aspects is described in **Section 11.3.2c)**.

Lake Water Quality Management Plan

Table 11-27 below sets out a conceptual Operational Lake Water Quality Management Plan.

TABLE 11-27 OPERATIONAL LAKE WATER QUALITY MANAGEMENT PLAN

EMP ELEMENT COMPONENT	DESCRIPTION OF CONTENT
Summary of environmental values	Water quality EVs within the lake (amenity and ecology). Water quality EVs within the receiving water of Richters Creek.
Summary of potential impacts	Loss of amenity and ecological function within the lake. Degeneration of lake water quality resulting in a loss of environmental values in Richters Creek if discharged.
Element / issue	**Water Quality - Lake Management Discharge / Intake**
Objective	To maintain a lake water quality and hence the discharge water quality consistent with the QWQG indicator values (i.e. physico-chemical values) or local receiving waters objectives, if determined, to ensure a no loss of environmental value is observed in Richters Creek.
Performance criteria	Compliance of lake and discharge water with performance criteria identified in **Table 11-12** based upon the QWQG and updated using local data.

EMP ELEMENT COMPONENT	DESCRIPTION OF CONTENT
Implementation strategies	Development and implementation of a Water Quality Monitoring Plan based on the water quality objectives and findings of the EIS, and subsequent baseline monitoring. Modify (refer to **Table 11-12** Physico-Chemical Stressor) or suspend (refer to **Table 11-12** - Toxicants) either intake or discharge of lake water in the event that environmental monitoring detects exceedance/s of trigger values.
Monitoring	**Reactive Monitoring (Water Quality)** Aquis Resort will implement the following reactive environmental monitoring programs: • Intake and Discharge Monitoring Program • Ecology Health Monitoring Program These monitoring programs underpin the reactive management response framework. Baseline monitoring will be undertaken to supplement the existing baseline data set presented in this report. On the basis of these baseline data, 'threshold' and 'intensity' guideline values will be developed based on QWQG and ANZECC guidelines. These guideline values will form the basis for implementing corrective actions. Contingency measures involving limiting the volume of discharge and / or the use of the swimming lagoon treatment plant will be implemented as required on the basis of this monitoring. **Additional Environmental Monitoring** Where required Aquis Resort will implement additional monitoring programs on sensitive receptors sites (if found).
Auditing	Aquis Resort will undertake a general audit of the environmental management systems and performance in accordance with its EMS at quarterly time periods during the operation of the lake.
Reporting	**Reactive Monitoring Program** The environmental officer will summarise all monitoring results into a data register within one week of each monitoring episode. A water quality register is to be archived and kept for a minimum of five years. The environmental officer will prepare a surveillance report at the completion of each monitoring episode. The surveillance report will be submitted to the Aquis environment manager within one week of each monitoring episode, and will identify any significant changes to water quality and corrective actions implemented. The environmental officer will provide an annual report to the Aquis environmental manager. The report will include a summary of all monitoring results and any contingency actions undertaken to avoid non-compliant intake or discharge reoccurring. **Incident Reporting** The environmental officer will prepare an incident report in the event of any corrective actions being implemented. The report will be submitted to the Aquis environment manager within one week of the implementation of corrective actions. The environmental officer will provide an annual incident report to Aquis environmental manager. The report will include a summary of all monitoring results and any contingency actions undertaken to avoid non-compliant intake or discharge reoccurring.

EMP ELEMENT COMPONENT	DESCRIPTION OF CONTENT
Corrective action	**Water Quality Monitoring Program** In the event of exceedance of trigger values, corrective actions will be implemented as follows: Level 1 Management Response - the lake operation will be optimised to reduce the risk of further impacting on the discharge to Richters Creek. These measures will remain in place until the lake operation return to normal operating conditions. Level 2 Management Response - discharge to Richters Creek will be suspended and treated in-place until such time as the Physico-Chemical levels falls below the discharge quality guideline. Upon reinstatement of discharge, Level 1 management measures will continue until normal operating conditions prevail.

Source: Appendix M (Table 14-1).

Sedimentation and Maintenance Dredging Plan

Table 11-28 below sets out a conceptual Sedimentation and Maintenance Dredging Plan.

TABLE 11-28 OPERATIONAL LAKE SEDIMENTATION AND MAINTENANCE DREDGING PLAN

EMP ELEMENT COMPONENT	DESCRIPTION OF CONTENT
Summary of environmental values	Water quality EVs within the lake (amenity and ecology); Water quality EVs within the receiving water of Richters Creek;
Summary of potential impacts	Reduced conveyance of flood flows. Mobilisation of contaminants from disturbance of either in situ sediments or sediments from floods affecting water quality. Loss of lake volume due to build-up of sediments. Smothering of aquatic flora and fauna with sediment in Richters Creek resulting in stress or mortality.
Element / issue	**Sedimentation and turbidity management - dredging**
Objective	To minimise the build-up of sediment within the lake and to minimise the effect of re-suspension / mobilisation of sediments that could impact on the receiving environment (i.e. Richters Creek) if discharged.
Performance criteria	With 0.5 m initial over-dredge (to be confirmed), annual lake surveys at defined sections will be undertaken, with the following trigger levels for dredging being: • when average depth has been reduced by more than 300 mm siltation • when individual points have silted more than 1 m.
Implementation strategies	Engage appropriate dredge plant to remove sediment and minimise the generation of turbid plume. Limit dredging on the non-discharge cycle to minimise discharge of turbid plumes. Provide silt curtain around the intake of the discharge pipe line to reduce discharging of turbid plumes. Development and implementation of a Water Quality Monitoring Plan based on the water quality objectives and findings of the EIS, and subsequent baseline monitoring. Modify or suspend dredging activities in the event that environmental monitoring detects exceedance/s of trigger values.

EMP ELEMENT COMPONENT	DESCRIPTION OF CONTENT
Monitoring	**Reactive Monitoring (Water Quality)** Aquis Resort will implement the following reactive environmental monitoring programs: • Discharge Monitoring Program • Ecology Health Monitoring Program These monitoring programs underpin the reactive management response framework for maintenance dredging. Baseline monitoring will be undertaken to supplement existing baseline data set presented in this EIS. On the basis of these baseline data, 'threshold' and 'intensity' guideline values will be developed based on methods outlined by McArthur *et al.* (2004). These guideline values will form the basis for implementing corrective actions. Contingency measures will be implemented by the dredger as required on the basis of this monitoring. **Additional Environmental Monitoring** Where required, Aquis Resort will implement additional monitoring programs on sensitive receptors sites (if found).
Auditing	Aquis Resort will undertake a general audit of the environmental management systems and performance in accordance with its EMS at least twice during the dredging campaign.
Reporting	**Reactive Monitoring Program** The environmental officer will summarise all monitoring results into a data register within one week of each monitoring episode. On completion of the dredge operations, the register is to be archived and kept for a minimum of five years. The environmental officer will prepare a surveillance report at the completion of each monitoring episode. The surveillance report will be submitted to the Aquis environment manager within one week of each monitoring episode, and will identify any significant changes to water quality and corrective actions implemented. The environmental officer will provide a final report to the Aquis environmental manager within 40 business days of the completion of dredging operations. The report will include a summary of all monitoring results and any contingency actions undertaken to avoid non-compliant dredge runs reoccurring. **Incident Reporting** The environmental officer will prepare an incident report in the event of any corrective actions being implemented. The report will be submitted to the Aquis environment manager within one week of the implementation of corrective actions. The report will include a summary of all monitoring results and any contingency actions undertaken to avoid non-compliant dredge runs reoccurring.
Corrective Action	**Water Quality Monitoring Program** In the event of exceedance of trigger values, corrective actions will be implemented as follows: Level 1 Management Response - the dredging operation will be optimised to reduce the risk of plumes further impacting on the Richters Creek discharge. These measures will remain in place until the completion of dredging activities. Level 2 Management Response - dredging will be suspended until such time as the median turbidity level falls below the Intensity Guideline. Upon reinstatement of dredging, Level 1 management measures will continue for the remainder of the dredging campaign.

Source: Appendix M (Table 14-2).

Specific Management Actions

Some of the matters described above are discussed in more detail below.

Lake de-silting

Accumulated sediments may wash into the lake and this could reduce its operating volume as well as lead to water quality problems due to breakdown of organic material contained in sediments. As discussed in **Chapter 9** (Flooding), a conservative estimate under severely adverse conditions is that the likely siltation will be, at worst, less than 6% of the lake depth if all of the sediments carried by a 1% AEP flood over the whole site fall out in the lake. It is estimated that on average, the lake would not require de-silting more than once every 10 years.

The lake bathymetry will be monitored through annual lake surveys at defined sections and trigger levels set to define when maintenance dredging will be required. It is unlikely that sedimentation would be evenly spread over the lake and it is far more probably that it will accumulate in specific locations. This permits two management options to be considered:

- use of a levelling bar dragged over the bed to distribute local mounds of sediment
- use of a small suction dredge to remove such mounds.

In any case, bed levelling and a small suction dredge located on-site for use in maintaining the required bathymetry of the lake. Accumulated sediment will be pumped to the silt disposal facility within the site for initial storage and treatment and exported off-site.

Containment and Treat In-Place

Normal top water level will be +1.5 m AHD and at that level the lake volume is approximately 1.3 GL. There is an additional volume of 0.17 GL between normal water level and the top of the surrounding bunds (approximately 2.0 m AHD). This provides temporary storage capacity (an additional 13%) for rainwater, floods, and an emergency volume for storing water that cannot be discharged for any reason.

As a final option to ensure acceptable water quality within the lake, a contingency option exists to temporarily suspend the lake pumping system and use the lagoon filtration system. The lagoon is a large man-made saltwater pool on the Resort Complex Precinct with a dedicated filtration system that could, in an emergency, be used to treat lake water which could then be directly discharged to Richters Creek or recirculated, depending on quality.

Flood Management During & After Flood Events

Following a flood event, initially the lake will drain back to Richters Creek via overtopping of the 2 m AHD bund system around the lake. As it drains below this level, the two proposed outlet weirs (i.e. invert level 1.5 m AHD) and channels will further drain the lake. By incorporating flood flaps (to prevent flood flow back into the lake up to 2 m AHD) and drop boards (to allow the weir to be lowered temporarily to 1.0 m AHD), gravity drainage can continue. The general process of flood management is as described below:

- Discharge as much of the contents of the lake water continuously on the receding portion of the flood until Richters Creek has returned to near normal / predicted tidal levels. Under these circumstances, natural water quality in Richters Creek will be quite low and the creek will have a substantial capacity to convey large volumes of water out to sea.
- It is anticipated that approximately 0.64 GL or 45% of the lake's dry-weather volume could be discharged back into Richters Creek within a 48 hour period when the creek is flood-affected.
- Following return to normal water quality levels in Richters Creek, in situ monitoring of the Barron River and Richters Creek turbidity would be required to determine the pump-out regime of the remaining lake water to align with appropriate trigger levels.

- Following maximisation of discharge to Richters Creek, flushing will resume on a 24 hour per day basis to maximise the inflow of clean and saline water. This will aid dilution of turbidity and nutrients and raise salinity. The natural flocculent ability of seawater will assist in settling out suspended solids – if further reduction in turbidity is required a flocculent such as gypsum may also be added, and/or the use of the internal filtration system for the lagoon as described above initiated.
- When the lake system is full and has returned to an acceptable quality then re-commencement of typical dry weather turnover regime to Richters Creek can occur.

A time frame in the order of one to two weeks is likely to be required before the normal lake operating procedure is completely achieved. It should be noted however, that the period of pumping and treatment will vary depending upon the in situ water quality that results from a flood event and the continuous settling that will occur during the pump-out period.

As noted above, settling of sediment particles will naturally occur within the existing lake following a flood event particular when saline water is added. This naturally occurring settling process will assist with meeting the discharge criteria limits and reduce the need for all flood waters to be treated prior to discharge.

c) Operation Phase – Aquatic Ecology Aspects

Overview

The intended lake environment is a saline waterbody expected to be equal to, or better than, water quality in the adjacent Richters Creek to which it will discharge water. Such an environment will be naturally colonised by a variety of marine flora and fauna species. Likely properties of the future lake environment have been given substantial consideration from a water quality perspective as described above. In addition, a number of ecological aspects have also been addressed, namely:

- protection of fish at the inlet and outlet works
- algal blooms and aquatic plants
- potential impacts to fish in the lake
- management of pest fish
- mosquitos and biting midges
- crocodiles (see **Chapter 20** – Health and Safety)
- sharks
- birds of concern for aircraft strike (see **Chapter 24** – Infrastructure).

These issues involve a combination of impact assessment and impact mitigation / management that are collected together in this section from a management perspective.

Protection of Fish at the Inlet and Outlet Works

The proposed inlet and outlet structures are shown on **Figure 11-15** and **Figure 11-16**. Important ecological criteria for the design of these structures have been discussed, namely:

- inlet issues, i.e. possible entrapment of fish and other marine organisms and / or entrainment of these into the inlet flow and hence transport to the lake
- outlet impacts, principally velocity of water but also including possible export of undesirable lake fauna.

Algal Blooms and Aquatic Plants

Blooms of micro-algae (phytoplankton) are commonly triggered by nutrient-rich stormwater inflow, or nutrient-rich sediments being re suspended. WSUD features will be extensively employed to effectively minimise the inflow of stormwater from the lake's catchment. An off-shore inlet, together with the proposed rate of water exchange (14 day turnover, able to be increased to a seven day turnover), will enable the rapid reduction of elevated nutrient concentrations.

Given the expected clarity of the water sourced via the off-shore intake, it is likely that, over time, seagrasses and macro algae will establish in the lake (propagules being both pumped in and brought to the lake by water birds). Again, the proposed rate of water exchange will prevent the build-up of nutrients and result in a very low risk of excessive macro algal growth.

Fish Kills

Likelihood

Although the inlet for lake water exchange will be screened and velocities will be sufficiently low to avoid the entrainment of adult fishes, the planktonic eggs and larvae of fishes and invertebrates will be carried into the lake by the flow in the pipe. Modelling described above indicates that water quality within the lake will be broadly similar to that of adjacent inshore waters, and able to support a similar assemblage of fishes and invertebrates. Therefore, any fish and other marine animals that survive the passage through the pump and end up in the lake are likely to survive under normal (dry) lake conditions.

Significant flood events (>50% AEP) will result in the reduction of salinity within the lake. Salinity will decrease by approximately 12% (a quantum unlikely to result in morbidity or mortality) before water flows from the lake via the designed overflows. Under severe flood conditions, however, freshwater may completely displace the lake’s saltwater. At this time, it is likely that many of the lake's fishes will be cued by the inflow of freshwater to swim downstream (as they would in the adjacent creek), thereby exiting the lake via the designed overflows.

However, it is also likely that a potentially large number of fish will be unable to escape the lake, and together with the lake's community of invertebrates (that may comprise an infaunal assemblage of the lake bed and epifaunal assemblage of the lake revetments), will be subjected to a potentially catastrophic decline in salinity. A decline in salinity from near oceanic levels by approximately 30% or more over a period of 24 hours or less will likely result in significant mortality of both fishes and invertebrates.

Management of Fish-Kills

Dead fish will initially sink, floating to the surface after approximately 24 hours (buoyed by the gases produced by microbial decomposition). Prevailing winds will then aggregate floating dead fish against downwind sections of the lake wall.

As a management response, dead fish will be collected from the surface of the lake, through an intensive effort over typically 48 to 72 hours, aimed at removing the majority of dead fish before putrefaction sets in. Dead fish will be disposed of to landfill off-site.

The proposed lake water exchange regimen will rapidly return lake water nutrient concentrations (likely to become elevated as fish, invertebrates and macrophytes decay) to background levels.

Whilst fish-kills are likely to be an inevitable consequence of significant flood events, preparedness and prompt action to remove dead fish will result in only a brief period of impact to both the amenity of the lake and its ecosystem health. The impact on downstream water quality and ecosystem health will be negligible in the context of the associated flood flow.

Management of Pest Fish

See **Chapter 19** (Biosecurity). This discussion includes recommendations for the development of a comprehensive pest fish management plan.

Mosquitos and Biting Midges

See **Chapter 20** (Health and Safety). This discussion includes recommendations for lake edge design and the development of a comprehensive mosquito and biting midge management plan.

Crocodiles

See **Chapter 20** (Health and Safety). This discussion includes recommendations for lake edge design and the development of a comprehensive crocodile management plan including a safety program for guests and staff.

Sharks

Screening of the inlet (and outlet) structure will prevent sharks from entering the lake via the seawater delivery pipeline. However, sharks such as the bull shark (*Charcarinus leucas)* are likely to be present in Richters Creek and may enter the lake via overland flood flow.

Given that the lake is not designed for active recreation (swimming or boating), and may support crocodiles, the presence of one or more sharks would not of itself justify a catch-and-release program. Over time, the lake may be able to support a number of sharks (the lake will likely support a healthy assemblage of smaller fish and crustacea. However provision will be made for their removal where a lack of prey contribute to evident morbidity or mortality. Drum-lining is the accepted most practical means of capturing sharks in large waterbodies and would be undertaken by specialist professional fishers.

Prominent signage will warn visitors of the risk of shark attack and education on-site safety will include material on sharks.

Birds of Concern for Aircraft Strike

See **Section 24.4**. This discussion includes recommendations for lake edge design and the development of a comprehensive bird strike management plan.

Summary / Project Implications

The main project implications arising from the consideration of lake management needs are:

- develop a series of management plans dealing with:
  - operational lake water quality
  - operational lake sedimentation and maintenance dredging
  - pest fish management plan as part of an overall fish stocking and management plan
  - crocodile management and other aspects of lake safety (stressing that the lake is not proposed to be used for contact recreation)
  - midge and mosquito management
  - harvesting of algal blooms and aquatic plants
- consider various design solutions to several issues, including:
  - lake edge treatment (several issues point towards a solution that give a preference to steep (perhaps vertical) walls rather than sloping beaches lined with mangroves, riprap, or structural elements)
  - screen and / or grill design for the inlet and outlet pipes
  - floodway works to reduce the risk of sharks entering the lake during floods.

Integrated Water Management Strategy

An important aspect of water resources planning is the overall management of the water cycle through Integrated Water Management (IWM).

Overview

IWM is a coordinated and strategic planning process for the holistic management of water, wastewater and stormwater systems. It promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment.

IWM takes a landscape view of water challenges by looking at competing water uses, and allows the leveraging of efficiencies and promotion of conservation. In urban design and development, it is best implemented using WSUD principles, which integrate land and water planning.

The integration of IWM and WSUD offers a diverse and versatile set of options for dealing with complex urban water challenges in the urban context, ensuring multiple and balanced economic, environmental and social benefits are achieved. An Aquis Resort Water Management Strategy is recommended, based upon the combined principles of IWM and WSUD, which are described further below.

Aquis Resort IWM / WSUD Principles

The proposed Integrated Water Management Strategy (IWMS) for the Aquis Resort site is guided by a series of principles aimed at directing subsequent planning stages to better facilitate the IWM / WSUD planning and design processes. These principles apply throughout the lifecycle of the development including the planning / design, construction, establishment and operational phases. Many of these principles are based on the National Water Commission's (2013) WSUD principles, and include the following:

Principle 1: Minimise the impact on existing natural features and ecological processes

Principle 2: Minimise impact on natural hydrologic behaviour of catchments

Principle 3: Protect water quality of surface and ground waters

Principle 4: Minimise demand on the reticulated water supply system

Principle 5: Improve the quality of, and minimise polluted water discharges to the natural environment

Principle 6: Incorporate collection treatment and / or reuse of runoff, including roof water and other stormwater

Principle 7: Reduce run-off and peak flows from development

Principle 8: If possible, re-use treated effluent and minimise wastewater generation

Principle 9: Increase social amenity through multi-purpose greenspace, landscaping and integration of water into the landscape to enhance visual, social, cultural and ecological values

Principle 10: Add value while minimising development costs

Principle 11: Account for the nexus between water use and wider social and resource issues

Principle 12: Design to reduce the urban heat island effect and warming of waterways

Principle 13: Monitor the efficacy of solutions as well as the response in receiving ecosystems

Principle 14: Adaptively manage the development so that it continually maintains the adopted IWM principles and best practice standards as they evolve.

These principles will inform a detailed IWMS to be completed in the next phase of the planning and design process. The IWMS will include a detailed IWM plan and initiatives to optimise the integration of these fourteen IWM principles for the development.

11.3.3 Residual Impacts

The following is a summary of the residual (i.e. post-mitigation) impacts determined using standard risk assessment methodology. This assessment includes the normal / dry, wet, and flood scenarios using the water quality results described previously. The assessment also considers impacts at both the 'local' scale (i.e. within the immediate discharge zone) and the 'regional' scale (i.e. near-shore area and Richters Creek 2 km away from the immediate discharge zone). The following tables deal with the lake and non-lake catchments.

TABLE 11-29 LAKE CATCHMENT IMPACT ASSESSMENT SUMMARY – WATER QUALITY

Primary impacting process	Potential impact	Magnitude of impact	Likelihood of impact	Risk rating	Mitigation measures	Residual risk
Discharge of lake water	Lake water quality exceeding the QWQG and ANZECC guidelines.	Local Scale: *High* Discharge of lake water that eithers exceed the QWQG or ANZECC physio-chemical guidelines to Richters Creek (i.e. at the point of discharge) may result in detrimental impacts or mortality to the ecological environment from potentially toxic or chronic effects.	*Possible*	*Medium*	Implementation of an ongoing water quality monitoring program with management actions implemented if trigger levels are exceeded, such as: accelerated inlet delivery slow or suspended discharge treat in-place.	*Low*
		Regional Scale: *High* Discharge of lake water that eithers exceed the QWQG or ANZECC physio-chemical guidelines to Richters Creek and Trinity Bay causing long-term degeneration of the ecological environment.	*Unlikely*	*Medium*	As above.	*Low*
Sediment accumulation and maintenance dredging	Internally and externally the lake water quality exceeds the QWQG and ANZECC guidelines.	Sediment Accumulation: *Negligible* A slight reduction in flood conveyance and the potential for mobilisation and / or re-suspension of contaminated or high nutrient sediment during a flood.	*Rare*	*Negligible*	With 0.5 m initial over-dredge and annual lake surveys, dredging will occur when: average depth has been reduced by more than 300 mm siltation individual points have silted more than 1 m.	*Negligible*
		Maintenance Dredging: *Moderate* Dredging of the lake has the potential to re-suspend sediment, and for this sediment to be discharged to Richters Creek through the lake turnover operation.	*Likely*	*Medium*	A silt curtain will be used to ensure any temporary increase in turbidity is not discharged to Richters Creek. Continuous in situ water quality monitoring to ensure discharge compliance (discharge will be suspended if turbidity is excessive).	*Low*

Primary impacting process	Potential impact	Magnitude of impact	Likelihood of impact	Risk rating	Mitigation measures	Residual risk
Flooding	Lake water quality exceeding the QWQG and ANZECC guidelines.	Local Scale (i.e. in lake): *Low* The lake is likely to receive sediment-laden runoff that has a turbidity level and high nutrient load during a flood. The resulting lake will most likely be fresh depending upon the size of the flood.	*Likely*	*Medium*	Release of flood waters from the lake will be in accordance with the Flood Management Plan. Water quality monitoring with site-based trigger levels and reactive management actions, such as: accelerated inlet delivery slow or suspended discharge treat in-place.	*Low*
	Discharge of lake water exceeds trigger level of Richters Creek.	Regional Scale: *Moderate* Discharging of lake water with high turbidity and nutrients to Richters Creek following the flood may impact upon the sensitive habitat within Richters Creek and Trinity Bay.	*Likely*	*Medium*		*Low*
Groundwater	Receipt of groundwater that is high in dissolved nutrients and/or contaminants.	Local Scale (i.e. in Lake): *Low* The lake is likely to received small quantities of inflow of groundwater that may be high in nutrients. An increase in nutrient load to the lake if in sufficiency quantity may promote algae / plant growth.	*Unlikely*	*Low*	The lake will be quarantined from groundwater to reduce / prevent groundwater exchange (see Note 1) Turnover of the lake will occur in a 14 day cycle to reduce build-up of nutrients.	*Low*
		Regional Scale: *Negligible* Discharging of lake water, if in sufficiency quantity of nutrients, to Richters Creek may impact upon the sensitive habitats within Richters Creek. It should be note that groundwater discharge to Richters Creek will continue to occur without the development.	*Unlikely*	*Negligible*	Groundwater will continue to discharge to Richters Creek without the development, hence forms part of the existing environment.	*Negligible*

Source: Study team compilation based on **Appendix M** (Table 12-1).

Note 1. Quarantining the lake from groundwater effectively mitigates this risk entirely.

TABLE 11-30 NON-LAKE CATCHMENT IMPACT ASSESSMENT SUMMARY

PRIMARY IMPACTING PROCESS	POTENTIAL IMPACT	MAGNITUDE OF IMPACT	LIKELIHOOD OF IMPACT	RISK RATING	MITIGATION MEASURES	RESIDUAL RISK
Stormwater runoff from development (i.e. golf course, tennis centre etc.).	Increased pollutant loads typically containing TSS, nutrients and gross pollutants to the receiving environments of Richters, Yorkeys and Half Moon Creek.	Local Scale: Low to Moderate An increase in pollutant loads at the discharge point could potentially affect water quality near sensitive habitats.	*Likely*	*Medium*	‘Best practice’ water sensitive urban design measures will be implemented to achieve the prescribed performance objectives. Stormwater harvesting and re-use will be implement further reducing the pollutant load that reaches the receiving environment.	Low
		Broad Scale: *Low* The increased in pollutant loads relative to the catchment size and existing cane farming runoff quality is unlikely to impact on the broader values due to quantum of dilution and dispersion.	*Possible*	*Low*	As above.	Low
Regional flooding	Flood water high in suspended sediment will be deposited upon or in stormwater treatment measures.	Local Scale: *Negligible* Sediment deposition on bio-filtration areas will reduce the permeability of the device and the treatment effectiveness. Sediment may also cause blockage of EnviroPods and stormwater filter devices resulting in ineffective treatment and by-pass of flows.	*Likely*	*Low*	Sediment will need to be remove and filter material replaced if required (top surface only) to maintain permeability and effectiveness. Filters for EnviroPods and StormFilter will need to be replaced	Low
	Sediment and associated nutrients will be deposited on hardstand areas could be washed off during local storm events to receiving environment.	Local Scale: *Moderate* An increase in pollutant loads at the discharge point could potentially affect water quality near sensitive habitats.	*Likely*	*Medium*	Sediment wash-off, capture and collection to sediment disposal area will be required. Street sweeping of all hardstand (car parking in particular) will be required following a flood event.	Low

PRIMARY IMPACTING PROCESS	POTENTIAL IMPACT	MAGNITUDE OF IMPACT	LIKELIHOOD OF IMPACT	RISK RATING	MITIGATION MEASURES	RESIDUAL RISK
	Contamination of stormwater harvesting tank water	Local Scale: *Low* Contamination may render the harvested stormwater un-usable.	*Unlikely*	*Low*	Tanks will be required to be located preferably above ground or sealed underground to prevent flood water infiltration. Where flood water could infiltrate this water will only be used for irrigation purposes if suitable.	Low

Source: Study team compilation based on **Appendix M** (Table 12-2).

Based on the lake impact assessment summary presented above, the risk rating varies from *Negligible* to *Medium*, while following implementation of mitigation measures the residual risk can be reduced to a *Low* level.