2020

Water Balance for Pink Lake and Lake Warden Esperance

- *Technical support document for the Esperance Pink Lake Feasibility Study*

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Prepared for the Shire of Esperance

1/1/2020

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1. Introduction

The water balance models of Lake Warden and Pink Lake were developed to assist in the feasibility study of Pink Lake for the Shire of Esperance (Figure 1). This water balance model report forms part of a technical support document for the '*Esperance Pink Lake Feasibility Study (2020)*'.

2. Background

The study area is located approximately 600 km south east of Perth and near the coastal town of Esperance on the south coast of Western Australia. The climate is Mediterranean, with cool, wet winters and warm to hot, dry summers. The average monthly temperatures for the study area range from 16 °C to 26 °C during summer (December-February) and from 4 °C to 17 °C during winter months (June-August). The average annual rainfall is 616 mm, and mainly occurs during winter. Average annual potential evaporation is 1600mm and is greatest during the summer months of December and February (Figure 2).

A conceptual model of the Lake Warden coastal wetlands system was developed using hydraulic, chemical and stable isotopic data (Marimuthu et al. 2005) and was used as the basis to understand the placement of the lakes within the wetlands system, particularly, the connectivity of the lakes and the interaction with surrounding groundwater and surface water.

Figure 1: Location map of the Pink Lake and Lake Warden: PL: Pink Lake and LW: Lake Warden.

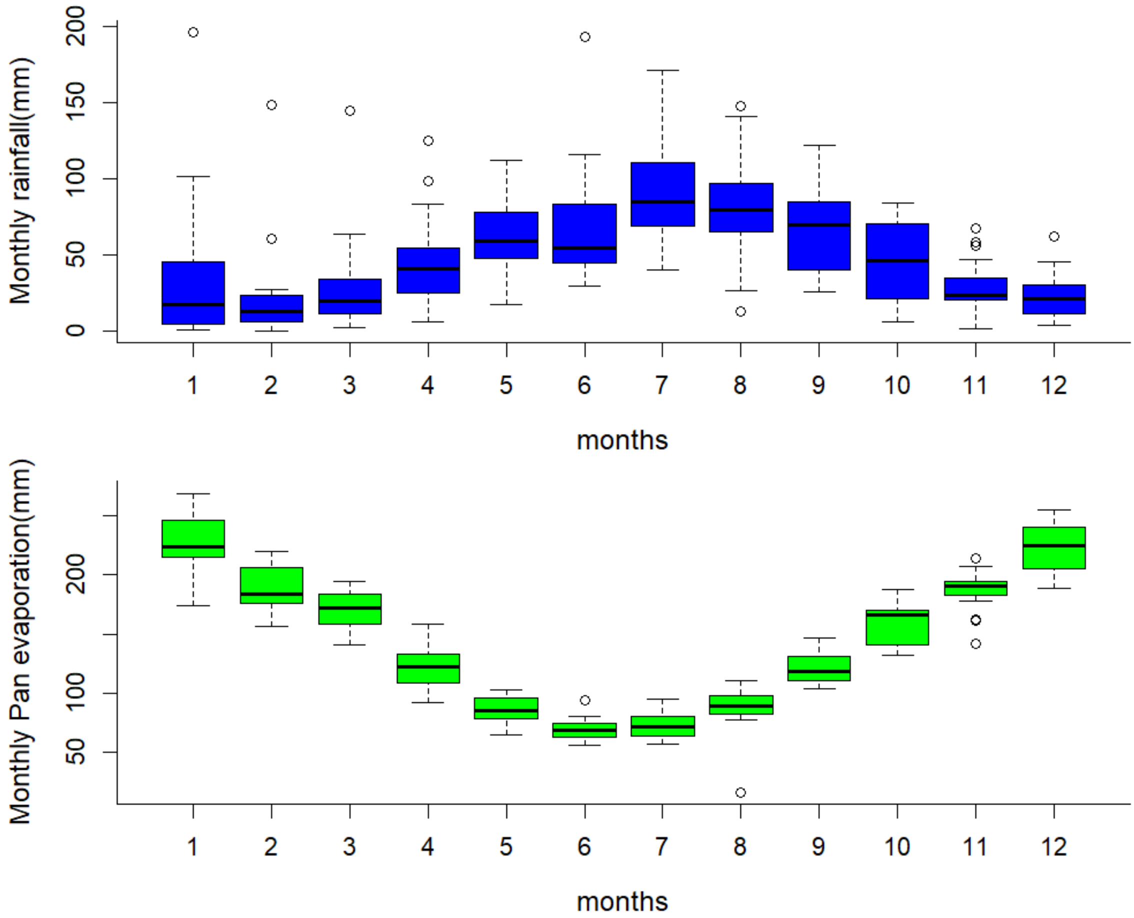

Figure 2: Seasonal variation of rainfall and pan evaporation.

Some of the required components for the water balance of the lakes do not have detailed historical measurements which have hampered the physically based water balance approach to quantifying the water balance of the lakes. However, techniques and results from similar studies from other areas were used as the basis for the computation of the water balance in this system (Marimuthu 2005 and Rich 2004).

3. Methodology

The water balance of the lakes was analysed by constructing a daily water budget that includes inflow, outflow and a storage change term. The daily inflows are the overland flow, groundwater inflow and precipitation on the lake surface. The outflow terms are evaporation and groundwater (Figure 3). The change in storage of the lakes was calculated from the measured lake levels and bathymetry. Evaporation, humidity and precipitation data were obtained from the Bureau of Meteorology Esperance located 2 km away from the study area and Australian Climate Data (SILO, 2019).

$$\frac{dV}{dt} = G(t)_i + P(t) + S_i(t) - G_o(t) - E_o(t) = 0 \qquad (1)$$

Where G_i and S_i are groundwater and surface inflow rate, P is the precipitation, G_o and E_0 are groundwater outflow and evaporation respectively, V is the volume of water in the lake, and t is the time.

Catchment inputs were estimated independently and fed into the model. There is no stream gauge to measure the stream flow to the lakes. The overland flow from 2 and 5 % slopes north of Lake Warden and Windabout Lake (Bennet and George, 2005) was a significant contributor to the water balance of Lake Warden. It was estimated using surface runoff model. In the modelling, surface runoff as saturated excess flow (Qse) was estimated using Qse=S-Sb if S > Sb; Qse=0 if S <= Sb where Sb=D*porosity & ET=S/Sb and change of S =P-ET-Qse. Porosity is 0.4 and soil depth varies.

Groundwater flow was estimated on the basis of groundwater hydraulic gradient (Q=Kidp); where Q- flow of water to the Lake (M^3/d); K=hydraulic conductivity (m/d); I= average hydraulic gradient (m/m); D= average aquifer flow depth (m); P=length of flow section (m). The groundwater contour map and parameters used in the groundwater flow estimation are shown Appendix 1.

There were no field measurements of lake evaporation made and since the effect of lake evaporation is significant, it was a big challenge to reasonably estimate lake evaporation for this study. Several different approaches were adopted to determine a reasonable lake evaporation. 1) constant pan evaporation coefficient (0.7), 2) seasonal varied pan evaporation coefficients (Rich 2004; Gongdon 1985; Marimuthu 2005) and 3) lake evaporation estimate using Morton (1986) approach. In addition, two types of seasonal varied coefficients were tested to account for seasonal varied pan evaporation, (Figure 4).

A gravitational pipeline from Lake Wheatfield to Bandy Creek was installed in 2008 to dewater the central suite of the Lake Warden wetlands system to restore the natural hydro periods of lakes on the LWWS to improve the available habitat for wading birds and the condition of riparian vegetation (Lizamore 2010). Since the construction, the pipeline was opened numerous times. The volume of water removed during this period have been approximated using flow measurements from discrete time periods and extrapolating this data and lake levels (Figure 5).

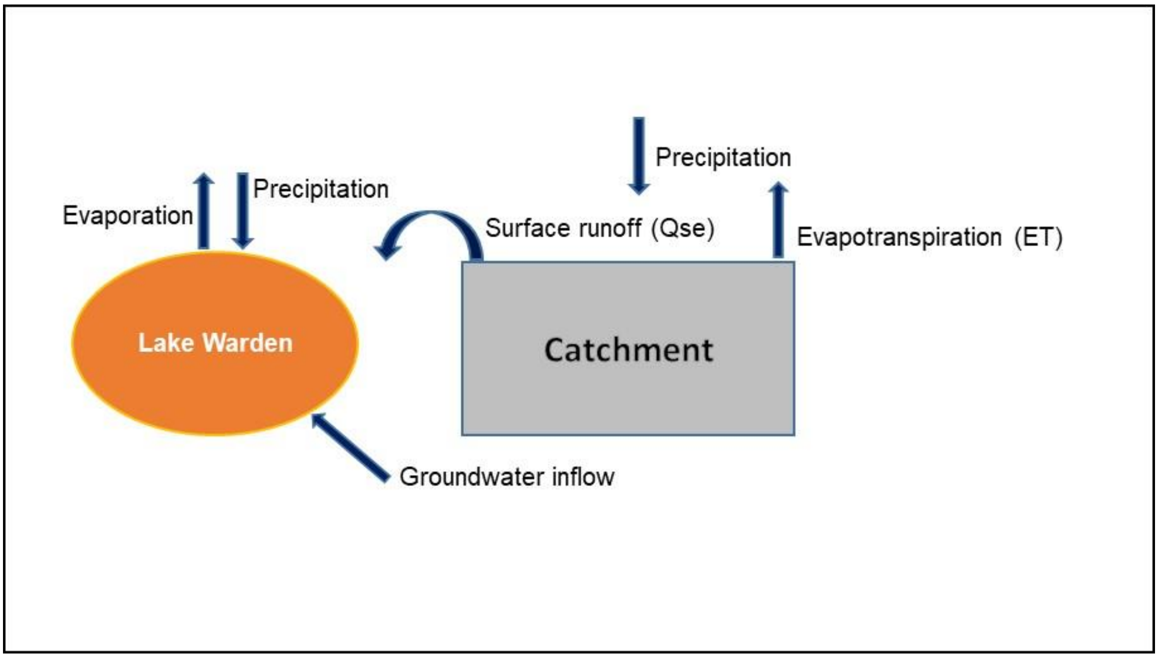

Figure 3: Schematic Water balance model for Lake Warden

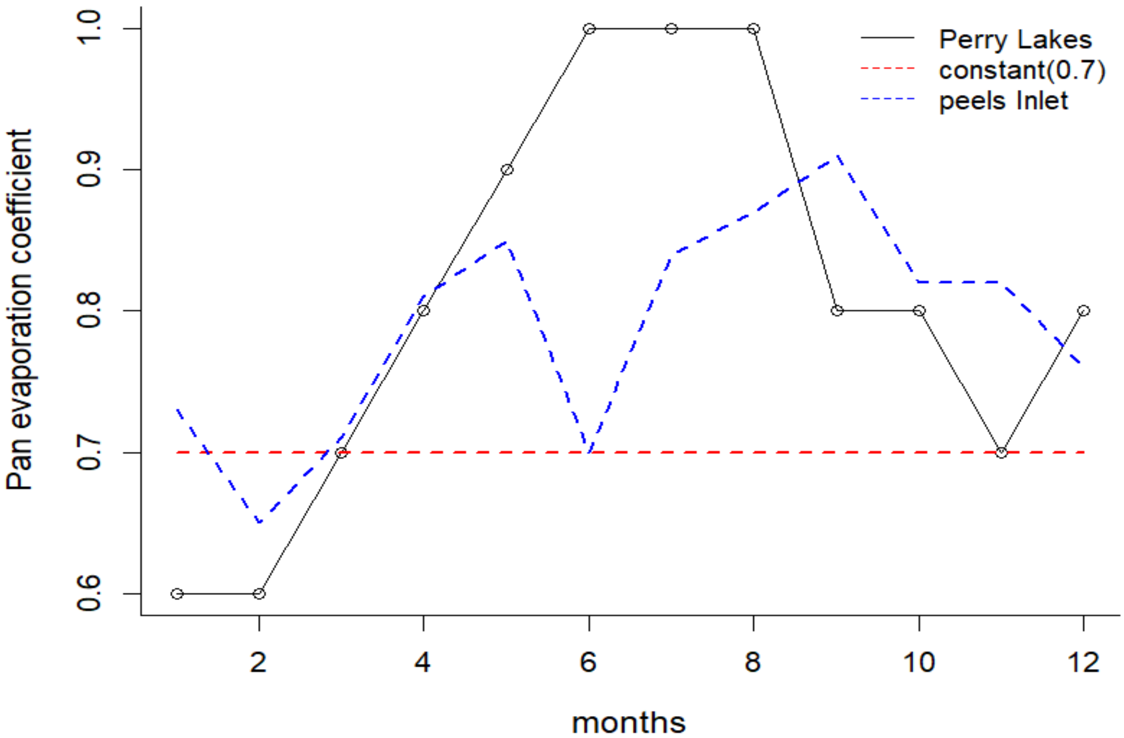

Figure 4. The different pan evaporation coefficient forms

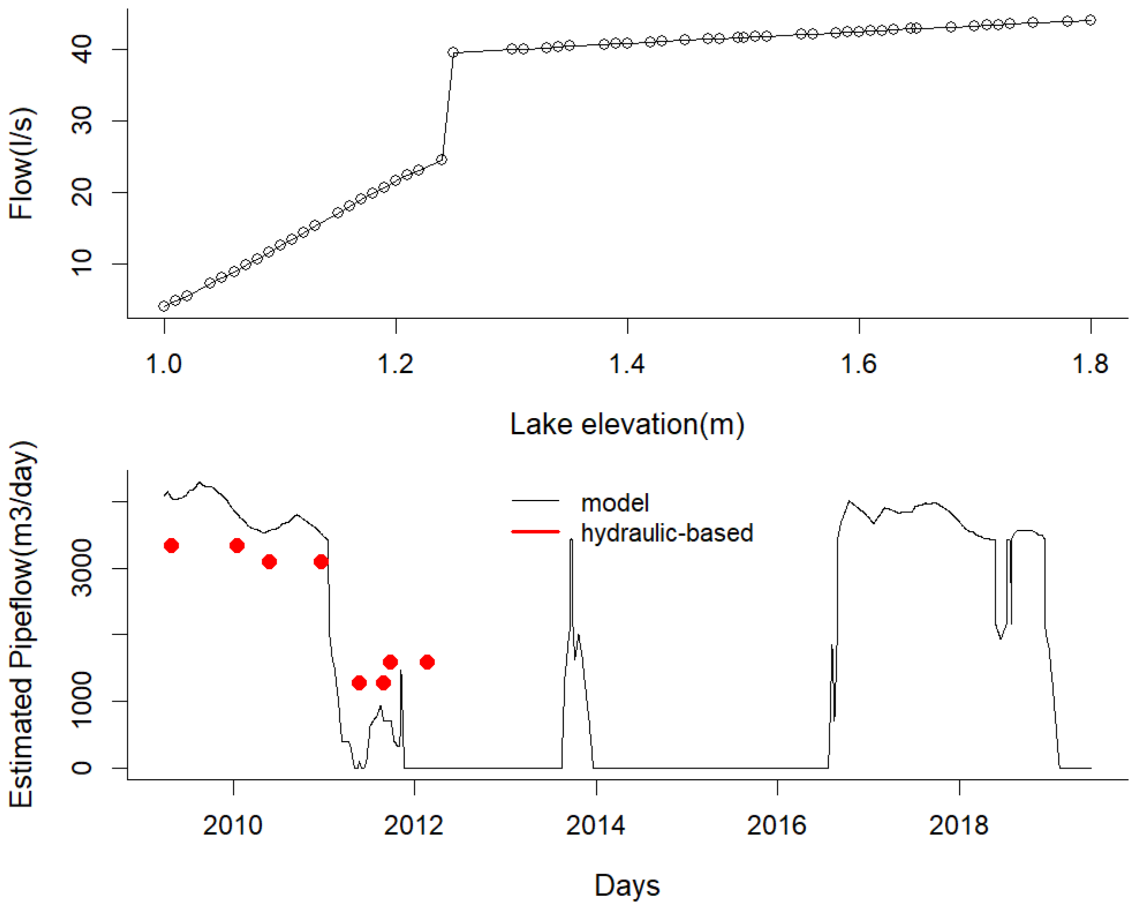

Figure 5. Modeled pipe flow and its comparison with hydraulic-gradient method

4. Results

Lake Warden water balance model

The study provides estimates of the various flow components that affect Lake Warden and effectively reproduces the observed lake volume for the period of 2002 to 2010. However, it over predicted during the period of 2010 to 2016 and under predicted from 2016 to 2019.

Evaporation is the main driver in the system and the relation of water budget components with different pan coefficients are shown in Figure 6, 7, 8 and 9. Sensitivity studies were performed to determine the influence of the various lake evaporation methods and lake evaporation estimate using Morton approach which seems to provide satisfactory results.

The approximated gravity pipe flows were included in the water balance model for the period 2009 to 2019, The volume of water removed during this period have been approximated using flow measurements from discrete time periods and extrapolating this data and lake volume. The contribution of pipe flow to lake volume is less than 4% (Figure 9). However, the model still overestimated the lake volume from 2010 to 2016.

Evaporation and precipitation contribute around 20 to 25% and 10 to 15% of the overall water balance respectively, and the magnitude and trend reflect the seasonal variations. The surface inflow components; overland flow was the largest component of the daily water balance. Groundwater is not a dominant water balance component in relation to other components, but it is a constant input. Though the groundwater input is small, it is critical in sustaining the lake system in drought conditions.

There was no direct measurement of the over land flow to the lake. During a major rainfall event as occurred in winter months, a large difference between the estimation is observed. The difference is believed to be the uncertainty in estimating overland flow to the lake.

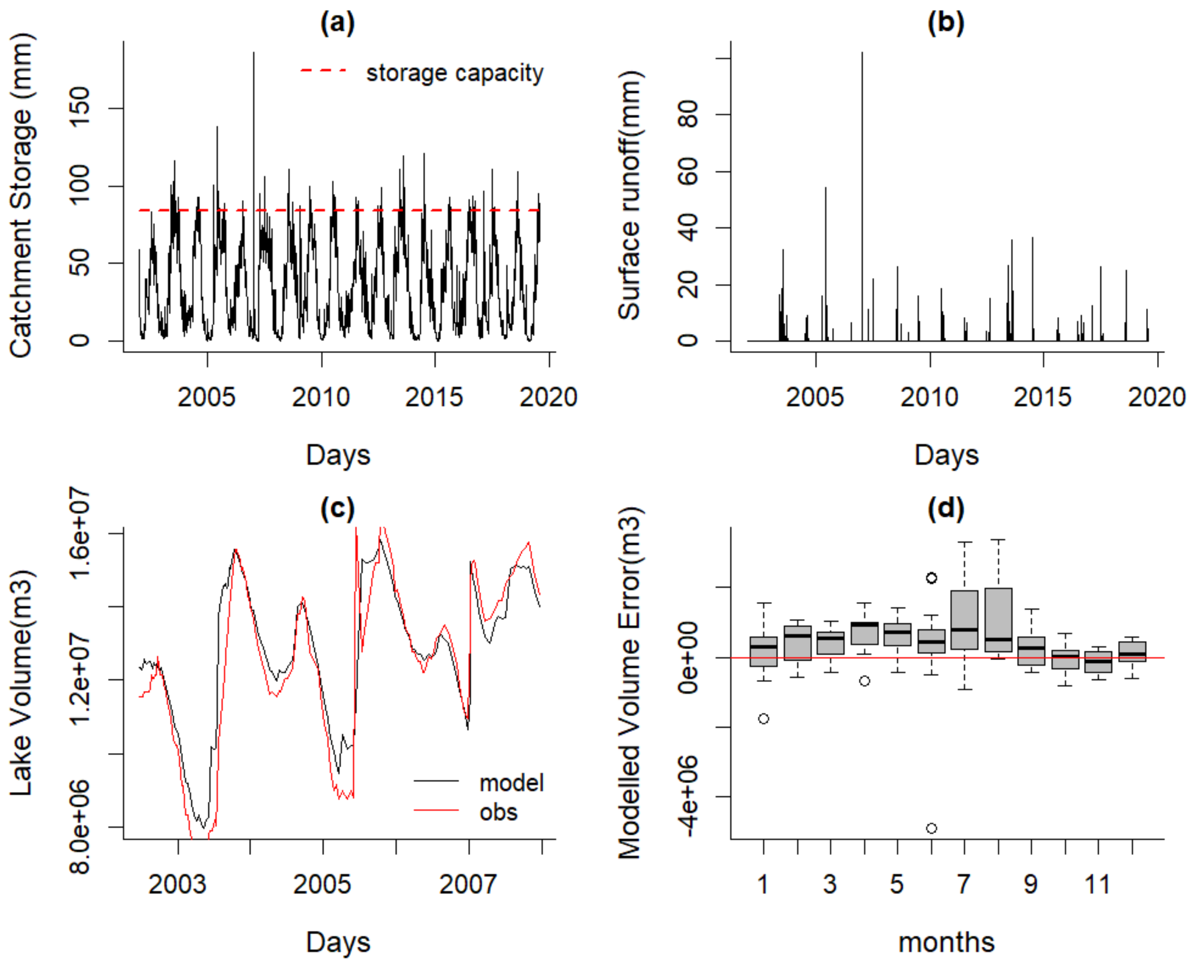

Figure 6: Daily Water Balance Model with constant pan evaporation coefficient (0.7)

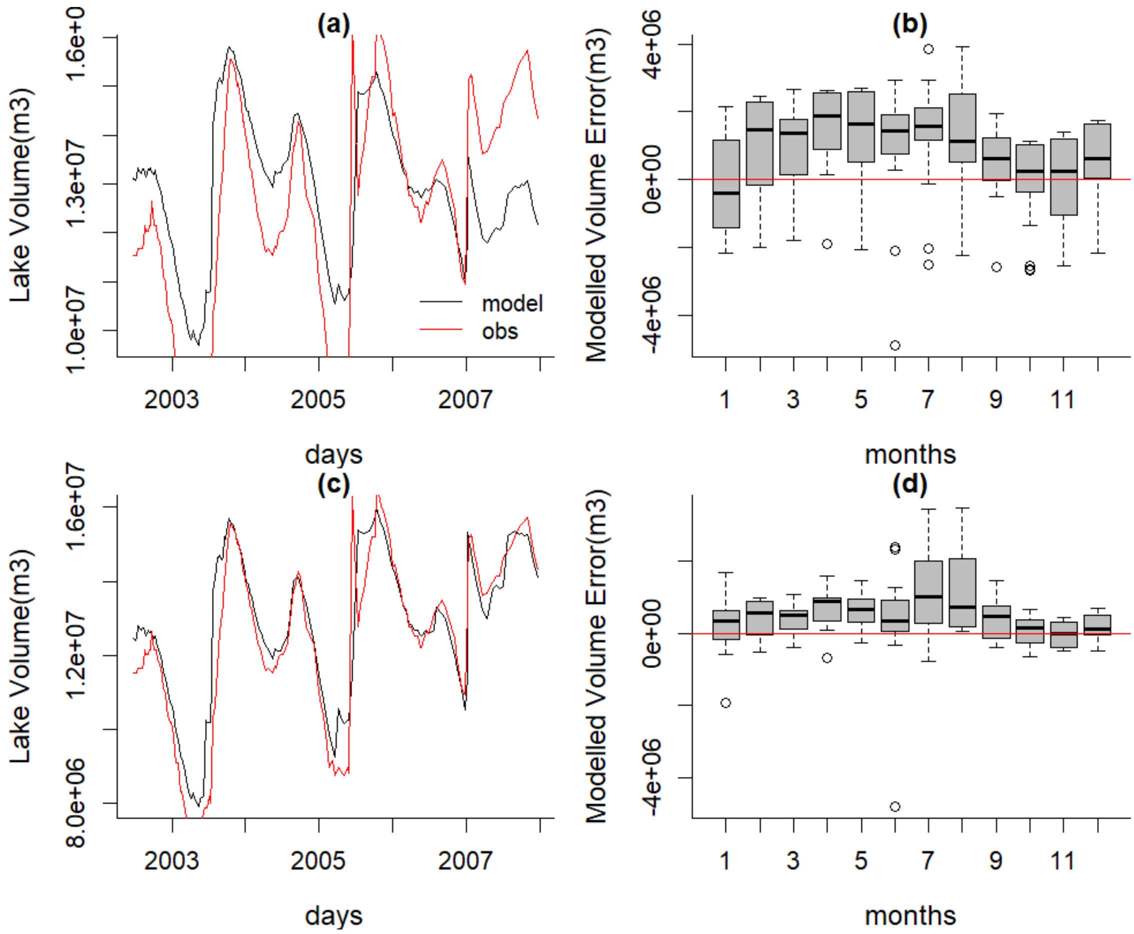

Figure 7: Daily Lake Warden water balance model with seasonal varied pan evaporation coefficient: (a) Modelled lake volume using Perry Lake coefficient, (b) Errors in using Perry lake coefficient, (c) Modelled lake volume using Peels inlet coefficient, (b) Errors in using Peels inlet lake coefficient.

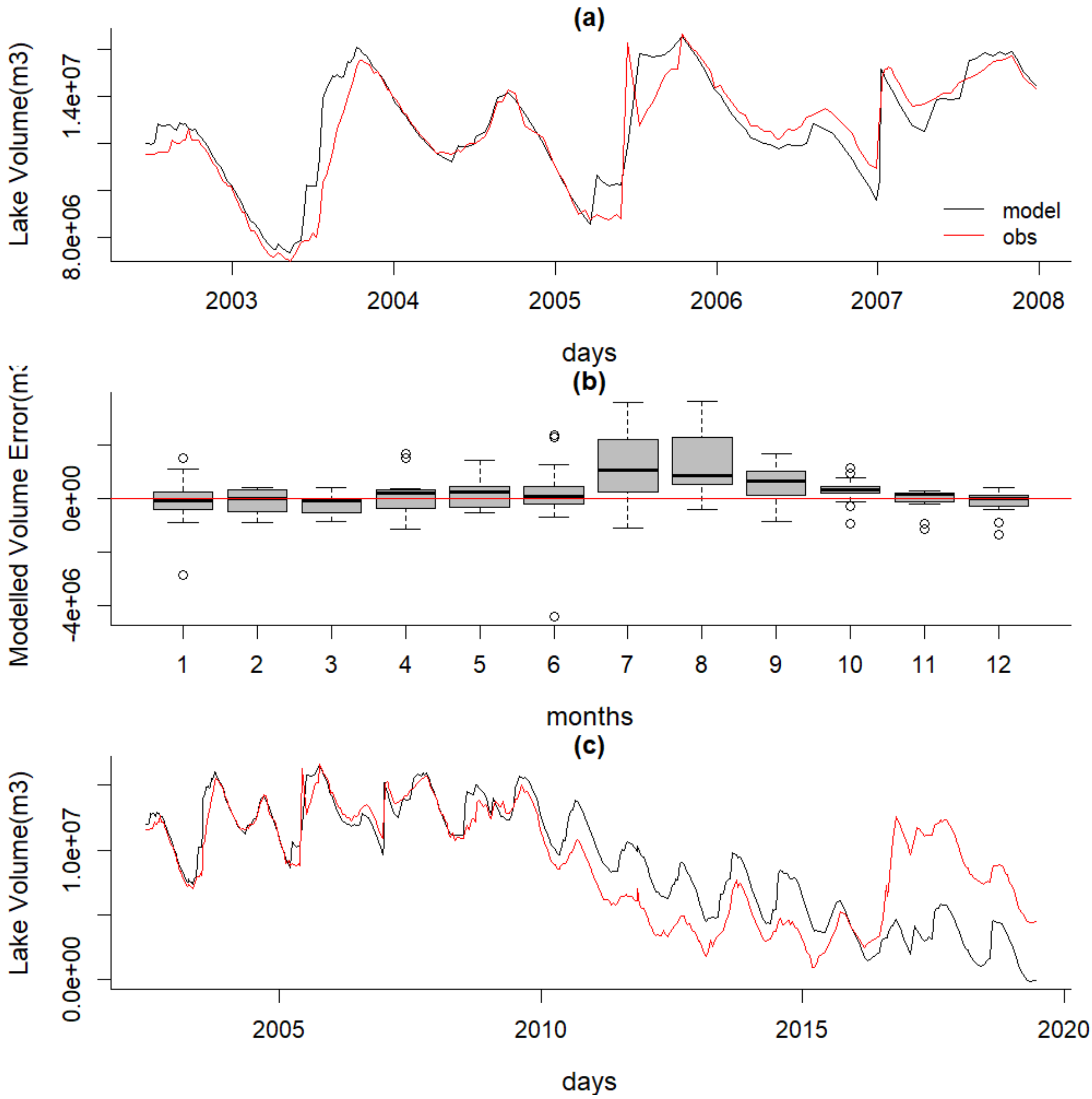

Figure 8. Daily Lake Warden water balance using Morton lake evaporation: (a) modeled lake volume vs observed volume (d) seasonal variation of errors in using modelled lake volume and (c) modeled lake volume without pipe inflow consideration.

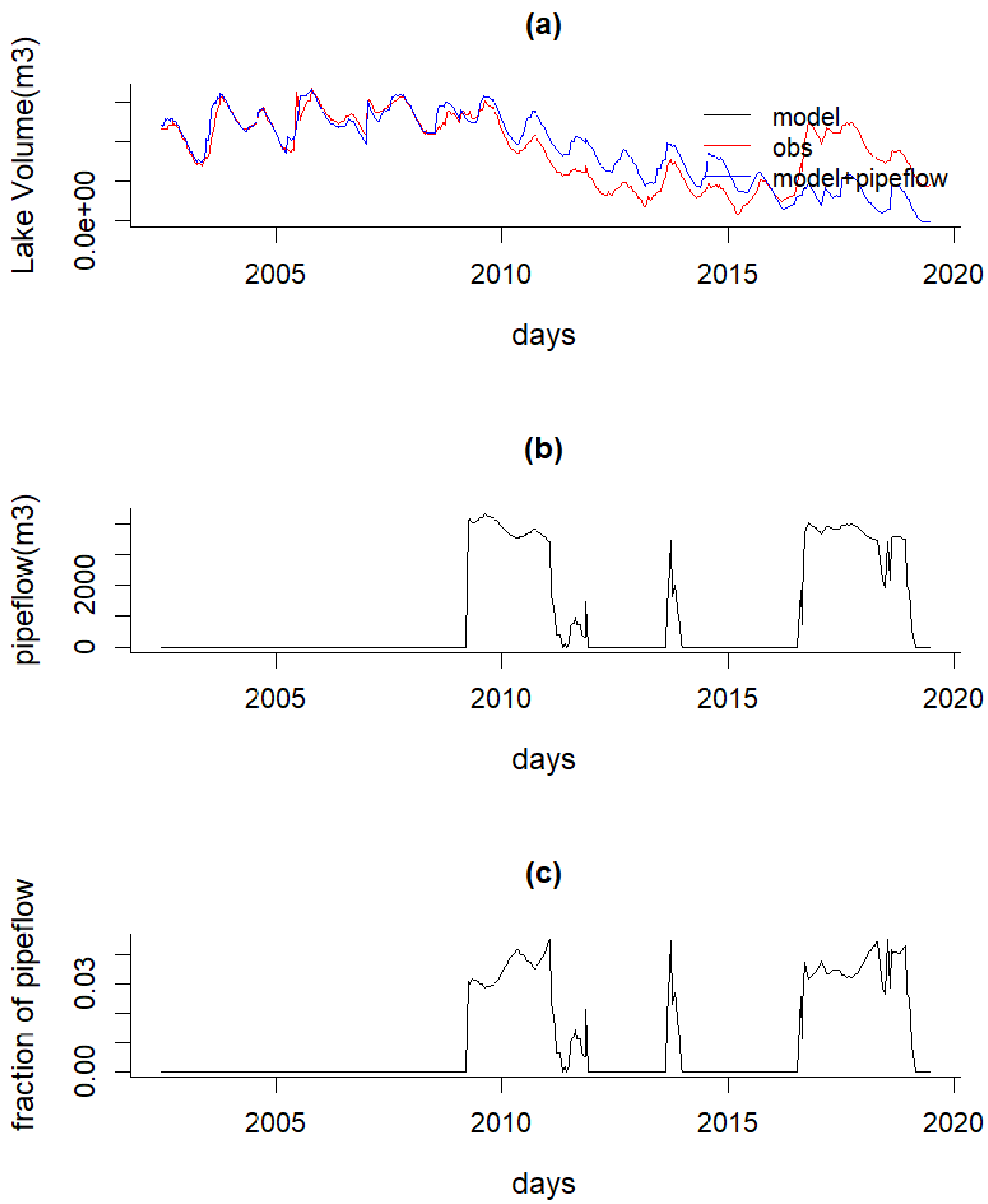

Figure 9. Modeled lake volume with pipe inflow: (a) modeled lake volume, (b) daily time series of estimated pipe flow and (c) fraction of pipe flow of lake volume.

Pink Lake water balance model

Lake Warden water balance model was used as the basis to develop the Pink Lake Water Balance model (Figure 11). Catchment overland flow, groundwater inflow, rainfall and lake evaporation are the inputs to the model. Pink Lake is considered a terminal lake.

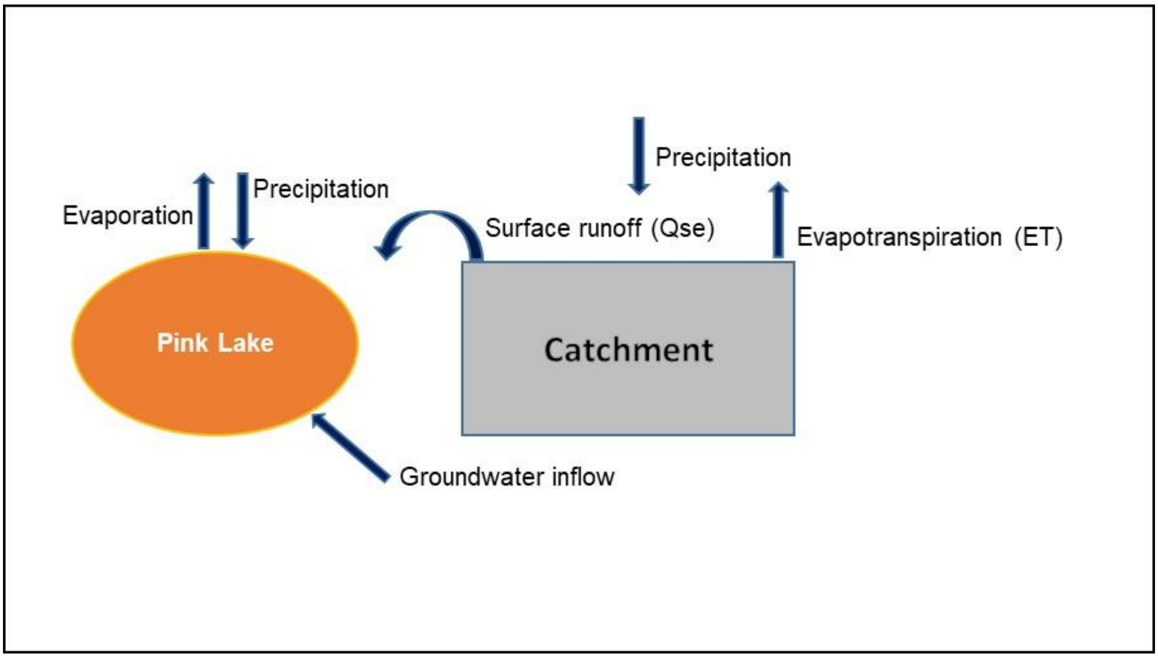

Figure 10. Conceptual model for Pink Lake Water Balance Model

Similar to Lake warden, groundwater flow for Pink Lake was estimated on the basis of groundwater hydraulic gradient (Q=Kidp); where Q- flow of water to the Lake (M^3/d); K=hydraulic conductivity (m/d); I= average hydraulic gradient (m/m); D= average aquifer flow depth (m); P=length of flow section (m). The groundwater contour map and parameters used in the groundwater flow estimation are shown Appendix 2.

The model effectively reproduces the observed volume in most periods, especially for high volume periods, but the model underestimates the volume in the dry season (Figure 12). The underestimation of lake volume in the dry season may be due to overestimated lake evaporation. In the Pink Lake, lower lake volume may result in increasing the salinity of lake that reduces the evaporation rate. However, our model assumes that lake evaporation is not limited by salinity, and accounting for the effect of lake salinity on evaporation will improve the model further. Besides there was no detailed bathymetry survey carried out on Pink Lake. The lake bed interpolated from depth measurement carried out by Esperance High School Students in 1984 may result in some inaccuracies in the lake bed estimates and lake volume.

The estimated lake water balance components are presented in Table 1. The modelled lake volume is lower than the observed volume. Evaporation from the lake amounts to $1.16X10^7m^3$ about twice the precipitation volume $6.22X10^6m^3$ thus represents an important part of the water budget. Besides, the results also indicate the overland and groundwater flow contribute equally.

The aquifer and Pink Lake show connectivity of both localised and regional groundwater flow system within the system (Marimuthu et al 2005). The groundwater levels in the surrounding aquifer are generally higher than the lake levels, as a result the lakes tend towards discharge regimes.

Table 1: Model estimated components of Pink Lake Water Balance (2013-2018).

Component/Term Value	Value
Lake Volume (m^3)	1813766
Precipitation over the lake (m^3/year)	6220500
Lake Evaporation (m^3/year)	11578097
Groundwater flux (m^3/year)	5020210
Overland flow (m^3/year)	425462.5
Discrepancy (% of lake volume)	3.9%

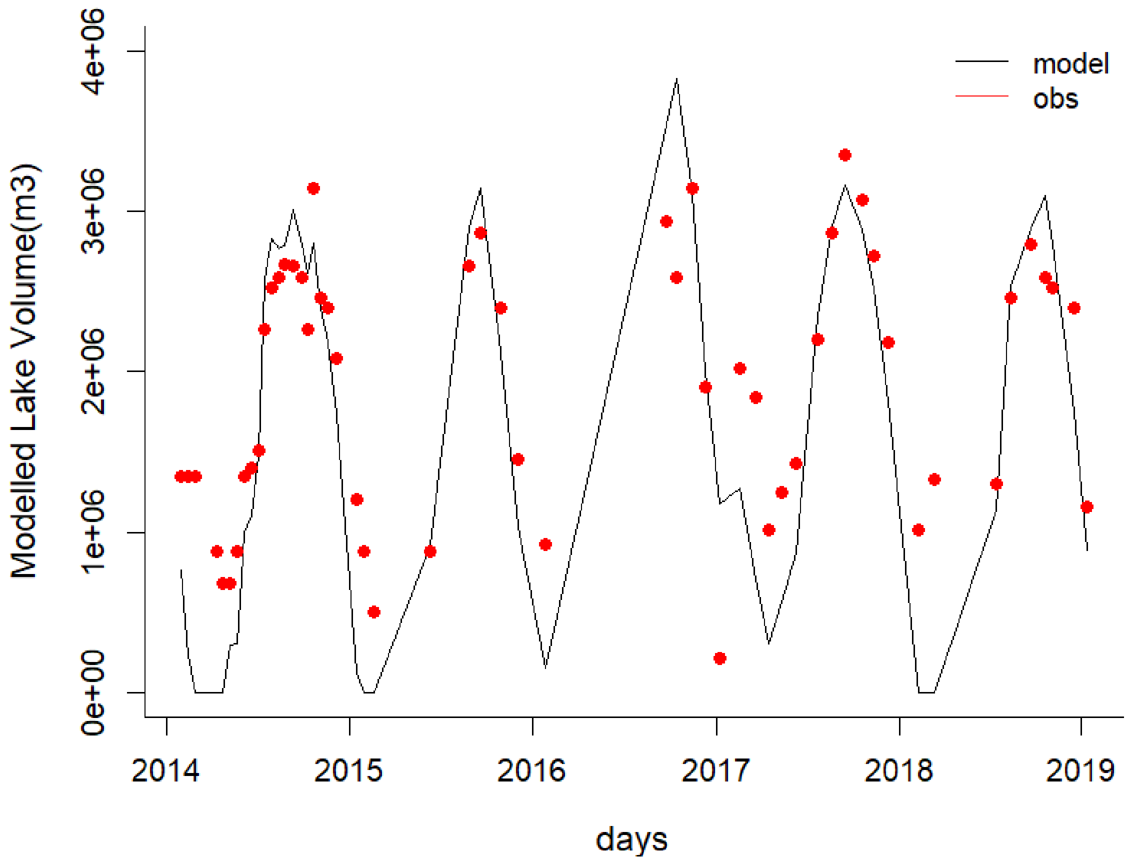

Figure 11: Modelled vs Observed Pink Lake Volume

5. Discussion and conclusion

The water balance model of Lake Warden was developed and calibrated using the available lake level data. The calibrated model was then used as the basis to determine the Pink Lake Water balance. The study area did not have detailed and rigorous measurements for most of the flow components.

Similarly, there were no field measurements of lake evaporation for Lake Warden and Pink Lake. The pan evaporation estimates of other lakes in a similar meteorological condition were used as the basis to estimate the lake evaporation. Sensitivity studies on the influence of the various lake evaporation show lake evaporation estimate using Morton approach seems to provide satisfactory results. The water balance model results for Lake Warden showed that it was consistent with the observed lake volume for the period of 2002 to 2010. It overestimated the lake volume during the period 2010 to 2015 and underestimated 2016 to 2020, however showing a similar trend as observed.

The operation of the gravity pipeline from the central suite has contributed to the decline in the Lake Warden water level from 2009 to 2015. The lowest levels (2.63m and 2.49 m) were observed in January 2013 & January 2015, respectively. The model over predicted the lake level during this period, however able to capture the declining trend. The discrepancy could be due to the underestimation of the actual outflow from Lake Warden. Considering the magnitude of the input and output, a small bias could lead to large variations in the modelled lake level.

The lake level in Lake Warden has increased rapidly since early 2016 and by August 2016 it reached 4.42 m. Several major rainstorms occurred since early 2016 (BOM 2019). The spatial and temporal frequent rainfall could have increased the unsaturated soil water storage in the permeable soils within the catchment. The subsequent storms may have increased the surface runoff to the creeks, neighbouring lakes and Lake Warden. These additional flows could have been the cause for the rapid water level rise in the Lake Warden. Kusumastuti (2006) explored the rainfall-runoff transformation, threshold-driven processes and implication of the flood frequency in Lake Warden Wetlands system. The excess contribution from other lakes and creeks to Lake Warden was not considered in this modelling. The lake level remains high until August 2017, since then on a declining trend. The model consistently underestimates the lake level over this period, however, the model was able to show the observed trend.

The modelled lake level changes have a similar amplitudes and phases but lag the observed cycle. This suggests that there is a certain period of the water in the lake, which is not taken into the consideration of the water balance model.

There was no stream flow gauge and stream flow was considered part of the overland flow. Field visits to the fringe of the two lakes also indicate that seepage is quite widespread as the ground is damp for most of the year. The overland flow contributes large flow during major rainstorm events, in line with the observed large lake volume changes in response to surface inputs. The significant contribution from overland flow has not been measured directly, however, it was estimated, which may contribute a large uncertainty to the overall water balance computation.

Evaporation is sensitive to changes to salinity and cloudiness. This modelling did not consider this parameter in the estimates. The groundwater component is significant in sustaining the saturation and reducing the temporal variability of the wetlands system. In addition, seepage to lakes from groundwater can also play an important role in determining the water quality of Pink Lake as it can be a source for the salt input to the system.

In the de-coupled approach, lake interactions with catchment processes and conditions such as lake-groundwater level interactions were neglected and those uncertainties inherent in various methods of estimating these internal fluxes are transferred into the lake model leading to relatively large discrepancies of the lake water balance. Some components of the balance are disproportionately large compared to others. For example, estimates of uncertainties in these water balance components were 3% for precipitation, 15% for evaporation, 30% for surface inflow, 10% for change in lake volume, and 7% for groundwater seepage. The uncertainties were determined using Winter (1981) approach.

Despite the shortcomings in the measurements and estimation of the flow components, the coordinated approach adopted in this study has provided a meaningful estimate for the overall flow components for the feasibility study of Pink Lake.

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Limitations of the report

This report was prepared for the Shire of Esperance. In evaluating information, reports and comments, MS Groundwater Management Pty Ltd (MSGM) relied in good faith on the information provided by the above parties and obtained from the publicly available information. I accept no responsibility for any deficiency or inaccuracy contained in this report as a result of my reliance on the aforementioned information.

The findings and conclusions documented in this report have been prepared for specific application to this project and have been developed in a manner consistent with that level of care normally exercised by professionals currently practicing under similar conditions in this jurisdiction. MS Groundwater Management Pty Ltd makes no other warranty, expressed or implied.

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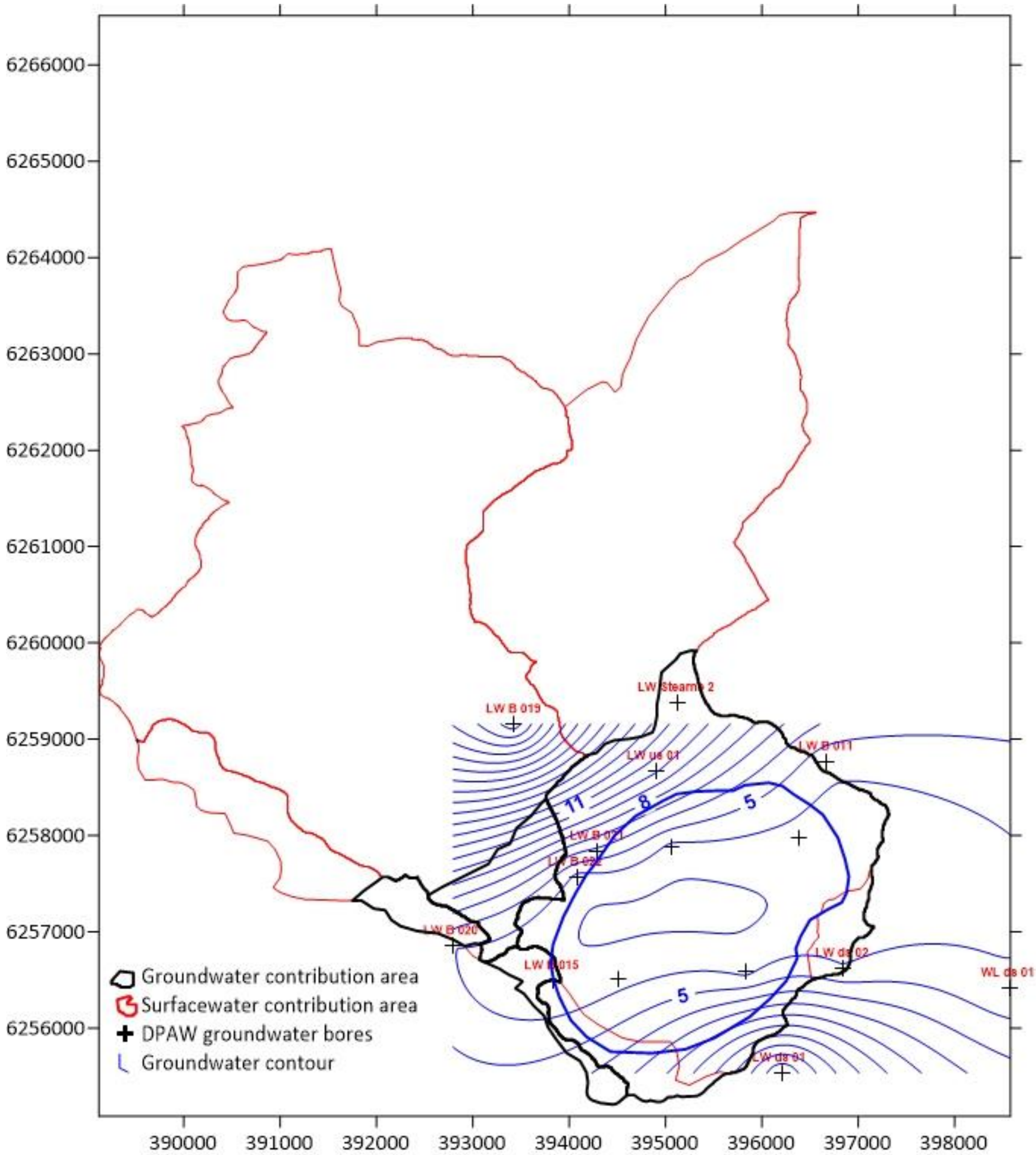
Principal
MS Groundwater Management Pty Ltd
17 January 2020

Appendices

Appendix 1 Estimation of groundwater flow to Lake Warden



Parameters

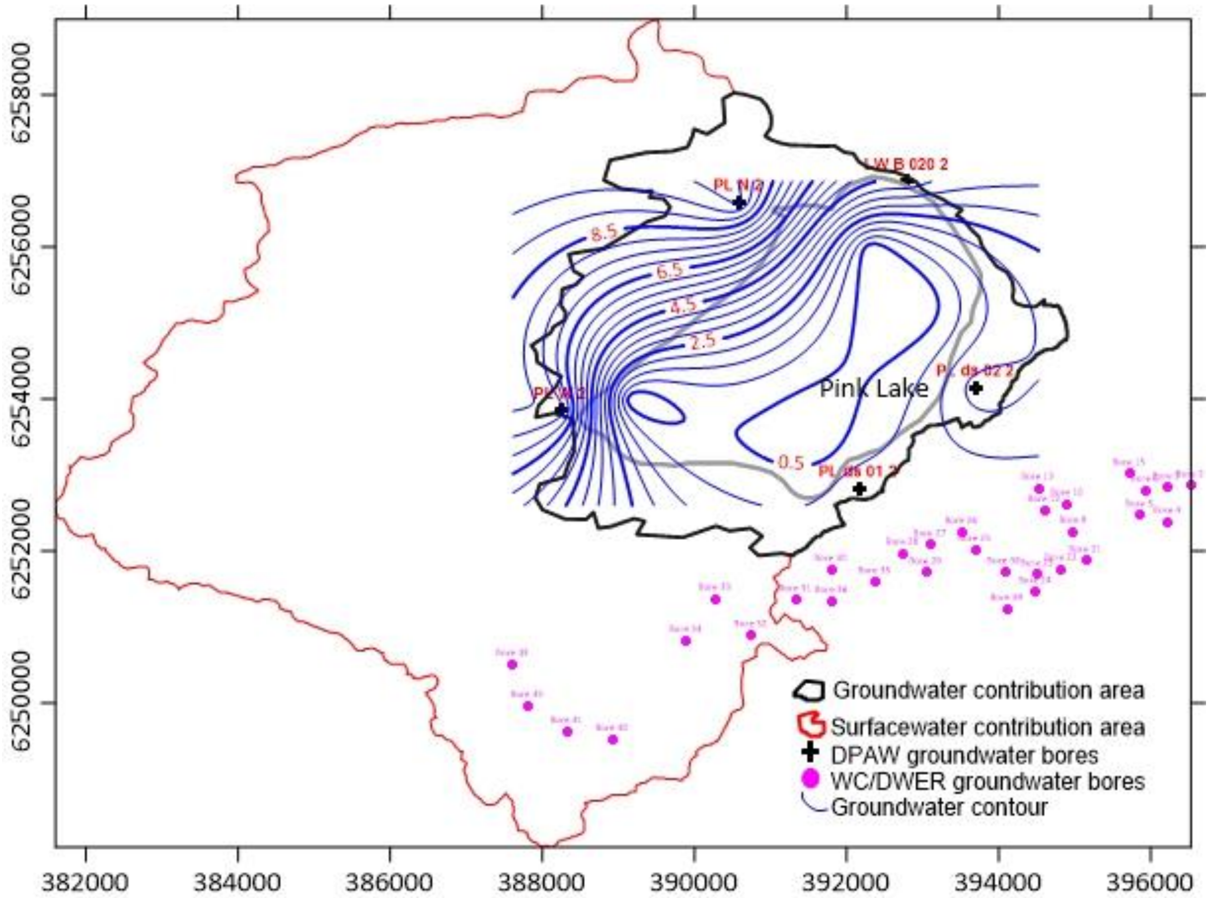
K=hydraulic conductivity (m/d) – 1.0 m/d

I= average hydraulic gradient (m/m) – 9 X10^{-3} m/m

D= average aquifer flow depth (m) – 5m

P length of flow section (m) – 3500 m

Appendix 2 Estimation of groundwater flow to Pink Lake



NB: Groundwater contour has been blanked on the south-eastern site due to insufficient data.

Parameters

K=hydraulic conductivity (m/d) – 32.0 m/d

I= average hydraulic gradient (m/m) – $8.33X10^{-4}$ to $6.22X10^{-3}$ m/m

D= average aquifer flow depth (m) – 10 to15 m

P length of flow section (m) – 1500 to 4250 m