AQUIS RESORT AT THE GREAT BARRIER REEF PTY LTD

ENVIRONMENTAL IMPACT STATEMENT

VOLUME 1

CHAPTER 10

WATER RESOURCES

10. WATER RESOURCES

10.1 SURFACE WATER

10.1.1 Existing Situation

The site is drained by Richters Creek (south to north-east), Half Moon Creek (south to north-west) and Yorkeys Creek (which bisects and drains the central and northern portions of the site). Parts of Yorkeys Creek and Half Moon Creek flow through the site while Richters Creek flows along its southern and eastern boundaries. Under flood conditions all of these creeks and the Barron River break their banks and under severe floods, most of the site and surrounds are inundated.

Tidal influx affects the hydrology of these creeks and mixes freshwater runoff with incoming seawater. It is likely that seasonal variations will occur in water quality across the site, particularly during high tides (biasing areas towards higher salinity conditions) and during the wet season with surface water and water table pressures (biasing areas towards lower salinity conditions).

Further details are provided in **Chapter 11** (Water Quality) where the ToR require a detailed discussion of hydrology and hydraulics of surface water and groundwater and **Chapter 9** (Flooding) where over-bank flows are addressed. There is an unavoidable overlap in the issues required to be addressed under Flooding, Water Resources, and Water Quality and judgment has been used in where these are discussed. In particular, it has been decided to detail the following maters as described:

- flooding (**Chapter 9**):
    - Barron River catchment and 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 (**this chapter**):
    - surface water hydrology and hydraulics
    - groundwater hydrology and hydraulics
    - quality of groundwater
    - use of surface water
    - use of groundwater
    - surface water / groundwater interaction
- water quality (**Chapter 11**):
    - quality of surface water
    - detailed operation of lake
    - stormwater drainage
    - numerical modelling of lake operation and interaction with the receiving environment
    - hydrodynamic impacts of sea water extraction and discharge.

Cross references between the three chapters are provided where appropriate.

a) Hydrology

Overview

The site is situated at the seaward limit of the delta of the Barron River and is within several hundred metres of the Coral Sea. At a local level, the site lies within the sub-catchments of Richters Creek, Yorkeys Creek, and Half Moon Creek. Of these, Richters Creek is the largest of the waterways, being a distributary of the Barron River due to its connection via Thomatis Creek.

A description of the catchment, typical land use and tidal limits is provided for each of the four waterways listed while further information is provided on the ecology of the waterways in **Chapter 7** (Flora and Fauna).

Barron River (Catchment 217 500 ha)

The Barron River with its headwater located on the Atherton Tableland has a contributing area of 217,500 ha and drains into Trinity Bay (i.e. Coral Sea) north of Cairns and north of Trinity Inlet.

The catchment contains five major dams and / or weir(s) with an extensive irrigation network located in the upper reaches, before the river drops through the Barron Gorge and forms the Barron River delta. The delta is also extensively developed with agricultural activities and cane farming with fringing residential development, although this agricultural use is quickly being transformed by urban, commercial and industrial uses. The tidal limit of the Barron River is located some 7 km upstream of the site, at Kamerunga near where the Cairns Western Arterial Road crosses the river (refer to **Figure 10-1**).

The combined Thomatis / Richters Creek system is a major distributary of the Barron River, with the confluence being approximately 9.2 km upstream from the mouth of the Barron River. Tidal exchange occurs between Thomatis / Richters Creek and the Barron River.

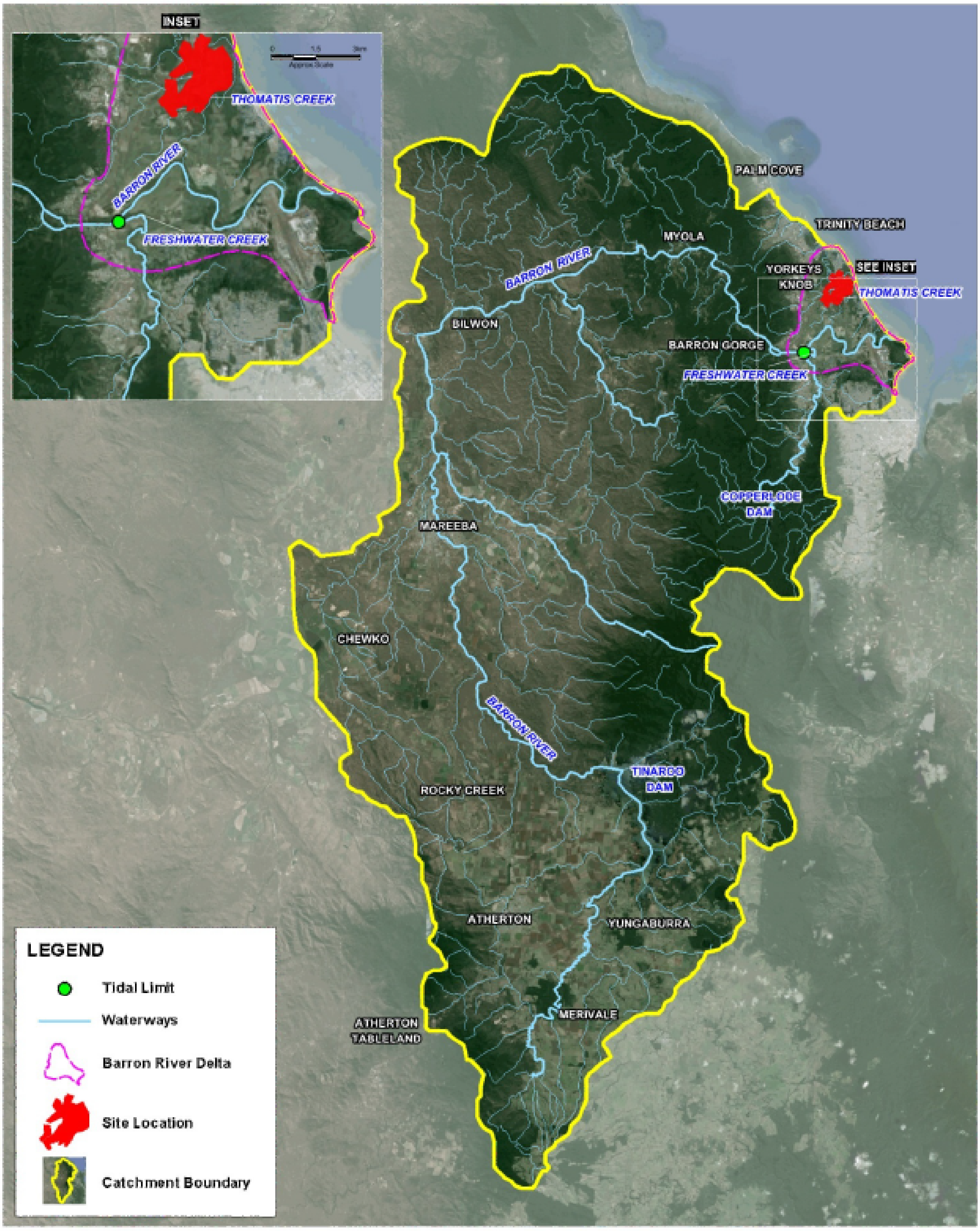

Figure 10-1 Barron River catchment.

Source: Appendix K (Figure 2-1).

Thomatis / Richters Creek (Catchment 449 ha)

Thomatis Creek is the tidal reach that commences at the confluence (‘bifurcation’) of the Barron River and joins Richters Creek approximately 2.7 km downstream. Richters Creek is also largely tidal and receives runoff from a large predominantly agricultural area with a catchment area of 449 ha. The Ponderosa Prawn Farm is located on the opposite bank of Richters Creek south-east of Lot 4 RP746114, and draws water from—and discharges into—this creek. This facility has a licensed discharge for prawn farm exchange water.

Richters Creek is tidal up to Yorkeys Knob Road and forms the south-western boundary of the site to the confluence with Thomatis Creek. Richters Creek continues seaward (to the east) from the confluence with Thomatis Creek and ultimately discharges into Trinity Bay (i.e. the Coral Sea) approximately 5.6 km north of the Barron River and adjacent to the mouth of Yorkeys Creek. On occasions the mouth becomes highly restricted due to sand accretion. However, it is understood that the mouth rarely, if ever, closes completely.

The creek averages about 50 m in width with an estimated depth of 3 m to 4 m.

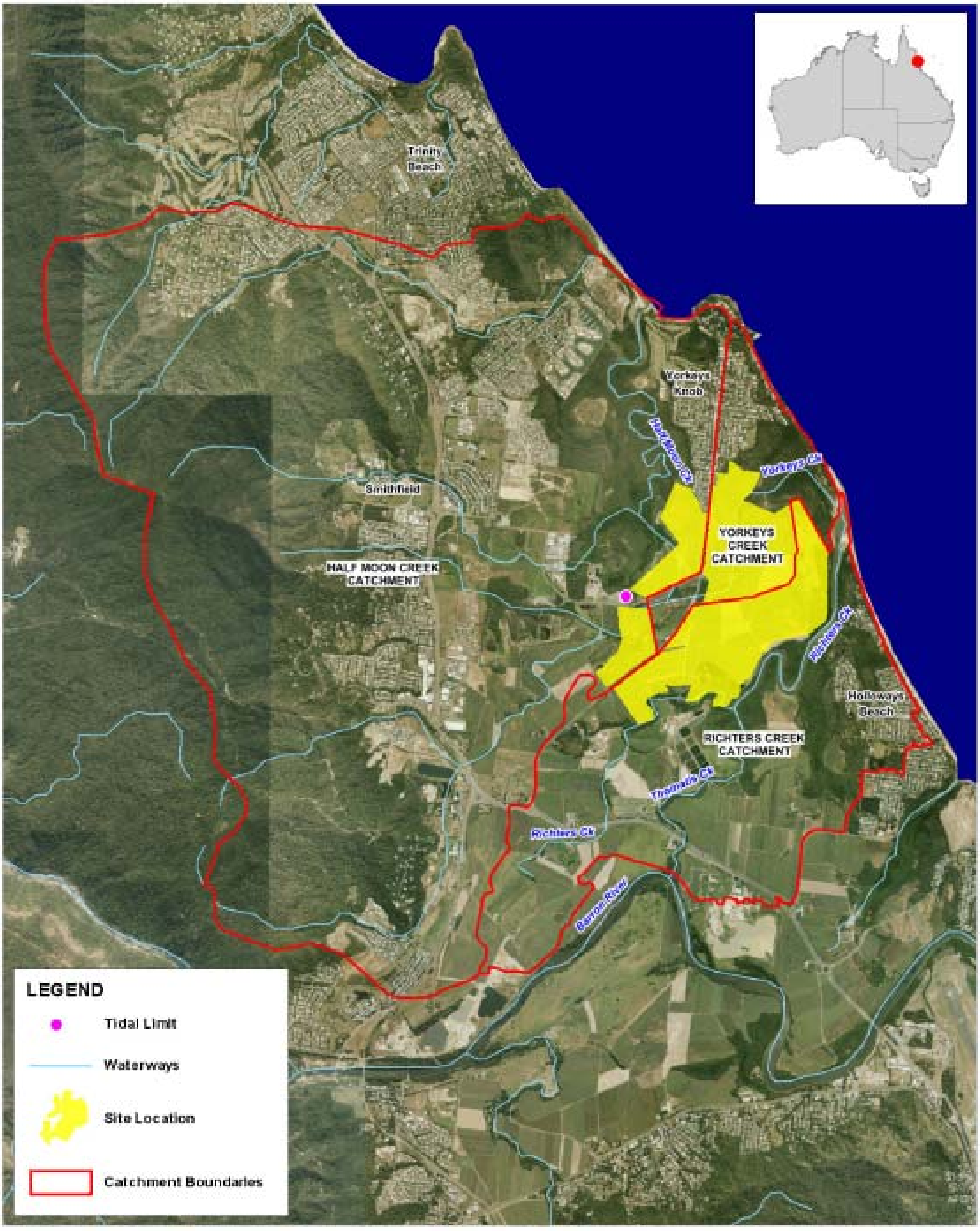

Figure 10-2 Sub-catchments of Barron River at Aquis site.

Source: Appendix M (Figure 2-2).

Yorkeys Creek (Catchment 267 ha)

Yorkeys Creek has a limited catchment area of 267 ha consisting of urban development in the north and agricultural (i.e. cane farming) use in the southern area of the Barron river delta. See **Figure 10-2**. Yorkeys Creek runs along the boundary between Lot 60 RP835486 and Lot 100 NR3818. Within the site Yorkeys Creek is an important ecological feature as described in more detail in **Chapter 7** (Flora and Fauna). It has an estimated depth of 2 m to 3 m.

	
Photo 10-1 Yorkeys Creek looking east from the tide gate just downstream of Lot 100 NR3818.	**Photo 10-2** Yorkeys Creek looking downstream to culvert under Yorkeys Knob Road. This is one of the (ecologically) undersized culverts proposed for upgrading to improve ecological connectivity.

Yorkeys Creeks is tidal to just upstream of Yorkeys Knob Road although tide gates installed approximately 300 m upstream of the mouth to the north of the site (just upstream of the site of **Photo 10-1** above) restrict tidal influence. The vegetation, however, is marine to upstream of the culvert under Yorkeys Knob Road (see **Photo 10-2** above). Yorkeys Creek discharges into the Coral Sea at approximately the same location as Richters Creek.

Half Moon Creek (Catchment 3,797 ha)

Half Moon Creek has a significant catchment area of 3,797 ha consisting of urban, agricultural (i.e. cane farming) and natural vegetation at the headwaters of the catchment. See **Figure 10-2**. Half Moon Creek forms the northern to north-western site boundary. The creek is 7 m to 9 m in width and its estimated depth is 2 m. Half Moon creek is tidal to approximately Dunne Road and discharges to the Coral sea approximately 250 m north-west of the Half Moon Bay Marina.

Waterbodies on-site

The site contains minor water resource features consisting of four different types, namely (see also **Chapter 7** – Flora and Fauna):

- natural freshwater ponds in the melaleuca wetlands on Lot 100 NR3818
- the large disused aquaculture ponds on Lot 1 RP800898
- small man-made dams, principally on Lot 100 NR3818
- agricultural drains constructed for stormwater drainage purposes throughout the farm.

Photos of these are included below.

Photo 10-3 Residual freshwater pond on north-east corner of Lot 100 NR3818 (July 2013).
Source: Appendix G (Plate 4).

Photo 10-4 Largest of the disused aquaculture ponds on Lot 1 RP800898 (July 2013).
Source: Appendix G (Plate 10).

Photo 10-5 Man-made dam on Lot 100 NR3818 (July 2013).
Source: Appendix F (p76 – Site 7a).

Photo 10-6 Cane drainage waterway on Lot 100 NR3818 (July 2013).
Source: Appendix F (p76 – Site 7).

b) Hydraulics

The Barron River and the Thomatis Creek / Richters Creek systems are hydraulically interconnected, sharing both drainage and tidal flows. Calibrated modelling (see **Chapter 11** (Water Quality) of the net seaward advection (i.e. net volume change) for the Barron River estuary reveals that:

- approximately 70% of the annual net seaward flow from the Barron River is discharged at the mouth of the Barron River
- approximately 30% of the annual net seaward flow from the Barron River is diverted first down Thomatis and then Richters Creek.

The net seaward advection was also calculated for the Thomatis and Richters Creek with the following results:

- approximately 95% of the annual flow from Richters Creek is contained within Richters Creek
- approximately 5% of the annual flow from the Richters Creek is diverted within the Thomatis Creek.

The net seaward flow rates are similar to those provided in the Barron River Delta Investigation (Department of Harbours and Marine 1981), indicating that the model is well-calibrated.

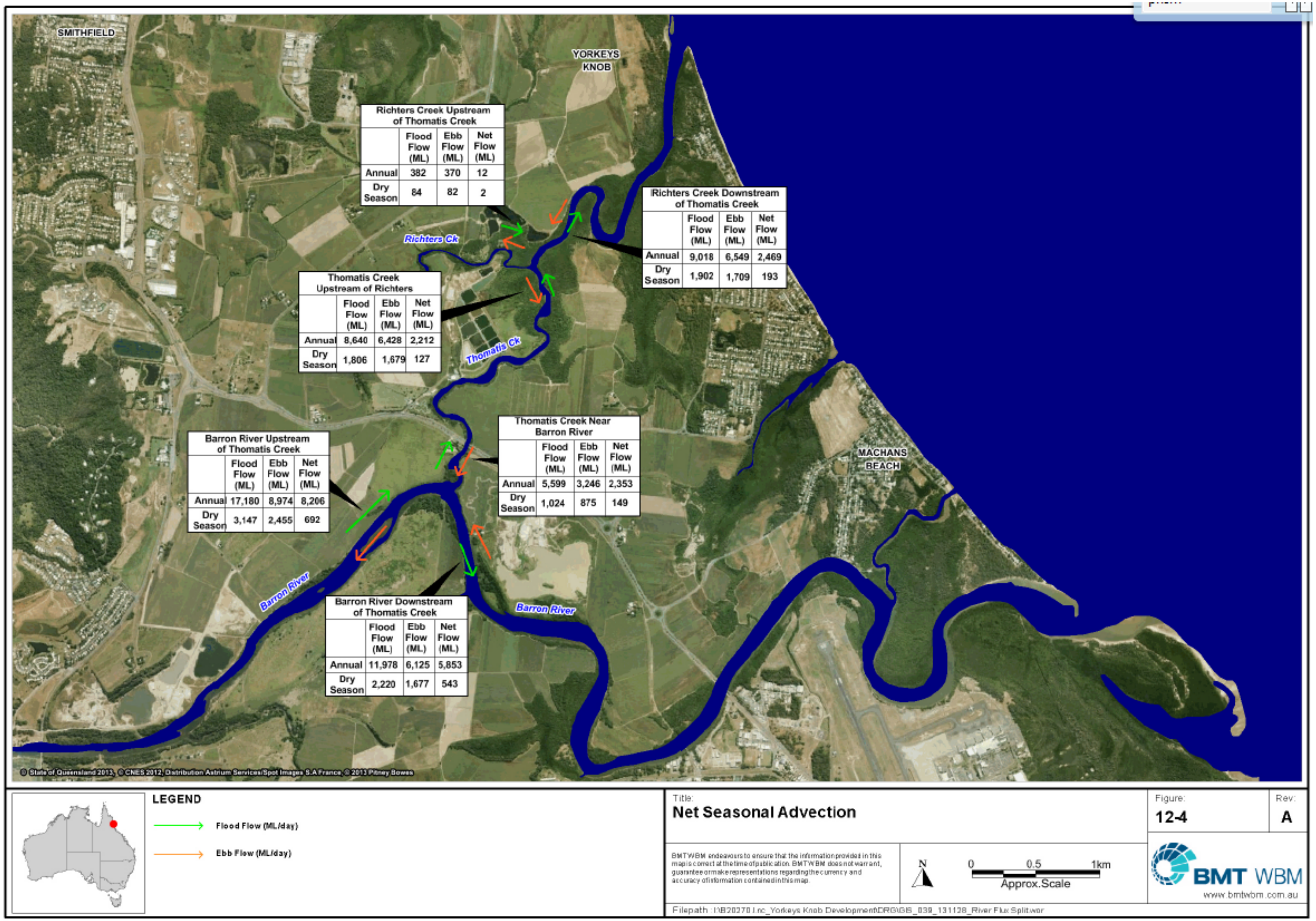

Figure 10-3 Hydraulic performance (net seasonal advection).

Source: Appendix K (Figure 12-4).

c) *Existing Use of Surface Water*

Water in the creeks surrounding the Aquis Resort site is predominantly saline and there is no use made locally of surface water. The few small freshwater ponds (natural and man-made) on the site itself are sustained by groundwater, although they also collect incident rainfall and runoff from small local catchments. The natural ponds lie within the melaleuca wetland and their water is not extracted for any purpose, while the various farm dams are used for a number of purposes, principally dust control.

The disused aquaculture ponds contain freshwater sustained by groundwater and their levels vary by up to 4 m throughout the year. Water from these ponds is not extracted for any purpose.

10.1.2 Impacts

Surface water is a constraint to the design of the Aquis Resort in terms of Barron River flooding (see **Chapter 9**). As noted, the design-related mitigation options to deal with site flooding are one or more of the following:

- adopting flood-tolerant land uses (e.g. golf courses) involving minimal earthworks that could affect external properties (see below), and accepting frequent inundation
- building habitable floors and important infrastructure above (at least) the 1% AEP level (plus freeboard) on piers such that floodwaters can pass beneath the development with no effect on external properties
- building habitable floors and important infrastructure above (at least) the 1% AEP level (plus freeboard) and provide compensatory waterways with appropriate flood plain storage (e.g. lake) to prevent floodwaters affecting external properties.

All man-made waterbodies on the site (i.e. the farm drains, farm dams, and the disused aquaculture ponds) are inconsistent with the development for various reasons:

- some lie within the footprint of the lake and Resort Complex Precinct
- ponds of freshwater attract birds that are undesirable for Cairns International Airport operations and are habitat for mosquitos, biting midges, and crocodiles
- the aquaculture ponds lie in a potential path of weakness for river erosion of Richters Creek are a potential source of poor water quality during floods.

The assessment of flooding (**Chapter 9**) concluded that:

- A lake solution is suitable for the eastern lots (subject to coastal erosion, ecological considerations, and the ability to maintain acceptable water quality by seawater exchange).
- A lake solution is not suitable for the western lots due to excessive distance from waterbodies suitable for seawater water exchange.
- Pier solutions are suitable on all lots, subject to cost criteria.
- Flood-tolerant uses are suitable on all lots, but, of course, are limited in practicality for an integrated resort development.

The main design response is a lake solution on the western lots to allow for the construction of the Resort Complex Precinct and the majority of the Aquis Resort infrastructure.

Overview of Lake Operation

A detailed description of lake operation is provided in **Chapter 11** (Water Quality). In brief:

- The lake is essentially a perched tidal waterbody with a bed level of -2.5 m AHD and a more or less constant top water level of 1.5 m AHD.
- In order to maintain good water quality, the lake will undergo tidal exchange by continuous pumped inflow of sea water delivered via a submerged pipeline from a point 2.2 km off-shore. Turnover will be achieved by pumping to an outlet at the mouth of Richters Creek on an ebb tide. This outlet will be fitted with a diffuser to prevent erosion and encourage mixing.
- Water levels in the lake are expected to vary by about 0.075 m due to the pumping cycle and lake turnover is expected to average 14 days.
- High level overflows (open channels fitted with tide flaps) are provided to discharge water to Richters Creek and Yorkeys Creek during wet weather and after a flood.
- During large floods, the lake will become inundated and join adjacent floodwaters across the adjacent part of the Barron River delta.

Hydrological Models

The modelling of the existing situation and likely impacts covers a number of issues, and accordingly has been dealt with as follows:

- flooding (**Chapter 9**) including interaction of floods with the lake for a number of flood frequencies between 20% AEP and PMF
- hydrodynamic (and water quality) performance of the lake including modelling of stormwater drainage inputs (**Chapter 11**)
- hydrodynamic (and water quality) interactions between the lake and the receiving environment, including a full hydrodynamic model of some of the Barron River, Richters Creek, and the GBR lagoon (**Chapter 11**)
- groundwater model to determine permeabilities needed to quarantine the lake from groundwater (**Chapter 10**).

Fate of Existing Waterbodies on-site

All natural ponds (i.e. those that lie within the melaleuca wetland) will remain. All man-made waterbodies (i.e. the farm drains, farm dams, and the disused aquaculture ponds) will be drained and filled as they are inconsistent with the development for various reasons.

Impoundment and Extraction of Surface Water

The flood mitigation lake will contain water to a level of 1.5 m AHD which is approximately 0.5 m below the general ground level of the surrounding land. The ‘normal’ operation of the lake is described in detail in **Chapter 11** (Water Quality) and involves constant pumped inflow of seawater and pumped discharge on an ebb tide. Under normal circumstances, lake water will be seawater pumped in from the Coral Sea, rather than an impoundment of surface flow.

During floods of sufficient level, the lake will fill with overland flow, as will all similar depressions in the Barron River delta. For large floods, the lake will be totally inundated and the floodwaters will pass through and over the lake and follow the normal pre-Aquis Resort path to the ocean as discussed in detail in **Chapter 9** (Flooding).

This overland flow will drop lake salinity (which is undesirable from a water quality perspective) and the management response will be to reduce the water level as soon as possible and raise the salinity by pumping seawater at an enhanced rate.

In summary, the lake is an artificial waterbody containing pumped seawater. Accordingly, the project does not involve impoundment, extraction, discharge, injection, use or loss of surface water.

Proposed Diversions of Surface Water

Overland flow diversion is required in the context of flood management as detailed above. This does not involve diversion or interception of surface water.

The effects of a 1% AEP flood in terms of afflux and velocity are shown on **Figure 9-8** and **Figure 9-9** respectively. These are reproduced below as **Figure 10-4** and **Figure 9-9** respectively.

As explained in **Chapter 9** (Flooding), flood level impact is represented below by a graphical plot which is generated by subtracting the pre-development flood levels from the post-development flood levels. The coloured contour bands represent the difference in water level as a result. Negative values (blue colours) represent a decrease in flood level when compared to the pre-development flood levels and the positive values (green through to red) represent increases in flood level when compared to pre-development flood levels.

Peak flood levels, depths and velocities are also represented by a coloured contour plot, with each colour band representing a range of values specific to each.

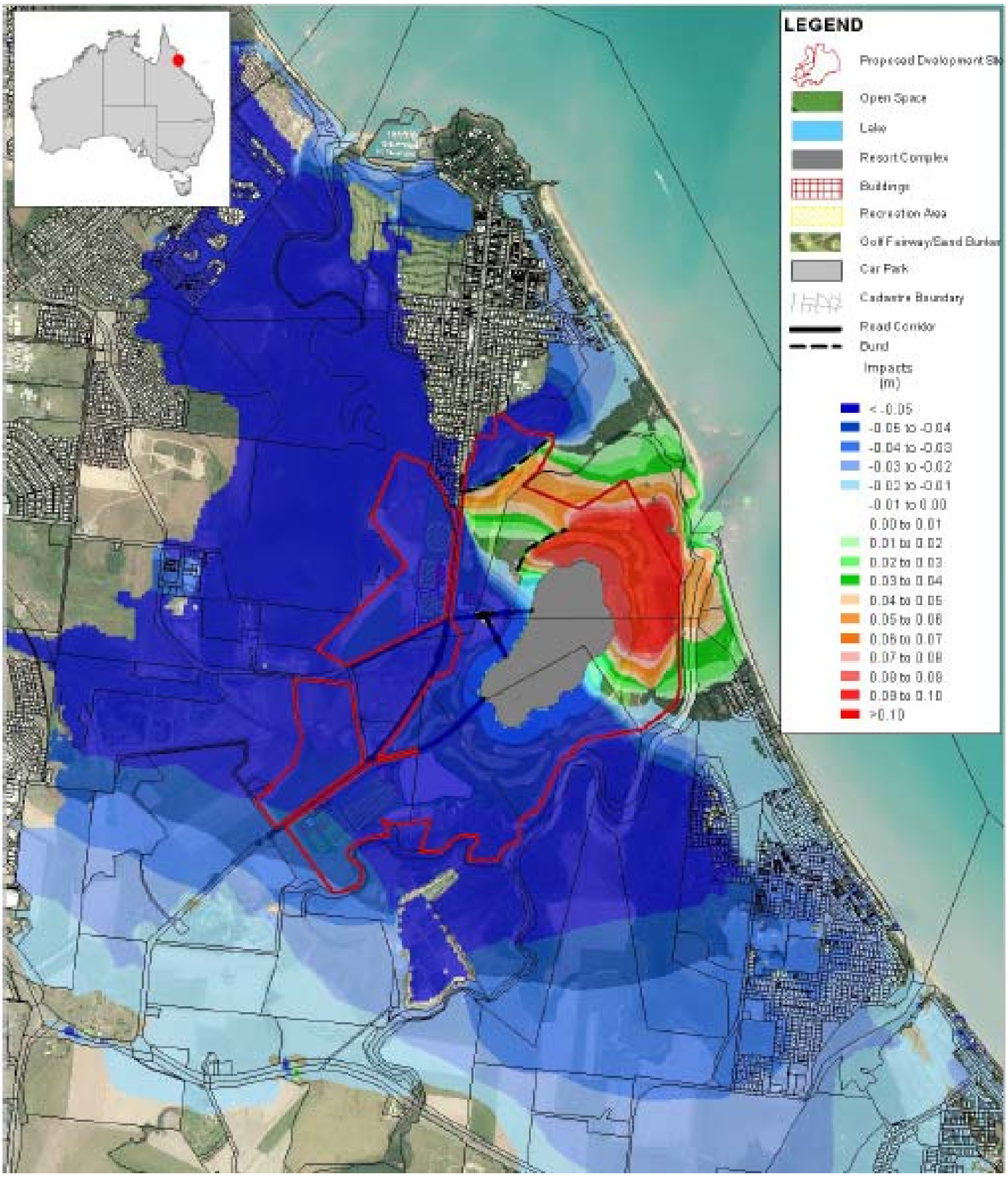

Figure 10-4 Flood modelling results of 1% AEP flood.
Source: Appendix K (Figure 5-1).

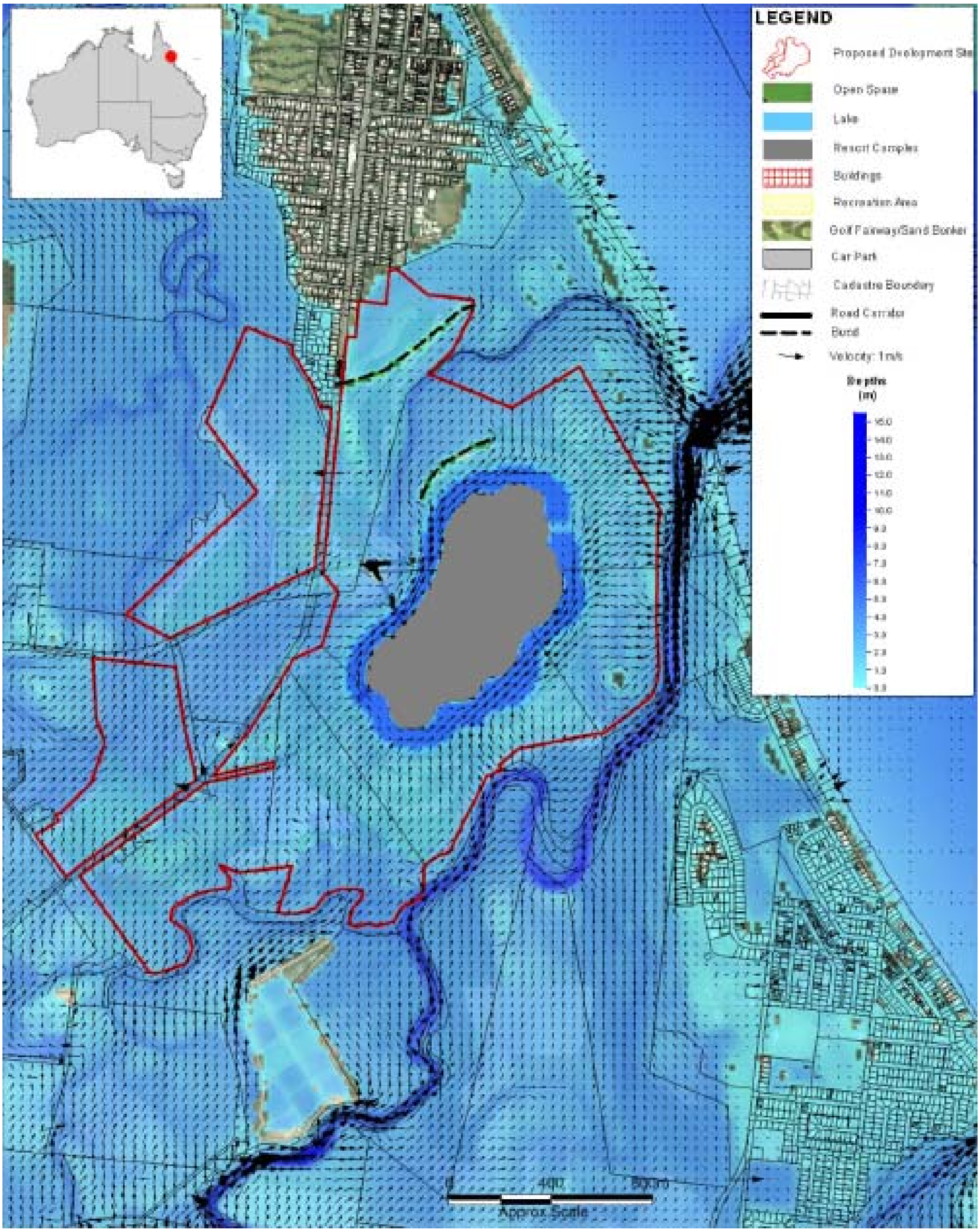

Figure 10-5 Velocity modelling results of 1% AEP flood.

Source: Appendix K (Figure 5-2). Arrows show the speed and direction of flow and colours indicate depth.

These figures show that, except in the immediate vicinity of the lake itself, a 1% AEP flood will pass through the site largely unaltered. Diversion is limited to the Aquis Resort site itself.

Changes in Flow Regimes from Structures and Water Take

These issues are dealt with in **Chapter 11** (Water Quality) as they are specifically related to lake exchange infrastructure and operations. In summary:

- Effect of water intake. The inlet is 2.2 km off-shore and will be close to the seabed which is at -8.1 m AHD (over 6 m deep at LAT). Even at the highest proposed intake rate, local velocities will be around 0.4 m / s (as low as possible a velocity is desirable to minimise the risk of ingesting marine organisms). This operation will not have any adverse impacts on water resources.
- Effect of lake discharge on tidal prism and the bed of Richters Creek at the discharge point. Modelling shows that lake discharge is between 7% and 20% of the tidal prism for spring and neap tides respectively. The bed at this location is highly mobile and will not be affected by lake discharge. Bed shear calculations show that even under the most adverse conditions, additional erosion caused by lake discharge is not likely to occur.
- Effect of (occasional) lake overflow on Richters Creek and Yorkeys Creek. See below for the Richters Creek overflow. In terms of the Yorkeys Creek overflow – this is located at a point where riparian vegetation is at a minimum and where overland flood flow currently joins the creek. It is likely that there will be little in the way of impacts on water resources at this point, although further assessment of local impacts will be made during detailed design.

Alterations to Riparian Vegetation and Bank and Channel Morphology

These issues are dealt with in **Chapter 11** (Water Quality) as they are specifically related to lake exchange infrastructure and operations. Issues include:

- Construction of lake overflow on the banks of Richters Creek. This is at a location where there is no existing natural vegetation and bank erosion is evident (see **Photo 10-7**). The proposal is to provide erosion protection at this location to serve the dual needs of bank erosion protection and local scour protection from occasional lake overflows. These will occur only after a flood when it is desired to draw the lake level down as quickly as possible as part of the strategy to promptly re-establish saline conditions and minimise fish mortality.
- Changes to bank and channel morphology. As noted above, normal lake discharge (i.e. through the diffuser at the mouth of Richters Creek) has been shown to involve insignificant impact on channel morphology. Under flood conditions, the lake overflow discharges will join already high flows and elevated water levels in the local creeks and are not expected to result in any impact on bank and channel morphology. Further assessment of local impacts will be made during detailed design.

Photo 10-7 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. Further details of proposed works at this location are provided in **Section 11.3.1b)**.

The bathymetry of Thomatis / Richters Creek was mapped as part of the water quality investigations (**Chapter 11**). The resulting digital elevation model (DEM) is shown below (**Figure 10-6**). This also shows the proposed lake and illustrates the post-construction morphology of the Aquis Resort site.

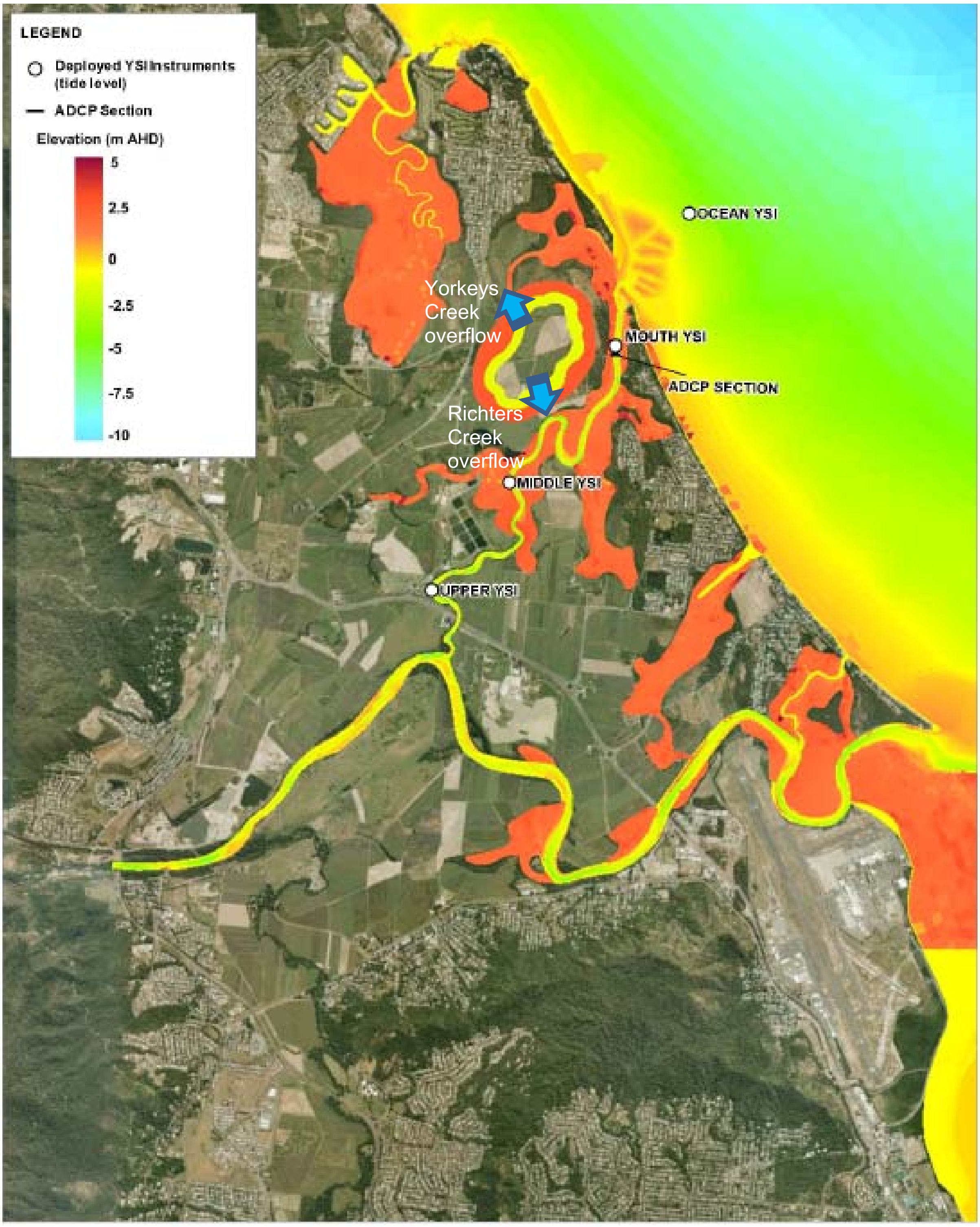

Figure 10-6 Digital elevation model showing lake overflow locations.
Source: Appendix M (Figure 10-4).

This figure shows that the existing network of channels will not change and that the lake is a local depression that is unconnected to this network except by high level lake overflows into Richters Creek and Yorkeys Creek as shown and the underground water exchange pipework. In terms of Barron River floods, this infrastructure has insignificant impact and is related to post-flood and normal operation.

In summary, there will be no need to clear any riparian vegetation or alter bank or stream bed morphology other than the proposed erosion protection works.

10.1.3 Mitigation and Management

Aspects of management of surface water are described elsewhere in this EIS as follows:

- **Chapter 11** (Water Quality) in terms of:
  - stormwater drainage
  - use of treated effluent
  - lake management (during 'normal' conditions as well as during and following a flood)
  - setting and utilising discharge criteria.
- **Chapter 15** (Geology and Soils) in terms of:
  - contaminated land
  - acid sulfate soil
  - erosion and sedimentation control.
- **Chapter 23** (Environmental Management Plan) in terms of:
  - strategies for further impact mitigation to be developed for the design, construction, and operation phases
  - environmental management framework.

10.1.4 Residual Impacts

The project is not designed to intercept, store, or otherwise use surface water resources. The 'use' of surface water occurs only during large Barron River floods (i.e. those with of a frequency less than 50% AEP). Any captured surface water is inimical to lake operations and is proposed to be discharged as quickly as possible as the overall catchment drains.

The loss of the small on-site water resources (i.e. farm drains, farm dams, and the disused aquaculture ponds) are not considered to be significant impacts on surface water resources.

No significant residual impacts on surface water are expected.

10.2 GROUNDWATER

10.2.1 Existing Situation

a) Hydrology

The majority of the Aquis Resort site is underlain by younger (Quaternary) creek alluvium with the outer parts of the properties bordering coastal flats and mangrove flats. Two aquifer types have been identified:

- shallow (an unconfined (water table) aquifer)
- deep (an underlying semi-confined aquifer (separated from the upper unconfined aquifer by lower permeability clay units)).

Groundwater associated with the underlying Palaeozoic bedrock is not discussed as it is too remote from possible impacts to be considered.

Recent field investigations reveal that groundwater first occurs between 0.5 and 3.5 m below ground level (bgl) and that there are both unconfined and semi-confined aquifers beneath the site. Bedrock occurs at depths of between 68 m and 94 m bgl with the overlying units consisting of older Palaeozoic meta sediments. This unit contains saturated sand layers that potentially form two to three semi-confined aquifers. Overlying this series is an aquitard made of stiff to hard clays with a thickness of between 4 m and 6 m. Above the aquitard are younger alluvial deposits consisting of coarse grained sands, gravels and clayey sands, with localised interbedded sequences of fine grained sandy clays and clays of between 7 and 10 m bgl. The layers of sandy sediments were noted to be moderately to highly permeable. A conceptual model of this description is presented below.

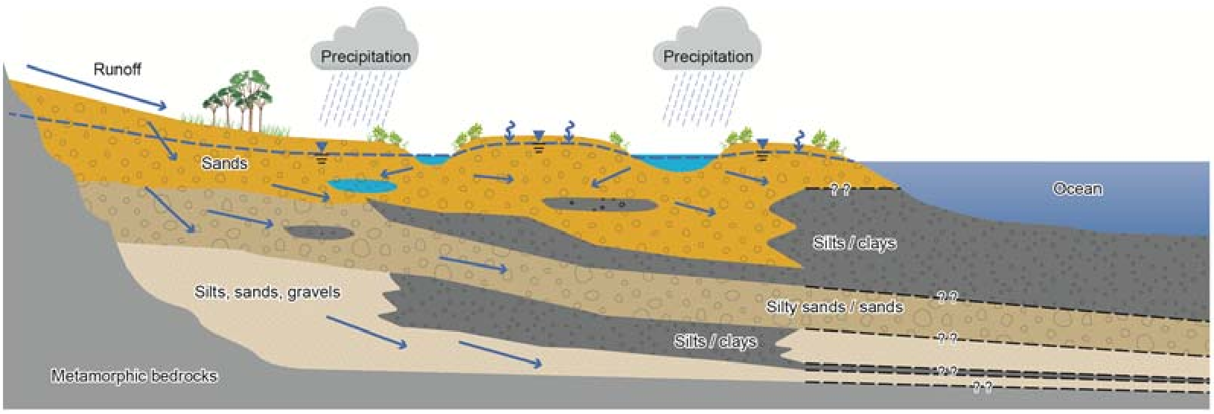

Figure 10-7 Conceptual site model.

Source: Appendix M (Figure 10).

b) Hydraulics

Historical groundwater level monitoring indicates that both the unconfined and semi-confined aquifers act as a single aquifer, possibly due to interconnections caused by well construction. Recent monitoring reveals that groundwater in the unconfined aquifer is also hydraulically linked to, and influenced by, tidal action.

Figure 10-8 shows the location of groundwater testing locations described in **Appendix M** and **Figure 10-9** shows a time series of groundwater levels for points YK1, 2, 3, 4, 8 and MWs.

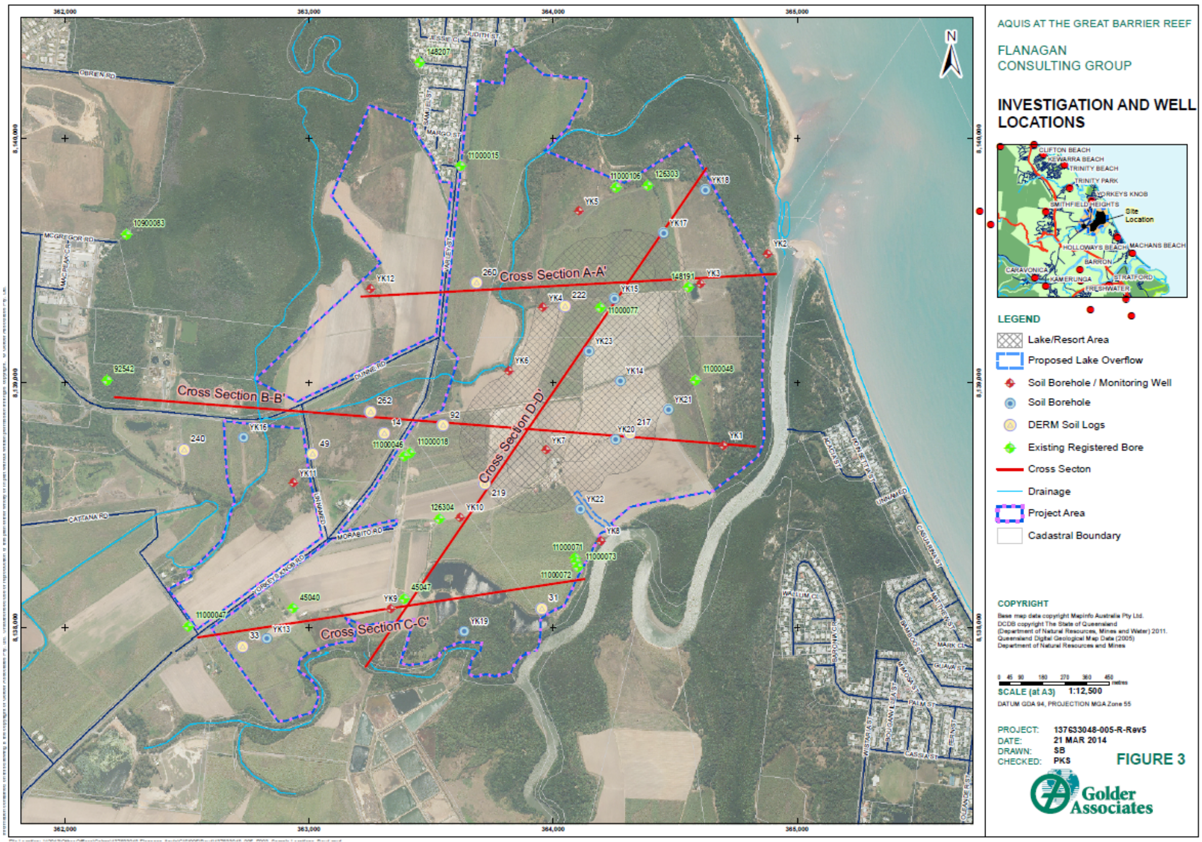

Figure 10-8 Map showing location of bores described in following figure.

Source: Appendix M (Figure 3). The lake location is shown on this figure for reference purposes only (i.e. data is based on the existing pre-lake situation).

Continuous water level logging of groundwater elevations at six locations within the unconfined aquifer is on-going. Results for the seven months to 7 March 2014 (spanning dry season and wet season conditions) show the groundwater response to tidal fluctuations and rainfall events. Long term data incorporating the DERM results reveals that the variability in groundwater levels at the site due to seasonal effects is of the order of 2 m to 3 m in the shallow and deeper aquifer systems.

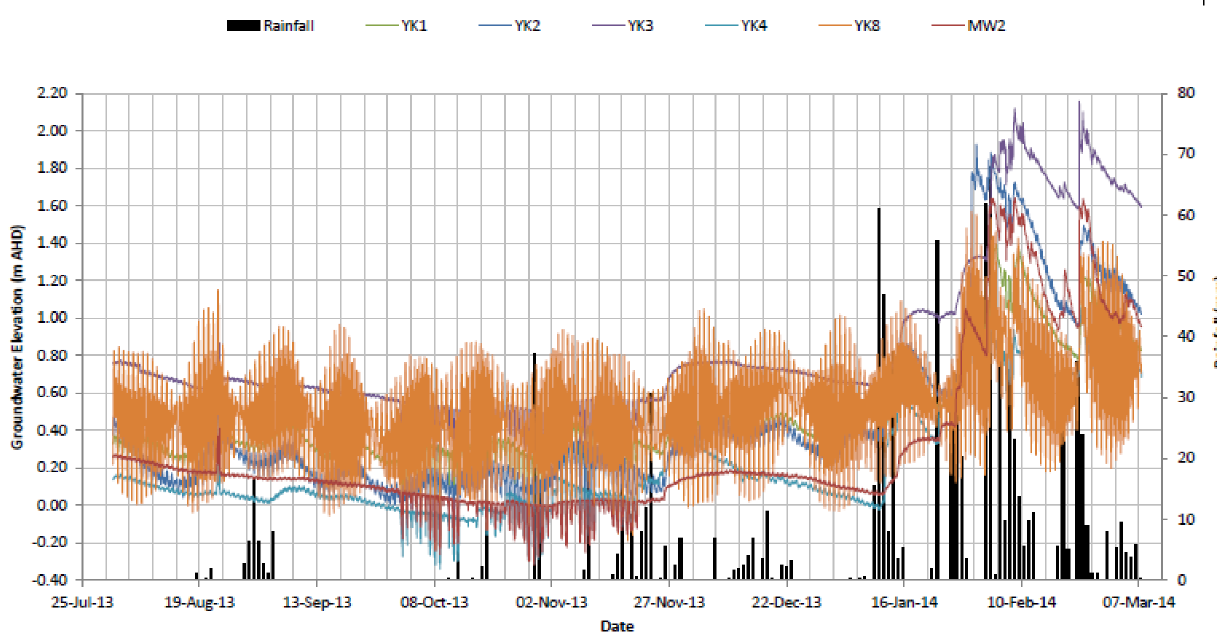

Figure 10-9 Groundwater response to rainfall events.

Source: Appendix M (Figure 7c). Locations of sites are shown on **Figure 10-8**.

Figure 10-9 above indicates recent seasonal effects in the order of 1.8 m in response to rainfall events over the seven months to March 2014.

Allowing for the limitations of the available survey data for existing groundwater wells, measured groundwater elevations within the unconfined aquifer are relatively consistent, with an average of between 0.3 m AHD and 0.5 m AHD in the dry season and between about 0.8 m and 1.8 m in the current wet season. As with the historical data, groundwater elevations within the semi-confined aquifer are generally consistent with the unconfined aquifer, suggesting a degree of connectivity between these two structures.

Figure 10-10 provides an idealised profile of groundwater on the site.

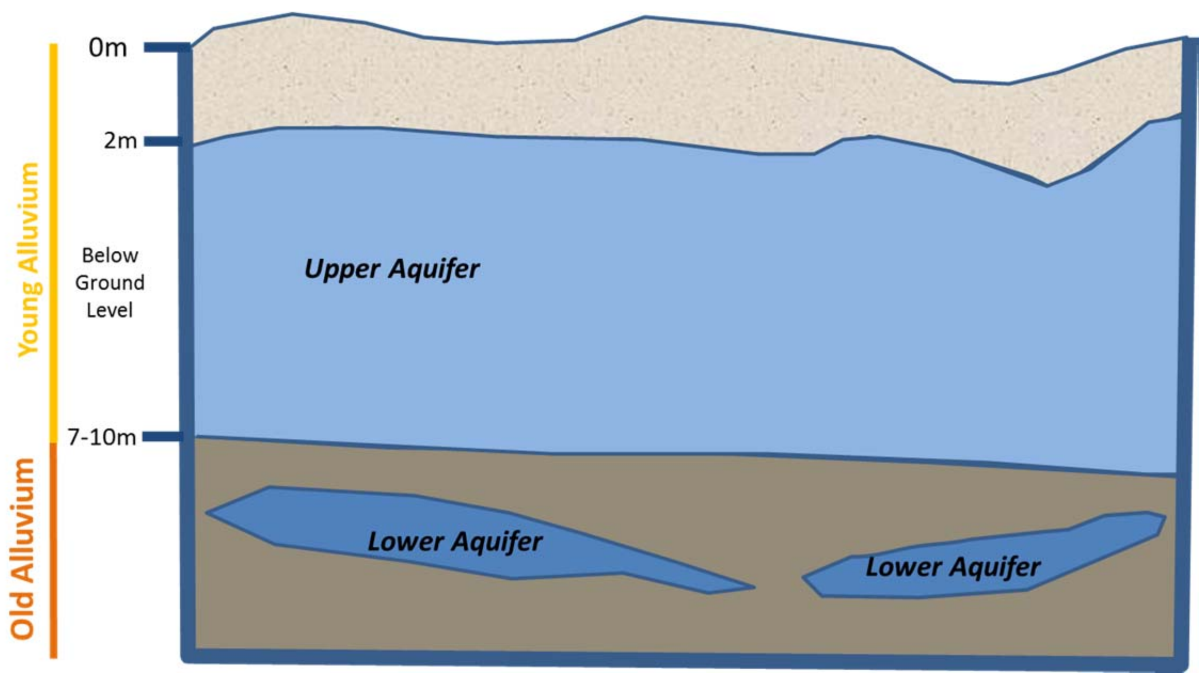

Figure 10-10 Idealised groundwater profile.

Source: Golder Associates (2013).

c) Groundwater Quality

<u>Characteristics</u>

Monitoring data indicates that the level of groundwater is tidally influenced. Groundwater quality data for the semi-confined aquifer is limited to EC measurement undertaken by the Queensland Department of Natural Resources and Water (Watling 2007). This data indicates that the water in the deeper aquifer ranges from fresh to brackish / saline.

Sampling and analysis of water contained in the shallower unconfined aquifer was undertaken for this project. Parameters analysed include chloride, sulfate, aluminium, iron, calcium, pH, electrical conductivity (EC), and chloride / sulfate ratio. The results are summarised as follows:

- The centre of the cultivated area on the eastern lots sits directly over an area of relatively fresh groundwater (shown on **Figure 10-13**).
- The EC concentrations from surface water and shallow unconfined aquifer become lower towards the middle of the study area (between Yorkeys Creek and Richters Creek). The shallow aquifer becomes more saline near these creeks.
- Mixing of lower salinity water with more saline water occurs in the upper unconfined aquifer.
- Farm drains appear to be hydraulically connected to the unconfined aquifer in some locations, and are likely to have historically contributed to salinisation of the unconfined aquifer.
- A general trend is that EC values in the deeper semi-confined aquifer become lower at depth, although some data anomalies were noted.

- An area to the east side of the site, toward the coast and adjacent to Richters Creek is thought to be brackish but not saline, based on an assessment of the extant vegetation. Wet season conditions resulted in significant lowering of EC in all monitoring wells across the site with the exception of a site adjacent to Yorkeys Creek, where conditions remained relatively static. The results suggest that seasonal variations influence the groundwater salinity with wet season impacts from surface water and water table pressures biasing areas towards more freshwater conditions.

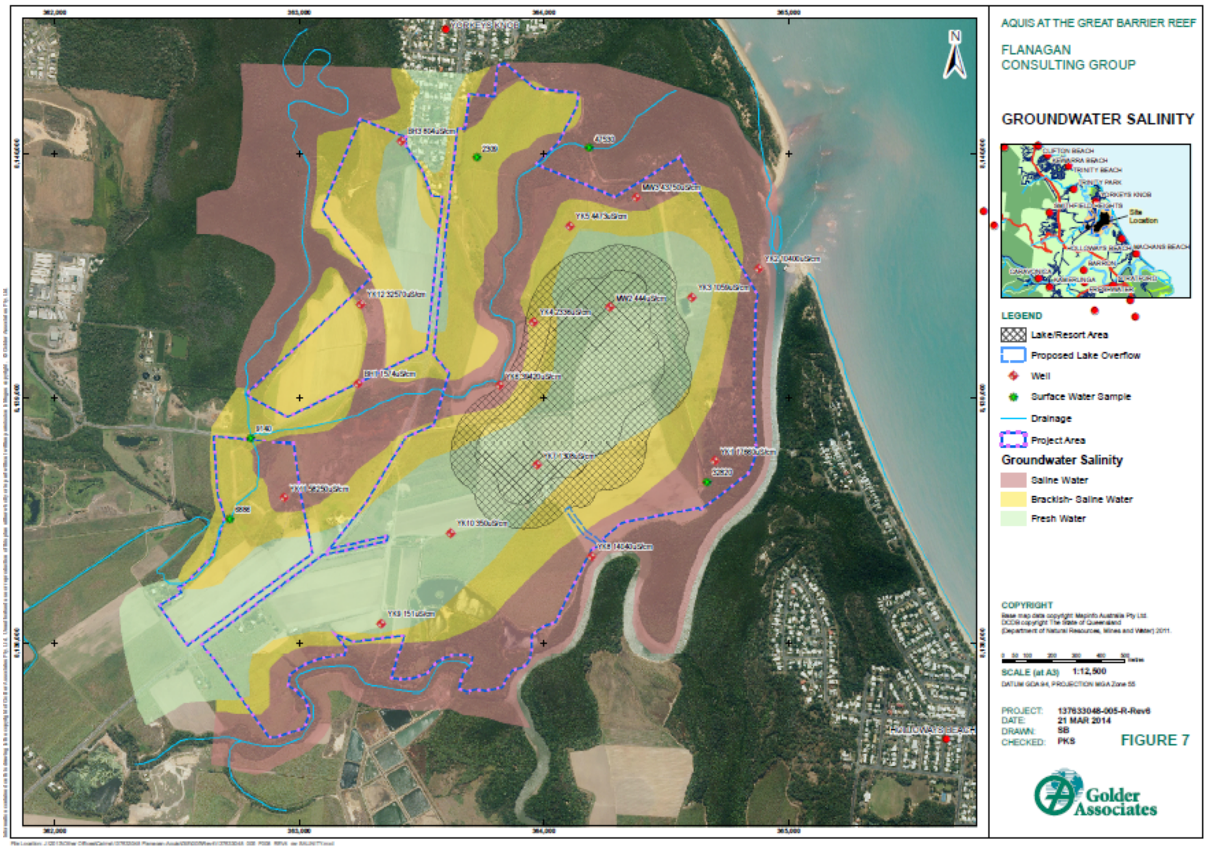

Figure 10-11 Salinity of the unconfined aquifer on the site.

Source: Appendix L (Figure 7). The lake location is shown on this figure for reference purposes only (i.e. data is based on the existing pre-lake situation).

In summary, the wide range in groundwater salinity quality is typical of the Aquis Resort site hydrogeological environment that comprises variable sediment types (from highly permeable sands and gravels to low permeability silty clays) and high salinity surface water in farm drains interacting with adjacent groundwater.

Contamination

Recent groundwater sampling identifies nutrient concentrations (nitrogen and ammonium) in the shallow unconfined aquifer across the site area that generally exceeded the published water quality guidelines (ANZECC 2000) for both freshwater waterways and tidal waterways.

However, it was noted that the nutrient concentrations identified were relatively consistent with previous experience from groundwater monitoring programs undertaken in coastal areas across the Cairns region, particularly adjacent to mangrove wetlands. Nutrient concentrations in the brackish to saline groundwater wells (YK5, YK6, YK11 on **Figure 10-8** above) could, therefore, be primarily associated with natural background conditions. Concentrations in the freshwater monitoring wells (YK3, YK7, YK10 on **Figure 10-8** above) could be indicative of a mixture of natural conditions and the influence of fertiliser use within agricultural areas. Further assessment of contaminated soils is provided in Chapter 15 (Geology and Soils). This reveals minor pockets of contamination arising from farm activities. These are typical of other farms in the Barron River delta and are not considered to be of concern. This degree of contamination is not considered to present any significant challenge to the development.

<u>Values</u>

The groundwater within the site provides the following environmental values:

- recharging mangrove wetlands associated with tidal waterways
- water source for remaining undisturbed / regrowth areas of terrestrial vegetation
- recharging constructed farm ponds
- licensed and unlicensed groundwater spear points targeting low salinity conditions within agricultural land use areas and urban areas to the north
- licensed groundwater wells (see below) extending to low salinity conditions at depths beyond 30 m within agricultural land use areas.

d) *Existing Use of Groundwater Water*

The locations of groundwater users within 500 m of the project boundary are shown on **Figure 10-12**.

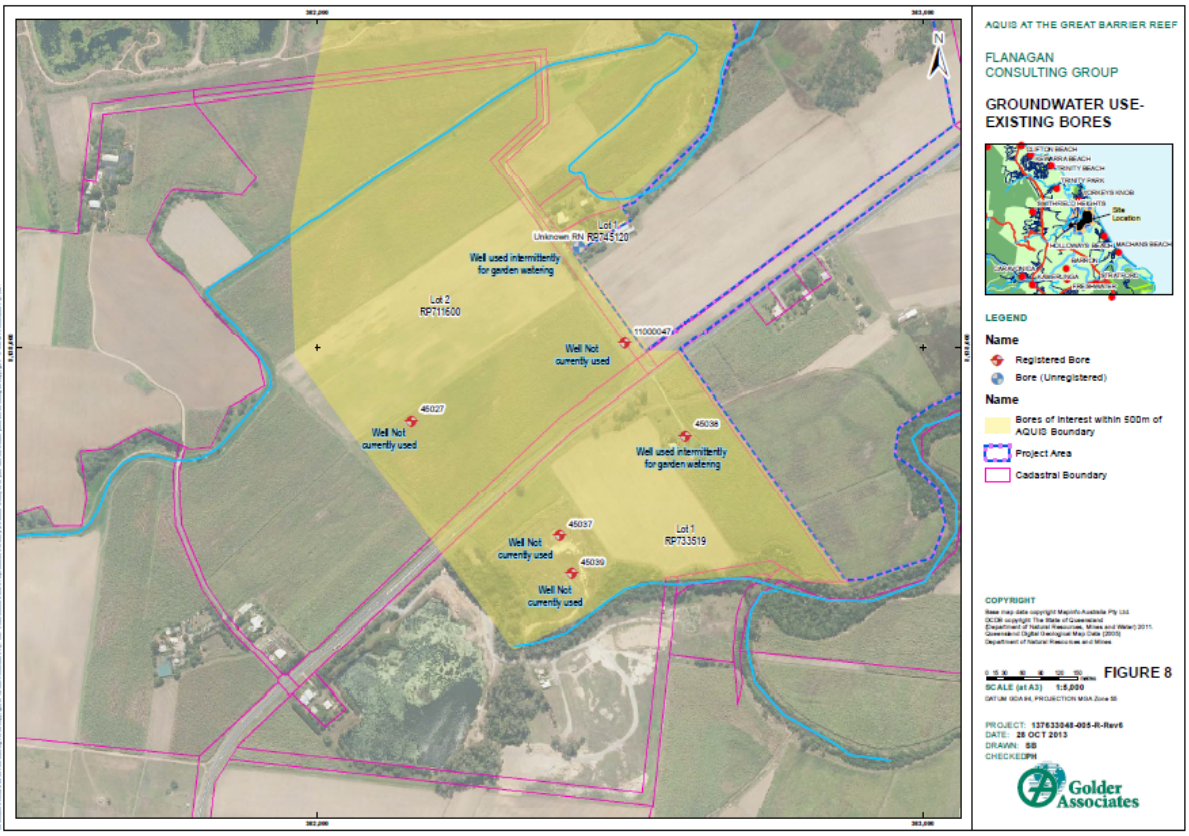

Figure 10-12 Existing nearby users of groundwater.

Source: Appendix M (Figure 8).

These groundwater users were contacted by Golder Associates in late October 2013 to obtain information about their historical and current use of groundwater. There are a total of six bores, of which five are registered. Key findings are:

- Four of the bores (45027, 45037, 45039, and 11000047) have been used for agricultural supply but are not currently used due to the costs associated with irrigation.
- The remaining two bores are located adjacent to the residential properties and are used for garden watering.

e) Surface Water / Groundwater Interaction

As shown on **Figure 10-13**, groundwater quality / salinity varies with distance from the creeks inward and across the site and demonstrates existing surface water / groundwater interaction.

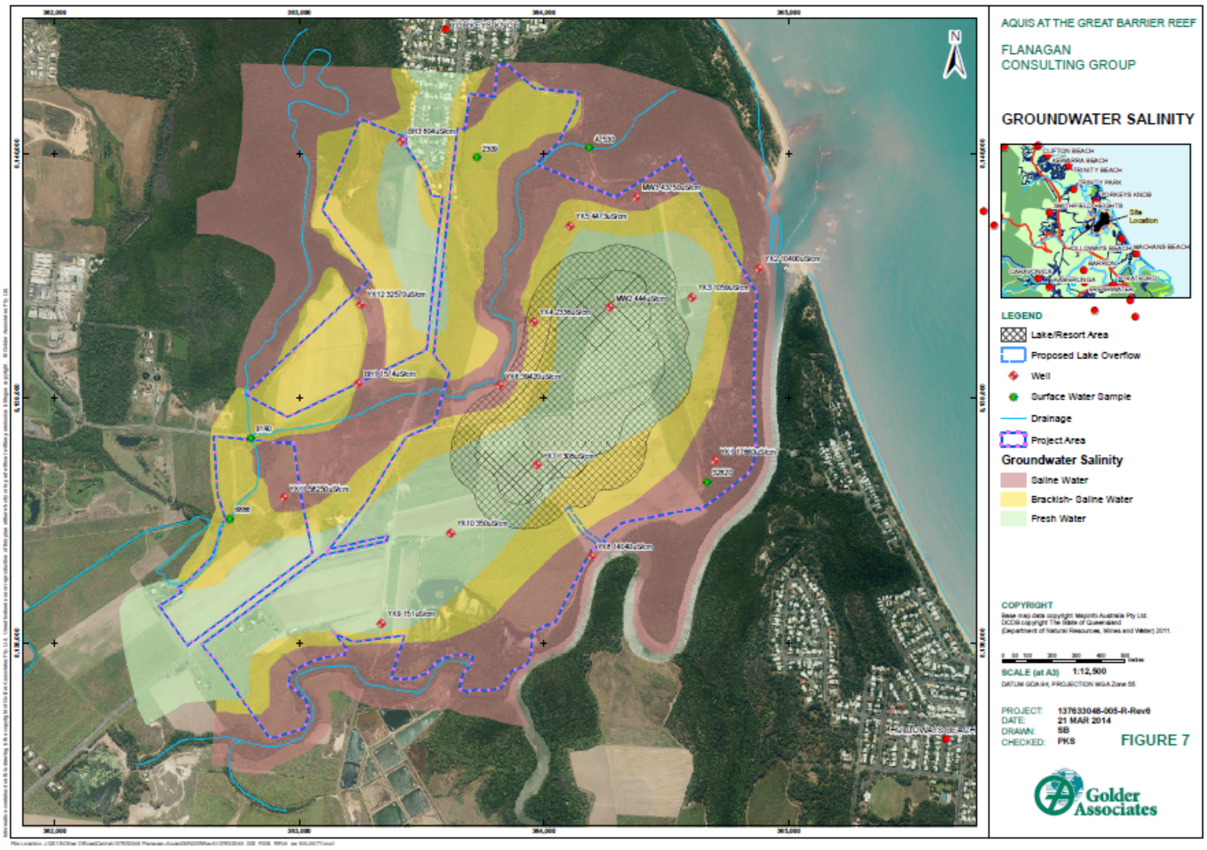

Figure 10-13 Salinity of the unconfined aquifer on the site.

Source: Appendix M (Figure 7). The lake location is shown on this figure for reference purposes only (i.e. data is based on the existing pre-lake situation).

Some key observations about existing surface water / groundwater interaction are as follows:

- Parts of the site can become flooded during king-tides, which may impact shallow groundwater quality at these locations.
- The area is underlain by a shallow unconfined aquifer which sits on a confining clay layer of varying thickness across the site. Beneath the clay layer are one or more semi-confined to confined aquifers. It is likely that there are areas where the underlying semi- confined aquifer may be contiguous with the overlying unconfined aquifer, based on observed thickness variations of the confining layer. These areas allow paths for interconnection between layers.

- Elevated EC values were recorded at distances up to 850 m from estuarine zones (for example, up to 44500 µS/cm from borehole 11000046 which is 48 m deep). These values indicate that the lower, semi-confined aquifer has variable and unpredictable salinity possibly related to the aquifer's mode of sedimentary deposition:
- braided stream channels of coarse, high permeability sediments lead to lower salinity groundwater
- lower energy units of fine, low permeability material lead to higher salinity groundwater.
- Other potential existing impacts on groundwater quality include contamination associated with intensive agricultural practices, including nutrient enrichment and minor hydrocarbon use.
- Based on a review of available data and EC data from the recently installed monitoring wells (refer to **Figure 10-13**), groundwater is not clearly defined (nor zoned) with respect to tidal influence.

f) Variability

The quality and flow of surface water and groundwater are quite complex issues that vary over a range of time scales as outlined below:

- Short-term (i.e. over a tidal cycle). Both the unconfined and semi-confined aquifers act as a single aquifer, possibly due to well construction or public and private use and certainly due to tidal action. As there is a strong hydraulic connection between groundwater and the waters of Richters Creek, it is highly likely that these are linked in terms of water quality as well. Water quality in Richters Creek also shows variability (particularly salinity) over a tidal cycle, complicated by the frequent formation of a salt wedge.
- Seasonal. It is known that groundwater levels fluctuate by more than a metre between the wet and dry season and that groundwater becomes increasingly less saline in response to heavy rainfall. Water quality in Richters Creek also shows seasonal variation in most parameters. Flows are also seasonally influenced, especially for Richters Creek which carries some a significant proportion of the flow from the entire Barron River catchment.
- Infrequent. The Barron River breaks its banks at the site for floods greater than a 50% AEP. Under this type of event, fresh water will directly permeate the surface aquifers and decrease their salinity. At the same time, flow rates and velocities increase significantly as the local creeks drain the floodplain and convey in-stream flows. The flood flows tend to dominate tidal effects, resulting in a substantial lowering of salinity in the near-shore area. Associated with these conditions is increased turbidity and nutrient levels.
- Extreme events. For more extreme events the above scenario applies although the effects are more extreme.

g) Seasonality and Data Limitations

Groundwater depth and quality information is typically available only at snapshots in time, such as when the well was drilled or at specific sampling times. For the majority of wells used, the number of water quality samples is small (<5) and it is not possible to plot seasonal trends. In the deeper aquifer it is unlikely that seasonal variations in water quality would occur. However, the values of salinity are consistent with the local environment, with freshwater encountered at depth, away from tidal water courses.

A comparison of groundwater quality data from the preliminary investigation (August 2013) and the most recent baseline sampling (10 March 2014) from monitoring wells constructed in the shallow unconfined aquifer shows considerable quality variability between dry season and wet season. Not surprisingly, wet season EC values in all but one monitoring wells across the site suggest that seasonal variations influence the groundwater salinity, with wet season impacts from surface water and water table pressures biasing areas towards more freshwater conditions.

10.2.2 Impacts

Analysis of site conditions (especially soils and topography) and groundwater modelling reveals the following key groundwater features of the site:

- The surface layer of soil is a firm to stiff clay layer to around 2 m below ground level. This is underlain by looser sands and gravels typically between 7 to 10 m (but as much as 13 m) below ground level. At greater depths, the soils vary depending on proximity to watercourses, with soft clays located along the eastern and southern margins near Richters Creek and sandy material in the central development area. Generally, there is a layer of stiff to hard clays interspersed with medium dense to dense sands plus gravels below the younger soils. These young alluvial deposits are underlain by older (Pleistocene age) consolidated alluvial deposits that extend down to bedrock (Barron River Metamorphics) that occurs at depths of between 68 m and 94 m (approximately -66 m to -92 m AHD).
- Rainfall and runoff from the west and on the site infiltrates into the highly permeable sandy sediments of the unconfined (water table) aquifer, and downwards into the semi-confined aquifer.
- A portion of rainfall is lost to evapotranspiration by vegetation, both native and cultivated, prior to infiltration to the unconfined aquifer.
- Groundwater in the semi-confined aquifer then flows eastward through sediments consisting of gravel, sand, and silt. Lenses of silt / clay impede groundwater movement and acting as local confining beds (aquitards).
- The unconfined aquifer is impacted by surface water drainage features which are in turn affected by tidal influences whereby higher salinity water can enter the upper part of the unconfined aquifer and move laterally. This raises the groundwater salinity in proximity to the drainage lines.
- Groundwater salinity in the unconfined aquifer is generally lowest about midway between adjacent natural drainage lines (creeks), although this may have been perturbed by antecedent pumping by landholders.
- The hydraulic conductivity of the near surface sand aquifer is of the order of 100 m/day. This is a highly permeable unit and will permit the flow of large volumes of water if there is a head difference between the lake and aquifer or the lake and adjacent waterways.
- Tidal diurnal fluctuations in groundwater level will propagate 100 m to 200 m within the sand unit.

The main design-related constraint to groundwater is the lake that is required to be constructed on the eastern lots as a flood mitigation solution (**Chapter 9**). The water quality needs of this lake (**Chapter 11**) require it to be some 4 m deep and this will intersect the upper aquifer and therefore interact with groundwater.

The main design-related mitigation option to avoid impacting groundwater is to not disturb it by extraction, excavation of soil below the water table, or increasing surface water / groundwater interaction. Not all of these 'non-disturbance' options are available given the decision to construct the lake as a flood mitigation solution. This is because:

- To implement the lake solution requires an excavation of approximately 2.8 m of material below the groundwater level over an area of approximately 33 ha. This will intersect the upper (unconfined) aquifer.
- The lake water quality solution described above requires that seawater be pumped into the lake constantly. Over a very short period of time, this will mean that the water in the lake will become saline, approaching the salinity of Richters Creek at most times. This water has the potential to interact with adjacent groundwater.

The following discussion firstly investigates the impacts on groundwater that could arise when saline water is introduced to the lake and maintained more or less permanently, and secondly considers groundwater extraction issues. Details of the proposed mitigation measures (design-related) are provided.

Surface water / Groundwater Interaction

Early in the concept design process, it was planned to limit lake / groundwater interaction by setting the lake level at about that of normal (dry season) groundwater. This is at roughly 0.3 m AHD. Modelling was undertaken and this found that it was likely that groundwater quality under and around the footprint of the lake would change from its present brackish condition toward a more saline quality, consistent with that of the lake exchange water derived from the Coral Sea. It was concluded that the small diurnal change in lake water levels then-contemplated would still be likely to be sufficient, over time, to change shallow groundwater beneath and around the lake from fresh and brackish to saline.

Figure 10-14 presents a view of the likely shallow groundwater quality after lake construction under these (un-mitigated) conditions and indicates the areas where groundwater quality was anticipated to become more saline.

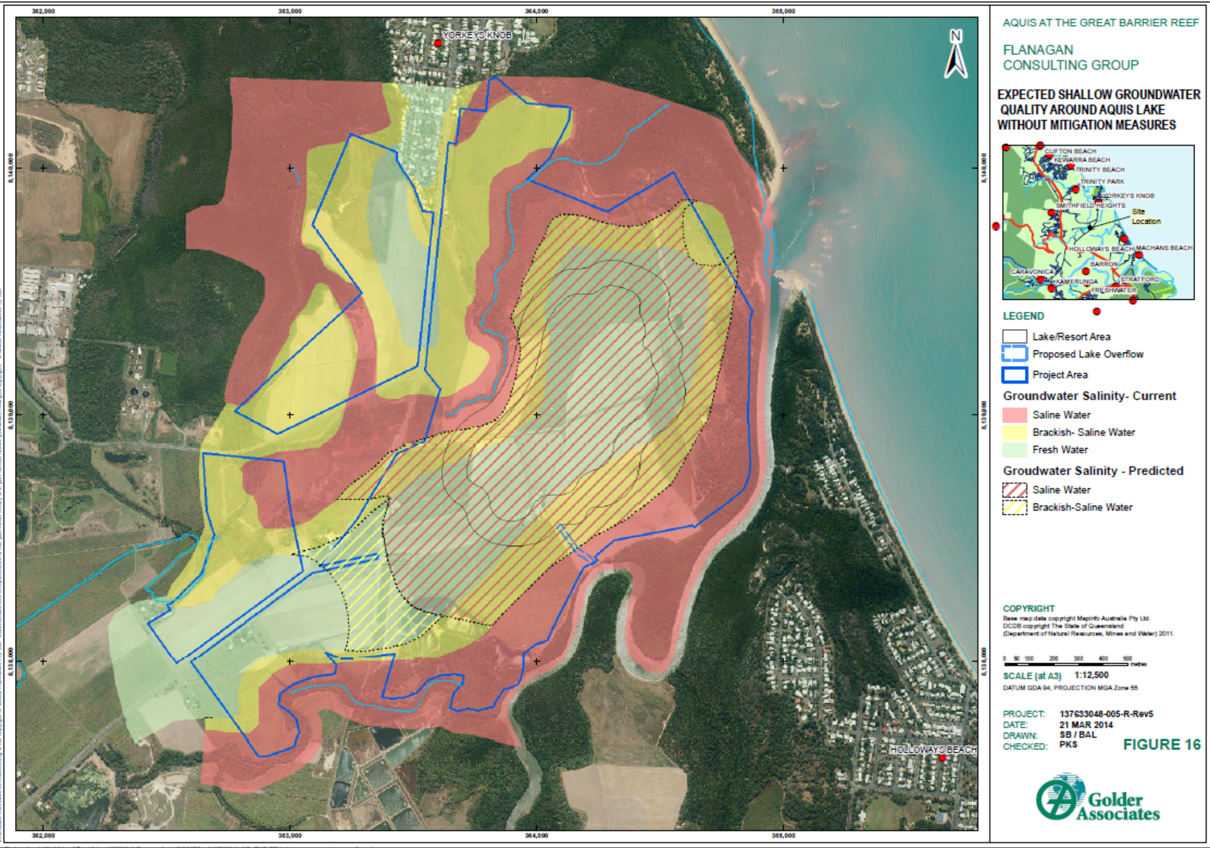

Figure 10-14 Likely changes in groundwater salinity resulting from lake exchange (un-mitigated).

Source: Appendix M (Figure 16).

This figure shows that while the area of predicted (un-mitigated) salinity increase is restricted to the Aquis Resort site, it would possibly impinge on the areas of natural vegetation in the northern and north-eastern parts of the site.

In summary, under this design scenario, the high transmissivity of the upper unconfined aquifer was found to present challenges to maintaining a large saline lake, including:

- Water levels rising and falling in conjunction with tidal and seasonal movements within adjacent waterways.
- Maintaining lake levels at existing groundwater conditions and / or adjacent waterways.
- Increased salinity under vegetated areas along the fringes of Richters Creek and Yorkeys Knob that are thought not to be saline water tolerant. At the very least, increased salinity will lead to a change in species towards more tolerant species.

At the time when these impacts were assessed the top water level of the lake was proposed to be at 0.5 m AHD. Since that time this level has been increased to 1.5 m AHD to minimise the excavation required and this will have the effect of increasing the level difference between lake water and groundwater, thus accelerating the interaction.

Mitigation Options

Available mitigation measures investigated were:

- providing a suitable buffer between saline lake and fresh groundwater outside the development (preliminary modelling indicates a minimum buffer distance of 200 m is sufficient)
- maintaining existing tidal waterways between the development and urban areas to the north to act as a natural hydraulic barrier
- selection of salt-tolerant species to replace those unlikely to survive increasing salinity
- construct hydraulic barriers (liners, cut-off walls) to separate water bodies containing salt water.

Although the likely effects of this surface water / groundwater interaction could be managed, the adopted mitigation is the fourth option listed above, namely to line the lake or otherwise quarantine lake water from groundwater. This solution allows the lake level to be varied relative to the dry season groundwater level as the two systems can be uncoupled.

Adopted Mitigation

The functional requirement to quarantine the lake from groundwater is to reduce the permeability of the system to minimise exchange of lake water and salinity horizontally out of the lake and into the shallow aquifer. Quarantining the lake from groundwater can be achieved in one of two ways:

- lining the lake walls and floor with an impermeable membrane
- using cut-off walls to create an impermeable barrier outside the lake walls that extends down into the more impermeable clays that exist at depth.

These options are shown schematically in **Figure 10-15** and **Figure 10-16** respectively.

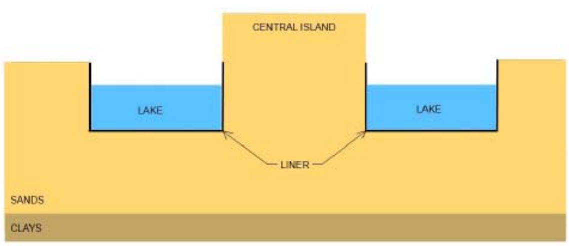

Figure 10-15 Liner option.

Source: Appendix M (Figure 15).

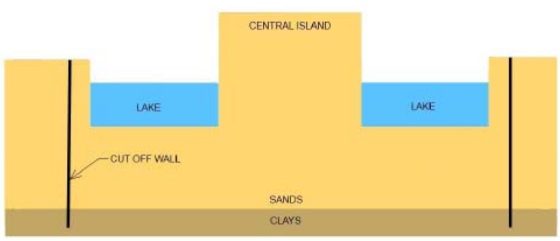

Figure 10-16 Cut-off wall option.

Source: Appendix M (Figure 15).

The consideration of salinity migration mechanisms was modelled and this shows that low permeabilities are required to minimise both horizontal and vertical migration of salt water. With the known high permeability of the shallow sandy sediments, a quarantining solution with a hydraulic conductivity of 0.001 m/d (~10^{-8} m/s) or lower is required.

Further details of quarantining options are shown below on **Figure 10-17** and **Figure 10-18**.

TYPE OF LAKE LINER	DESCRIPTION	EASE OF CONSTRUCTION	EFFECTIVENESS	DURABILITY	POTENTIAL FOR ENVIRONMENTAL IMPACT
Compacted Clay 	Low permeability clay is placed to form a lining layer to hold water within the lake and minimise leakage out of the lake.	Can be constructed using conventional earthworks equipment. Source of suitably low permeability clay has not been identified and may preclude this as a feasible option for this site.	Compacted clay liners are typically specified to achieve a maximum permeability in the order of 1×10^{-8} m/sec. Effectiveness of the liner requires a good quality control/quality assurance program. Prevention of drying out following construction is critical to maintaining permeability.	Compacted clay liners can remain effective for periods of more than 50 years when appropriately designed and constructed.	Construction of a lined lake will require significant dewatering and may result in the draining of ASS. This has potential for major impact and is the less desirable option as a feasible option without other control measures (such as temporary sheet piling to prevent groundwater draw down external to the lake).
Synthetic Liner 	A synthetic liner (HDPE, LDPE, GLC, etc.) clay is placed on a prepared surface to hold water within the lake and minimise leakage out of the lake. Protective layers of geofabric and soil over the liner to prevent damage/puncture.	Requires specialist installation contractors to weld/join and place liner.	Synthetic liners typically achieve permeabilities of at least 1×10^{-11} m/sec. Effectiveness of the liner requires a good quality control/quality assurance program.	Synthetic liners typically have design lives of more than 50 years. Design life is typically shortened were the liner is exposed to UV degradation.	

Figure 10-17 Lake liners.

Source: Appendix M (Table 6).

TYPE OF LAKE LINER	DESCRIPTION	EASE OF CONSTRUCTION	EFFECTIVENESS	DURABILITY	POTENTIAL FOR ENVIRONMENTAL IMPACT
Structural	These measures can be incorporated into structures including the lake walls or support for buildings.				
Steel Sheet Piles with Interlocking Sealing System 	Steel sheet piles are driven into the stiff clay materials underlying the water bearing sand layer (the upper aquifer). This forms a cut off wall around the perimeter of the lake. Where the sheet pile forms a vertical lake wall, additional tie back/wall anchors may be required.	Can be constructed rapidly using conventional sheet piling equipment. Lead in time for supply of this volume of sheet pile may be a factor in the feasibility of this option.	Sheet piles without joint seals can achieve permeabilities in the order of 8 x 10^{-7} m/sec. When joint interlocking sealing systems are incorporated, permeabilities in the order of 1 x 10^{-10} m/sec can be achieved with a good quality control/quality assurance program.	A sacrificial thickness of steel would be part of design to meet a design life. Typical corrosion rates are 0.01 mm/yr below the soil surface, with rates of >0.05mm/yr in exposed water zones. Additional durability can be attained through use of protective coatings (including galvanising) or cathodic protection. Design lives of greater than 50 years should be achievable.	Some potential for vibration and noise during installation works.

TYPE OF LAKE LINER	DESCRIPTION	EASE OF CONSTRUCTION	EFFECTIVENESS	DURABILITY	POTENTIAL FOR ENVIRONMENTAL IMPACT
Diaphragm Walls 	A bentonite slurry trench is formed into the stiff clay materials underlying the water bearing sand layer (the upper aquifer). Reinforcing cages are inserted. Concrete is then tremied into the base of the trench to displace the slurry and form a cast in place wall panel. Progressive installation of these panels forms a cut off wall around the perimeter of the lake.	Requires specialist equipment and experienced contractors. Has the longest construction time frame.	Diaphragm walls are constructed to be effectively a water-tight barrier.	Design lives of greater than 50 years should be achievable.	Storage and use of significant quantities of concrete and bentonite will require management measures to prevent environmental impact.
Non-structural	These types of cut off walls are set back away from the edge of the lake and do not or are not suitable to integrate into a structural element.	-	-	-	-
Steel Sheet Piles with Interlocking Sealing System	As above	As above	As above	As above	As above

TYPE OF LAKE LINER	DESCRIPTION	EASE OF CONSTRUCTION	EFFECTIVENESS	DURABILITY	POTENTIAL FOR ENVIRONMENTAL IMPACT
Slurry Walls (soil-bentonite, soil-cement-bentonite or cement-bentonite) 	A slurry trench is formed into the stiff clay materials underlying the water bearing sand layer (the upper aquifer). The slurry trench may be formed using various techniques including 'soil mixing' slurry of existing soil and bentonite) or removal of soils and replacement with a bentonite/cement slurry. The slurry is allowed to set to form a cut off wall around the lake.	Requires specialist equipment and experienced contractors.	Slurry walls can typically achieve permeabilities in the order of 1×10^{-8} to 1×10^{-9} m/sec.	Design lives of greater than 50 years should be achievable.	Storage and use of significant quantities of concrete and bentonite will require management measures to prevent environmental impact.
Composite Slurry (slurry with synthetic liner insert)  Photo © Manard Bachy	For this option a synthetic liner (e.g. HDPE) is inserted into the slurry trench to provide a lower permeability barrier. The liner is overlapped (rather than welded) with the pressure of the slurry wall against the overlapped sheets maintaining the seal.	Requires specialist equipment and experienced contractors.	These types of wall can achieve permeabilities in the order of 1×10^{-11}.	Design lives of greater than 50 years should be achievable.	Storage and use of significant quantities of concrete and bentonite will require management measures to prevent environmental impact.

Figure 10-18 Lake cut-off walls.

Source: Appendix M (Table 7).

As is evident from the above analysis, there are several quarantining options that could be employed. A decision on which of these to adopt will be made during detailed design. One advantage of the sheet pile wall option is that it can be used as the edge of the lake (i.e. as a vertical wall to either top water level (with a sloping 'beach' above this to the top of the lake wall at the natural surface if desired) or all the way to the top of the bund around the lake (in which case a rail or balustrade may be required for safety and aesthetic reasons).

This is an ecological and aesthetic consideration whose solution does not affect the groundwater performance.

Groundwater Extraction

Further to the above summary of groundwater conditions:

- a fresh groundwater resource exists within the semi-confined aquifer at depths below approximately 50 m
- although there are known localised salinity issues, existing users of this resource are present in the areas surrounding the site
- surface water and groundwater ecology are in a state of balance that it is not desirable to disturb.

In addition to the lake salinity / groundwater interaction issue described above, the main option to avoid impacting groundwater is to not disturb it by extraction.

<u>Surface water / groundwater interaction</u>

Modelling

A groundwater model was established to assess the impacts on groundwater of the quarantined lake solution. It was not necessary to choose between the liner and cut-off wall options (or variations of these): the methodology adopted was to select a range of permeabilities that are known to be achievable with proven real-world solutions and test the impacts. Once acceptable impacts are determined, a selection can be made of the best design and construction solution.

Figure 10-19 presents a schematic cross-section through the lake. The figure shows the potential locations of vertical cut-off walls on either side of the lake. Note that although this section looks 'thin', the vertical exaggeration on this figure is x10 (that is, the figure is stretched vertically by a factor of 10 to reveal small differences in height).

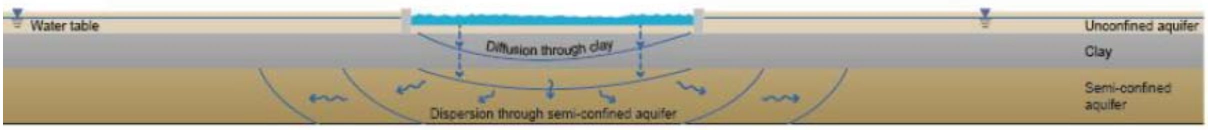

Figure 10-19 Conceptual section through lake with cut-off walls and diffuse through clay.
Source: Appendix M (Figure 11).

An analysis was undertaken into different means and directions by which salinity may migrate from the lake into the ambient groundwater. The two potential mechanisms considered for salinity migration are identical to those described for surface water, namely:

- **Advection** – transport of salinity where a hydraulic head difference occurs between the lake and the local groundwater. In this case flows could be forced from the lake into the shallow aquifer horizontally and vertically.

- **Diffusion** (or dispersion) of salinity due to the difference in concentration between the water in the lake and the ambient groundwater. Note that diffusion of salinity can occur even without a driving head difference.

Most frequently encountered sites where solute (e.g. salt) transport causes problems involve advective movement with groundwater flow. At low flow rates in low permeability material eventually diffusive transport can dominate.

Results

Figure 10-20 shows the breakthrough of salinity through a low permeability barrier. With a hydraulic conductivity of 0.01 m/d (~1 x 10^{-7} m/s) advective flow dominates and salinity may migrate through the barrier in 10-40 years. With a hydraulic conductivity of 0.001 m/d (~1 x 10^{-8} m/s) or lower, the time for salinity to move through the barrier is greatly extended to 50-100 years. Also the eventual flux of salt though a low permeability (1 x 10^{-8} m/s or lower,) barrier would be too small to affect the shallow or deeper aquifers.

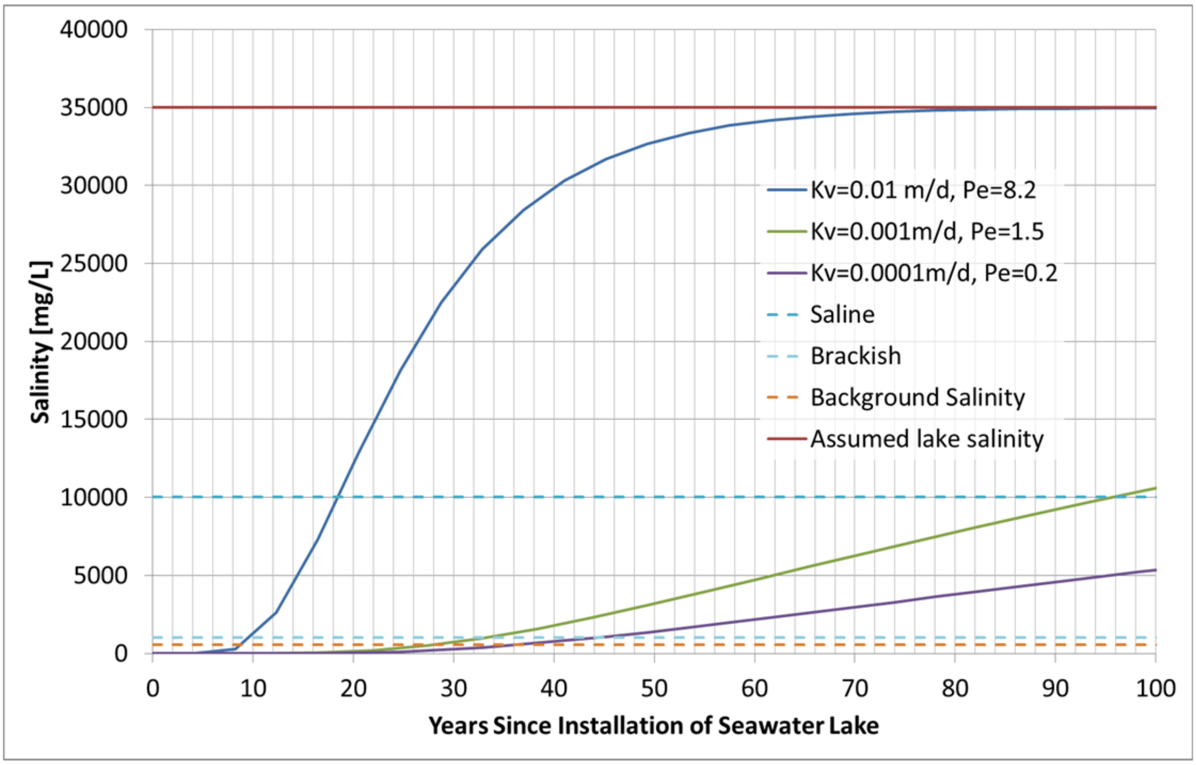

Figure 10-20 Salinity breakthrough concentrations different permeabilities.

Source: Appendix L (Figure 14).

The modelling reveals that with the quarantined groundwater solution, there will be effectively no surface water / groundwater interaction.

Implications for Cut-off Wall and Liner Design

The consideration of salinity migration mechanisms shows that low permeabilities are required to minimise both horizontal and vertical migration of salt water. With the known high permeability of the shallow sandy sediments, a cut-off wall of 0.001 m/d (~10^{-8} m/s) or lower hydraulic conductivity is required.

In the vertical direction, the vertical permeability and continuity of the stiff clay unit needs to be confirmed to be 0.001 m/d (~10^{-8} m/s) or lower. If the unit is discontinuous, thin or has a higher permeability, then the lake will require lining or ground treatment measures to mitigate impacts on the deeper natural groundwater system. Feasible solutions such as soil mixing and grout injection exist for this treatment.

Provided that the quarantining layer is provided as recommended above, there will be no surface water / groundwater interaction.

Groundwater Extraction

Inside Quarantined Area

Quarantining the lake from groundwater means that inside the quarantined area, the available groundwater resource will be limited to the volume present at the time of quarantining. Although this could be sustainably extracted, the quarantined area will be cut off from recharge and therefore the supply is strictly limited. The approximate yield from within the quarantined area is 900 ML and approvals would be required for this extraction. The current proposal is that no groundwater extraction will take place, other than dewatering associated with the lake excavation.

Extraction of groundwater from the unconfined aquifer for use in the construction and operation of the development is not proposed, although dewatering will mean that the resource is effectively consumed in any case.

Approximately 900 ML of groundwater will be lost inside the quarantined area as an unavoidable consequence of lake construction.

Outside the Quarantined Area

Freshwater conditions present in the unconfined aquifer within the site extend outside the site boundaries to the north and south-west. There are existing users of the unconfined aquifer in relatively close proximity to the site boundaries in these areas. Extraction of groundwater from the unconfined aquifer outside the lake footprint, for use during both construction and operation of the development, is not proposed on the basis of:

- supporting the identified need to maintain a buffer zone between the saline water lake and site boundary
- reducing the risk of moving the freshwater / saline water interface towards existing groundwater users.

As extraction is not proposed, there will be no impacts on this resource.

Semi-confined Aquifer

Extraction of (fresh) groundwater from the semi-confined aquifer for use during both construction and operation of the development is not proposed.

As extraction is not proposed, there will be no impacts on this resource.

10.2.3 Mitigation and Management

No further mitigation of groundwater impacts is proposed, other than construction controls. The proposed construction methodology recognises that the quarantining solution must be in place before groundwater is extracted from the lake area in order to avoid saline intrusion caused by dewatering activities. This will most likely be required early in the construction period for constructability reasons.

Management of groundwater during construction is proposed to be addressed in the site's EMP (Construction) described in **Section 23.4**.

10.2.4 Residual Impacts

The principal risk to groundwater is interaction with saline lake water and this has been effectively mitigated by quarantining. As part of the construction of the lake, approximately 900 ML of groundwater (i.e. the resource within the quarantined area) will be unavoidably consumed by the dewatering process. This could be used beneficially, subject to appropriate approvals.

Other than this volume, it is not proposed to extract or use any other groundwater.

Commitments to further investigations on groundwater are described in **Section 23.6.4**.