SALINITY MODELLING AND MANAGEMENT OF THE LOWER LAKES OF THE MURRAY–DARLING BASIN, AUSTRALIA

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ABSTRACT

The Murray–Darling River basin occupies 14% of the Australian land mass and it is the longest and the most iconic river system in Australia. This river basin is the most important agricultural region and supports 71% of irrigated crops that is 1/3 of the nation's food supply. Two major cities Adelaide and Canberra as well as another eight major town totalling a population of over 2.1 million people is supported by this basin. At the end of the basin, the river flows into the lower lakes, Lake Alexandrina and Lake Albert, before it flows into the sea via the Coorong wetlands. Due to various flow diversions, upstream agricultural use, irrigation returns, climate variability and historical mis-management of the basin, the water quality and in particular, the salinity of the lower river and the fresh water Lake Alexandrina have worsened particularly during drought periods. This had serious implications to the water supply for Adelaide as well as for water availability of Coorong wetlands. A 2D numerical model is used to analyse the hydrodynamic and water quality (salinity) processes in the lower lake system based on historical upstream data from the Murray River. The results show that the 2D model coupled with a 1D model for the barrages is able to predict water level and salinity changes accurately for various river flow events. Possible management implications of the river–lake system are proposed based on the results of the model.

Keywords: Murray–Darling River basin, Lake Alexandrina, Lake Albert, numerical model, salinity.

1 INTRODUCTION

The Murray–Darling Basin (MDB) has an area of 1,042,730 km^2 and includes parts of the states of Queensland, New South Wales, Victoria, South Australia and the Australian Capital Territory [1]. At the end of the basin, the river flows into the lower lakes, Lake Alexandrina and Lake Albert. Five barrages separate Lake Alexandrina from the Coorong Lagoon and the Murray estuary, which are the Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere barrages. This study used the MIKE 11 to simulate the operation of the five barrages located in the Murray Mouth estuary. MIKE 21 is used to simulate and analyse the hydrodynamic conditions and salinity variations within the Lower Lakes. This approach combined the advantages of the hydraulic structures simulated by MIKE 11 and the hydrodynamic simulation made by MIKE 21, provided technical support to simulate hydrodynamic process and salinity change of the Lower Lakes.

2 THE LOWER LAKES MODEL

The lake hydrodynamic model was set up using the MIKE 21 Flow Model FM [2]. In the hydrodynamic module, the parameters used include: the domain; solution technique; flood and dry; eddy viscosity; bed resistance; Coriolis forcing; wind forcing; ice coverage; tidal potential; precipitation/evaporation; wave radiation; sources; boundary conditions; and initial conditions. Barrage operation is set up as follows.

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2.1 Barrage operation

There are five barrages separating the Lower Lakes from the sea and the nature of control structures on these barrages are summarized in Table 1.

The barrage typical operation rule is that each gate discharges between 300 and 500 ML/day [3]. This rule of thumb is an approximate estimate based on the available information. The [3] study found there were three main methods that could be used to provide a more accurate estimate for the barrage flows. These three methods are: (1) observed data; (2) BIGMOD model for Lower Murray; (3) TUFLOW Model (2D hydrodynamic model). In this study, the 1D channel models are used to calculate the flow through the five barrages (Fig. 1). In the 1D model, the inner portion of the 1D model is based on the upstream water level before each barrage; these data can be obtained from Water Connect, South Australia. The outer portion of the 1D model is based on the outside water level of each barrage.

Table 1: Basic hydraulic information for the barrages.

Barrage	Full opening width	Sill level
Goolwa	485.4 m (128 gates)	two logs removed = 0.45 m AHD fully open = -2.5m AHD
Mundoo	90 m (26 gates)	-1 m AHD
Boundary Creek	21.5 m (6 gates)	-1.12 m AHD
Ewe Island	431.35 m (121 gates)	-0.05 m AHD
Tauwitchere	1251.3 m (322 gates)	-0.05 m AHD

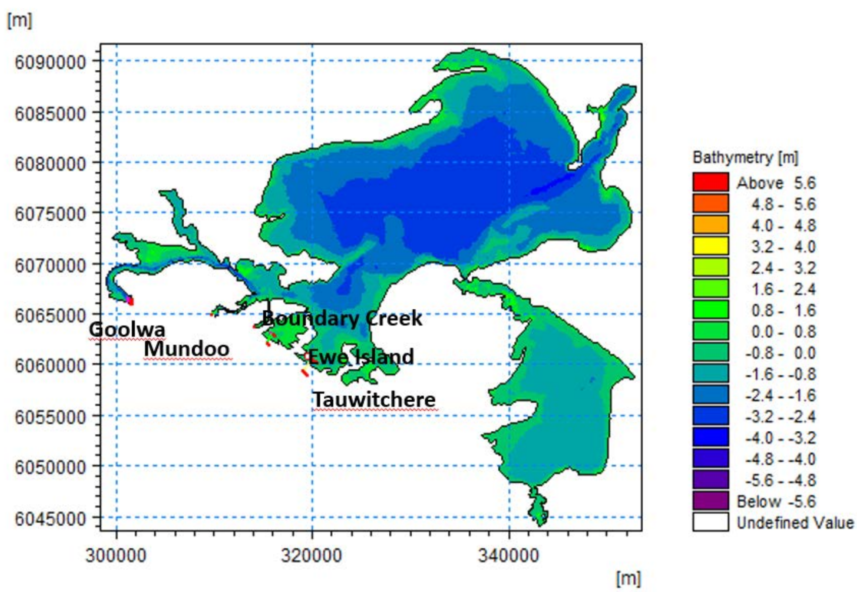

Figure 1: 1D structure (red dots) locations in the Lower Lakes.

In the above methods, for Method 1, there are only weir formulas for Goolwa and Tauwitchere radial gates. Formulas for other barrages (like Ewe Island, Mundoo and Boundary Creek) were not available and there are no data for the number of stop logs. The results for the other three methods are shown in Figs 2–6 [4].

Figs 2–6 show that estimated barrage flows from the hydrodynamic model using the BIGMOD, TUFLOW and MIKE methods are closely matched even though flows from the BIGMOD method exhibit more pronounced lower values in some barrages. Over the 5-month period, the flows at Boundary Creek, Mundoo, Goolwa using the BIGMOD method and MIKE model are basically very similar.

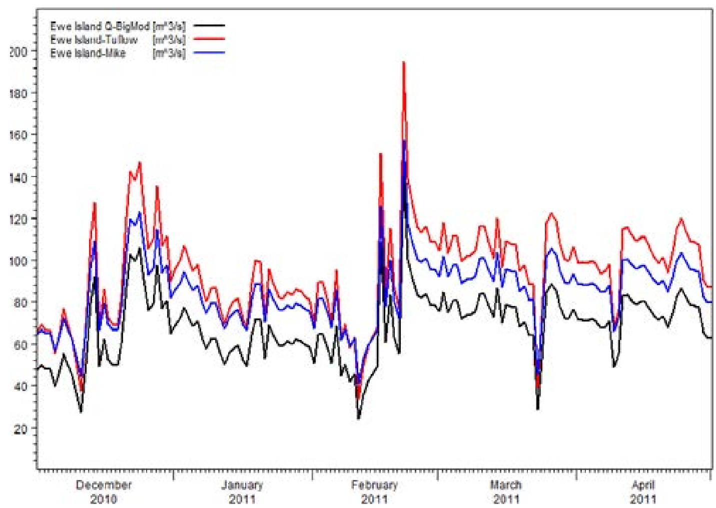

Figure 2: Simulated flows at Ewe Island by using BIGMOD, TUFLOW and MIKE 11.

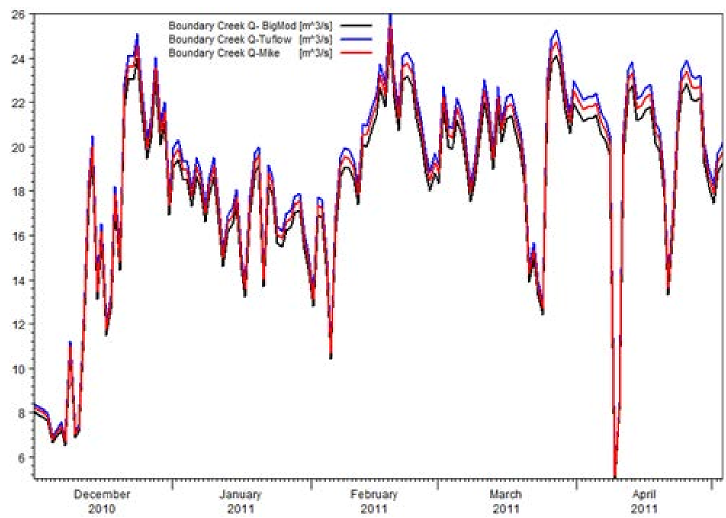

Figure 3: Simulated flows at Boundary Creek by using BIGMOD, TUFLOW and MIKE 11.

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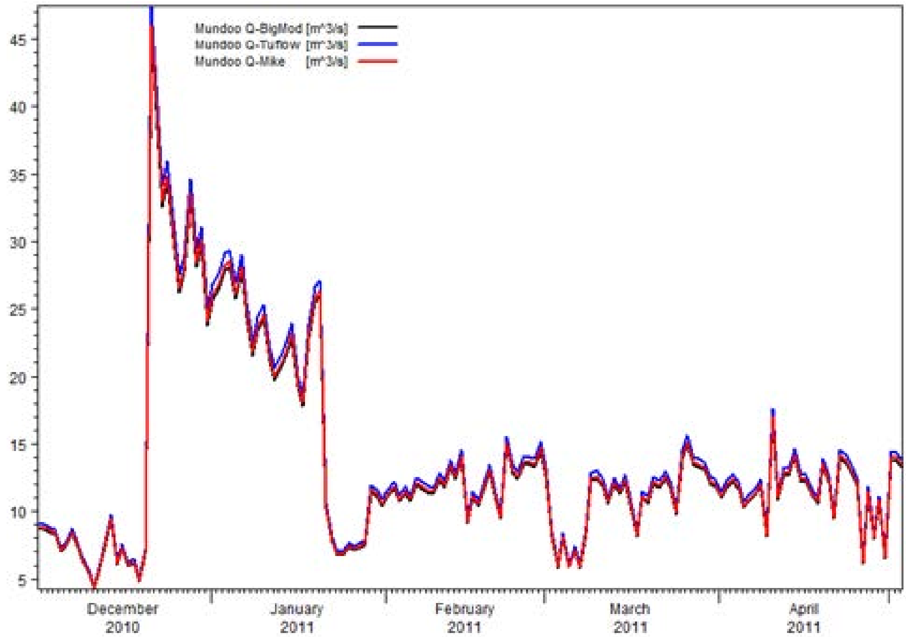

Figure 4: Simulated flows at Mundoo by using BIGMOD, TUFLOW and MIKE 11.

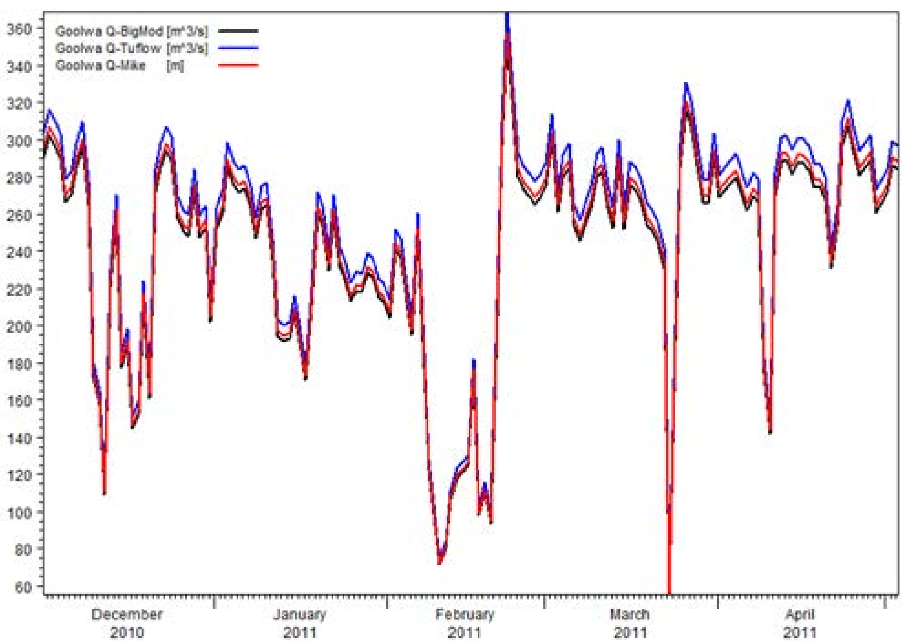

Figure 5: Simulated flows at Goolwa by using BIGMOD, TUFLOW and MIKE 11.

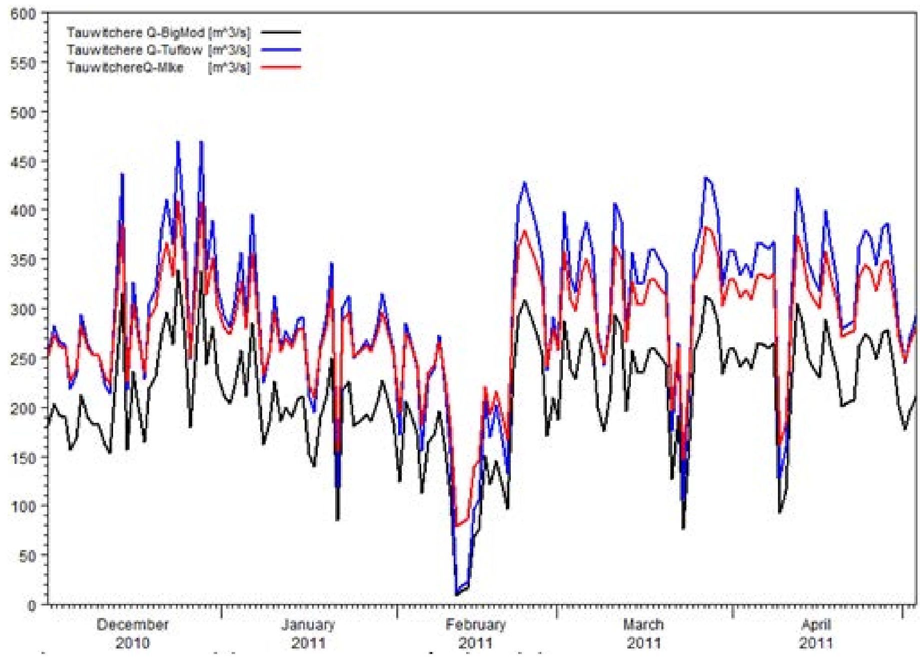

Figure 6: Simulated flows at Tauwitchere by using BIGMOD, TUFLOW and MIKE 11.

The flow calculated by the MIKE model at Ewe Island and Tauwitchere are on average 20 m^3/s and 40 m^3/s larger than those calculated using the BIGMOD method. This is because Ewe Island and Tauwitchere are long barrages – 431.35 m (121 gates) and 1251.3 m (322 gates), respectively – and the weir formulae are different for TUFLOW and MIKE 11. The discharges calculated using the TUFLOW model and the MIKE model are similar.

3 THE LOWER LAKES CALIBRATION

The model calibration period in this study covers a three-month period from 08/12/2010 to 01/03/2011 as the selection of a suitable calibration period because of the availability of both side for boundary condition data. Also, in this period, the quality of the water level and salinity data are continuous and reliable. The start date was selected at 08/12/2010 based on the availability of spatially varying salinity data for Lake Alexandrina. Given the above objectives, the approach to model calibration included: (a) ensuring that the model can simulate the hydrodynamic conditions in the Lower Lakes which is shown by water levels; and (b) ensuring that the model can simulate salinity change, which requires the Transport Module to run well and is shown by salinity curves.

For calibration process, the 4 km west of Pomanda, Mulgundawa, Poltalloch and Milang data sites were chosen for Lake Alexandrina. Waltowa and Meningie were chosen for Lake Albert (Fig. 7). These sites have good data sets, which are important for model's calibration.

3.1 Water level calibration

Figs 8–13 show the comparisons between measured and modelled water surface elevation at each site around the Lower Lakes from 08/12/2010–01/03/2011. It is seen that the simulated values fit very well with the measured values at the 4 km west of Pomanda, Mulgundawa and Milang sites during the whole calibration period. The Poltalloch site (Fig. 12) is somewhat overestimated but follows the trend. This model captures the variations of actual water surface elevation well except for some slight differences.

The Waltowa and Meningie sites are in Lake Albert and were chosen for the model calibration of Lake Albert. The results are as follows.

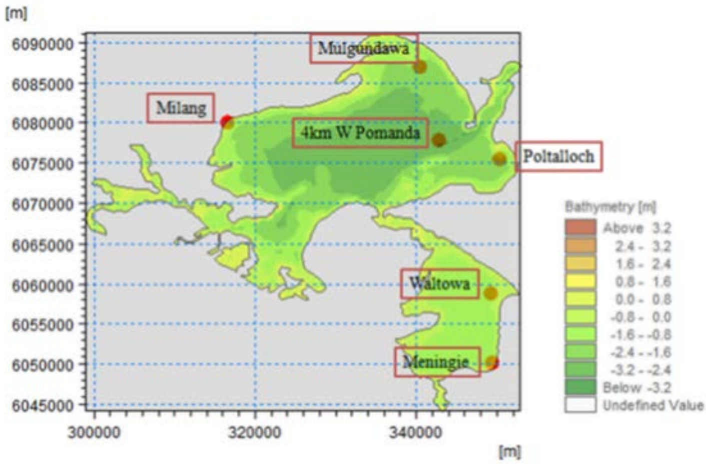

Figure 7: Site locations used in the model calibration and validation.

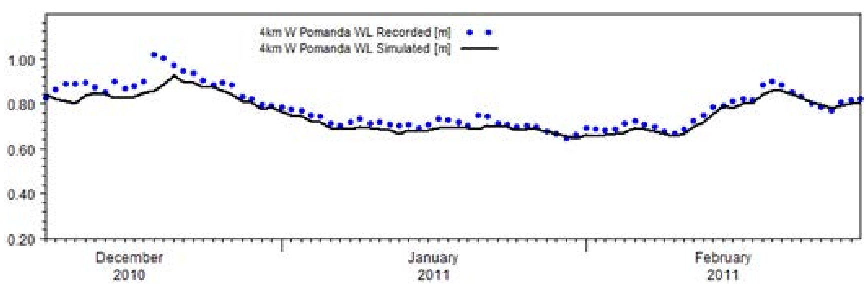

Figure 8: Recorded and modelled water levels from 4 km west of Pomanda.

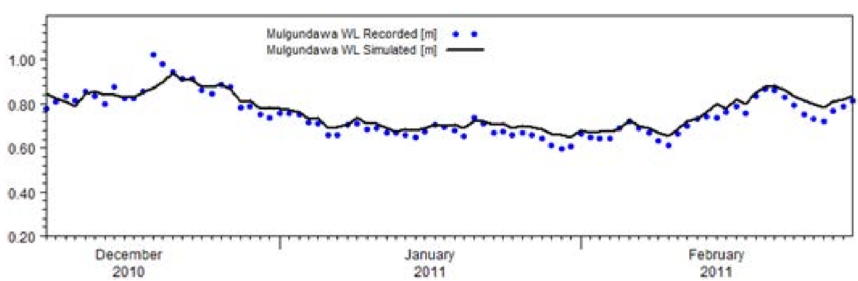

Figure 9: Recorded and modelled water levels at Mulgundawa.

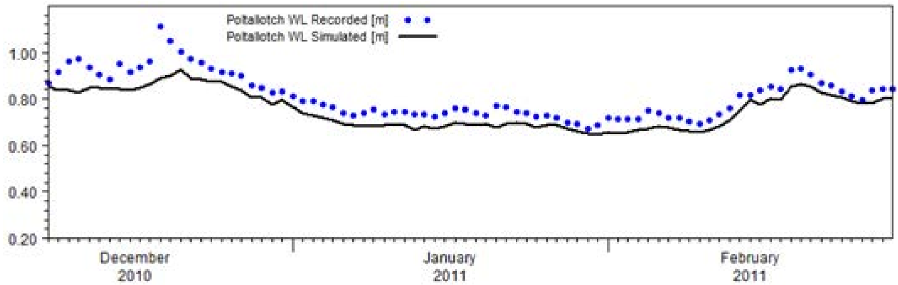

Figure 10: Recorded and modelled water levels at Poltalloch.

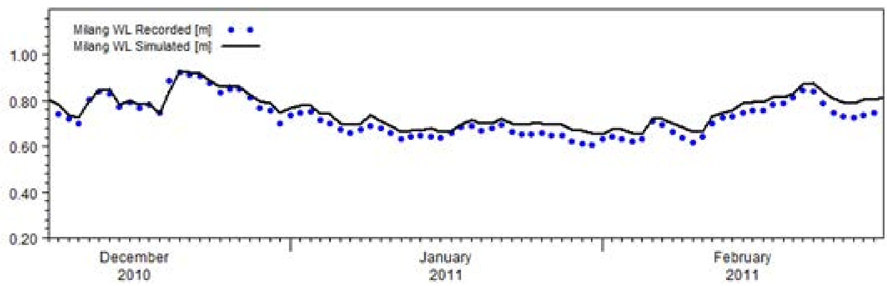

Figure 11: Recorded and modelled water levels at Milang.

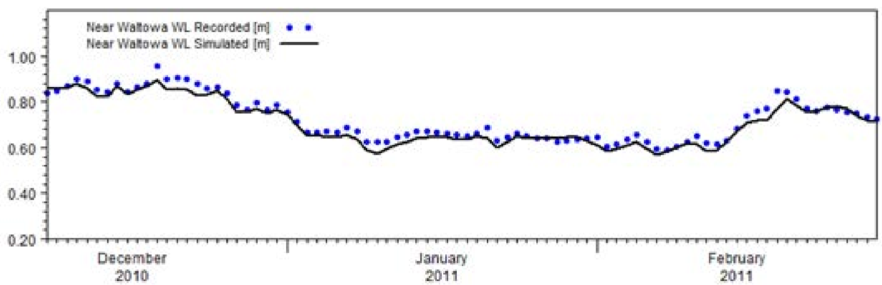

Figure 12: Recorded and modelled water levels near Waltowa.

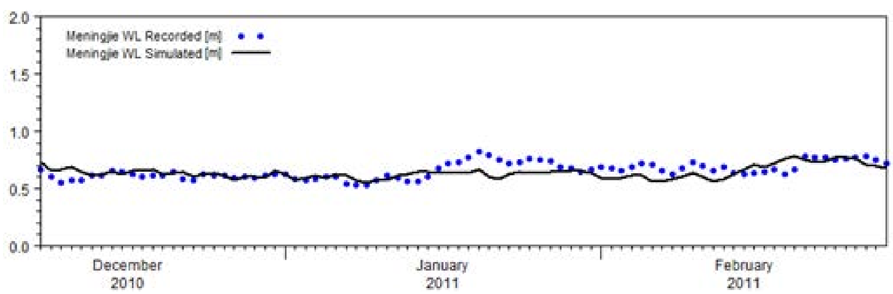

Figure 13: Recorded and modelled water levels at Meningie.

From Figs 8–13, it is seen that the model can reproduce the observed water levels within Lakes Alexandrina and Albert. In Fig. 10, 4 km west of Pomanda Point, is broadly representative of water levels within Lake Alexandrina, since the calibrated curve was able to closely reproduce the measured water levels. The Mulgundawa, Poltalloch and Milan sites are in different areas around Lake Alexandrina and therefore represent the whole hydrodynamic situation in Lake Alexandrina.

The water level in Lake Albert also generally follows the trend of Lake Alexandrina (Figs 12 and 13), the constriction along the Narrung Narrows means that there is generally a lag between water level changes in the two lake systems, and that wind events can cause significant short-term water level differences. The differences between observed and modelled water levels may be due to: (1) overbank losses, which may occur easily during periods of high discharge [5]; (2) errors in the data for barrage/gate closures and openings; (3) some of the measurements of Lock 1 discharge could be inaccurate. The reason for the calibration difference between Lake Alexandrina and Lake Albert may be related to the combined effect of inflow from Murray River and the wind is much more significant in Lake Alexandrina compared to those effects of on Lake Albert.

3.2 Salinity calibration

In the database, there are salinity measurement data at the stations 4 km west of Pomanda, Mulgundawa, Poltalloch, Milang, Waltowa and Meningie on 01/12/2011. By interpolating the salinity measured value into the model domain, the initial salinity domain was obtained using the salinity simulation (Fig. 14).

A discussion of the achieved salinity calibration for Lake Alexandrina and Lake Albert is provided below.

In the simulated salinity during the calibration period in Lake Alexandrina is presented in 4 km west of Pomanda, Mulgundawa, Poltalloch and Milang. It is seen that the model can model the salinity for most of stations in Lake Alexandrina. The model appears to slightly over-predict the salinity at Mulgundawa and Milang (Figs 16 and 18) which may be due to inaccurate initial conditions. At 4 km west of Pomanda (Fig. 17) the model significantly over-predicts the observed salinity in December. This is most likely related to the initial conditions

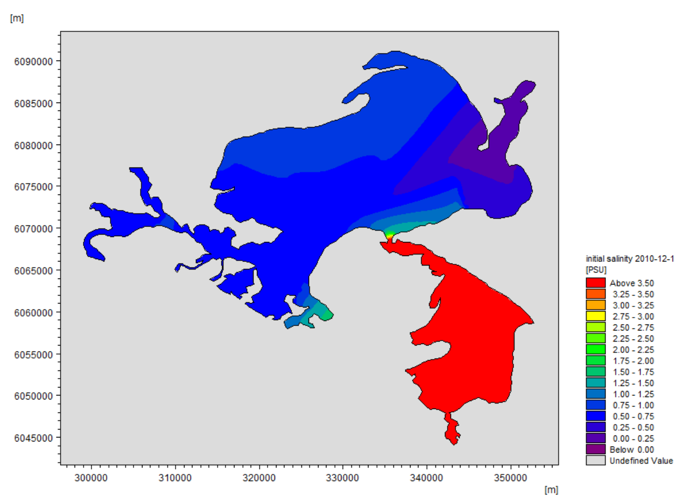

Figure 14: Initial salinity for model calibration.

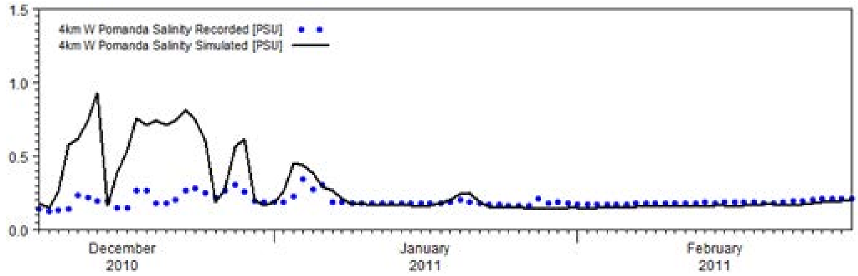

Figure 15: Recorded and modelled salinity at 4 km west of Pomanda.

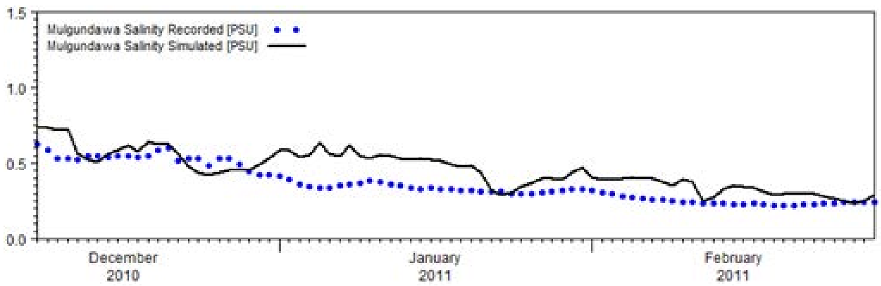

Figure 16: Recorded and modelled salinity at Mulgundawa.

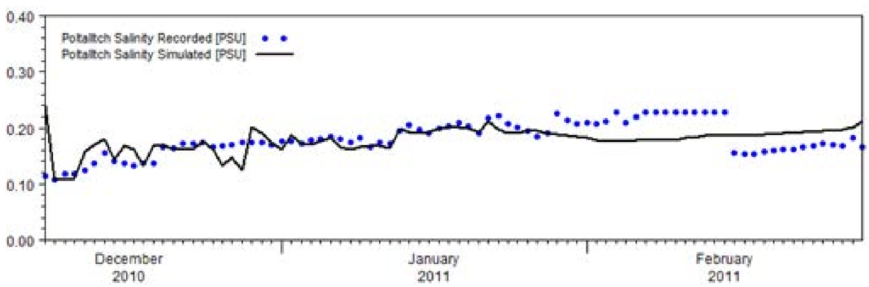

Figure 17: Recorded and modelled salinity at Poltalloch.

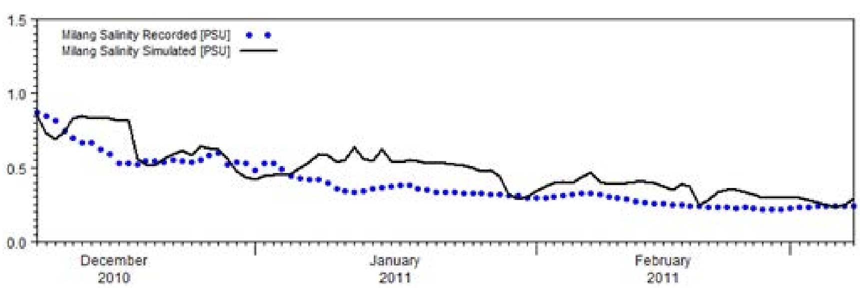

Figure 18: Recorded and modelled salinity at Milang.

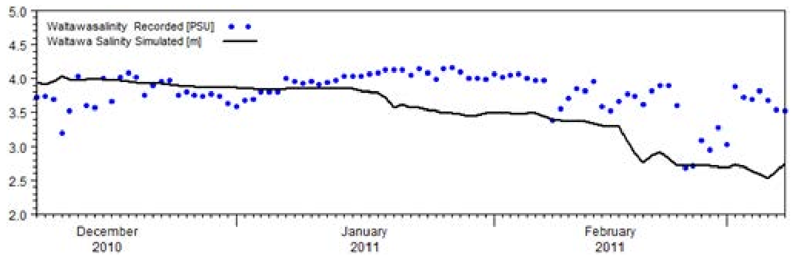

Figure 19: Recorded and modelled salinity near Waltowa.

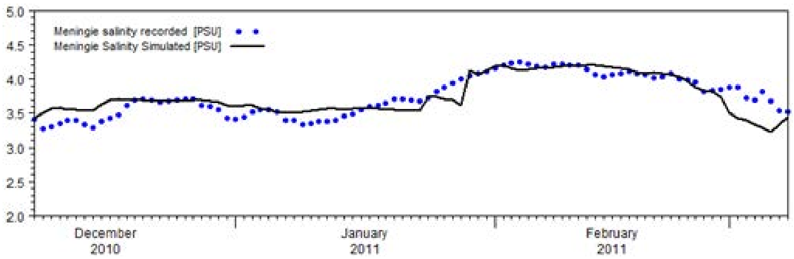

Figure 20: Recorded and modelled salinity at Meningie.

but may also be influenced by inaccurate inflow salinity data. For the Poltalloch site, there are major discontinuities in the measured salinity, which is mainly due to the rainfall at the end of January and the first of February 2011, which increased regional inflow and rapidly raised the lake levels. For Poltalloch, the water level was nearly up to 1 m (Fig. 10), which may reflect an inundation that led to a significant salinity recovery and discontinuities in the measured salinity data.

Figs 19 and 20 show that the model is able to closely reproduce the salinity over most of the time in Lake Albert. For Waltowa, the curve of the simulated salinity result was less than the observed salinity due to lower initial salinity conditions. A lack of spatially varying initial conditions in Lake Albert means that the model is unable to exactly match observed salinity changes, especially at the start of the simulation.

4 DISCUSSION

Quantitative assessments where the model simulations match the observations are used to provide an evaluation of the model's predictive abilities [6]. In this section, correlation coefficients Rand Nash-Sutcliffe efficiency coefficients are calculated to assess the predictive accuracy of the model.

The correlation coefficient describes the degree of collinearity between simulated and measured data. It ranges from -1 to 1 and is an index of the degree of linear relationship between observed and simulated data [7]. If $\boldsymbol{R}^2 = 0$, no linear relationship exists. If $\boldsymbol{R}^2 = 1$, a perfect positive or negative linear relationship exists. Its equation is expressed as:

$$\boldsymbol{R}^2 = \left\{\frac{\sum_{i=1}^{n}(Y_i - \overline{Y_i})(Y_{si} - \overline{Y_{si}})}{\left[\sum_{i=1}^{n}(Y_i - \overline{Y})^2\right]^{0.5}\left[\sum_{i=1}^{n}(Y_{si} - \overline{Y_{si}})^2\right]^{0.5}}\right\}^2 \quad (1)$$

The NSE ($\boldsymbol{E_{NS}}$) is used to assess the predictive power of models [8]. It is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance and indicates how well the plot of observed versus simulated data fits the 1:1 line. It is defined as:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(Y_i - Y_{si})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y_i})^2} \tag{2}$$

The values of NSE can range from -∞ to 1. An efficiency of 1 (NSE = 1) corresponds to a perfect match of the simulation to the observed data. An efficiency of 0 (NSE = 0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (NSE< 0) occurs when the observed mean is a better predictor than the model or, in other words, when the residual variance (described by the numerator in the expression above), is larger than the data variance (described by the denominator). Essentially, the closer the model efficiency is to 1, the more accurate the model is. The minimum performance requirement for the application of the model in this study is that the trend of simulation results basically follows the measured data trend. For water level, the error analysis $\boldsymbol{R}^2$>0.9; for salinity, the error analysis $\boldsymbol{R}^2$>0.8; both of which are acceptable results [8].

The calculated values of the coefficient of correlation ($\boldsymbol{R}^2$) and the Nash-Sutcliffe efficiency coefficient (***NSE***) are listed in Table 2 and 3 to quantitatively describe the accuracy of model outputs for water surface elevation at the seven gauging stations. It is seen that for water level simulation, all values of $\boldsymbol{R}^2$ and ***NSE*** at all stations are over 0.9, which indicates that the computed results agree very closely with the observations. For salinity simulation, all values of $\boldsymbol{R}^2$ and ***NSE*** at all seven sites are over 0.80, which is acceptable for salinity. Thus, acceptable simulation results have been achieved.

Table 2: Model performance for water level in the calibration period.

Site	R^2	NSE
4km west of Pomanda	0.954	0.947
Mulgundawa	0.947	0.943
Poltalloch	0.952	0.939
Milang	0.962	0.957
Near Waltowa	0.963	0.962
Meningie	0.962	0.961

Table 3: Model performance for salinity in the calibration period.

Site	R^2	NSE
4km west of Pomanda	0.833	0.813
Mulgundawa	0.916	0.903
Poltalloch	0.928	0.919
Milang	0.902	0.897
Near Waltowa	0.847	0.822
Meningie	0.913	0.892

5 CONCLUSION

Lake Alexandrina and Lake Albert are located at the terminus of Murray River. Five barrages separate Lake Alexandrina from the Coorong Lagoon and the Murray estuary. 1D and 2D numerical models are used to analyse the hydrodynamic and water quality (salinity) processes in the lower lake system based on historical upstream data from the Murray River. The results show that the 2D model coupled with 1D model for the barrages is able to predict water level and salinity changes accurately for various river flow events. Based on the results of the model, suitable management strategies can be implemented for the Lower Lakes.

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