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SOUTHWEST CORRIDOR DEVELOPMENT AND EMPLOYMENT FOUNDATION

Cape Peron Marina Development

Groundwater Fatal Flaw Assessment

302/09333

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PROJECT 302/09333 - CAPE PERON MARINA DEVELOPMENT

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1. INTRODUCTION

To cater for increasing pressure on boating facilities within the City of Rockingham, a range of marina and associated canal development options have been proposed for Mangles Bay, east of the Cape Peron Causeway.

To assist with assessing canal development options, the Southwest Corridor Development & Employment Foundation Inc. (SWCDEF) has commissioned WorleyParsons Services Pty Ltd (WorleyParsons) to undertake a preliminary assessment of the potential impact that proposed canal developments could have on Lake Richmond, and any groundwater bores in the area.

The level of assessment is to identify the potential for any unacceptable or 'fatal flaw', which includes all hydrologically-related environmental impacts which could potentially prevent development from proceeding. In this regard the two keys issues under consideration relate to impacts on water quality, primarily any increase in salinity of fresh ground and lake water in the area adjacent to the proposed development site, and any changes to naturally occurring fluctuations in local groundwater and lake water levels.

1.1 Scope of Works

The Scope of Works is to provide a preliminary fatal flaw assessment of the potential hydrological impacts that the proposed canal developments could have on Lake Richmond and any groundwater bores in the area resulting from:

- Movement of the saltwater-groundwater interface post canal development; and
- Dewatering to -2.4m AHD during canal construction.

For the purpose of this report, the project may be considered 'fatally flawed' if it can be shown that there is a significant and unacceptable risk that canal construction could lead to:

- Significant incursion of the saltwater-groundwater interface towards Lake Richmond, thus leading to an increase in lake salinity.
- Significant changes in water level fluctuations in the lake in excess of measured seasonal (1m) or long term variations.

2. GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

The Project area lies on the Safety Bay groundwater 'mound'. The mound is an important recharge site for the fresh coastal groundwater regimes including Lake Richmond. The site is underlain by approximately 30m of superficial formations, comprising Safety Bay Sands and Tamala Limestone. These formations are in turn underlain by an approximately 100m thick sequence of Rockingham Sand.

2.1 Superficial Formations

The Safety Bay Sand formation which blankets the surface of the site overlies the Tamala Limestone, which consists of cream, unlithified, calcareous fine-grained to medium-grained quartz sand and shell fragments.

The Tamala Limestone unit is a calcareous eolianite that unconformably overlies the deeper Rockingham Sand formation. It contains various proportions of quartz sand, fine-grained to medium-grained shell fragments and minor clay lenses. The limestone typically exhibits secondary porosity in the form of numerous solution voids, channels and cavities. The average base elevation of the Tamala Limestone in the project area is estimated to be -30m AHD (Department of Environment Groundwater Atlas).

2.2 Rockingham Sand

The Rockingham Sand occupies what is thought to be a paleo-channel (erosional channel) incised into the bedrock Cretaceous sediments, which extend offshore from Rockingham to beneath the southern end of Garden Island. The unit comprises mainly slightly silty, medium-grained to coarse-grained sand of shallow marine origin. The maximum thickness of the Rockingham Sand is approximately 110 metres at the southern end of Cockburn Sound in the Rockingham area.

2.3 Groundwater Occurrence and Flow

Groundwater occurs in two main aquifer systems at the Cape Peron Site, in the superficial aquifer; collectively made up of the Safety Bay Sands and Tamala Limestone, and the underlying Rockingham aquifer, made up of the Rockingham Sand formation.

2.3.1 Superficial Aquifer

Groundwater in the superficial aquifer (top 30 m of site) generally flows in a westerly direction. As this aquifer is the surface aquifer and is relatively shallow, flows tend to discharge to the near shore marine environment along the coastline, rather than deeper sections well below sea level.

The coastal strip of the superficial aquifer is generally characterised by high transmissivity and relatively flat hydraulic gradients (1:1000 to 1:2000), due mainly to the hydraulic effects of the secondary porosity (cavities etc.) in the Tamala Limestone.

Horizontal hydraulic gradients across the Project Area are typically in the range 0.001 to 0.0002. Tidal lag measurements have indicated that the sands underlying the project area have an average hydraulic conductivity of about 5 m/day (Coffey Partners, 1997). In specific areas dominated by Tamala Limestone estimates of horizontal hydraulic conductivity in this aquifer can be as high as 3000 m/day (Smith and Hicks, 2001).

The potential for high variances in hydraulic conductivity across discrete zones of the project site is one factor which makes it potentially difficult to assess the hydrological impacts of marina and canal development proposals.

2.3.2 Rockingham Aquifer

The Rockingham aquifer is defined as the Rockingham Sand and can be locally confined by discontinuous clay lenses located towards the base of the superficial formation (Tamala Limestone). Flow in this aquifer is generally in a westerly direction. As this aquifer is the deeper aquifer at the site, freshwater flows mainly discharge into the ocean well below sea level.

As the Rockingham aquifer is thicker and deeper than the superficial aquifer, salt water intrusion can potentially penetrate quite deep and further inland. The aquifer contains saline groundwater beneath about -65m AHD, while the top 40 m contains groundwater of salinity less than 1000 mg/L (Smith and Hick, 2001).

The confinement of landward incursion of seawater below the Tamala Limestone may to a large extent limit mixing of deeper groundwater with the fresher groundwater flows in the superficial aquifer.

3. LAKE RICHMOND

Lake Richmond is a regionally significant wetland with high conservation status and values. It is located within 200 m of the proposed canal development. Lake Richmond is unusual compared with virtually all other lakes of the Swan Coastal Plain, in that it is deep (maximum depth 15 m), perennial and fresh.

Water level records for Lake Richmond for the period from 1945 to 2005 were obtained from the Department of Environment. Water levels do not vary greatly seasonally, ranging from 0.2 to 1.2 mAHD. The long term average water level is 0.75 mAHD.

Due to the lakes regional significance it is important to assess the potential impact the proposed canal development may have on the lakes hydrological regime. Of particular concern is the potential for the existing saltwater-groundwater interface to move inland as a result of dewatering during canal construction, or as a result of the canal developments themselves. This could affect both the salinity and ranges in water level fluctuations in the lake. Such changes to the current hydrological regime could potentially adversely impact the freshwater ecology of the lake impacting local terrestrial and aquatic biota and vegetation.

4. FATAL FLAW ASSESSMENT

4.1 Saltwater Intrusion

Groundwater within the superficial aquifer in the Project Area discharges to the coast (Point Peron Peninsula). As the groundwater underlying the ocean is saline, a wedge shaped boundary or interface is formed between the higher density ocean water and the lower density fresh groundwater beneath the land. In coastal areas, there is a 'zone of diffusion' at the interface where fresh and saline groundwater mixes. The thickness of this 'zone of diffusion' and the shape and movement of saltwater-groundwater interface depend on factors such as the direction and gradient in groundwater flow, density difference between the salt and fresh water, aquifer permeability and tidal and storm surge heights and gradients.

The position of the saltwater-groundwater interface is often approximated using the Ghyben-Herzberg equation. In simple terms the equation predicts that at a specific location fresh water extends below sea level by about 40 times the height of the water table above sea level (Fetter, 1994) measured at that location, i.e. a 1:40 ratio between groundwater head and depth to salt water occurrence.

This relationship is based on the assumption of hydrostatic equilibrium, that is, no groundwater flow and no tidal movements. It also assumes that the soil is homogeneous, highly transmissive and that there is no diffusion zone. Therefore the relationship mainly accounts for the effects of differences in density between fresh and saline groundwater and assumes there is a sharp, discrete interface between fresh groundwater and saline sea water.

In Perth, groundwater discharge from the superficial aquifer to the ocean results in a freshwater-saltwater interface located deeper and closer to the ocean than predicted by the Ghyben-Herzberg equation. In addition, tidal movements and seasonal variations in groundwater levels inland result in considerable daily and seasonal lateral migration of the saltwater-groundwater interface and a reasonably thick zone of diffusion at the interface between these systems.

Where there is significant groundwater head (hydraulic gradient) and flow, a modified version of the Darcy equation can be used to take into account the effects of groundwater flow when predicting the slope of the saltwater-groundwater interface (Davidson, 1995). Predicting interfaces using this approach are considered valid approximations by the regulators for assessments for developing urban areas south of Perth, where the superficial aquifer consists mainly of sand (Davidson, 1995). The predicted position of the saltwater-groundwater interface relative to Lake Richmond, under both existing conditions and post canal conditions, is presented schematically in Figure 1.

In predicting the locations of the freshwater-saltwater interface the following assumptions were adopted:

- The superficial aquifer is homogeneous (i.e. that the hydraulic conductivity of the Safety Bay Sand is the same as that of the underlying Tamala Limestone).
- The thickness of superficial aquifer is 30m.

- No tidal variations (sea level held constant at 0m AHD).
- No ‘zone of diffusion’.

Groundwater monitoring of the superficial aquifer has shown that the saltwater-groundwater interface actually intrudes up to 2 km inland from the coast through solution cavities in the Tamala Limestone (Smith and Hick, 2001). This results in an almost flat saltwater-groundwater interface within this aquifer and a thin layer of saline water at the base of the superficial aquifer within the Tamala Limestone. Based on these observations, the shape and position of the saltwater-groundwater interface is more likely to be similar to that presented in Figure 1 (dashed line).

Tidal variations and seasonal variations in groundwater levels inland will also cause ‘seiching’ at the interface, that is, the lateral position of the saltwater-groundwater interface will vary with tidal fluctuations, moving further inland during high tidal conditions and retreating seawards during low tidal conditions. Diffusion (mixing) at the saltwater-groundwater interface will also increase the inland migration of saline groundwater. The effect tidal movements and diffusion has on the position of the saltwater-groundwater interface has not been considered in this preliminary assessment (Figure 1).

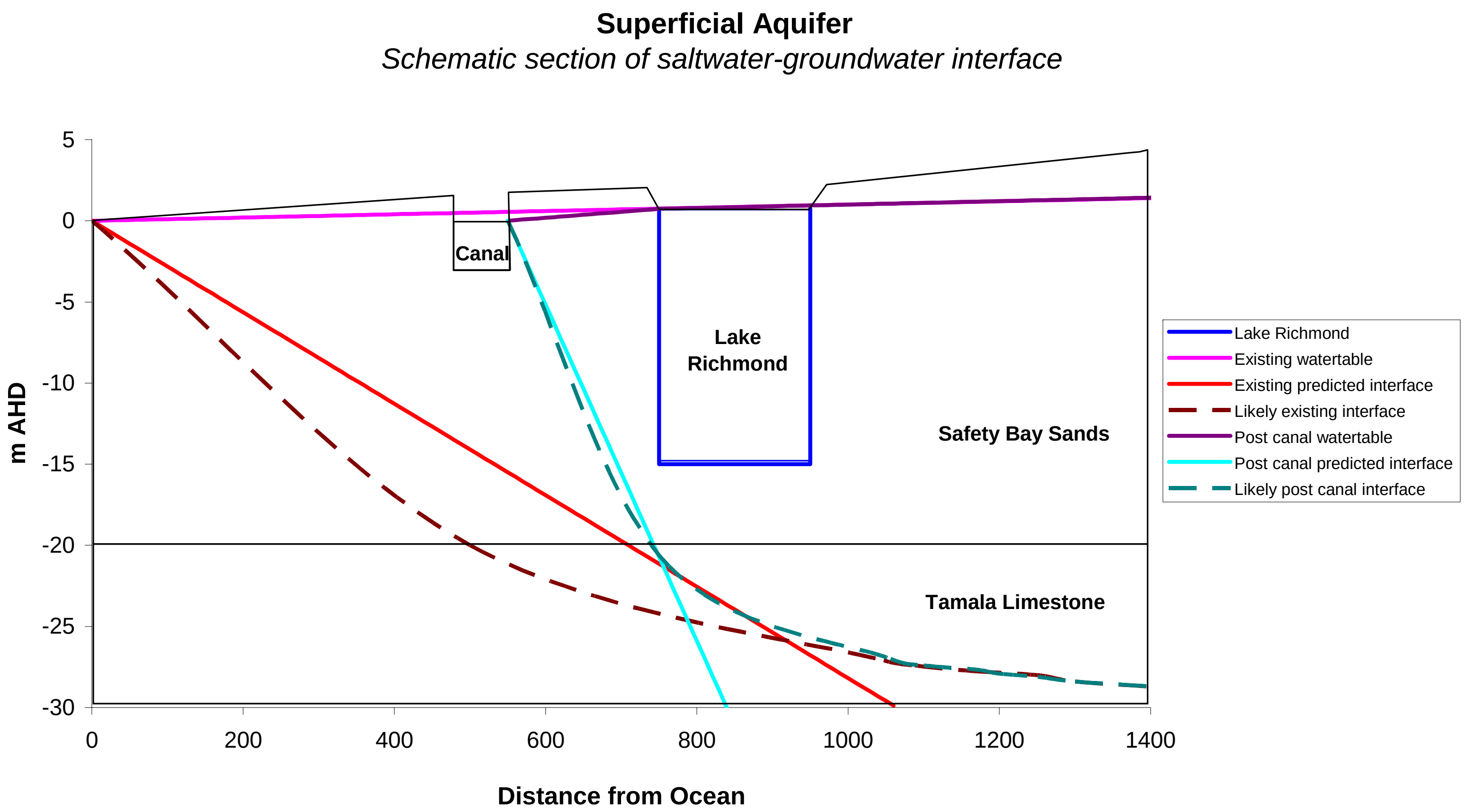

Figure 1. Schematic section of saltwater-groundwater interface

4.1.1 Impact on Bores

Figure 1 indicates that the predicted movement of the saltwater-groundwater interface may contaminate bores located within 200 m of the proposed canal development with saltwater, particularly those screened in the upper 20 m of the superficial formations.

A regional search of the Department of Environment (DoE) AQWABase database reveals that there are approximately 6 bores located within the area which are at risk of contamination by saline intrusion. It is highly likely that there are additional bores in the area. It may therefore be necessary to undertaken a bore census in the area to confirm this and also to be sure that there are not other bores which could potentially be impacted by saltwater intrusion.

4.1.2 Impact on Lake Richmond

Construction of the proposed canal development may result in both a steepening and lateral inland movement of the saltwater-groundwater interface. The theoretical buffer zone between the saltwater-groundwater interface and the base of Lake Richmond under current conditions is approximately 200 m. This maybe reduced to approximately 50 m following canal construction.

Based on the preliminary assessment, there is a risk that Lake Richmond could be impacted by saltwater. Although calculations indicate that there would be an approximate 50 m buffer zone following canal construction, tidal fluctuations, diffusion and local variations in aquifer properties may further reduce this buffer. This would need to be confirmed by a more detailed investigation.

4.2 Dewatering

To determine the potential impact of lowering groundwater levels to -2.4m AHD during canal construction will have on levels in Lake Richmond, a simple analytical computer model was constructed using aquifer geometry and properties obtained from the Department of Environment AQWABase database and the Coffey Partners Geotechnical Report (Coffey Partners 1997).

The analytical model was developed using the HOTSPOTS modelling system (Figure 2). HOTSPOTS was developed by the University of Technology Sydney and the NSW Department of Infrastructure, Planning and Natural Resources for assessing water allocation and trading applications, and for management of localised declines in groundwater levels due to over-abstraction (Merrick et al. 2002; Ross et al. 2004). The model applies a series of analytical equations similar to the Hantush-Jacob approach to calculate the cumulative effect of multiple pumping bores on water levels at any location in an aquifer.

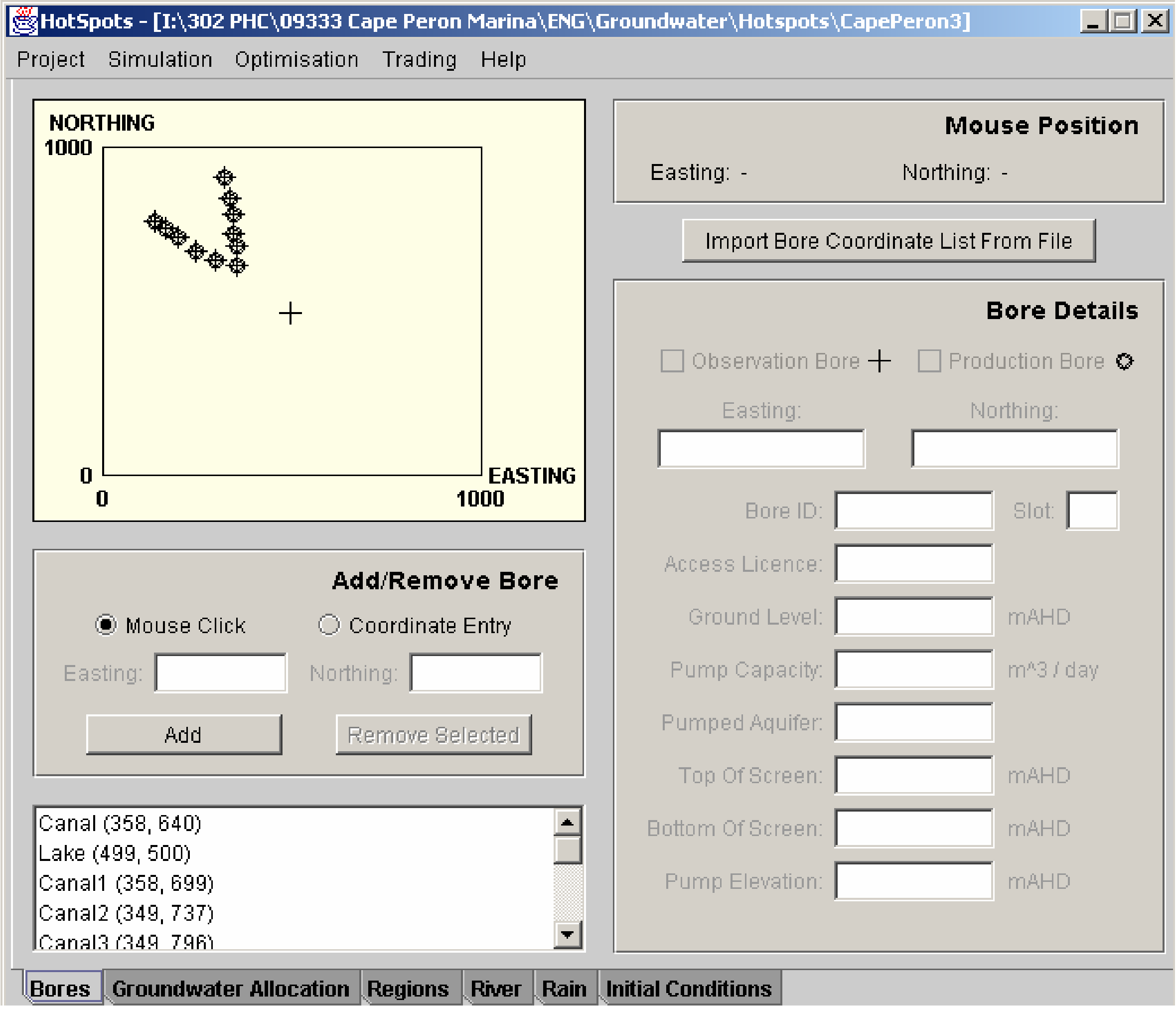

Figure 2. The HOTSPOTS modelling interface

The groundwater system was modelled as a single layer, representing the superficial aquifer, as the superficial aquifer is of primary concern in the assessment of saltwater impacts on local bores and Lake Richmond. The aquifer properties used in HOTSPOT modelling are provided in Table 1.

A series of dewatering bores were entered into the model at locations approximate to the proposed canal alignment. An initial scenario was run with all dewatering bores pumping at 350 m^3/day for 30 days, based on the assumption that the dewatering contractor will dewater to -2.4m AHD within a 30 day period. Pumping rates were adjusted to ensure that each bore was dewatering to -2.4m AHD at the end of the thirty day period.

The model was then run for a 30 day period at the prescribed abstraction rates to simulate the effect dewatering is likely to have on water levels further afield and at Lake Richmond.

Table 1. Aquifer properties used in HOTSPOTS modelling

Aquifer Property	Value	Reference
Hydraulic Conductivity	5 m/day	Coffey Partners, 1997
Specific Yield	0.3 (typical for sandy soils)	Davidson, 1995
Saturated Thickness	30 m	Department of Environment "Perth Groundwater Atlas" and CSIRO technical report 6/01 (Smith and Hicks 2001).
Regional Hydraulic Gradient	1:1000 (to the northwest)	DoE AQWABase database

Modelling indicates that lowering groundwater levels to -2.4m AHD during canal construction could result in a drawdown of the watertable of approximately 15 cm at Lake Richmond. This preliminary assessment therefore suggests that the project is unlikely to adversely affect lake water levels as the predicted impacts from dewatering are well within recorded seasonal variations (1m).

However, as tidal variations and local variations in aquifer properties are likely to influence drawdown during canal construction more detailed modelling is required to quantify the impact these variations could ultimately have on the drawdown at Lake Richmond.

5. DISCUSSION

This preliminary 'fatal flaw' groundwater assessment was conducted to assess whether canal construction at Cape Peron may lead to:

- Intersection of saltwater-groundwater interface and Lake Richmond, thus leading to an increase in lake salinity,
- A reduction in lake levels in excess of measured seasonal variations.

An initial prediction of the position of the saltwater-groundwater interface following canal construction indicates that the saltwater-groundwater interface is likely to steepen and move from 200 m to 50 m north west of Lake Richmond.

Although calculations indicate that following canal construction, there would be an approximate 50 m buffer zone between the saltwater interface and Lake Richmond; tidal fluctuations, diffusion and local variations in aquifer properties (which have not been accounted for in this preliminary investigation) may further reduce this buffer to unacceptable levels of risk.

More detailed/advanced modelling is required to confirm the likely position of the saltwater interface post canal construction, and ensure that the risk of Lake Richmond being impacted by ingress of saltwater is negligible.

Should further modelling/groundwater investigations indicate that there is a high risk of salt water ingress into Lake Richmond following construction of the proposed canal development, then there are engineering solutions available that can be employed during construction (e.g. impermeable cut off walls) to ensure against saltwater ingress to Lake Richmond. Some of these solutions could be low cost but this still needs to be ascertained.

Predicted drawdown of the watertable at Lake Richmond in response to dewatering during canal construction could be in the order of 15 cm. Given that water levels in Lake Richmond vary by up to one metre seasonally, we do not believe that an additional 15 cm of drawdown during construction would have a significant adverse impact on the ecology of Lake Richmond.

There is likely to be a silty clay (lower permeability) layer lining the base of the lake which may affect actual drawdown of the lake water level. This was not considered at this 'fatal flaw' level of assessment and would require further investigation to determine the impact this would have on actual Lake water level drawdown.

The lower permeability layer at the base of the Lake may act to reduce likely drawdown in the Lake. For the purposes of this fatal flaw assessment it was therefore considered conservative to measure drawdown of the watertable at the Lake.

6. CONCLUSIONS

Preliminary conclusions drawn from the study are:

- There is a low risk that Lake Richmond could be impacted by saltwater following canal construction, caused by the inland movement of the saltwater-groundwater interface.
- More detailed modelling/assessment would be required to determine with greater certainty the level of risk posed by potential salt water ingress into Lake Richmond as a result of construction of the proposed canal development.
- Should a more detailed investigation indicate that there is a significant risk of salt water ingress into Lake Richmond as a result of construction of the proposed canal development; engineering solutions are available at the construction stage which could mitigate the potential risk (e.g. impermeable cut off walls).
- Predicted drawdown of the watertable at Lake Richmond in response to dewatering during canal construction could be in the order of 15 cm, which is within the range of seasonal variations in recorded lake levels (1m). Therefore this is not expected to have significant adverse impact on Lake Richmond ecology.
- Based on the criterion set out in Section 1.1 of this report, the project is not considered “fatally flawed.”

7. RECOMENDATIONS

As the outcomes of this fatal flaw assessment indicate the possibility that marina and canal developments could impact the freshwater status of bores located in the superficial aquifer in close proximity to the proposed development site and also Lake Richmond, it is our recommendation that more detailed groundwater investigations be undertaken to better quantify this risk.

Storm surge, tidal fluctuations and local variations in aquifer properties were not taken into account in the preliminary assessment; these aspects should be considered in the next phase of modelling.

Additional field work may also be required to ascertain the local variations in the hydraulic properties of the superficial aquifer between Lake Richmond and the proposed development site. This may require installation of pumping and monitoring bores, and pump tests.

It is our opinion that an integrated surface water and ground water modelling approach, together with additional field verification work and a risk-based assessment would most likely satisfy the relevant regulators that the risk of landwards saline incursions has appropriately been assessed and evaluated for development approvals purposes.

8. INTERPRETATION OF THIS REPORT

This report has been prepared to assist in carrying out a fatal flaw assessment of the proposed marina/canal development at Cape Peron. The findings presented are preliminary and intended for this purpose only.

9. REFERENCES

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