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CEDAR WOODS PROPERTIES LIMITED
MANGLES BAY MARINA BASED TOURIST PRECINCT

PEER REVIEW OF GROUNDWATER MODELLING

September 2011

1 BACKGROUND

Rockwater was engaged by Cedar Woods to provide a peer review of groundwater modelling by ERM which was conducted to determine the impacts of construction and the presence of the planned marina, and also dewatering for the planned Water Corporation duplication of the SDOOL pipeline, on Lake Richmond and other groundwater users.

It is now planned to construct the marina without dewatering, to minimise any groundwater impacts, and this is commended.

The following reports were provided to Rockwater; they provided the basis of the conceptual hydrogeological model which was used by ERM in constructing the numerical model:

1. MWH, April 2011, Final report Cape Peron drilling and test pumping program;
2. MWH, April 2011, Annual report Cape Peron groundwater study;
3. MWH, April 2011, Conceptual hydrogeology for the Mangles Bay area; and
4. ERM, 30 August 2011, Mangles Bay Marina groundwater modelling: revised conceptual site model report.

Most of the site investigations which included drilling, geological and geophysical logging, bore construction, groundwater sampling, a pumping test and the first conceptual site model, were completed by MWH. ERM supervised the drilling and construction of bores LR1 and LR2, revised the conceptual site model and carried out the numerical groundwater flow and salinity modelling.

The Scope of Work given by Strategen to ERM, and ERM's submission for the work were also provided; as was the initial ERM report "Mangles Bay groundwater modelling, conceptualisation and calibration report".

Finally, the ERM groundwater modelling and impact assessment report was received for review: ERM, August 2011, Proposed Mangles Bay Marina Based Tourist Precinct, groundwater modelling and impact assessment.

The conceptual site model and the three-dimensional numerical groundwater model evolved following the preliminary review by Rockwater (May, 2011) and subsequent discussions between P Wharton of Rockwater and P Whincup of ERM, and additional field and desk-top investigations by ERM. Many of the original concerns raised in the preliminary review have been addressed – only the remaining concerns and items of conjecture are covered in this review.

2 COMMENTS ON HYDROGEOLOGY/CONCEPTUAL MODEL REPORTS

Comments on the above reports that are directly related to the conceptual hydrogeological model are given below. They refer to the reports as numbered above.

1. Test bore PB1 was not open to the aquifer and was not suitable for test pumping. There have been no useful determinations made of aquifer parameters in the project area, in particular the horizontal hydraulic conductivity of the Tamala Limestone (TL) and vertical permeability of the silty sand/clay layer between the TL and the Safety Bay Sand (SBS). The geology and thickness of the SBS, the geological unit which will be intersected by the marina and pipeline, were well defined.

2. Bores MB01, 03, 05, 07, 10, 11, and 12 were slotted through the SBS and into the TL. Water levels and water quality measured in these bores will be dominated by those of the TL which has much higher hydraulic conductivity, and generally higher heads. This can be seen by the increase in salinities with time throughout the depth profiles of bores such as MB10 and 12. The bores should be cemented up to the base of the SBS to prevent saline water from flowing up through them into the SBS.

3. Saltwater in the base of the SBS in the shallow bores away from the coast probably originates from the TL, due to the upward-decreasing hydraulic heads and seepage across the silty sand aquitard. It also could possibly originate from Lake Richmond from when the lake contained saline water, as has been suggested by ERM.

   Licensed groundwater users within 2 km of the planned marina have been identified, and ERM conducted a bore census along the SDOOL pipeline corridor that showed there were many private bores north and east of Lake Richmond. There are probably also private bores in areas west and east of the planned marina that were not surveyed that could potentially be impacted by construction of the marina and the introduction of seawater to it.

The higher-yielding licensed bores could be screened in the Rockingham Sand or Leederville Formation as stated in the conceptual site model report, but most of the unlicensed bores are probably shallow "spears" in the Safety Bay Sand.

3 PEER REVIEW OF MODELLING

3.1 Objectives of the Modelling

The objectives of the modelling are as follows:

1. Determine the relationship between groundwater within the SBS and TL and water levels and water quality in Lake Richmond.
2. Assess the potential impacts over time of the Proposal on:
   - water levels and quality of the groundwater resource within the SBS and TL
   - water levels and quality of Lake Richmond
   - water levels and quality of groundwater available to nearby third party groundwater users.
3. Provide advice on the groundwater volume required to dewater the marina to allow for safe excavation of the marina water body and expected drawdown impacts of dewatering.

3.2 Modelling Scope of Works

The scope of works given by Strategen to ERM included the following sections:

1. <u>Refinement</u> of the existing numerical groundwater model to be able to adequately address the needs of the project.
2. <u>Calibration and verification</u> of a numerical groundwater model to the existing monitoring data currently being collected as part of this Proposal and from long term regional monitoring bore network. The results and observations of the test pumping would also be utilised in the calibration of the groundwater model.
3. <u>Simulation</u> of various scenarios, including dewatering and marina configurations to assess likely areal extent of impacts.
4. Construction and calibration of a <u>solute transport model</u> to allow simulations of the potential changes in groundwater salinity likely to result from the marina connection to the ocean.

The modelling should involve a range of recharge scenarios that reflect the range of likely future climatic conditions. These should include a consideration of potential climate change predictions.

Predictions shall be presented from the modelling simulation as a time series as well as mapping.

3.3 Revised Conceptual Site Model Report (ERM, August 2011)

The conceptual site model (CSM) is largely based on the data collected and the CSM developed by MWH, as well as the results of some additional investigations by ERM.

The report presents a good picture of the conceptual hydrogeology, and forms a solid basis for the numerical groundwater model, except for a lack of hydraulic parameters based on local field data. The SBS in the project area is typical of the formation in other areas where aquifer parameters have been measured.

There are aspects of the hydrogeology that are of particular interest:

1. The natural gamma logs for most of the deeper bores indicate the presence of a clayey layer of around 1 m thickness at the base of the SBS. The gamma counts are not very high – about 20 cps above baseline values (less in bore MB9D), possibly because of the thinness of the layer or else there is a moderately high proportion of silt or sand in the layer. Also, the gamma response has probably been attenuated as the logs were run inside the uPVC casing. Silty sand or sandy silt was recorded in most of the holes over a wider interval and partly above the level of the gamma peak. This suggests that the 1 m-thick layer has some clay content – clay was identified in strata cuttings from only one hole, LR1, from 23 to 24 m depth, although it is difficult distinguishing such a thin layer with cuttings from mud-rotary drilling.

   A thin clay layer has been recorded at the base of the SBS (or silty Becher Sand) in other parts of the Rockingham–Kwinana area. Smith et. al. (2003) report that at the BP Refinery the clay layer appears to infill the lower parts of depressions in the underlying limestone and pinches out where the limestone surface is more elevated. Kevin Haselgrove (pers. comm.) reports that the clay is also discontinuous further north at the Alcoa plant.

2. Saline water in the lower part of the SBS might originate from upward groundwater flow from the TL. This might have been shown by the modelling results if the adopted vertical hydraulic conductivity of the aquitard between the aquifers was higher.

3.4 Groundwater Modelling and Impact Assessment (ERM, 1 August 2011)

Sensitivity analysis was carried out for the SBS but not the TL. The TL has been down-played as an aquifer in the ERM reports, as in the project area it contains saline water indicating that tidal flows dominate over groundwater flows. However, from Lake

Richmond to the east, sand and limestone of the formation forms a fresh-water aquifer. It is interpreted that much of the fresh groundwater in the TL has discharged by upwards leakage to the SBS, east from lake Richmond.

The second last paragraph of page 6 states that saline conditions in the TL extend inland to approximately the groundwater divide, with a reference to Smith and Hick (2001). This is not the case, as is described above, nor is it shown by Smith and Hick. Instead, they state that saltwater is known to intrude up to 2 km from the coast (the groundwater divide is about 5 km from the coast).

The horizontal hydraulic conductivity value used for the TL in the project area (3,000 m/d) is beyond the range given in Davidson and Yu (2008) of 100 to 1,000 m/d, with a value of around 50 m/d said to be more applicable to regional groundwater flow due to the presence of sandy facies and low-permeability zones. Lower values were used in the model at Point Peron (1,000 m/d) and east of Lake Richmond (200 m/d).

The high value of horizontal hydraulic conductivity adopted in the modelling is probably the reason why the model could not be calibrated to a vertical hydraulic conductivity of around 0.01 m/d that would be expected for the silty sand and discontinuous clay aquitard. The model would be able to be calibrated with such a value if horizontal hydraulic conductivities for the TL were in the range 80 to 200 m/d. The high value of horizontal hydraulic conductivity has also resulted in high model-calculated salinities in the formation at bore LR1 of about 12,000 mg/L TDS, compared to measured salinities of 5,000 mg/L at the top and 8,000 mg/L TDS at the base of the formation. Tidal measurements could be made in bores such as LR1 that are screened in the formation to calculate the hydraulic conductivity of the limestone.

The adopted vertical hydraulic conductivity for the silty sand layer of 0.00013 m/d for a 3 m thick bed is too low and unrealistic.

The root mean square error in the calculated water levels of 9 % exceeds the limit of 5 % recommended by Middlemis (2000).

Irrespective of the above, water-level and salinity changes in the SBS will be largely dependent on the hydraulic conductivity of that formation, rather than the hydraulic characteristics of the TL and the aquitard. The adopted value (16 m/d) is the same as or similar to values determined in a number of studies and is realistic. Consequently, the predicted impacts on the water level and water quality of Lake Richmond are also considered to be realistic.

The lower water level in the marina will lower groundwater levels in the SBS, resulting in additional flow to that formation (and the marina) from the TL. If the vertical hydraulic conductivity of the aquitard between the formations is 100 times higher than has been assumed, the quantities of water to be pumped during any dewatering in constructing the marina would be much higher than have been calculated. Also, it could result in some increase in salinity in the lower part of the SBS.

Dewatering for the SDOOL pipeline will be over short periods and require only a small lowering of groundwater level of up to about 1.5 m. A calculation by Rockwater using a simple numerical model with more appropriate parameters for the aquitard and the TL indicates that only about 5 % of the water pumped would originate from the TL.

4 CONCLUSIONS

Monitoring bores slotted in both the SBS and TL should be cement grouted, at least to the base of the SBS, to minimise inter-aquifer flow. Unless sufficient grout flows out into the gravel pack, a complete seal might not be possible.

The conceptual site model generally provides a good basis for the numerical groundwater flow and transport model, although there is a lack of measured aquifer parameters, locally. Also the silty sand and thin clayey aquitard at the base of the SBS might not restrict flow between the SBS and TL as much as has been assumed – upward flow from the TL may be the origin of the saline water in the base of the SBS.

A transient groundwater flow model was used with a model that can simulate variable density groundwater flow – SEAWAT. The latter model is commonly used for that purpose and is suitable for determining future salinity around the planned marina.

The value of hydraulic conductivity used for the TL in the project area is considered to be too high, and an unrealistically low value of vertical hydraulic conductivity has been used for the silty sand and the thin, probably discontinuous, clayey aquitard between the TL and SBS. However, water level changes in the SBS and Lake Richmond will largely be controlled by the hydraulic conductivity of the SBS and the adopted value of that parameter is suitable. The predicted impact on the level of Lake Richmond has been checked by Rockwater using the simple numerical model referred to above, and was found to be very similar.

If the vertical hydraulic conductivity of the aquitard is much higher than has been assumed there could be higher groundwater flows to the marina, particularly if it was dewatered, with the additional flows originating from the TL. This could result in some salinity increases in the lower part of the SBS.

We understand that it is now planned to construct the marina without dewatering, in order to minimise the impact of the marina on groundwater levels and salinity.

Dated: **8 September 2011** **Rockwater Pty Ltd**

P H Wharton
Principal

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