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Lake Albert Salinity Reduction Study

Preliminary Investigations

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FINAL

Lake Albert Salinity Reduction Study

Report on Preliminary Investigations

Prepared For: South Australian Department of Environment, Water and Natural Resources

Prepared By: BMT WBM Pty Ltd (Member of the BMT group of companies)

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Title :	Lake Albert Salinity Reduction Study - Report on Preliminary Investigations
Author :	Rohan Hudson
Synopsis :	BMT WBM was commissioned by the South Australian Department of Environment, Water and Natural Resources (DEWNR) to undertake a range of studies aimed at improving the understanding of salinity transport and mixing mechanisms in Lake Albert so that a number of potential management options devised to reduce salinity levels in Lake Albert can be evaluated.

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1 INTRODUCTION

BMT WBM was commissioned by the South Australian Department of Environment, Water and Natural Resources (DEWNR) to undertake a range of studies aimed at improving the understanding of salinity transport and mixing mechanisms in Lake Albert.

Following a period of severe drought in the Murray Darling Basin, high rainfall through 2010 and early 2011 resulted in significant flows in both the Darling and Murray Rivers for the first time in over a decade. These high flows refilled the Lower Lakes and flushed considerable amounts of salt from Lake Alexandrina. While salinity levels in Lake Albert have been significantly reduced, its terminal nature has prevented complete flushing and salinity levels remain considerably higher than long term pre-drought averages.

In December 2012 an investigation into options for improving Lake Albert's water quality was initiated by the South Australian Government. Potential management actions currently under consideration for the reduction of salinity include:

- Dredging of Narrung Narrows;
- Removal or modification of the Causeway;
- Connection to the Coorong;
- Permanent water level structure in Narrung Narrows; and
- Water level manipulations.

The aim of this initial investigation is to increase our understanding of salinity dynamics within Lake Albert and to provide an initial assessment of the proposed management options. The investigation also recommends a scope of work to evaluate the management options using a numerical model in a subsequent phase of the investigation.

1.1 Background

The Lower Lakes (Lake Alexandrina and Lake Albert) are located at the terminus of Australia's largest river system. The Lakes are physically separated from the Coorong by five barrages (Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere) built in the 1930's (Figure 1-1). The Coorong is connected to the Southern Ocean (Encounter Bay) at the Murray Mouth.

Historically the barrages have been used to maintain the water level in the Lower Lakes at between approximately 0.5 - 0.75 m AHD with River inflows (see Figure 1-2) being typically greater than evaporative losses and extractions. A severe drought that started in the late 1990's and lasted over a decade significantly reduced River inflows (see Figure 1-3) into the Lower Lakes. Prior to 2007, inflows were sufficient to maintain lake levels above 0.5 m AHD. However, as River discharge fell below ~1000 ML/Day, extractive and evaporative demands exceeded inflows and water levels began to fall significantly (see Figure 1-4).

Title: STUDY SITE AREA AND HYDRAULIC CONTROL LOCATIONS

Figure: 1-1

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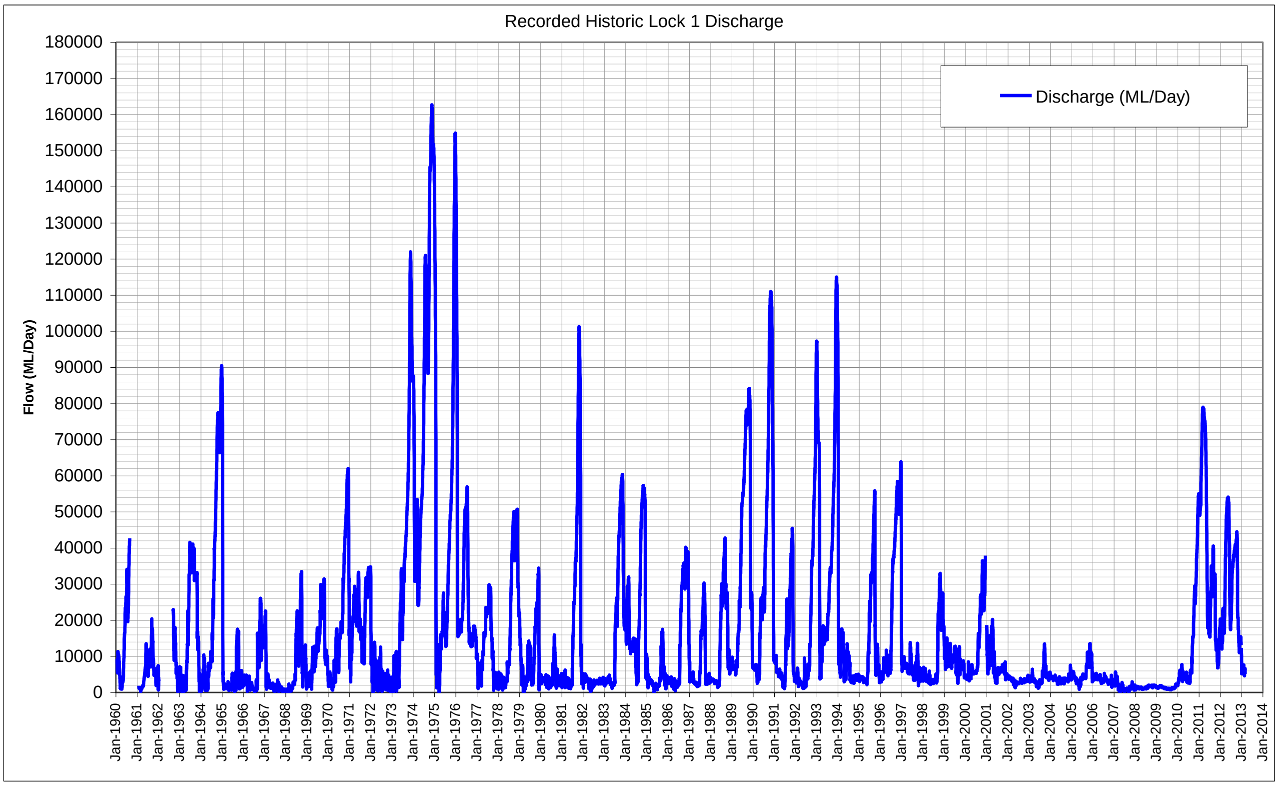


Figure 1-2 Historic Lock 1 Inflows (1960 – 2013)

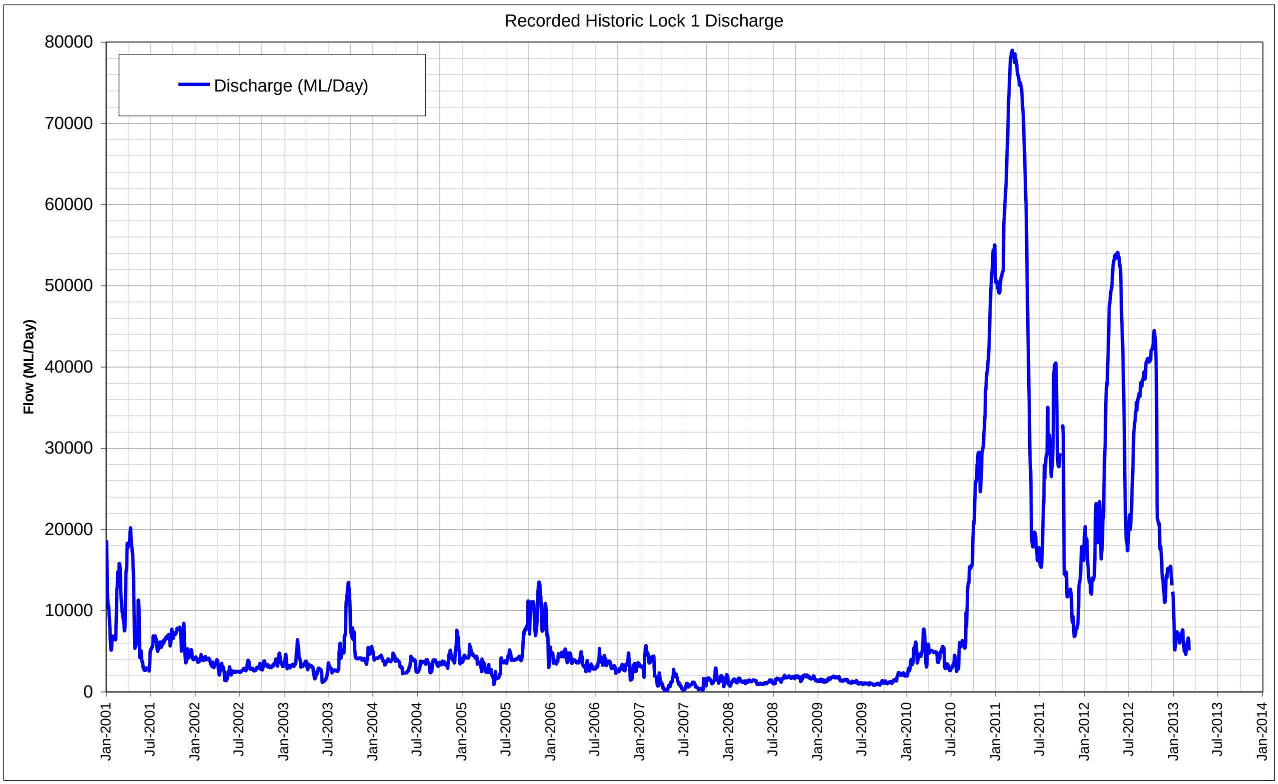


Figure 1-3 Recent Lock 1 Inflows (January 2001 – March 2013)

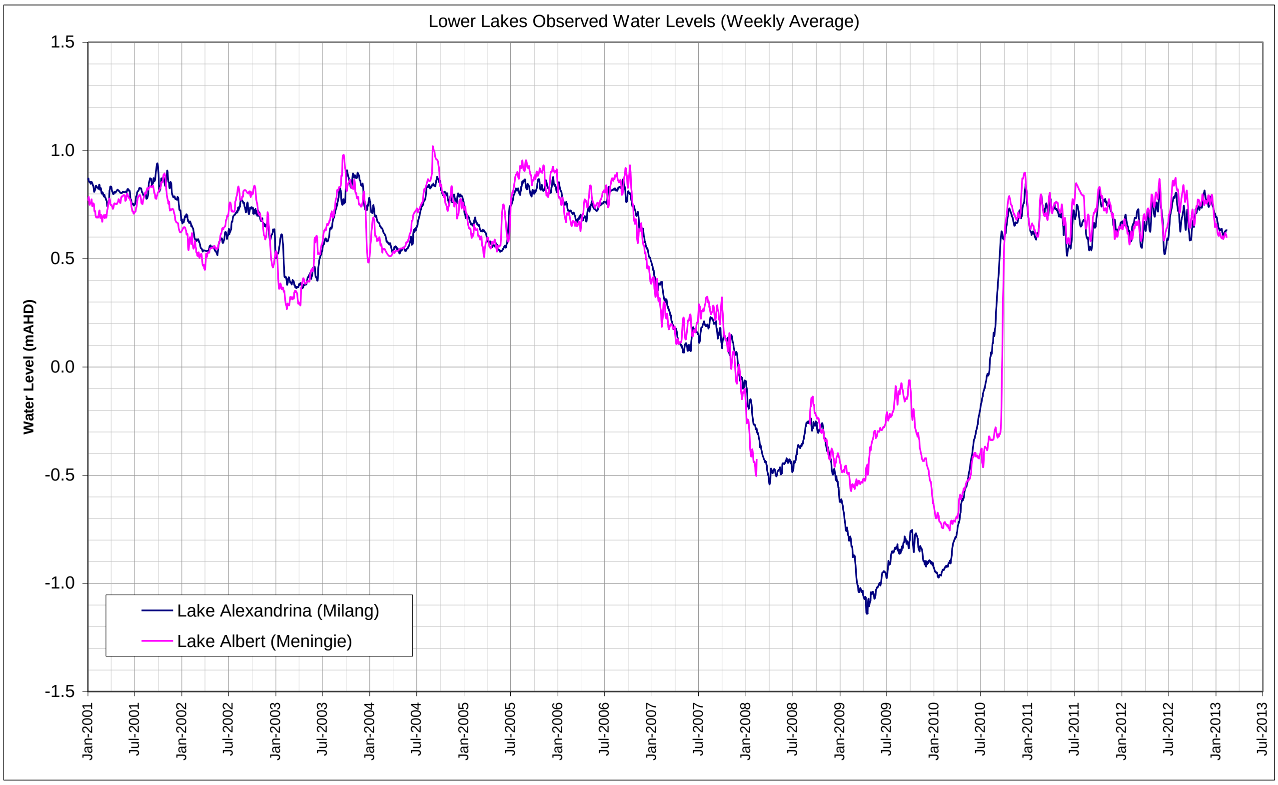


Figure 1-4 Recent Lower Lakes Water Levels (January 2001 – March 2013)

The falling water levels meant that from 2006 until late 2010 there was no discharge through the barrages. Evaporation concentrated salts in Lakes causing a rise in salinity as presented in Figure 1-5.

The presence of sulfidic soils in the Lower Lakes, which if exposed to air can oxidise to form sulphuric acid, prompted the construction of a number of regulators (see Figure 1-1) aimed at maintaining water levels above the level required to prevent acid generation. The construction of the Narrung Regulator, in conjunction with the pumping of water from Lake Alexandrina into Lake Albert, prevented water levels in Lake Albert from falling to the same level as that in Lake Alexandrina. While pumping is likely to have prevented adverse acidification of Lake Albert, it transported salt into the Lake which, when further concentrated through evaporation, resulted in maximum electrical conductivities above 20,000 µS/cm being recorded in March 2010.

In early 2010, River inflows increased above evaporative and extractive demand, resulting in the start of water level recovery in the Lower Lakes. Good rainfall across the Murray Darling Basin including a number of floods in both the Darling and Murray catchments meant that by September 2010, River inflows were above 10 GL/day for the first time since late 2005 (refer Figure 1-3). In late September 2010, with Lake Alexandrina at ~0.75 m AHD, the Narrung Regulator was breached to allow water to flow into Lake Albert. This resulted in a massive inflow of water with the Lake completely filling in a fortnight, diluting the salt mass to a concentration of below 8,000 µS/cm by the start of October 2010.

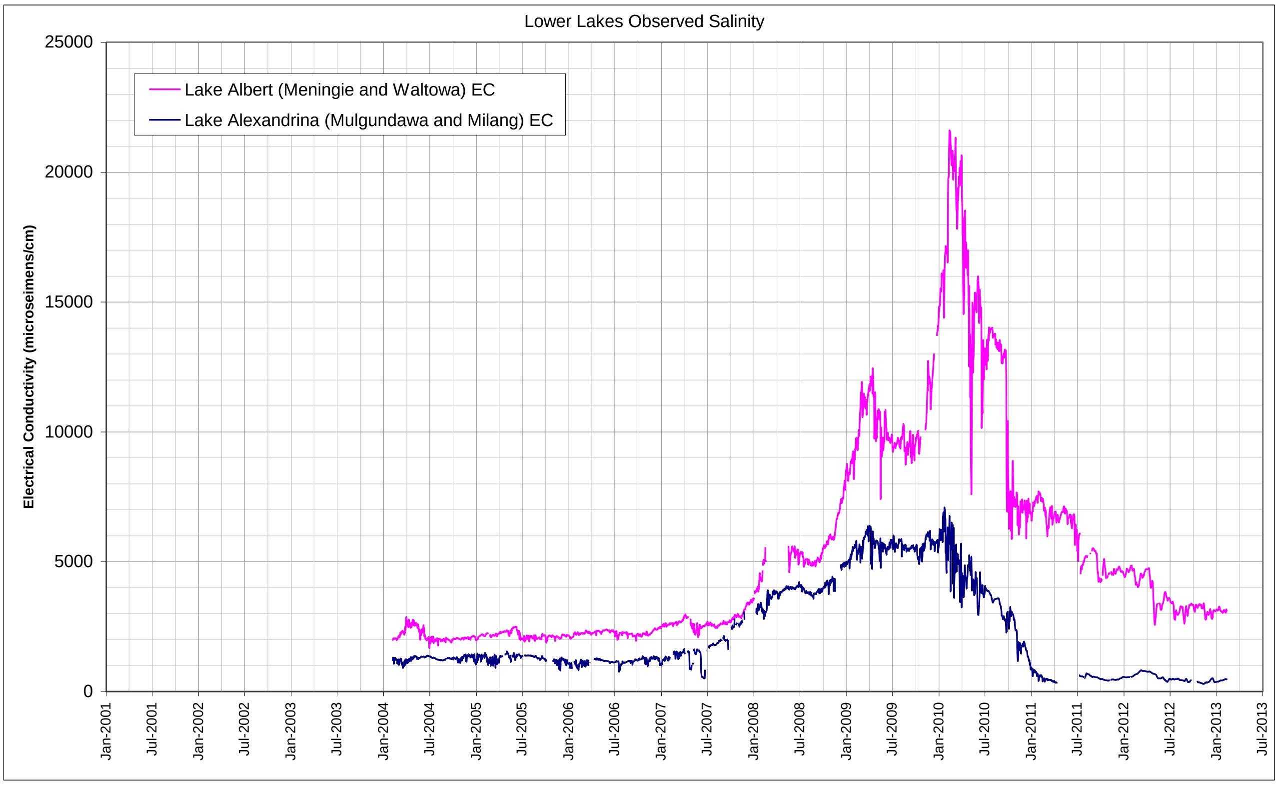


Figure 1-5 Recent Lower Lakes Salinity (January 2001 – March 2013)

During 2011 and 2012 flows have typically remained high, rarely dropping below 10 GL/day, and four significant flood events have resulted in the excellent hydrodynamic conditions to assist with recovery of the Lower Lakes. These high flows have resulted low salinities (for long periods below 500 µS/cm in Lake Alexandrina), and frequent large water level fluctuations which have significantly assisted in diluting and flushing salt from Lake Albert. The considerable water level variations, coupled with wind mixing, were able to reduce salinity levels within Lake Albert to below 5000 µS/cm by the second half of 2011 and to ~3500 µS/cm by mid-2012. By the end of March 2013, salinity levels in Lake Albert were still ~3500 µS/cm.

1.2 Structure of Report

An outline of the remainder of this report is:

Section 2 – provides a description of the environmental characteristics of Lake Albert. This includes a review of long-term water level and salinity data sets, the relationship between lake level (stage), lake surface area and storage volume, a summary of the rainfall and evaporation influences on the system and also a quantification of changes to mass of salt between April 2011 and February 2013.

Section 3 – provides a summary review of previous studies that characterise the hydrodynamics and salinity dynamics of Lake Albert. The review focuses on extracting information that may assist in the assessment of the five management options currently being considered to enhance salt export from Lake Albert. Further relevant details (including figures and summary tables) from the previous studies are presented in Appendix A.

Section 4 – describes a conceptual model of the key factors that influence the salinity dynamics of Lake Albert. Quantification of key drivers of salt mass change is provided to assist in the evaluation of the potential management options.

Section 5 – describes important features of a numerical model that would be required to accurately quantify the five management options. The section details the benefits of model calibration and validation as well as detailing a suggested matrix of model scenarios. These scenarios will provide an envelope of salinity forecasts, enabling a robust assessment of likely salinity levels in Lake Albert under a range of conditions.

Section 6 – provides a summary of key investigation outcomes and relevant conclusions and recommendations.

Appendix A – Provides further relevant details of previous reports (including figures and summary tables).

Appendix B – Provides review of the data available for future model scenarios and calibration exercises.

2 ENVIRONMENTAL CHARACTERISTICS

2.1 Review of Long Term Salinity and Water Level Data

Water level and salinity data are collected at a number of locations throughout the Lower Lakes and Coorong (see Figure 2-1).

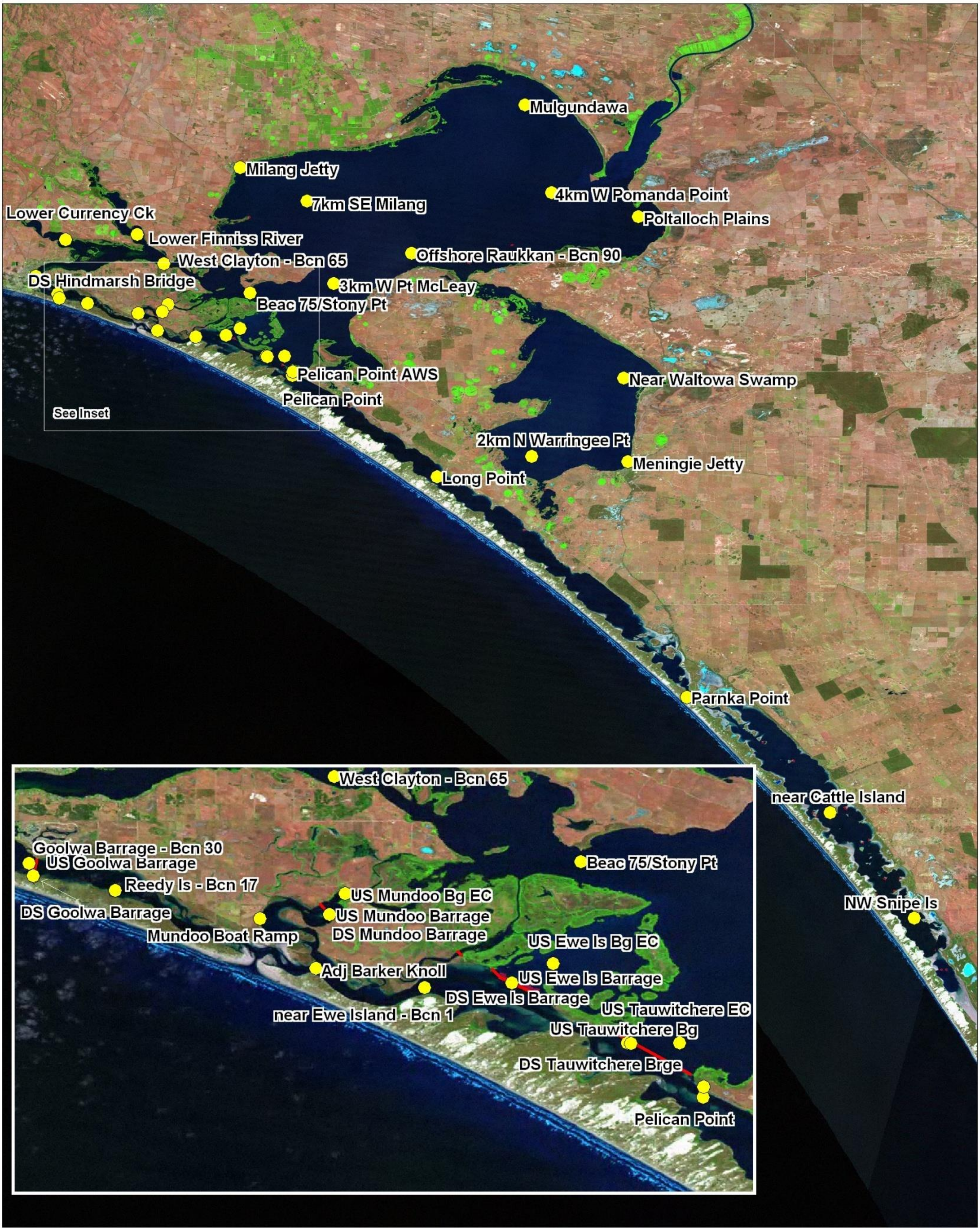
An analysis of long term water level (Figure 2-2) and salinity (Figure 2-3) data sets for the Lower Lakes allows us to gain an understanding of how anomalous the late-2010 lake conditions were. These figures also show that Lake Albert salinity levels are still significantly above long-term typical values (~1500 to 1800 µS/cm).

Water level data for Lake Alexandrina is represented by data for Goolwa Barrage (available from the Surface Water Archive (SWA), since 1974) and Milang (available from SWA since December 1986). Water level data is available for Lake Albert at Meningie since August 1983 (SWA).

Salinity data (electrical conductivity) has been at recorded at approximately weekly intervals in Lake Alexandrina (Milang) and Lake Albert (Meningie) since 1969. For this study only a record of salinity at the start (September) and end (April) of the irrigation season was made available for Meningie. Automated gauges were installed at Milang and Meningie in February 2004 and more frequent (~ weekly) readings are available since December 1986 (though both data sets have significant gaps in them). The Milang salinity data set has been augmented by data from the SA EPA which provides approximately monthly to weekly salinity readings at Milang. Salinity data for Murray Bridge is also presented.

From the data we can see that with the exception of 1981 to 1984 and 2004 to 2011 salinity in Lake Albert is typically between 1000 and 2000 µS/cm and prior to 2003 Lake Alexandrina salinity readings were typically lower than 1000 µS/cm and were as low as 250 µS/cm. The data also show that, prior to 2003, there was a strong correlation between salinity in the River Murray (at Murray Bridge) and Lake Alexandrina.

Lake level data presented in Figure 2-2 shows that lake levels were typically between 0.6 and 0.9 m AHD and, apart from the extremes of 2007 to 2011 (see Section 1.1), rarely fell below 0.5 m AHD.



Title:

LOCATION OF LEVEL AND SALINITY GAUGES

Figure: 2-1

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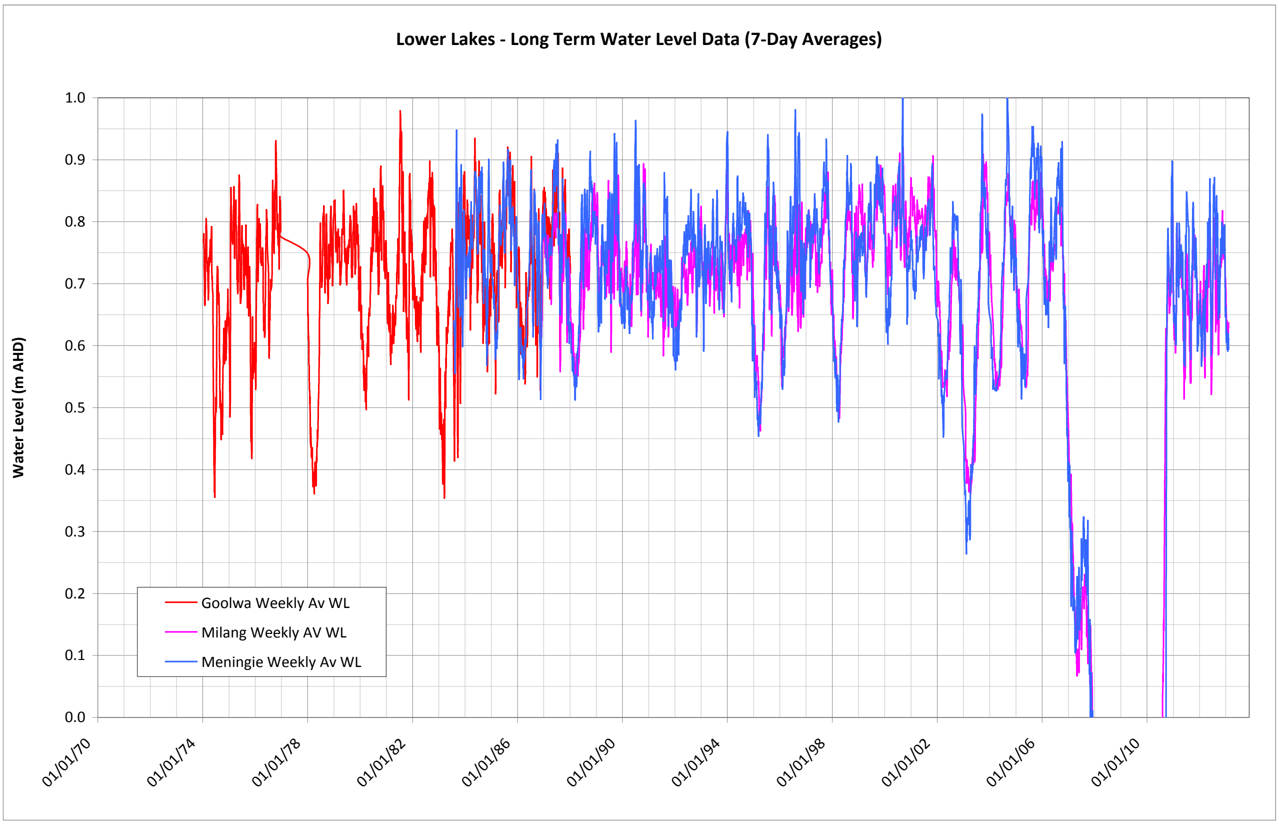


Figure 2-2 Lower Lakes Water Level Data (1974 – 2013)

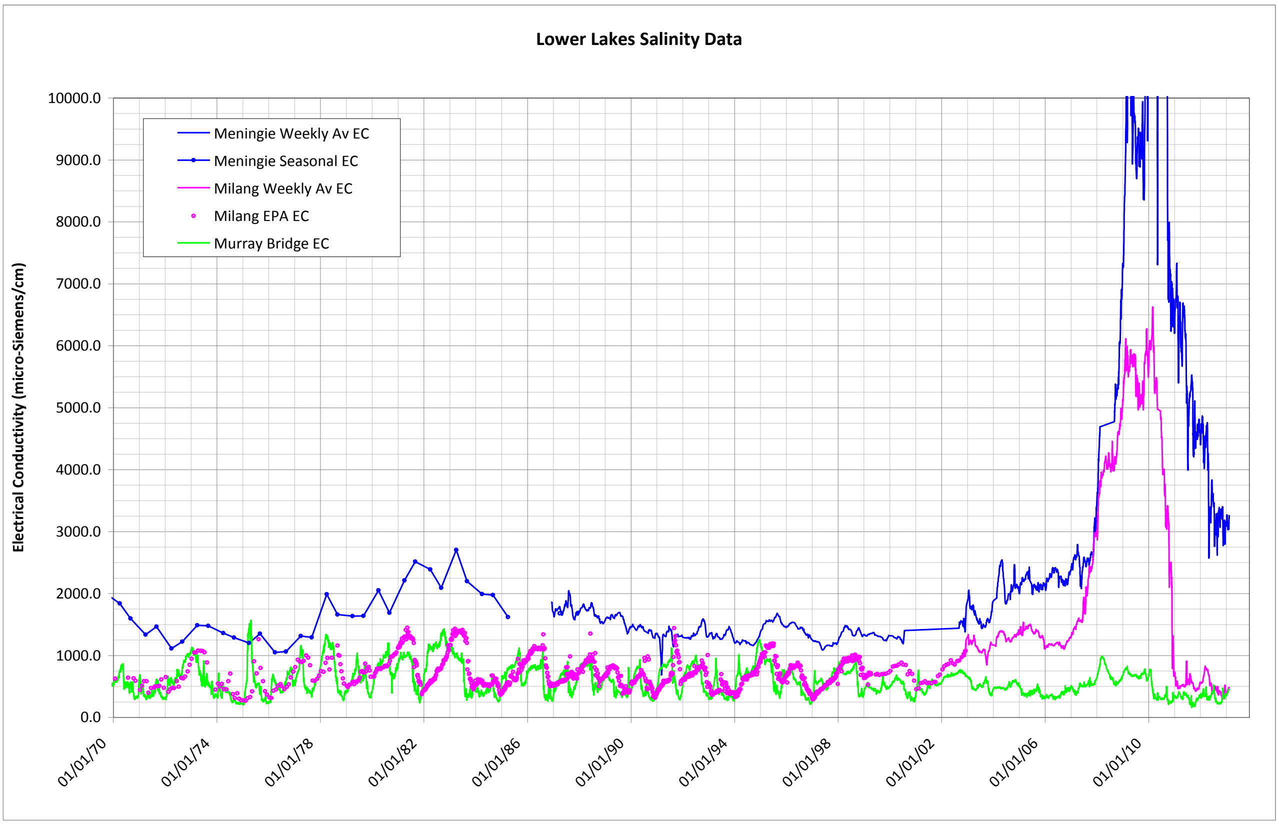


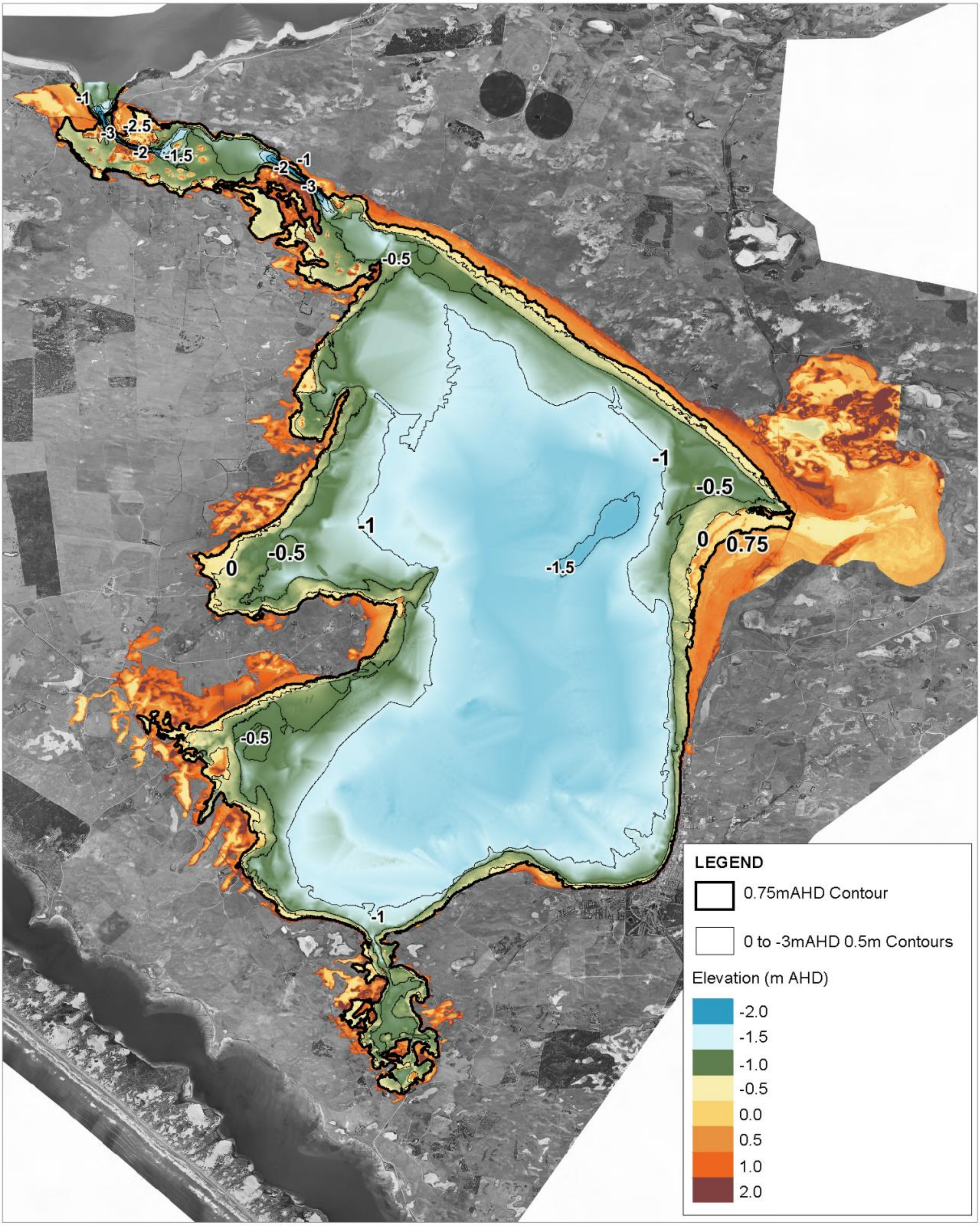
Figure 2-3 Lower Lakes Salinity Data (1970 – 2013)

2.2 Stage, Area Volume Data

Bathymetry data for Lake Albert is presented in Figure 2-4 and shows that the bed of much of the lake sits between -0.5 and -1.5 m AHD. The relationship between water level in the Lakes, the waterway surface area and the volume of water contained within the Lakes (i.e. stage – area – volume data) is presented in Table 2-1 and Figure 2-5. The data shows that at typical water levels (0.75m AHD) the storage volume of the Lower Lakes is ~1910 GL with Lake Albert containing ~280 GL (15% of total volume) while the majority of the storage volume ~1630 GL (85% of total volume) is held in Lake Alexandrina. Total lake surface area is ~840 km^2 with the smaller Lake Albert having a waterway area of 177 km^2 (21% of total area) while the area of Lake Alexandrina is 662 km^2 (79% of total area). The higher surface area to volume ratio of Lake Albert (due to its relatively shallow nature) means that the effects of evapo-concentration have a greater impact on Lake Albert than Lake Alexandrina.

Table 2-1 Water Level and Lake Area (km^2) and Volume (GL) Characteristics

WL (mAHD)	Alexandrina Area	Albert Area	Total Area	Alexandrina Volume	Albert Volume	Total Volume
-1.00	498.6	86.7	585.3	595.0	22.4	617.4
-0.75	521.1	110.3	631.5	722.5	47.3	769.8
-0.50	544.6	137.7	682.2	855.5	77.5	933.0
-0.25	583.8	151.8	735.6	997.1	114.0	1111.1
0.00	614.5	163.3	777.8	1146.9	153.4	1300.4
0.25	639.0	170.3	809.3	1303.6	195.2	1498.9
0.50	651.6	173.9	825.6	1465.3	238.3	1703.6
0.60	655.1	175.2	830.3	1530.6	255.8	1786.4
0.70	659.3	176.4	835.7	1596.3	273.3	1869.7
0.75	662.3	177.1	839.4	1629.4	282.2	1911.5
0.80	666.0	177.9	843.9	1662.6	291.0	1953.6
0.90	675.5	180.2	855.7	1729.6	308.9	2038.6
1.00	686.5	183.1	869.6	1797.7	327.1	2124.8



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Lake Albert Bathymetry Data and 0.5m Contours

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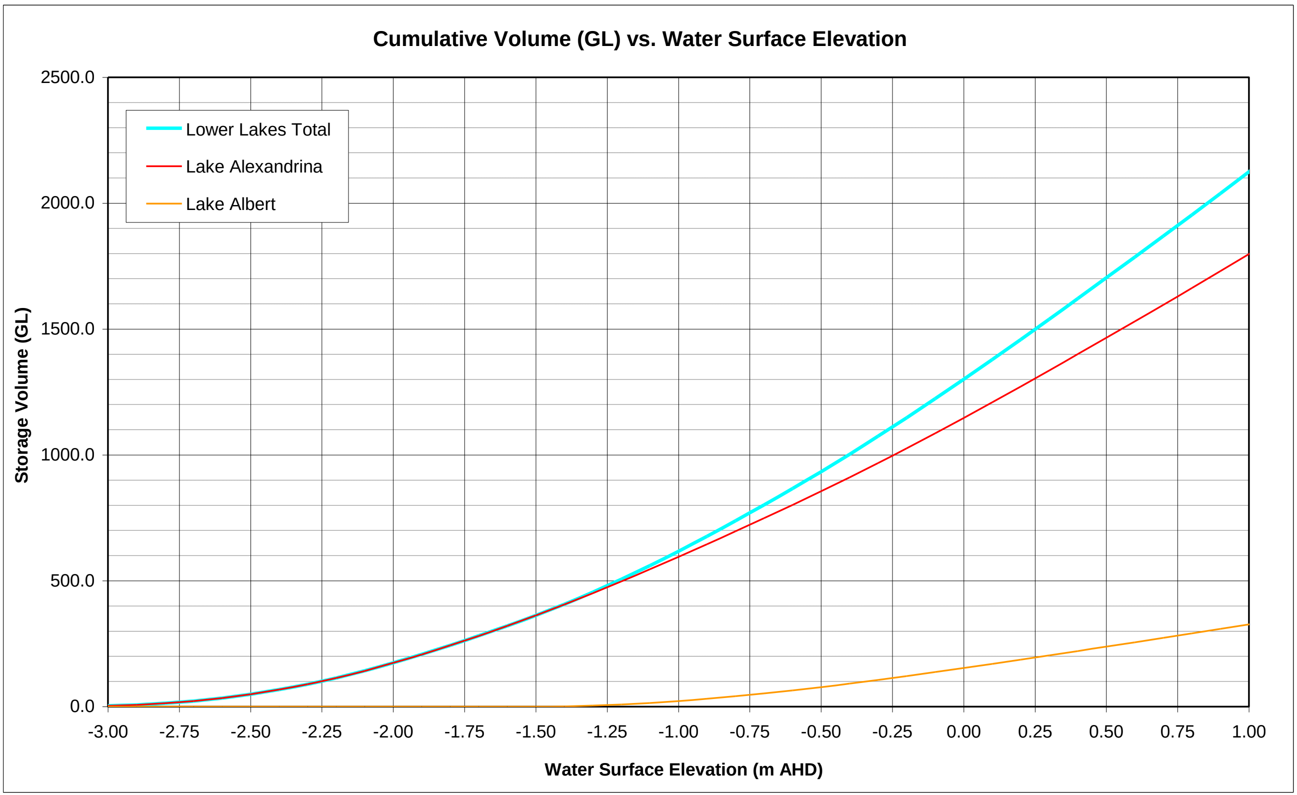


Figure 2-5 Lower Lakes Stage – Volume Relationship

2.3 Net Rainfall – Evaporation Data

Net evaporation is a key driver of salinity dynamics in Lake Albert, so an understanding of the variability in evaporation and rainfall is necessary to quantify the water and salt mass balance for the system. Daily net evaporation is defined as the difference between daily rainfall and daily evaporation. Over 100 years of evaporation data were purchased from the Australian Bureau of Meteorology, SILO (gridded data set) data base. The Morten's shallow lake estimate (MLake) of evaporation was selected for analysis as it provides a good match to actual Lake evaporation (BMT WBM 2011b and 2012a). A summary of monthly and annual net evaporation statistics is presented in Table 2-2, while cumulative monthly totals are presented in Figure 2-6.

The data show that average annual net evaporation is 820 mm with the highest monthly (average net) evaporation occurring in January (164 mm), while in June, there is typically 17 mm more rainfall than evaporation. In the 111 years of available data, a maximum net evaporation of 1024 mm is indicated by the data while a minimum of 497 mm net evaporation is indicated. However, by examining the 10th and 90th percentile a more likely range of net evaporation is between 680 to 941 mm. Examination of Table 2-2 and Figure 2-6 indicates that typically 80-90% of net evaporative demand occurs in 6 months between October and April.

Average monthly evaporation data was supplied by Theresa Heneker (DfW) for use in a number of previous projects is also summarized and presented in Table 2-2 and Figure 2-6. It is believed that these data are typical of average net evaporative conditions. We understand that the data are based on estimates of pan evaporation for 1996. The DfW (975 mm) data does appear to be comparatively high (conservative), falling outside the 90th percentile range of the SILO data.

Table 2-2 Summary of Monthly Net Evaporation (mm) Data (1900 – 2011)

	Average	Median	Min	Max	10 %ile	90 %ile	DfW Data
Jan	-164	-165	-75	-210	-140	-187	-177.3
Feb	-129	-137	-20	-170	-93	-153	-153.0
Mar	-102	-107	-14	-133	-72	-125	-112.5
Apr	-44	-48	25	-90	-7	-72	-58.5
May	-3	-4	49	-49	30	-27	-24.7
Jun	17	14	125	-29	51	-14	-0.9
Jul	11	8	63	-32	37	-11	-10.4
Aug	-10	-11	64	-60	17	-37	-25.7
Sep	-43	-44	14	-88	-16	-70	-49.4
Oct	-86	-90	-19	-140	-50	-121	-85.5
Nov	-120	-125	-36	-165	-88	-149	-126.1
Dec	-149	-154	-5	-201	-120	-177	-151.0
Total Annual	**-822**	**-823**	**-497**	**-1024**	**-684**	**-941**	**-975.0**

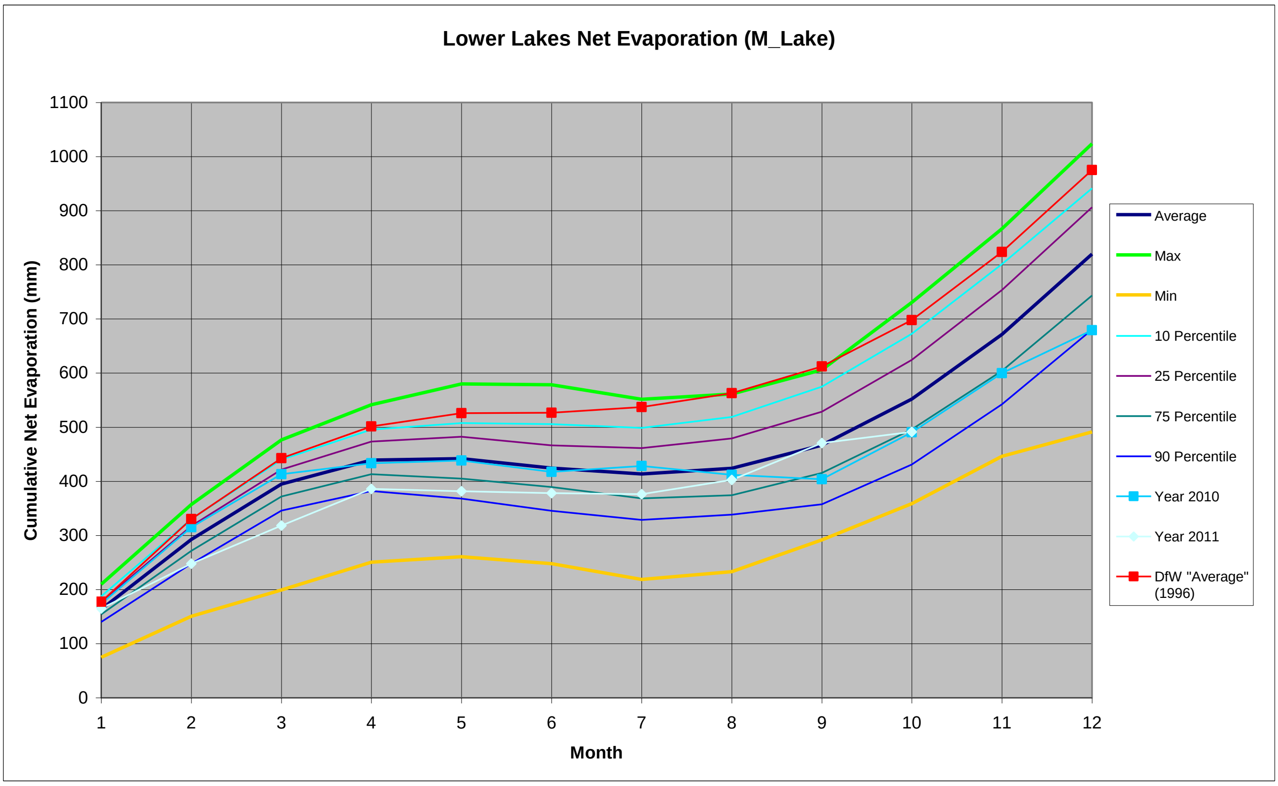


Figure 2-6 Monthly Cumulative Net Evaporation Statistics

2.4 Calculation of Lake Albert Salt Mass (April 2011 to February 2013)

Salinity transect data for Lake Albert have been collected at approximately monthly intervals from the April, 2011. The nineteen salinity data sets that were collected (up to the end of February 2013) have been analysed to help determine changes in the total mass of salt contained within Lake Albert over the past two years.

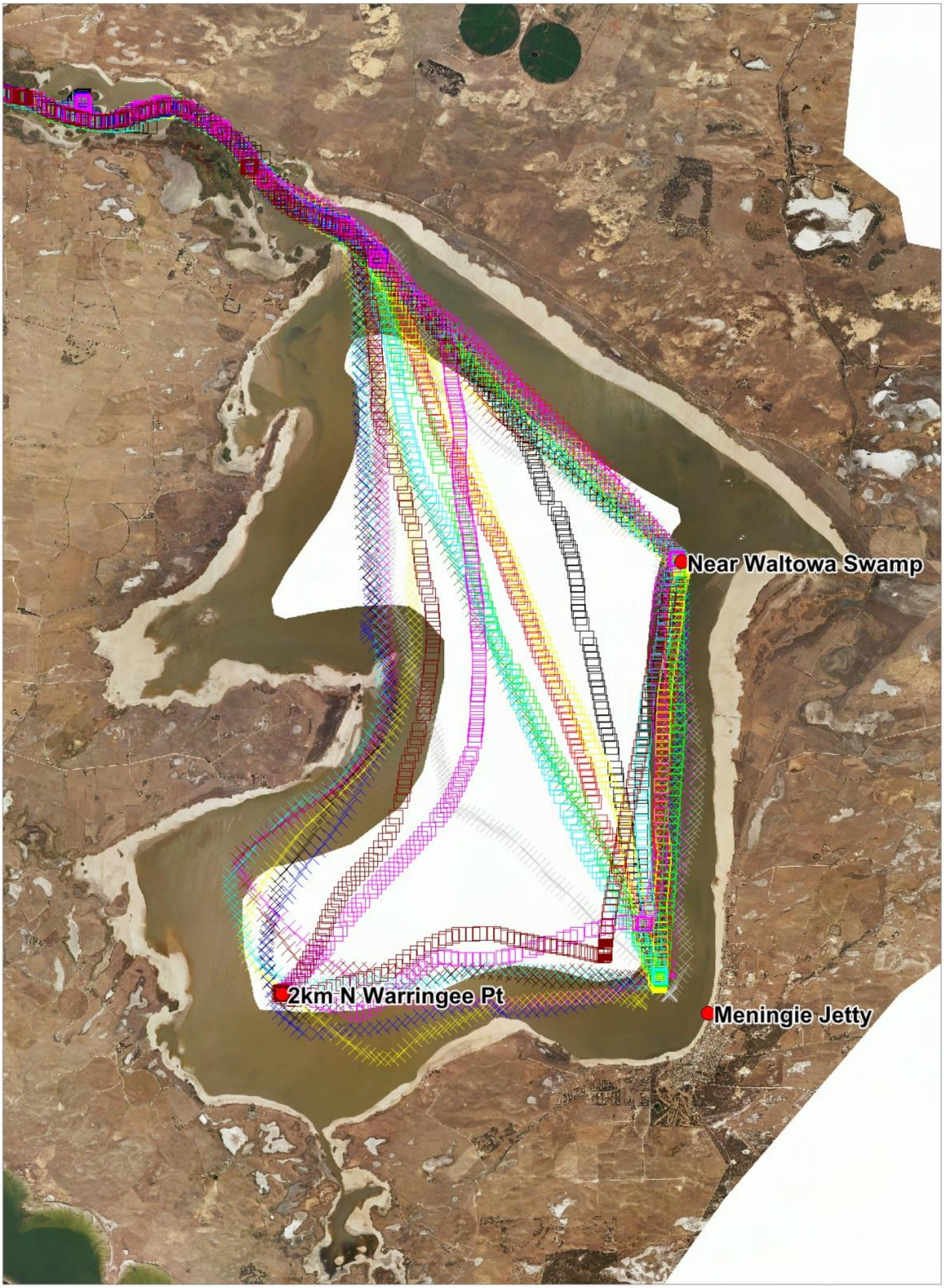
The path of the salinity transects is presented in Figure 2-7. Each individual salinity transect was extrapolated using GIS software to produce a digital surface model (DSM) grid (100m resolution) of salt concentration covering Lake Albert. A representative water level for Lake Albert at the time of the salinity transect taken was then determined by examining DEWNR gauge data. A depth grid (100m resolution) for Lake Albert was then calculated by subtracting the representative water level from a digital elevation model (DEM) of Lake Albert's bathymetry. The salt mass of each 100m grid cell was then determined by multiplying the grid salt concentration (kg/m^3) by the volume of the cell (cell depth (m) x 100m x 100m). The total salt mass of Lake Albert at the time the salinity transect was collected was then calculated by summing the salt mass in each cell. A summary of the salt mass associated with each transect as well as the details of the Lake average, minimum and maximum salinity readings; and the adopted water level used in the calculation is presented in Table 2-3 and Figure 2-8.

Observed salinity data at the three DEWNR gauges in Lake Albert and the average salinity of the Lake DSM grid is also presented in Figure 2-8 while corresponding Lake Albert water level data is presented in Figure 2-9. The data suggests that the Meningie gauge typically provides a good representation of average salinity throughout Lake Albert. The data shows that salt mass is strongly correlated to salinity, but the influence of increases in water level can also be seen in the 18/10/2011, 12/4/2012 and 10/9/2012 data sets where the short term small increase in Lake salt mass can be attributed to an increase in Lake water level.

The salt mass calculations show that on the 27/4/2011 there were approximately 1.1 million tonnes of salt in Lake Albert but, nearly two years later on 14/2/2013, this had reduced to a little over half a million tonnes.

Assuming a target salinity of ~1670 µS/cm in Lake Albert (i.e. 1 kg/m^3, matching a typical pre-drought condition), a Lake water surface at 0.8 m AHD (290 GL) would correspond to a target salt mass of around 290,000 tonnes. This means that from February 2013 the removal of 200,000 tonnes of salt would result in salinities close to target levels.

If we consider that it has taken less than two years to remove ~500,000 tonnes of salt from Lake Albert, if similar levels of mixing and salt export rates occur in the future, than it would appear likely that an additional 200,000 tonnes of salt could be exported by early 2015. However, it is important to consider that, as the salinity of Lake Albert falls further, efficiency of salt export through mixing with Lake Alexandrina will reduce. Significant water level fluctuations during 2011 and 2012 (see Figure 2-9) are also an important factor to consider as these are a primary driver of salt export from Lake Albert.



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Lake Albert Salinity Transect Data (27/4/2011 to 14/2/2013)

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Table 2-3 Summary of Salt Mass and Salinity Transect Data

Date	Mass Salt (tonnes)	Water Level (mAHD)	Av EC	Min EC	Max EC
27/04/2011	1090585	0.76	6866	3515	7222
26/05/2011	1056896	0.71	6781	1156	7182
26/07/2011	931668	0.68	6196	5560	6476
23/08/2011	911536	0.62	6180	5267	6291
18/10/2011	932897	0.80	5644	531	6199
15/11/2011	887488	0.76	5515	1265	5884
13/12/2011	755836	0.57	5330	3139	5659
12/01/2012	731721	0.64	4937	2143	5835
14/03/2012	722198	0.60	5046	3912	5144
12/04/2012	754304	0.74	4745	446	5421
15/05/2012	709040	0.82	4264	486	5246
26/06/2012	631596	0.64	4310	3660	4456
14/08/2012	563197	0.70	3688	3236	3846
10/09/2012	573002	0.80	3511	1452	3661
9/10/2012	533617	0.65	3600	2183	3664
7/11/2012	534529	0.79	3269	419	3692
13/12/2012	541832	0.79	3303	458	3622
10/01/2013	501548	0.60	3475	776	3643
14/02/2013	509194	0.62	3453	541	3782

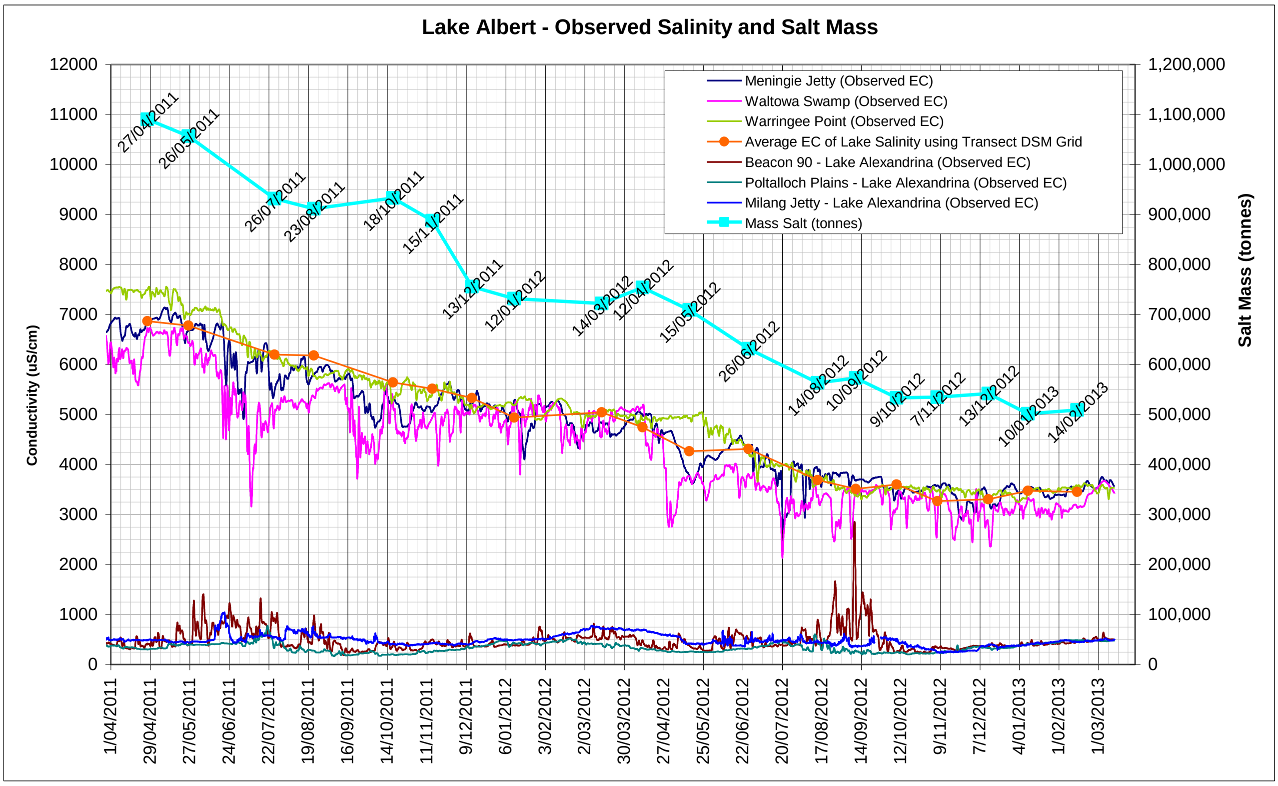

Figure 2-8 Lake Albert - Salinity and Salt Mass

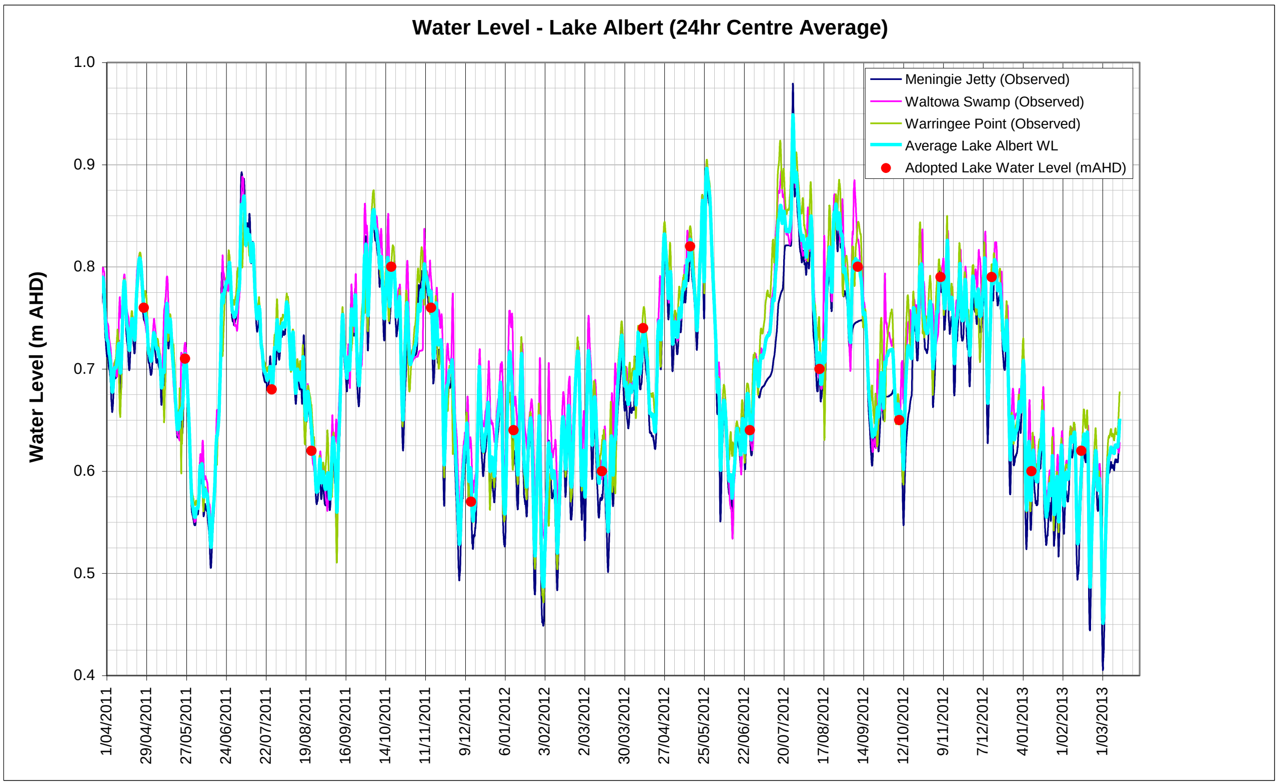

Figure 2-9 Lake Albert – Observed Water Levels

2.5 Discussion of Lake Albert Salt Mass Change (September – October 2010)

The salt mass calculations show that there were approximately 1.1 milllon tonnes of salt in Lake Albert on the 27/4/2011. An examination of Lake Albert salt mass change due to removal of the Narrung Bund is presented below.

Gauge water level and electrical conductivity data shows that just prior to re-connection the level of Lake Albert (in late-September 2010) was ~-0.3 m AHD (106 GL) while salinity was 12800 µS/cm (i.e. 7.67 kg/m^3). This means of 813,200 tonnes of salt had accumulated in the Lake during the drought.

170 GL of water would have been required to refill Lake Albert from -0.3 to a little over 0.7 m AHD. Assuming the lake was filled by water with an average salinity of 2500 µS/cm (i.e. 1.5 kg/m^3) then 255,000 tonnes of salt would have been transported into Lake Albert when it re-filled. This means that in early-October 2010, after re-connecting the Lake, the total salt mass of Lake Albert was approximately 1.07 million tonnes. This is close to the calculated value of salt mass based on the salinity transect data in April 2011 and indicates minimal salt reduction between October 2010 and April 2011. However, the above calculation of salinity is heavily dependent on the assumed inflow salinity and it is likely that a slightly higher value of inflow salinity (and hence post-connection salt mass) may be appropriate, with some loss between October 2010 and April 2011. However, considering the high amount of evaporation that is likely during this period it is possible that there was minimal salt export. This could be better quantified using a numerical model of the Lakes.

3 Review of Previous Studies

A review of previous studies investigating salinity dynamics in Lake Albert has been undertaken. The review showed that some of the proposed management options have been previously investigated. An understanding of the limitations of previous assessments is presented here, alongside any conclusions that can be drawn regarding the effectiveness of the proposed management option.

A list of the studies reviewed includes:

- Lake Albert Salinity Study (Ebsary, 1983)
- Lake Albert Connection Modelling Assessment (WBM, 2006)
- Model Calibration and Validation Reports (BMT WBM, 2011b & 2012a)
- Initial Salinity Reduction Model Investigations (BMT WBM, 2011d)
- Model Investigations and Scenario Runs (BMT WBM, 2011f)
- CLLMM Forecast Modelling – 12 Month Forecast Report (BMT WBM, 2012b)
- Modelling Of Lake Albert Flushing Scenarios (BMT WBM, 2012c)
- Development of Flow Regimes to Manage Water Quality in the Lower Lakes, South Australia (Heneker, 2010)

Relevant details of these investigations have been copied into Appendix A while a short summary of the key study outcomes is presented below.

3.1 Lake Albert Salinity Study (Ebsary, 1983)

A Public Environmental Report (PER) for mitigation of salinity in Lake Albert was prepared by the Engineering and Water Supply Department in 1983 to investigate options for reducing salinity levels within Lake Albert. In January 1983, salinity levels in Lake Albert were above 2300 EC and were believed to be causing reduced productivity for the 40 irrigators who drew some 18 GL/year to irrigate 2200 ha for dairy and Lucerne production. The report examined two options to reduce salinity levels in the Lake including:

a) A channel connection between Lake Albert and the Coorong; and
b) Fluctuating lake levels to enhance salt transport through Narrung Narrows.

A further four options were briefly investigated but, due to adverse cost/benefit ratios no detailed modelling was undertaken. These options included:

i) Dredging of Narrung Narrows to enhance wind driven exchange;
ii) A lock and barrage option across Narrung to isolate Lake Albert from poor water quality in Lake Alexandrina;
iii) A groyne through the centre of Lake Albert to enhance circulation; and
iv) A bund within Lake Albert to reduce evaporation.

Option (b), lake level fluctuation showed substantial benefit at very low cost and was selected as the preferred engineering option. The channel to the Coorong (option (a)) showed a considerable net benefit though at much greater cost.

Further detail of the preferred engineering solution (lake level fluctuation) is presented in Appendix A.

3.2 Lake Albert Connection Modelling Assessment (WBM, 2006)

Detailed modelling was undertaken on behalf of SA DWLBC to investigate the effects of incorporating a barrage controlled connection from Lake Albert to the Coorong. Short term (6 weeks) and long term (5 year) model tests were undertaken using both the WBM (RMA finite element) and Cardno Lawson Treloar (CLT) (Delft3D curvilinear finite difference) models. These models were developed to simulate the hydrodynamics of the Coorong and morphological processes at the mouth, and were subsequently extended to include the entire Lakes system. In addition to the 2D hydrodynamic models, CLT established a simplified 'box' model of the Lakes to assist in fast analysis of the key factors affecting salinity upstream of the barrages. The report sets out the results of two short (6 week) and two long (5 year) scenarios. Results were assessed by comparing base case (no connection) and connected cases for each scenario

The model study indicated that a channel connecting Lake Albert to the Coorong could significantly reduce salinity levels in both Lake Albert and the Coorong. The results (see Figure A-3) showed that within six months a Coorong connector could reduce salinity in Lake Albert from ~2500EC to ~500EC and maintain it below 1000EC for the remaining four years of the simulation. The study was limited to simulating a five year period (1993-1998) in which lake inflows were fairly high. The study highlighted a number of modelling issues including a need for more refinement of morphological processes and determining an appropriate spatial resolution for evaporation of the Lower Lakes and Coorong. The development of a calibrated box model capable of rapidly simulating salinity in the Lower Lakes indicated that this might be a useful tool to consider in future investigations.

Further detail of the study including detail of the model and scenario simulations is presented in Appendix A.2.

3.3 Model Calibration and Validation Reports (BMT WBM, 2011b & 2012a)

BMT WBM was commissioned by the SA Department of Environment and Natural Resources (DENR) to undertake a range of studies aimed at improving the understanding of key environmental hydraulic processes in the Coorong, Lower Lakes and Murray Mouth (CLLMM). The investigation included development and calibration of a numerical model capable of simulating hydrodynamic, salinity and morphological processes within the CLLMM. The built model was able to calculate the dynamic discharge across the barrages separating the Lower Lakes from the Coorong.

The model comprises a combination of hydrodynamics (TUFLOW-FV), waves (SWAN) and morphology (TUFLOW-MORPH). The geometric flexible mesh used by TUFLOW-FV to describe the model area covers the Lower Lakes (Lake Alexandrina and Lake Albert), the Coorong, the Murray Mouth and adjacent coast as presented in Figure 3-1.

Title:

TUFLOW-FV Mesh

Figure: 3.1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 10 20km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N1874_CLLMM_FullyOpenedBarrageAssessment\docs\Figures\CalibReport\Fig3_1_TuflowMesh.WOR

BMT WBM (2011b) described the model calibration covering a five month period (25/11/2010 to 1/5/2011), while BMT WBM (2012a) described model validation for a six month period (1/5/2011 to 31/10/2011). The calibration and validation achieved a close match between observed and modeled water levels and salinities, allowing a high level of confidence to be associated with model predictions. However, no salinity transect data for Lake Albert was available during the study.

Useful output from the numerical model included calculation of barrage discharge (which is far more accurate than existing estimates (see Figure A-5)) and calculation of salt export from Lake Albert (see Figure A-6 and Table A-1) which calculated that the mass of salt in Lake Albert fell by 25% (266,750t) from 1,044,170 tonnes in 1/5/2011 to 777,415 tonnes on 1/11/2011.

Further detail of the calibration and validation studies including detail of the model setup, boundary conditions and model results are presented in Appendix A.3.

3.4 Initial Salinity Reductions Model Investigations (BMT WBM, 2011d)

The initial salinity reduction model investigations were part of a series of investigation BMT WBM undertook on behalf of DENR to gain understanding of key environmental hydraulic processes in the Coorong, Lower Lakes and Murray Mouth (CLLMM).

The study investigated the effectiveness of five proposed water level management regimes and the influence of three different wind conditions on salinity dynamics in the Coorong and Lower Lakes. The model scenarios included use of the recently developed automated barrage logic which is able to control barrage openings based on a time-series of target lake levels. This automated barrage logic is important in the simulation of long term scenarios in such a dynamic environment.

Seven simulations of the Lower Lakes and Coorong were completed for the period 1 May to 1 August 2011. Five simulations investigated the influence of a range of varying magnitude and duration water level manipulations, on salinity levels within Lake Albert and the Coorong. Three model simulations investigated the impact of varying wind conditions on wind mixing and the transport of salt within the study area.

Finding from this investigations include:

- Actual wind conditions appear to have a significant influence on salinity levels within Lake Albert (see Figure A-12)
- The frequency and magnitude of managed water level fluctuations in the Lower Lakes appears to have less influence on the removal of salt from Lake Albert for the simulated conditions (see Figure A-13). However, the use of higher magnitude, more frequent water level fluctuations do appear to be the most effective at removing salt from Lake Albert. However, in the absence of significant wind events, managed water level fluctuation are likely to still be important.

Further detail of the calibration and validation studies including detail of the model setup, boundary conditions and model results are presented in Appendix A.4.

3.5 Model Investigations and Scenario Runs (BMT WBM, 2011f)

This study was the final in a series of six investigation commissioned by DENR aimed at improving the understanding of key environmental hydraulic processes in the Coorong, Lower Lakes and Murray Mouth (CLLMM).

The report discusses a range of model simulations used to investigate the processes affecting salt migration from Lake Albert and the Coorong. The adopted base case simulation was from 1 May to 1 August, 2011 using predominantly observed boundary condition data sets. This period was adopted as (i) the model is known to perform well under these conditions (BMT WBM, 2011c); and (ii) it is broadly representative of typical non-drought inflow conditions.

The results indicated that the following factors have minimal direct influence on salt transport from Lake Albert:

- Murray Mouth Bathymetry;
- Wave Conditions;
- Barrage Release Distribution; and
- Lake Inflow.

Conversely, the following scenarios simulations highlighted processes that have a more significant influence on salinity dynamics in Lake Albert and hence have been described in greater detail in Appendix A.5.

- Winds and Tides (including seasonality);
- Evaporation and Other Investigations (including additional bund removal at Narrung)

Key results from the study included:

- Short term events can significantly change model results (in particular salt flux calculations). Therefore longer simulations (preferably a year or more) give a better indication of scenario outcome;
- For the base case simulation ~153,000 tonnes of salt was exported from Lake Albert over the three month simulation period (1/5/2011 to 1/8/2011). This represents a 16% reduction in total salt mass compared to the initial salt mass of 949,200 tonnes at the start of the simulation. Observed salt reduction (see Section 2.4) over this period was approximately 160,000 tonnes indicating reliable model performance;
- Increased Summer and Spring evaporation can reduce total barrage discharge due to evaporative loss in the Lower Lakes. It also reduces water levels in Lake Albert and increases salt concentrations in Lake Albert;
- Inter-annual differences in wind may influence predicted salt export from Lake Albert; and
- By completely removing the Narrung bund, salt export from Lake Albert could be increased by nearly 10%. However, salt export is more sensitive to the applied evaporation boundary data.

Further detail of the scenario runs and model results are presented in Appendix A.5.

3.6 CLLMM Forecast Modelling – 12 Month Forecast Report (BMT WBM, 2012b)

BMT WBM was commissioned by DENR to provide forecasts of salinity and water levels based on a range of possible future River inflows and 'target' lake levels over a 12 month period 18/4/2012 to 18/4/2013. The model was adapted to open and close barrages on the basis of the required target level at any given time during the simulations.

The study involved producing a base case forecast using average/typical boundary conditions to produce a reasonable estimate of water level and salinity.

For comparison, a range of additional model scenarios were used to determine error bands associated with the base case forecast. The additional scenarios investigated the sensitivity of the base case forecast to different: (i) lake inflows, (ii) evaporation, (iii) wind and tide conditions, (iv) target lake levels; and (v) changes to barrage release distributions.

The model utilized in the study was the full CLLMM TUFLOW-FV model including: hydrodynamics, wave, morphology, salt transport and automated barrages as previously discussed in Appendices A.3, A.4 and A.5.

Relevant Findings of the Base Case Forecast

Using the base case assumptions which included the use of observed 2008/2009 wind and tide conditions, the salt mass in Lake Albert was expected to fall by 91,400 tonnes in 12 months. This represented a 12% reduction compared to the mass of salt in Lake Albert at the start of the simulation (757,820 tonnes). This would have reduced salinity in the centre of the Lake from ~5000 µS/cm to ~4600 µS/cm over the 12 month period.

A comparison of the base case forecast to subsequent calculations of actual salt mass over nearly the same period indicated that a salt mass reduction of 250,000 tonnes from ~750,000 to ~500,000 tonnes was achieved. However, it is important to note that actual lake inflows were significantly greater than those used in the base case forecast simulation and the wind field was different. Both these factors resulted in significantly greater water level variations and hence a greater export of salt mass.

Relevant Findings of Scenario Simulations

- The four inflow scenarios tested resulted in only a minor difference (< 1%) in salt export from Lake Albert as the differing inflows caused only a minor change to lake levels
- Wind conditions have a significant influence on the salt dynamics of Lake Albert (see Figure A.17). For the base case (2008/09 winds), the model predicts the export of 91,400 tonnes (a 12% reduction compared to the initial salt mass in Lake Albert). The other three scenarios predicted reductions in salt mass of between 126,300 tonnes (-19%, for the 2007/08 scenario) and 173,650 tonnes (-23%, for the 2009/10 scenario) over the 12 month period. Accordingly, use of the 2008/09 boundary condition may under predict actual salt loss significantly, and .
- The deliberate raising and lowering of lake levels can cause a significant increase in the flushing of salt from Lake Albert (see Figure A.20). Using the standard series of target lake levels, the model predicted a salt mass reduction of 92,277 tonnes from Lake Albert (which is a 12.2%

reduction in mass compared to the initial salt mass in Lake Albert) of salt would be exported from Lake Albert. However, using the manipulated target lake level series, 142,000 tonnes (-18.7%) would be exported from the Lake. This is a near 50% increase in salt mass removal compared to the non-manipulated scenario.

- The selection of net evaporation time series can have a significant influence on predicted salinity levels within Lake Albert (see Figure A.21). In Lake Albert a final salinity of ~4600 μS/cm is predicted for the DfW (975 mm/year) evaporation series compared to ~4000 μS/cm predicted using the SILO South Lagoon (605 mm/year) evaporation series. In Lake Albert, the base case DfW scenario produces a loss of 91,434 tonnes of salt (which is a 12.1% reduction in salt mass compared to the initial mass of salt in Lake Albert). Using the SILO daily Lake Alexandrina (834 mm/year) series around ~30% more salt (120,752 tonnes) is exported, while the SILO daily South Lagoon (605 mm/year) scenario predicts the export of 167,972 tonnes, which is 84% more than the base case.

Study Conclusions

- Differences in adopted wind conditions may result in significant (up to 100%) differences in the predicted annual salt transport from Lake Albert.
- The deliberate raising and lowering of lake levels can cause a significant increase in the flushing of salt from Lake Albert.
- The selection of evaporation conditions can significantly influence the prediction of salt transport and salinity within Lake Albert and the Coorong. This is likely to be a very important consideration especially for long term simulations.
- Forecast predictions of salt mass change may differ significantly from those observed if there is a significant difference between the boundary conditions and hence water level variations within Lake Albert.

Further detail of the scenario runs and model results are presented in Appendix A.6.

3.7 Modelling Of Lake Albert Flushing Scenarios (BMT WBM, 2012c)

BMT WBM was commissioned by DENR to undertake ten hydrodynamic model simulations of the Lower Lakes, Coorong and Murray Mouth to predict if changes to lake water levels may improve the flushing of salt from Lake Albert. Five different water level management options and two different wind and tide conditions were modelled. Model simulations covered the approximate 3 month period from the 1/6/2012 to the 7/9/2012.

Wind and tide conditions between June to September in both 2008 and 2010 were used to simulate five different lake water level management options listed below and defined in Figure A.22.

- 0.7 m AHD
- 0.8 m AHD
- 0.9 m AHD
- 0.1 m cycled
- 0.2 m cycled

Relevant Findings of Scenario Simulations

Modelled changes to Lake Albert salt mass for the ten scenarios are presented in Figure A.25 (2008 winds) and Figure A.26 (2010 winds) and are summarised in Table A-10. The initial salt mass in Lake Albert at the start of the simulation (1/6/2012) is 740,000 tonnes. The model predicts a reduction in salt mass over the 3 month simulation ranging from 83,433 tonnes to 142,749 tonnes. These represent reductions of between 11.3% and -19.3%. Examination of the results indicates that the selection of applied winds can cause a considerable difference to total net salt export (see Table A-11). An average of the five water level simulations using the 2010 winds predicted an average salt loss of 118,293 tonnes. This is ~23% greater than if the 2008 wind series is used which predicts an average salt loss of 95,933 tonnes.

To determine the potential benefit of adopting either a higher static lake level or the deliberate raising and lowering (cycling) of lake levels, changes in salt mass should be compared to the 0.7 m AHD (do nothing) scenario. Using 2008 wind conditions the 0.9 mAHD water level scenario resulted in 24,145 tonnes (28.9%) more salt being exported compared to the “do nothing”, 0.7 m AHD scenario. Under 2010 wind conditions, the 0.2 m cycled water level scenario indicated that 36,859 tonnes (35.2%) more would be exported compared to the “do nothing”, 0.7 m AHD scenario.

Further examination of the results indicated that water level manipulations typically increase the mass of salt exported and that the change is typically related to the magnitude of the water level variation. However, it is also apparent that the relative timing of bulk water level changes when compared to wind events can significantly influence the amount of net salt export.

Study Conclusions

Ten model scenario runs examined predicted changes to Lake Albert salt dynamics under the influence of five different lake water level management options and two different climatic (wind) conditions. The results indicated that during winter, wind mixing alone is able to cause significant salt export from Lake Albert. The model simulations indicate that during the simulation period, 2010 wind conditions were 20% more effective at removing salt than 2008 wind conditions.

The model scenarios also indicated that by deliberately raising and lowering lake levels, up to 35% more salt could be exported from Lake Albert than if a static 0.7 m AHD lake level was adopted. The model results also indicated that no increase in salt export was likely to occur if lake water levels were deliberately raised (without cycling) above typical operating levels

The model results indicated that large lake level fluctuations are likely to enhance salt export from Lake Albert. However, adaptive management should be used to ensure that targeted water level changes do not reduce the impact of wind driven salt export events.

Further detail of the scenario runs and model results are presented in Appendix A.7.

3.8 Development of Flow Regimes to Manage Water Quality in the Lower Lakes (Heneker, 2010)

This report presents the results of an investigation into the development of inflow and outflow regimes required for the Lower Lakes in South Australia, for the purpose of maintaining a desired ecological character, which was described using threshold water quality (defined in terms of salinity) and water level targets. This work formed an integral component of the Department of Environment and Natural Resources' Coorong, Lower Lakes and Murray Mouth program for determining the environmental water requirements to manage the Coorong, Lake Alexandrina and Lake Albert Ramsar Wetland of International Importance. The environmental water requirements recommended through this program have been presented by the South Australian Government to the Murray–Darling Basin Authority (MDBA) for use during the development of their Basin Plan

Description of BIGMODl

BIGMOD (MDBC 2002) is a computer model that conceptualises and simulates the River Murray system by dividing the river into a number of river reaches. In each river reach, the major processes modelled include the routing of flow and salinity, losses, inflows, extractions, the operation of storages and weirs based on specified rules and the diversion of water into branches. It has been calibrated to available data and is regularly re-calibrated as new data or information becomes available or operating rules are changed.

At the Lower Lakes, *BIGMOD* maintains a continuous water and salt balance and the key requirements from this component of the model was to provide a good representation of water levels and salinities as well as an ability to estimate the flow over the Barrages. The major components of the water balance are inflows (surface flows from the River Murray and Eastern Mount Lofty Ranges (EMLR) tributaries and groundwater inflows), barrage outflows, rainfall, evaporation, seepage, water supply and irrigation extractions.

Relevant Findings

The use of a water balance model within BIGMOD to represent the Lower Lakes means that it is unable to closely match observed water level fluctuations (refer Figure A-27. While the model is able to represent long-term fluctuations the inability of the model to match short term-fluctuations in water level (an important driver of salinity dynamics in Lake Albert) mean that there are limitations for the use of the model in evaluating the proposed management options.

The model (BIGMOD) was calibrated for salinity for the period 1975 to 2007. The overall correlation between model predictions and observed data was 0.93 for Lake Alexandrina and 0.8 for Lake Albert. The model appears to typically under predict Lake Albert salinity between 1975 and 1995 and slightly over-predict salinity from 1995 – 2007 (refer Figure A-28). In order to represent the exchange of salt between Lake Albert and Lake Alexandrina a calibrated constant exchange of 600 ML/day was assumed with no intra- or inter-annual variation considered. This 600 ML/Day represents the exchange due to wind seiche and dispersive processes and would require a daily water level change in the order of 3 cm to achieve the exchange.

A summary of salinity statistics (refer Table A-12) show that the observed mean salinity for Lake Albert for 1975 – 2007 is 1475 µS/cm while the modelled mean salinity for the same period is 1560 µS/cm. Heneker (2012) reports that BIGMOD calculates a long term (1895 to 2009) Lake Albert average salinity of 1695 µS/cm.

4 Conceptual Model of Salinity in Lake Albert and Desktop Evaluation of Proposed Management Options

Based on an examination of recent model studies, long term water level and salinity data sets, and calculations of recent changes to salt mass in Lake Albert, a conceptual model of key factors influencing salinity levels in Lake Albert has been developed.

The terminal nature of Lake Albert (due to its single connection (to Lake Alexandrina) through Narrung Narrows) means that the region's high net annual evaporation will always result in Lake Albert having a higher salinity than Lake Alexandrina.

Evaporation is a key driver in the Lake Albert water and salt balance and will draw an average annual inflow of 145 GL into Lake Albert, which is approximately half the typical lake volume (~280 GL at ~0.75 m AHD). This evaporation demand imports a mass of salt that is directly correlated to the salinity of Lake Alexandrina. This mass for a range of typical Lake Alexandrina salinities (ranging from 400 - 1600 µS/cm) could vary between 36,250 tonnes to 145,000 tonnes.

Wind induced setup can produce a significant water level gradient across both Lake Alexandrina and Lake Albert and provides significant opportunity for mixing and salt mass transport. A 10 cm change in Lake Albert water level will move ~18 GL (~6.5% of total volume) through Narrung Narrows and potentially export a significant mass of salt. Wind induced water level change produces a temporary change in Lake volume so that when the wind drops significantly, in the absence of Lake inflows or barrage outflows, the same volume of water transported into or out of Lake Albert during a wind event will eventually return through the Narrows. The efficiency of wind driven salt mass transport depends on the exchange mass that occurs during each event. This means that while the same volume of water is exchanged during a wind event, mixing processes mean that the mass of salt (exported or imported during a wind event) is unlikely to be the same that returns when the wind dies down. This difference in salt mass exchange during wind events drives an eventual net export of salt from Lake Albert for each wind event.

Water level induced net transport can also occur through bulk water level changes in the Lower Lakes, however it requires ~190 GL of water to change the combined lakes by the 0.1 m required to alter the volume of water in Lake Albert by 18 GL.

For the current range of potential export salinities (i.e. ~1665 to 3330 µS/cm (~1 to 2 kg/m^3)) a water level change of 0.1 m, (a volume of ~18 GL in Lake Albert) could export between 18,000 and 36,000 tonnes of salt. However, due to mixing, processes, between 4,500 and 9,000 tonnes of salt is likely to flow from Lake Alexandrina to Lake Albert (assuming a return salinity of 400 - 800 µS/cm (~0.25 to 0.5 kg/m^3)). Accordingly, a coarse estimate of salt export resulting from a single 0.1 m water level fluctuation is between 9,000 and 31,500 tonnes. During 2011 and 2012 when Lake Albert salinity was above 5,000 µS/cm and Lake Alexandrina salinity levels were below 500 µS/cm, each 0.1m variation in water level may have exported approximately 50,000 tonnes of salt. This estimate corresponds well with the observed reduction in salt mass, from ~1,100,000 tonnes of salt in early-2011 to 510,000 tonnes in early 2013, considering the significant water level variations (and low Lake Alexandrina salinity levels) that occurred during this period.

Irrigation and other extractions from Lake Albert represent another potential for salt export and salinity reduction in the terminal Lake. The total available annual allocation is ~ 18 GL (in 2003) and the actual 2011 and 2012 utilization was in the order of 5.5 – 5.9 GL/year. Assuming an extraction salinity of 3330 µS/cm this would remove ~ 10,000 tonnes of salt each year. This is fairly minor compared to other components of the salt budget.

A connection to the Coorong would allow for more effective flushing of Lake Albert to be achieved and would greatly assist in reducing the current high levels of salinity in the system. Based on Ebsary (1986) a channel system capable transferring 30 GL/month seems to be optimal with reduced benefit above this rate. This 30 GL/month release could export ~60,000 tonnes/month of salt per month (at current salinity levels) and would import fresher Lake Alexandrina waters. Mixing and a further reduction in Lake Albert salinity levels would begin to reduce the efficiency of salt export, however, it is likely that a 30GL/month channel could reduce salinity values within Lake Albert to below 1800 µS/cm within 6 to 12 months of operation. Numerical modelling is recommended to confirm the available discharge characteristics of such a scheme and also the rate at which salinity reduction would occur. The modelling would also help quantify the potential for such a channel to reduce the salinity in the Coorong.

Previous modelling has revealed that salt export is strongly dependent on the applied wind field and considerable differences exist between the potential for salt export between annual wind fields. Dredging and enlarging the connection (Narrung Narrows) between Lake Albert and Lake Alexandrina has not been examined in detail in previous model studies but may enhance wind driven salt export processes. In BMT WBM (2011f) increasing the breach size of the Narrung Bund helped increase salt export by approximately 10 percent above the base case (as discussed in Appendix A.5). Causeway removal and/or dredging of Narrung Narrows may help increase the efficiency of volume exchange and hence salt export. However, this increased efficiency would provide minimal benefit if deliberate water level fluctuation is adopted, as the lakes are likely to reach a full equilibrium in less than a week without dredging. Numerical modelling would be able to quantify the benefit of these management options.

Deliberate manipulation of water levels in the Lower Lakes may be able to provide sufficient enhancement of natural salt export process to return Lake Albert salinity levels to more acceptable values. It was the preferred management option presented in the Ebsary (1986) study and provided reasonable river discharge is available over the next few years, it is likely to provide the best cost benefit ratio of the management options under current consideration because no capital cost is associated with this option. The time taken to reduce Lake Albert's salinity to acceptable levels will depend on the magnitude and frequency of targeted lake water level manipulations, the background level of wind induced export, interactions between deliberate and wind induced water level fluctuations and the actual net future evaporation that occurs. The available magnitude and frequency of targeted water level manipulations will depend on: (i) lake inflows (including rate and salinity); and (ii) the available barrage discharge characteristics which are in turn dependent on tidal conditions in the Coorong.

During the previous period of historically high salinity levels in Lake Albert in the early 1980's (see Figure 2-3) it took approximately two years for salinity levels to fall from nearly 3000 µS/cm to 1900 µS/cm.

Quantification and optimization of managed water level fluctuations would help evaluate the length of time required for salinity levels in Lake Albert to fall to more acceptable levels. Running a numerical model under a variety of, inflow, wind, evaporation, and tidal conditions for a range of target water levels would help establish the range of possible forecast outcomes so that variability in the system is appropriately considered and salt export can be optimised.

The installation of a permanent water level structure in Narrung Narrows to be able to isolate Lake Albert during periods of high salinity in Lake Alexandrina would not assist in the reduction of the currently high levels of salinity in Lake Albert. Such a structure may have future merit in assisting with the maintenance of low salinity levels by potentially only filling Lake Albert with lower salinity (typically winter) waters. However, until Lake Albert salinity levels are significantly reduced such a structure would have most likely negligible benefit.

5 RECOMMENDED MODELLING APPROACH FOR DETAILED OPTION ASSESSMENT

5.1 Recommended Model Features and Model Extent

The complex nature of hydrodynamics and salt transport in Lake Albert and the Lower Lakes, Murray Mouth and Coorong mean that to properly evaluate proposed management options for enhancing the recovery of salinity levels in Lake Albert a two dimensional numerical model of the system is required. While a simpler 1D or box model could be of assistance in preliminary assessment of the Coorong connector options, the inability to confidently determine mixing exchange co-efficients results in these simpler models being of limited use to accurately determine salt export from Lake Albert.

Previous investigations have shown that a fully 2D hydrodynamic numerical model solving the shallow water wave equation is required to represent the movement of water within the Lower Lakes. The model must also include a suitable scalar transport routine to calculate the transport, mixing and dispersion of salt through the system. The model must also be able to represent wind induced mixing and transport processes as well as spatially varying rainfall and evaporative processes.

The model will also need suitable numerical routines to appropriately represent the complex barrage structures separating the Lower Lakes from the Coorong. A suitable level of structure logic will also be required so that barrage openings can be adjusted based on a target lake level, as required for lake forecast scenarios.

The dynamic nature of the Murray Mouth means that the model also requires a suitable morphology routine to be able to calculate the changeable conveyance of the Murray Mouth. The influence of wave induced sediment transport and occurrence of wave setup at the Murray Mouth mean that both the hydrodynamics and sediment transport modules will need to be coupled dynamically to a coastal wave model.

The model mesh would need to cover both the Lower Lakes, Coorong and Murray Mouth to at least 1 m AHD. Inclusion of the River Murray from Wellington to Lock 1 may be required for low river flow simulations. An offshore area surrounding the Murray Mouth is also required to calculate long-shore sediment transport processes and wave setup, which control infilling of the mouth following scour events.

5.2 Model Calibration and Validation

To increase confidence in model predictions, appropriate model calibration and validation is recommended. The calibration process requires the adjustment of available mixing and transport co-efficients so that the model is able to replicate observed changes in water level, salinity and salt mass across the Lower Lakes and Coorong.

Validating the model to a separate period of time to which the model was calibrated would further increase confidence in model predictions. However, previous modelling has indicated that uncertainty regarding some boundary conditions (including lake inflows and barrage operations) means that a key part of the model calibration and validation process involves a thorough evaluation of available boundary condition data, with adjustment or replacement when justified.

It is recommended to calibrate (and / or validate) the model to cover the period where lake salinity transect data is available (from 27/4/2011 to at least the 14/2/2013). The majority of boundary conditions (BC's) used in the calibration and validation simulations are likely to be an ideal base case set of conditions. Sensitivity testing of the model (and proposed management options) would require adjusting a single BC at a time to assess what the model (and therefore the system) is sensitive to.

A review of the availability of data required to undertake further model calibration is presented in Appendix B. The review indicates that a significant portion of water level data for Victor Harbour is missing due to gauge failure. However, despite this being a important boundary condition, the ability to provide a good estimate of it from tidal predictions and an estimate of tidal anomaly (based on other Coorong water level data) means that sufficient data is available for an additional model calibration exercise.

During the model calibration and validation process the possible requirement for three dimensional should be assessed. However, we note that most of the Lakes and Coorong are shallow and well mixed by wind.

The existing TUFLOW-FV model of the Coorong, Lower Lakes and Murray Mouth has been calibrated so that it is able to closely match observed water level and salinity data for the twelve months from 1/11/2010 to 31/10/2011. However, the initial investigation reported here has revealed additional salinity transect data sets which could be used to improve confidence in the model predictions.

5.3 Model Forecasts

A series of model forecasts evaluating the base case (i.e. do nothing) and effectiveness of the proposed management options is recommended. It is likely that a 2 to 3 year forecast will be necessary to evaluate the management options. However, as the accuracy of the forecast is highly dependent on similarity between assumed and actual boundary conditions, it is important undertake a number of forecasts that cover the range of likely boundary conditions. A suggested matrix of boundary conditions may include:

- 3 (high, medium and low) lake inflows;
- 3 (high, medium and low) net evaporation;
- 3 different series of waves, winds and tides;

A single series of targeted water levels would be required for these simulations. A full set of runs for the 3 x 3 x 3 different BC series would require 27 runs, however, it is recommended to reduce this by only running the variations about the medium (i.e. typical) case, reducing the required number of runs in this series to 9. An additional 3 worst case (i.e. low flow, high evaporation) runs could be assessed for the three different wind and tide conditions, bringing the total number of base case simulations to 12. Inter-annual sequencing should be considered in determining scenario boundary conditions. The assessment of different initial salinity conditions could be included by specifying additional tracers to be simulated in each scenario run.

The number and details of required forecast simulations should be developed in consultation with DEWNR.

5.4 Model Scenarios

The suggested strategy for modelling the five proposed management options is presented below.

5.4.1 Managed water level fluctuations

The model could be used to determine the performance of the deliberate cycling of lake water levels through use of the automated barrage routines and the specification of a time series of target lake levels.

A number of scenarios that consider the impact of different magnitude (say 0.1, 0.2 or 0.3m) and duration (or frequency) of water level cycling would be used to determine an optimal set of water level targets. The time series of water level targets would be constrained by available lake inflows and other ecological considerations, while the actual lake level achieved by the model will also be dependent on downstream conditions and the discharge characteristics of the barrages.

The performance of this management option would be assessed by comparing total salt mass export against the equivalent base case scenario (in which a typical (non-cycled) set of water level targets was adopted). Because of the potential interaction between wind setup and targeted water level changes it is recommended that the cycling scenarios be run using a number of different wind boundary conditions.

An initial evaluation on the influence of water level variation on Lake Albert salt export could be achieved by running the historic April 2011 to March 2013 period with a target flat lake level.

Some adjustment to automated barrage parameters may be necessary to achieve a realistic model scenario if conditions differ significantly from those used in their current formulation.

5.4.2 Coorong Connection

The performance of a connection between Lake Albert and the Coorong could be assessed in the 2D model by representing the channel in the model mesh and setting up a suitable structure routine to represent gate operation. The existing TUFLOW-FV structure routine that represents the existing barrages would be appropriate to use for this scenario.

Existing studies indicate that discharges up to 1 GL/day should be investigated. The actual discharge capacity of the proposed connector would depend on upstream and downstream water levels as well as channel widths, depths and the design of the regulator structure (most likely a radial (or spindle) gate similar to that used on the existing barrages). It is assumed that an automated barrage type structure to prevent reverse head would be used. The use of pumping would reduce the influence of upstream and downstream conditions and could be beneficial for a temporary management option.

A number of channel widths and depths could be investigated as well as structure configurations and operational rules. The option will need to be evaluated both against available discharge capacity and also available discharge volume.

It should be noted that the initial assessment would only assess this option in regard to salinity benefit to Lake Albert and the Coorong. The positive influence on Coorong salinity is likely to be relevant to assessing the performance of this option, however, additional water quality modelling to assess the impact of potentially highly turbid water entering the Coorong is likely to be required as part of a more complete assessment of this option.

The use of box model to determine influence of different channel capacities and discharge volumes may be useful to provide a coarse, rapid assessment of this option.

5.4.3 Dredge Narrung Narrows

The potential for increased salt export due to dredging in Narrung Narrows could be assessed in the 2D model by incorporating a dredged channel into the model mesh. While a number of different channel widths and profiles could be assessed to determine an optimal dredge volume. An initial assessment of a large dredge profile is recommended.

It is recommended that a number of different wind time series be used to assess this option

The interaction of this option with managed water level fluctuations should also be considered.

5.4.4 Causeway Removal

The potential for increased salt export due to removal of the causeway at the western end of Narrung Narrows could be assessed in the 2D model by altering the model mesh to further increase channel conveyance.

It is recommended that a number of different wind series be used to assess this option

The interaction of this option with managed water level fluctuations should also be considered. Likewise the combination of this option with the dredging option should be considered.

5.4.5 Lake Albert Water Level Regulator

An automated structure representing this regulator could be implemented in the TUFLOW-FV model. A series of logical rules defining gate openings and closures would be developed through discussions with DEWNR. The assumptions regarding gate types and structure dimensions would also be formulated through discussions with DEWNR.

6 SUMMARY AND CONCLUSIONS

This study details a desktop investigation used to provide an initial assessment of a number of potential management options aimed at improving salinity levels within Lake Albert. A review of relevant environment characteristics of the Lower Lakes including: long-term water level and salinity data, the stage-area-volume relationship of the Lakes, typical rates of net evaporation and recent changes to salt mass have been examined to help provide a conceptual model of key factors influencing salinity dynamics within Lake Albert. A review of previous investigations into the hydrodynamics of the Lower Lakes and Coorong has also been used to help better understand salt dynamics in Lake Albert and provide an initial evaluation of the proposed management options.

This investigation has found that:

- The terminal nature of Lake Albert (due to its single connection (to Lake Alexandrina) through Narrung Narrows) means that the regions high net annual evaporation will always result in Lake Albert having a higher salinity than Lake Alexandrina.
- Evaporation is a key driver in the Lake Albert water and salt balance and will draw an average annual inflow of 145 GL into Lake Albert, which is approximately half the typical lake volume (~280 GL at ~0.75 m AHD).
- An examination of long-term salinity data shows that, with the exception of 1981 to 1984 and 2004 to 2011, salinity in Lake Albert was typically between 1000 and 2000 µS/cm and, prior to 2003, Lake Alexandrina salinity readings were typically lower than 1000 µS/cm and with minimum values around 250 µS/cm.
- An examination of long-term Lake level data showed that lake levels are typically between 0.6 and 0.9 m AD and apart from the extremes of 2007 to 2011 (see Section 1.1) rarely fell below 0.5 m AHD.
- Assuming a “pre-drought” salinity target within Lake Albert of ~1670 µS/cm (i.e. 1 kg/m^3) then a corresponding target salt mass of the lake would be 290,000 tonnes, if the lake is at 0.8 m AHD (290 GL).
- Following a decade of drought and opening of the Narrung Bund in early-October 2010, the total salt mass of Lake Albert was approximately 1.1 million tonnes.
- Calculations of Lake Albert salt mass (based on salinity transect data) showed that the mass of salt has fallen from ~1.1 million tonnes in April 2011 to ~0.5 million tonnes by February 2013.
- Wind induced setup can produce a significant water level gradient across both Lake Alexandrina and Lake Albert. This encourages mixing and salt mass transport. A 10 cm change in Lake Albert water level will move ~18 GL (~6.5% of total volume) through Narrung Narrows and potentially export a significant mass of salt.
- For the current range of Lower Lake salinities, each 0.1m water level fluctuation generates an estimated net export of salt from Lake Albert of between 9,000 and 31,500 tonnes.

A review of previous investigations into the hydrodynamics of the Lower Lakes and Coorong has also been used to help better understand salt dynamics in Lake Albert and provide an initial evaluation of the proposed management options.

This review has found that:

- The Ebsary (1983) investigation into Lake Albert salinity recommended that water level cycling was the most cost effective option of reducing salinity levels within Lake Albert. However, a Coorong connector channel was also investigated and was found to be an effective (though costly) measure and discharge rates up to 30GL/month were optimal.
- The WBM (2006) Lake Albert Connection Modelling Assessment investigated a channel connecting Lake Albert to the Coorong using two different 2D models. The model scenario results show that within six months a Coorong connector could reduce salinity in Lake Albert from ~2500EC to ~500EC and maintain it below 1000EC for the remaining four years of the simulation.
- BMT WBM (see BMT WBM, 2011b and 2012a) has successfully developed a numerical model capable of closely simulating observed water level and salinity changes across the Lower Lakes and Coorong between 25/11/2010 and 1/11/2011. The model calculated that the mass of salt in Lake Albert fell from 1,044,170 tonnes in 1/5/2011 to 777,415 tonnes on 1/11/2011 (i.e. reduction of 25% or 266,750t).
- Automated barrage logic was incorporated into the calibrated numerical model allowing it to be used in a wide range of forecast simulations aimed at improving the understanding of key environmental hydraulic processes in the Coorong, Lower Lakes and Murray Mouth (CLLMM). Findings from these investigations include:
    - Actual wind conditions appear to have a significant influence on salinity levels and salt export from Lake Albert. An evaluation of four different annual wind series indicated that differences of annual salt mass export may be as high as 50% depending adopted winds (and tides);
    - Given short term events can significantly change model results (in particular salt flux calculations), longer simulations (preferably a year or more) are likely to provide a better indication of scenario outcome.
    - For a base case forecast simulation (using observed wind and tides), the ~153,000 tonnes of salt exported from Lake Albert over the three month simulation period (1/5/2011 to 1/8/2011) represents a 16% reduction in the initial total salt mass (949,200 t) tonnes. Observed salt reduction over this approximate period was approximately 160,000 tonnes indicating good model performance.
    - The deliberate raising and lowering of lake levels can significantly increase (by up to 50% (for the modelled scenario)) in the flushing of salt from Lake Albert (see Table A-7).
    - By completely removing the Narrung bund, salt export could be increased by nearly 10% (based on the modelled scenario). However, this impact is small when compared to sensitivities relating to the adopted evaporation boundary data.
    - Model scenarios also indicated that by deliberately raising and lowering lake levels (over a three month period), up to 35% more salt could be exported from Lake Albert than if a static 0.7 m AHD lake level was adopted.
    - Model results indicated that water level manipulations typically increase the mass of salt exported and that the change is typically related to the magnitude of the water level

variation. However, it is also apparent that the relative timing of bulk water level changes when compared to wind events can significantly influence that amount of net salt export

An initial assessment of the proposed management options indicated that:

- Provided future river flow is adequate, and that deliberate cycling of lake levels results in a similar future rate of salt export to that observed in 2011 and 2012, an additional 200,000 tonnes of salt could be exported by early 2015 resulting in a return to Lake Albert salinity levels of ~1800 µS/cm. However, it is recommended that numerical modelling be undertaken to better quantify the rate of salt export and salinity recovery over a broad range of environmental conditions.
- A channel connecting Lake Albert to the Coorong capable of transferring 30 GL/month is likely to be able to reduce salinity values within Lake Albert to below 1800 µS/cm within 6 to 12 months of operation. This option would also assist in the reduction of salinity in the Coorong and would be less dependent on reasonable Lock 1 flows to be effective.
- There has been only limited previous investigation into the benefit of dredging Narrung Narrows or Causeway removal. A scenario which widened the channel through the Narrung Bund indicated this would lead to a 10% increase in salt mass export for the conditions simulated. While dredging or causeway removal will slightly increase wind exchange efficiency, it is unable to generate any increase in net volume change though a small amount of net mass change is likely during wind events. Further numerical modelling of these options would help quantify the benefit of these potential management options. However, initial indications are that these options would provide relatively limited benefit.
- The installation of a permanent water level structure in Narrung Narrows to isolate Lake Albert during periods of high salinity in Lake Alexandrina is the least likely option to assist in the reduction of the currently high levels of salinity in Lake Albert.

The required features of a numerical model able to suitably assess these proposed management options have been presented in Section 5. A matrix of suggested scenarios to be able to develop an envelope of likely forecast salinity levels in Lake Albert has also been provided. A brief methodology of how to use a numerical model to assess the five management options has also been provided.

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APPENDIX A: DETAILS OF PREVIOUS INVESTIGATIONS

This report section contains relevant data from a number of previous studies that relate to the current investigation into salinity management options for Lake Albert.

A list of the studies reviewed includes:

- Ebsary (1983) Lake Albert Salinity Study
- WBM (2006) Lake Albert Connection Modelling Assessment
- Model Calibration and Validation Reports (BMT WBM, 2011b & 2012a)
- BMT WBM (2011d) Initial Salinity Reductions Model Investigations
- BMT WBM (2011f) Model Investigations and Scenario Runs
- BMT WBM (2012b) CLLMM Forecast Modelling – 12 Month Forecast Report
- BMT WBM (2012c) Modelling Of Lake Albert Flushing Scenarios
- Heneker (2010) Development of Flow Regimes to Manage Water Quality in the Lower Lakes

Relevant details of these investigations have already been summarised in Section 3. The below sections contain additional data as well as relevant report figures and table.

A.1 Lake Albert Salinity Study (Ebsary, 1983)

A Public Environmental Report (PER) for mitigation of salinity in Lake Albert was prepared by the Engineering and Water Supply Department in 1983 to investigate options for reducing salinity levels within Lake Albert. In January 1983 salinity levels in Lake Albert were above 2300 EC and were believed to be causing reduced productivity for the 40 irrigators who drew some 18 GL/year to irrigate 2200 ha for dairy and Lucerne production. The report examined two options to reduce salinity levels in the Lake including:

c) A channel connection between Lake Albert and the Coorong; and

d) Fluctuating lake levels to enhance salt transport through Narrung Narrows.

A further four options were briefly investigated but due to adverse cost/benefit ratios no detailed modelling was undertaken. These options included:

v) Dredging of Narrung Narrows to enhance wind driven exchange;

vi) A lock and barrage option across Narrung to isolate Lake Albert from poor water quality in Lake Alexandrina;

vii) A groyne through the centre of Lake Albert to enhance circulation; and

viii) A bund within Lake Albert to reduce evaporation.

Option (b), lake level fluctuation showed substantial benefit at very low cost and was selected as the preferred engineering option. The channel to the Coorong (option (a)) showed a considerable net benefit though at much greater cost.

The preferred engineering solution (lake level fluctuation) comprised:

a) For a month in which mean Lock 1 flow is greater than 15 GL/day, the level of the lakes would be lowered to EL 0.64 to produce flow out of Lake Albert. The lakes would then be filled to EL 0.84 with the better quality was passing down the river. After allowing the Lake Albert waters to mix, the level would be lowered to full supply level of EL 0.75 or El 0.64 if surplus flows were still available. Each such fluctuation would replace 36 GL of Lake Albert with less saline River Murray water, thus reducing the salinity of Lake Albert.

b) If it is known that a flood is advancing along the River Murray, the level of the lakes could be lowered below full supply level prior to the flood arrival without placing undue stress upon lake users. Lowering the Lake level by 0.25m to EL 0.5 would release 220 GL from the lakes system including 43GL from Lake Albert.

c) If no surplus flow is expected during the irrigation season, the level of the lakes should be raised to EL 0.84, if feasible, prior to the irrigation season to ensure lake levels are maintained as close to full supply level as possible during the irrigation season.

The report also acknowledges that improved irrigation practice could enhance crop yields.

A conclusion of the study is that if the system is managed to promote a flow of water out of Lake Albert, salinities in the Lake will be reduced by an average of at least 430 EC.

Another conclusion is that a Coorong connector channel would be the most efficient option in terms of salinity reduction however, would cost in excess of $10 million while the benefits would be $6.4 million.

The report also believes groundwater inflow is a contributing factor to lake salinity. However intercepting groundwater flows would only partially solve salinity issues but would not be cost effective due to the length of the shoreline.

The report also details:

- Groundwater salinity around the lake of 10000 to 20000 EC. Salt pans along the Narrung Peninsula may be > 40000 EC.
- Salinity around the shoreline for 30/11/1982 and 2/3/1983 (i.e. start and end of irrigation season).
- Salinity survey through the lake for 20/1/1983.
- Diversion from Lake for 1975 – 1982. Min 15.7 GL/year to Max 22 GL/year. Total available is 33 GL/year.
- Weekly recording of salinity at Meningie (Lake Albert) commenced in late 1969 and at Milang (Lake Alexandrina) since 1968.

The report includes modelling results of monthly Meningie salinities from 1896-1972 (Close and Bradshaw, 1983). Actual salinities have been considerably lower than predicted by the model (i.e. indicates the model isn't that good (but were at least conservative)).

Report includes several agricultural considerations to improving crop yields.

Cost / benefit ratio is based on a potential average annual Lucerne yield of 10t/ha/year. Using a crop yield salinity reduction curve a yield increase of delta EC/1000 x 11/100 x 10t/ha/annum results.

Channel Connecting Lake Albert to the Coorong:

Channel is 1.6km long. Channel capacities of 0 – 150 GL//month were assessed a chart showing the expected reduction in mean lake albert salinity shows a 30GL/month option would reduce salinity by 800 EC. There is diminishing benefit above this rate.

A.2 Lake Albert Connection Modelling Assessment (WBM, 2006)

A.2.1 Introduction

This report was commissioned by the SA Department of Water, Land and Biodiversity Conservation to assess the potential improvement to salinity levels in Lake Albert if a connection between Lake Albert and the Coorong was established.

Detailed modelling was undertaken to investigate the effects of incorporating a barrage controlled connection from Lake Albert to the Coorong. Short term (6 week) and long term (5 year) model tests have been undertaken using both the WBM (RMA finite element) and Cardno Lawson Treloar (CLT) (Delft3D curvilinear finite difference) models. These models were developed to simulate the hydrodynamics of the Coorong and morphological processes at the mouth, and have been extended to include the entire lakes system. In addition to the 2D hydrodynamic models, CLT set up a simplified 'box' model of the lakes to assist in fast analysis of the key factors affecting salinity upstream of the barrages. The report sets out the results of two short and two long scenarios, assessed in terms of comparison between base case (no connection) and connected cases in each scenario.

A.2.2 Description of Lake Albert Connection & Barrage

The Lake Albert connection consisted of a channel and barrage of 50m width (at base) and base level of –1m (AHD), with side slopes at 1:3. The barrage was assumed to be located at the northern end of the channel and would be of a type directly equivalent to the Tauwitchere barrage. It is expected that this barrage will have a total capacity of about 3500Ml/day.

Actual barrage flow through the Lake Albert connection would depend on water levels in Lake Albert and the Coorong at any time. The modelling has incorporated the effect of high water levels in the Coorong, resulting from either the barrage releases or ocean water level and wave influences, on the flow rate through the Lake Albert connection.

A.2.3 Short Term Scenarios

Short term (six week) scenarios investigated the influence of the Coorong Connector for a 2000 and 75000 ML/day barrage release six week event. The results show the positive influence of the connector on Lake Albert and Coorong salinities. Due to the short term nature of the simulations only limited conclusions can be drawn from the results.

A.2.4 Details of Long 5yr Scenario

- Each run extends for 5 years.
- These runs use a synthesized suite of boundary data as described below, with river inflows data (including EC) based on those recorded during 1993 to 1998.
- Tidal water levels are based on observed Victor Harbour data for the years 2000 to 2002.
- Winds and Waves are based on a BMO global model for the period July 2000 to July 2005.

- Evaporation is described as being: “Net evaporation (evaporation minus rainfall) for this scenario was adopted as monthly mean values as derived from available data at the time” . The use of a pan evaporation co-efficient is not clearly mentioned.
- Initial Salinity: The adopted Lake Albert initial salinity distribution is based on reported data with values ranging from about 1600EC (0.66 ppt) near the connection to Lake Alexandrina, up to nearly 3000EC (1.35 ppt) in the southern parts. The initial salinity of Lake Alexandrina is adopted as 1500EC (0.65 ppt) in all locations.

Barrage operating procedures included:

- Discharge begins when lakes are at 0.75m AHD or above.
- First 25GL to be discharged from Goolwa.
- Goolwa then closed and the Lake Albert Channel opened.
- When Lake Albert channel reaches capacity, other barrages are opened, beginning with Tauwitchere using gates at the Pelican point end of Tauwitchere until the Tauwitchere discharge reaches 5GL per day.
- Above 5GL per day flows through Tauwitchere, releases are evenly balanced between Tauwitchere and Goolwa – to the extent that equal gate capacities will be provided for in the model. Note that this may not lead to strictly equal flows due to variations in lake levels, as occurs in practice.

Two equivalent runs have been undertaken using each model, being a base case (no Lake Albert channel) and then a scenario with the Lake Albert channel option operational.

The barrage operations accorded with the above rules as far as is practicable within the constraints of the modelling procedure, ensuring that the lake level does not fall below RL 0.75m at its upstream end.

Many unforeseen issues arose in both models during the simulations, relating to:

- operation of the models in a manner that attempts to anticipate the various responses of water level, flows and mouth behaviour, and
- substantial cumulative morphological changes at and outside the river mouth that progressively became unrealistic and created instabilities in the model.

These resulted in delays in completing the model tests and the need to undertake the simulations as a series of discrete annual tests, with ‘hot restart’ linkage to ensure compatibility from one year to the next.

A.2.5 Box Model Development and Calibration

As a consequence of the issues arising in the primary models and resulting delays, Cardno Lawson Treloar (CLT) established a simplified ‘box’ model of the lakes system. This is described in Appendix C of WBM (2006) and is based on approximation of the lakes as simple averaged entities with the processes of water levels, flows, mixing and salinity responses determined by relationships derived from conventional physics or empirical factors derived from the Delft3D model.

The model simulates the different water and salt mass fluxes into, out of, and between the lakes. It basically keeps track of the total salt mass and water volume in both lakes through mass balance equations, as well as the water levels in both lakes. It could be used to quickly assess several scenarios of evaporation rates, river flow, salinity exchange between the lakes and discharges through the proposed Lake Albert Channel and the existing barrages in a simplified manner.

Development of this model was prompted by the benefit seen in having a faster investigative tool that can assess a range of factors to provide a preliminary indication of responses and to inform the more comprehensive models. As such, the box model may be run over the 5 year period in seconds. However, due to a number of limitations the results from the model must be treated as indicative only.

Calibration

The Lake Albert salinities as calculated in the box model have been calibrated against the limited data available for the period 1993 to 1998, including river flows and salinities and a time series of lake salinity at Meningie. Coefficients for mixing between the two lakes and for evaporation rates (relative to the longer term mean) were used for the calibration. Base case results for the optimum settings are shown in Figure A-1.

Also shown in Figure A-1 are the base case results from the RMA model for comparative purposes. It must be noted that the start salinity distribution for the RMA (and Delft3D) model were not that as measured at Meningie in July 1993, nor was the evaporation data used in the simulation the actual values for the period, and direct comparison is not feasible. Nevertheless, once the initial period of salinity reduction has occurred, the RMA model shows a similar trend to that of both the recorded salinity data and the optimised box model, indicating that both behaved reasonably.

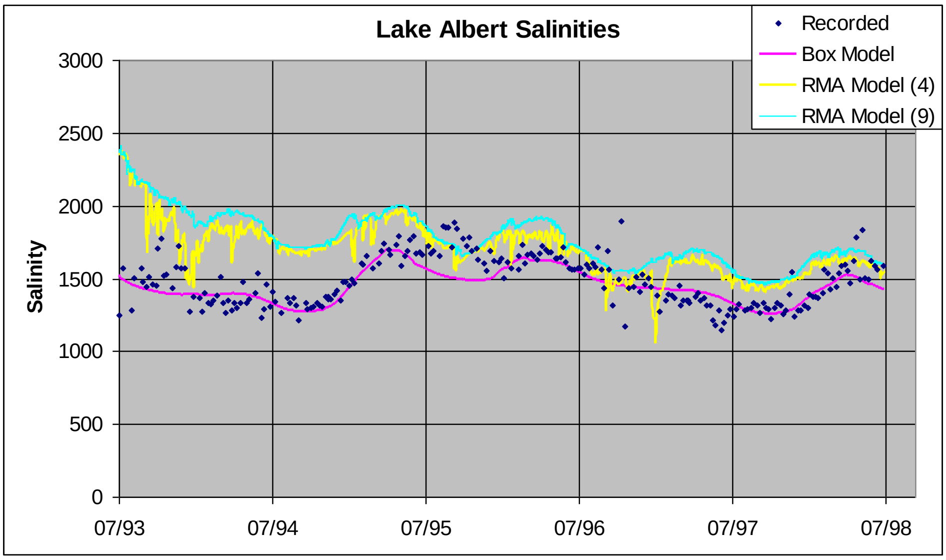

Figure A-1 Optimised Box Model & RMA Model Calibration Results (for 1993 – 1998)

A.2.6 Results of Long 5yr Scenario Simulations

Lake Alexandrina Salinities

The salinity in Lake Alexandrina responds quite directly to that of the inflowing river flow. During low flow periods, the salinity increases due to evaporation. These salinities are thence the controlling values for input to Lake Albert and to the Coorong. The modelled salinities at representative locations 11 (approx. West Pomanda Point) and 18 (approx. West Clayton) are shown in Figure A-2 for both the base and developed cases, showing minimal effect of the Lake Albert connection, as expected.

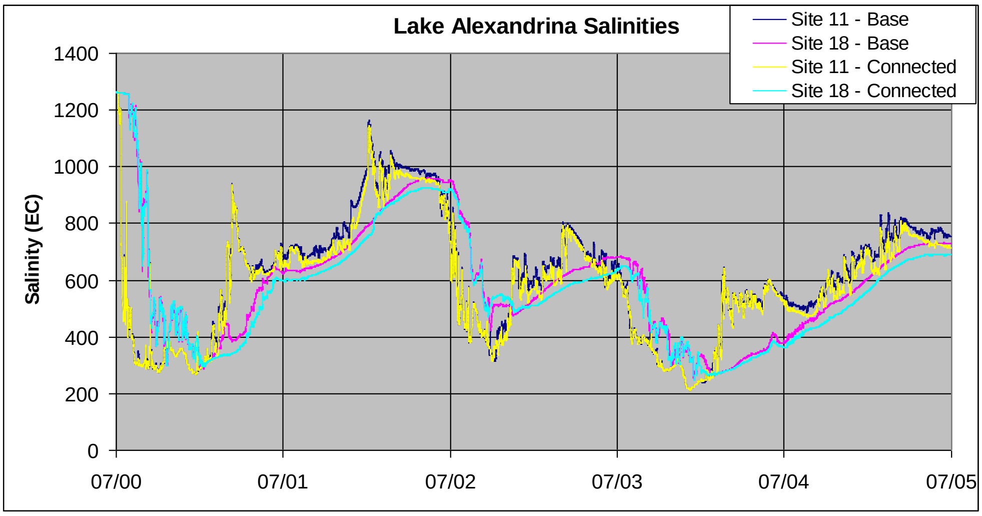

Figure A-2 Salinities in Lake Alexandrina – RMA Model

Lake Albert Salinities

As shown in Figure A-3 and Figure A-4, the RMA and CLT box models show a very similar pattern of marked reduction of salinity in Lake Albert as a result of the connection, when compared with the base condition.

All models indicate a substantial reduction in salinity during the first half-year for the connected option, because of the significant amount of flow from Lake Alexandrina through Lake Albert, despite any blocking effect of elevated Coorong water levels that occurred. There was no significant recovery from that reduction over the subsequent duration of the model run, indicating a permanent benefit.

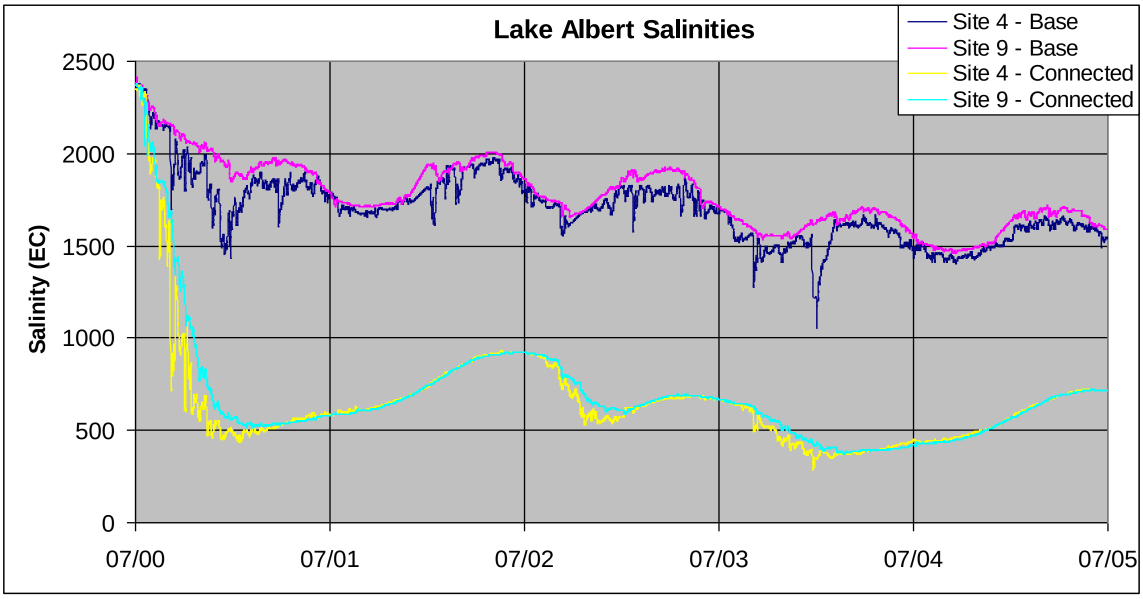

Figure A-3 Salinity in Lake Albert – RMA Model

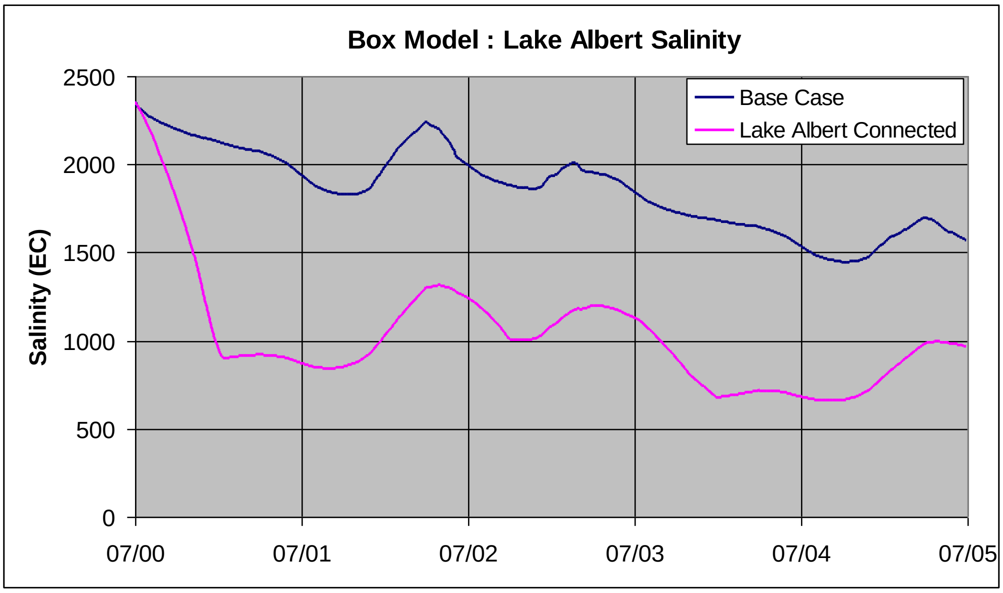

Figure A-4 Salinity in Lake Albert – CLT Box Model with Optimised Parameters

Coorong Salinities

The model results show that a connection between Lake Albert and the Coorong could significantly reduce salinity levels in both the North and South Lagoons. However, the results indicate that the applied evaporation rate is too high. A finding of BMT WBM (2012b) was that a single estimate of evaporation across both the Lower Lakes and the Coorong ignores the increased rainfall that typically occurs of the Coorong South Lagoon.

A.2.7 Discussion of Relevant Findings

The model study indicates that a channel connecting Lake Albert to the Coorong could significantly help reduce salinity levels in both Lake Albert and the Coorong. The study was limited to simulating a five year period (1993-1998) in which lake inflows were fairly high. The study highlighted a number of modelling issues including a need for more refinement of morphological processes and also determining an appropriate spatial resolution of evaporation of the Lower Lakes and Coorong. The development of a calibrated box model capable of rapidly simulating salinity in the Lower Lakes indicates that this may be a useful tool to consider in future investigations.

A.3 Model Calibration and Validation Reports (BMT WBM, 2011b & 2012a)

A.3.1 Introduction

BMT WBM was commissioned by the SA Department of Environment and Natural Resources (DENR) to undertake a range of studies aimed at improving the understanding of key environmental hydraulic processes in the Coorong, Lower Lakes and Murray Mouth (CLLMM) system. The investigation included the development and calibration of a numerical model capable of simulation hydrodynamic, salinity and morphological processes within the CLLMM system. The model also needed to calculate the dynamic discharge across the barrages separating the Lower Lakes from the Coorong.

A.3.2 Model Description

The model comprises a combination of hydrodynamics (TUFLOW-FV), waves (SWAN) and morphology (TUFLOW-MORPH). The geometric flexible mesh used by TUFLOW-FV to describe the model area covers the Lower Lakes (Lake Alexandrina and Lake Albert), the Coorong, the Murray Mouth and adjacent coast. The mesh, which has been developed and applied to many projects during the past few years, is presented in Figure 3-1. The barrages at Goolwa, Mundoo, Ewe Island and Tauwitchere have been represented within the TUFLOW-FV model using a special structure element that defines the relationship between flow and a given upstream and downstream water level.

A more detailed description of the hydrodynamic (TUFLOW-FV), wave (SWAN) morphology (TUFLOW-MORPH) model, and structure representation is given in BMT WBM (2011b).

Boundary condition data used for the model calibration included:

- Lock 1 inflows (observed Lock 1 inflows applied at Wellington);
- Direct net rainfall – evaporation (BoM Gridded SILO data – Morten's estimate of shallow lake evaporation);
- Offshore water levels (Victor Harbour tides);
- Wind speed and direction (from Pelican Point AWS);
- Barrage operations/openings (as recorded by SA Water);
- Offshore wave data (as calculated by ARGOSS global wave model);
- Local catchment inflows (recorded by DfW).

BMT WBM (2011b) describes the model calibration for the approximate five months period 25/11/2010 to 1/5/2011, while BMT WBM (2012a) describes further model validation for 6 month period from the 1/5/2011 to the 31/10/2011.

A.3.3 Available Data

In addition to the boundary condition data (see above) a range of other data sets were used for model setup and calibration. These data sets included:

- Good Lake and Coorong bathymetry data;

- Regular (every 1 – 2 month) Murray Mouth bathymetry survey;
- Salinity transect data of the Lower Lakes and Coorong; and
- An excellent network of WL and EC gauges across the Lower Lakes and Coorong (see Figure 2-1).

A.3.4 Model Calibration

The study shows that an excellent model calibration was achieved with the model being able to closely replicate observed WL's and salinities in both the Lower Lakes and the Coorong of the five month period presented in BMT WBM (2011a) and the six month period presented in BMT WBM (2012a).

While the calibration and validation showed a close match between observed and modelled water levels and salinities no salinity transect data for Lake Albert was made available during the study.

A.3.5 Calculation of Barrage Discharge and Salt Mass Flux

Barrage Discharge

Development of the numerical model has allowed for the calculation of actual barrage discharge to occur. The output from the model is significantly more accurate than the current estimates of barrage discharge (i.e. 200-400 ML/day/gate) and do not account for tidal influence, or a range of other factors. Figure A-5 presents the modeled barrage discharge and the operator estimate of total barrage and shows that there are often significant differences between the predicted discharge and the actual discharge.

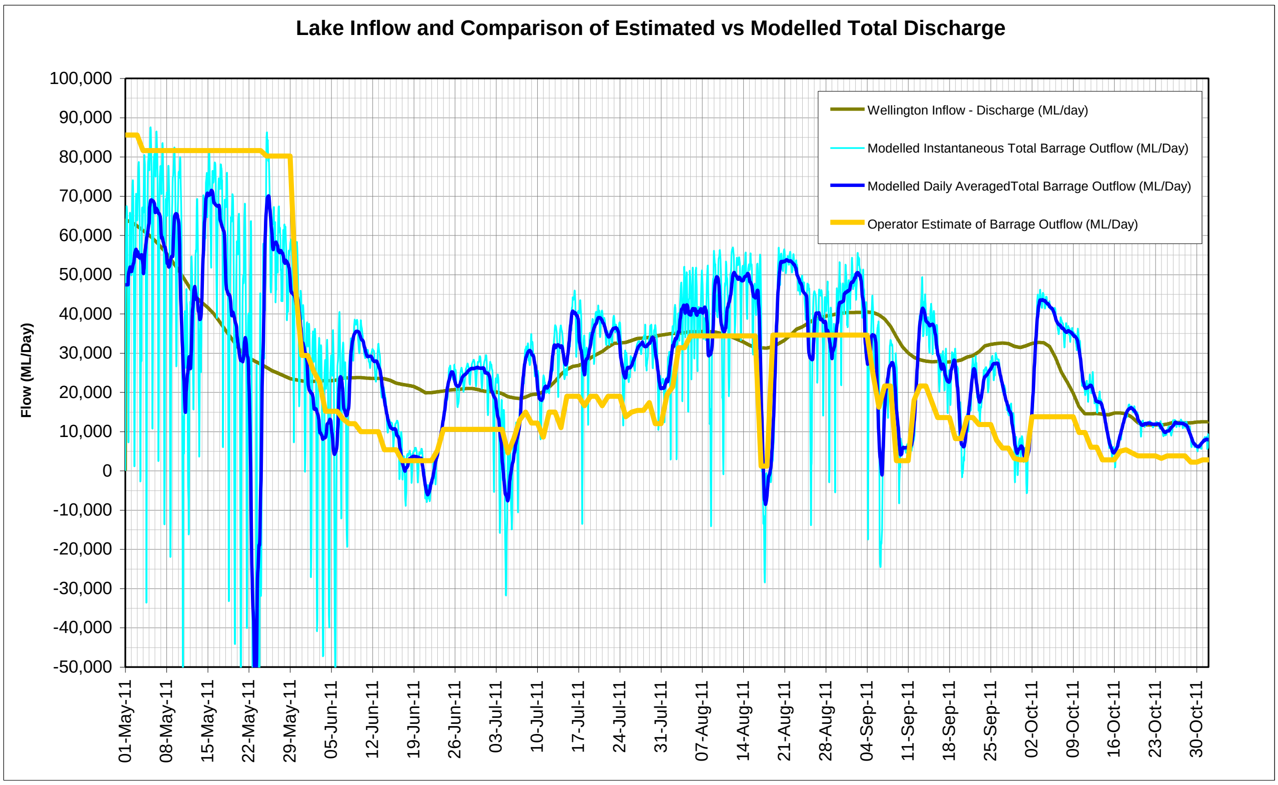

Figure A-5 Comparison of Modelled and Estimated Total Barrage Discharge

Salt Mass Flux

Interrogation of the model output has also allowed the calculation of salt mass flux between the Lakes to occur and for a calculation in salt mass of the various water bodies covered by the model.

A time-series of salt mass change in Lake Albert is presented in Figure A-6. From the graph it appears that falls in water levels result in significant quantities of salt being exported from Lake Albert, while there is a much smaller positive mass flux when water levels rise. This is because the concentration of salt is much lower in Lake Alexandrina (~0.2 ppt) then in Lake Albert (~4-5 ppt) and there are sufficient currents to move salt water away from Narrung before it moves back into Lake Alexandrina. This flushing means that even though the evaporative demand resulted in ~28.1 GL of net flow into Lake Albert (see Figure A-6), ~266,000 tonnes of salt moved from Lake Albert into Lake Alexandrina between 1/5/2011 and 1/11/2011, resulting in a drop in salinity of ~1500 µS/cm (from ~6,500 to ~5,000 µS/cm). Table A-1 shows that this is approximately a 25% reduction of salt mass from Lake Albert over the validation period.

Table A-1 Summary of Total Salt Mass Change

Area	Salt Mass (tonnes) 1 May 2011	Salt Mass (tonnes) 1 Nov 2011	Change (tonnes)	% Change
Lake Alexandrina	331,489	295,881	-35,608	-10.7
Lake Albert	1,044,169	777,415	-266,754	-25.5

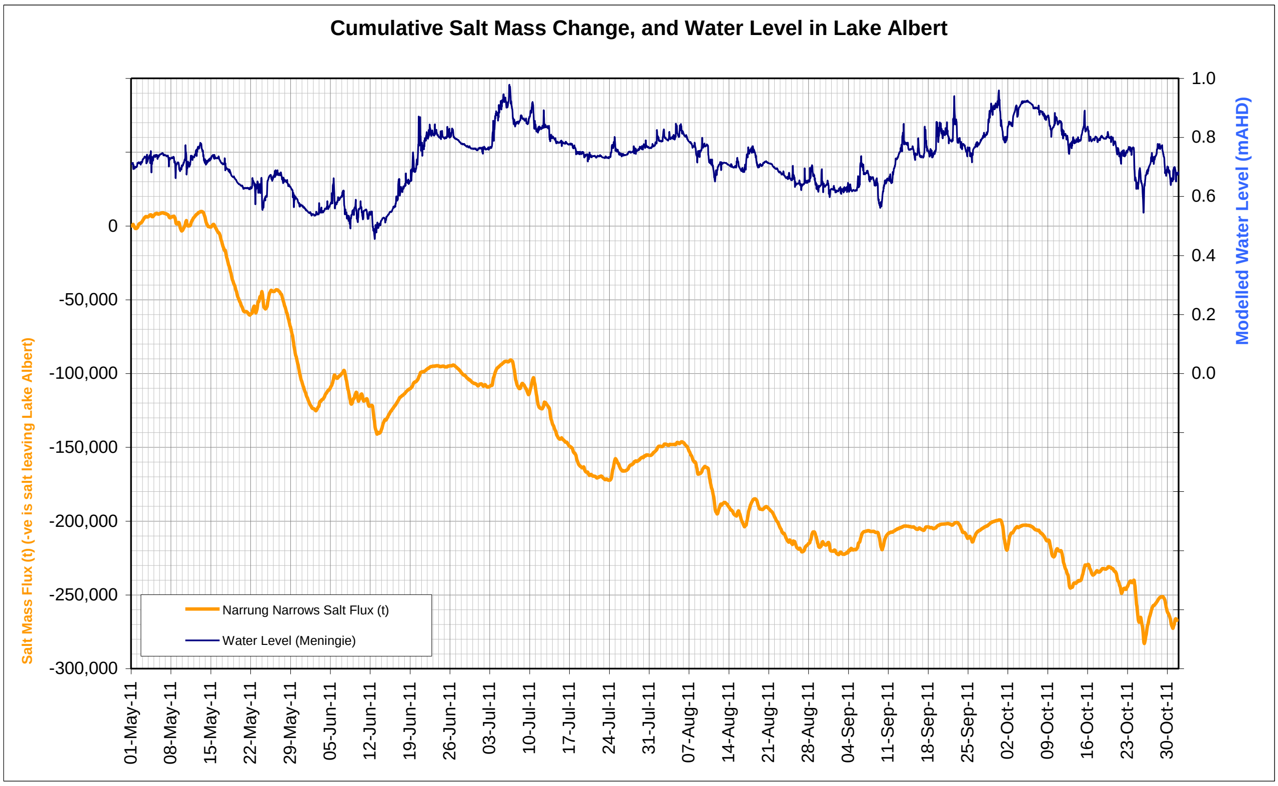

Figure A-6 Modelled Salt Mass Change in Lake Albert

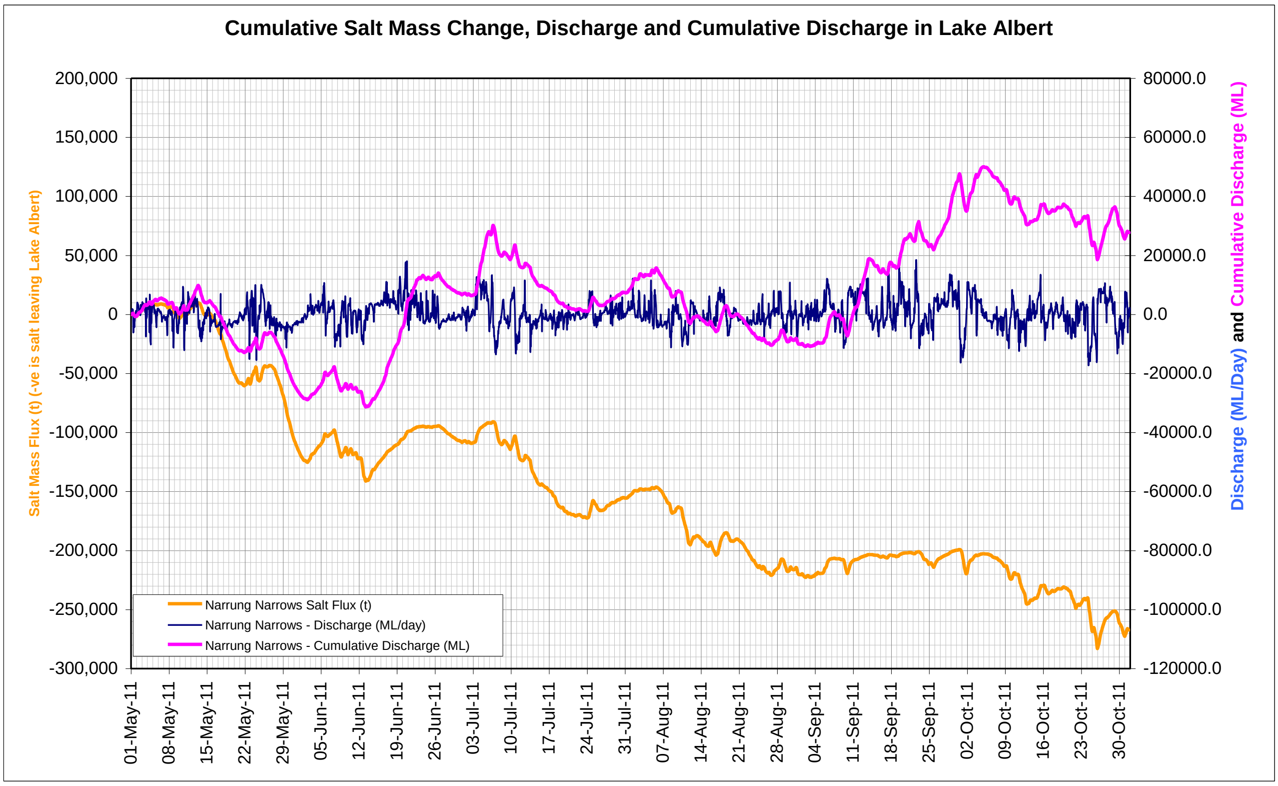

Figure A-7 Modelled Salt Mass Change, Discharge and Volume Change in Lake Albert

A.3.6 Discussion of Relevant Findings

The calibration and validation reports contain a number of relevant finding including:

- SA Water only records number of barrage openings and not he individual sill levels at Goolwa Barrage.
- Understanding the accuracy of WL and EC data sets. A number of the gauges appear to have incorrect datums or suffer from datum drift.
- Model was well calibrated for WL and EC for a five month period of high Lake inflow (40 – 80 GL/day) and a six month period of moderate Lake inflow (typically 10 to 40 GL/day).

The model predicts a 25% reduction in salt mass in Lake Albert over the six month period 1/5/2011 to 1/11/2011, whereas an examination of salinity transect data and associated salt mass calculations (see Section 2.4) indicate that salt mass in Lake Albert did not fall to this level for a further 2 to 6 weeks. This indicates that extended model calibration using the latest data (including salinity transect data) is warranted.

Despite the above possible discrepancy between observed and modeled data salt mass data, the models ability to reproduce observed water level and salinity data throughout the Lower Lakes and Coorong means that a good degree of certainty can be associated with model scenario predictions.

While a good model calibration and validation was achieved, it is important to understand the limitations of the existing model as well as potential improvements that would be possible through further model development and calibration/validation. These include:

- More frequent collection of salinity transects along the Coorong and Lake Albert to provide better estimates of initial conditions for salinity.
- Ongoing calibration and verification (especially at lower flows and after the removal of Clayton Regulator).
- Inclusion of River between Lock 1 and Wellington (especially at lower flows).
- Inclusion of abstractions (SA Water and Irrigation) (especially at lower flows).
- Better estimates of catchment inflow for lower flows (and winter simulations).
- Use of multiple (spatially varying) net rainfall - evaporation estimates (i.e. given the large extent of the study area, it is likely that there is a difference between the estimates for net evaporation between the Lower Lakes and the Coorong).
- An update to the model code to reduce the rate of evaporation at high salinity. This would allow the model to more closely predict salinity changes in the southern lagoon, where surface evaporation is reduced during periods of very high salt concentration.
- Ability to model variable barrage sill levels. This is required to be able to better represent Goolwa Barrage, where the removal of individual stop logs defines the structure sill level. This would also require the collection/reporting of suitable barrage data information.
- Ability to swap between structure (barrage) discharge calculations and free surface flow conditions at structures. This is required when Goolwa and Mundoo Barrages are fully open and the use of a broad crested weir approximation for structure discharge results in greater than observed afflux due to a loss of flow momentum.
- Increased model resolution in the Murray Mouth to better predict morphological change.
- Use of 3D code to better predict salt spikes in the Coorong and also morphological change.

It is important to note that ongoing management of the system requires that the model be updated to reflect a number of changes including:

- Update bathymetry near Clayton (complete removal by February, 2012) and Currency (complete removal by March 2013) regulators to reflect changes in these areas.
- Update bathymetry in Goolwa, Mundoo and Tauwitchere Channels to reflect potential morphological changes during the recent periods of high system flows.
- A number of the above would require the collection of up-to-date bathymetry survey data.
- The collection of sediment data within the Murray Mouth (particularly the flood tide delta) would also be beneficial to future model calibration/validation exercises. In addition to this bathymetric survey data offshore of the Murray Mouth and in the nearshore zone along Encounter Bay would be useful.

A.3.7 Conclusions

A numerical model of the Lower Lakes, Coorong and Murray Mouth was developed and calibrated for the period 25th November 2010 to 1st May 2011 (BMT WBM, 2011b). An additional model validation study, covering the six months from 1st May to 1st November, 2011 is presented in (BMT WBM, 2012a). A good level of model validation (including comparison to water levels, salinity and morphology) has been achieved over this period. A lack of spatially varying initial salinity data and the failure of the Victor Harbour tide gauge towards the end of the simulation period have contributed to differences between observed and modelled water levels and salinities. Model accuracy could also be improved with an upgrade of the code to allow variable sill geometry at the barrages, though this would also require the collection of actual sill level data at Goolwa Barrage. A update to the code to allow the use of spatially varying net rainfall/evaporation as well as the ability to automatically reduce evaporation at high salinity should also be considered.

The model's ability to reasonably replicate observed water levels and salinities during this period, give confidence in its ability to predict future changes to water level and salinity for predicted future conditions (provided they are not too different to those of the validation or calibration period).

The model can be confidently applied to evaluate a range of management options (i.e. water level manipulation targets) aimed at reducing salinity within Lake Albert and the Coorong as well as predicting future conditions based on a reasonable estimate of future inflows and an appropriate set of climatic conditions.

A.4 Initial Salinity Reductions Model Investigations (BMT WBM, 2011d)

A.4.1 Introduction

BMT WBM was commissioned by the SA Department of Environment and Natural Resources (DENR) to undertake a range of studies aimed at improving the understanding of key environmental hydraulic processes in the Coorong, Lower Lakes and Murray Mouth (CLLMM) system.

These initial salinity reduction scenarios investigated the effectiveness of five proposed water level management regimes and the influence of three different wind conditions on salinity dynamics in the Coorong and Lower Lakes.

A.4.2 Model Description (including Automated Barrages)

The model used to simulate the salinity reduction scenarios is detailed in BMT WBM (2011b) and adopted the automated barrage logic described in BMT WBM (2011e). The use of automated barrage logic (a new feature in TUFLOW-FV) and a time-series of target lake water levels allows for more realistic scenario simulations to be modelled. Without the ability to use automated barrage operation logic, a pre-defined sequence of gate openings would have to be developed for each model scenario. This would be very difficult as barrage discharge is heavily influenced by actual winds, lake levels and tide conditions. Barrage openings are typically altered on a daily-weekly basis, using lake inflow and water level data for the preceding 3 and 7 days. This means that predicting a gate opening sequence to maintain a target management lake water level would be extremely difficult and would likely to have required significant model iteration, before an appropriate boundary condition was achieved.

It should be noted that further refinement of the automated barrage opening parameters were completed after the completion of BMT WBM (2011d) allowing for smoother barrage operation and reduced high frequency water level variation.

A.4.3 Description of Scenario Simulations

A number of scenario simulations were formulated in conjunction with DENR. These included a range of scenarios investigating the use of different Lake Alexandrina water level targets that could enhance the removal of salt from Lake Albert to reduce salinity levels back towards pre-drought ranges. Both the magnitude and frequency/duration of water level changes were investigated. A number of simulations which investigated the influence on wind mixing were also developed. The aim of these simulations was to gain an understanding of the role wind mixing and transport plays in salt dynamics within the CLLMM system.

The five scenarios which considered the influence of adopting five separate water level management regimes included:

Run A - Base case (maintain WL at 0.75mAHD)

Run B - 1 large (0.2 m) water level variation

Run C - 2 small (0.1 m) water level variations

Run D - 1 small (0.1 m) water level variation

Run E - 2 large (0.2 m) water level variations

The three scenarios which considered the influence of three different wind conditions (while maintaining a lake level of 0.75 m AHD) included:

- **2011 Winds**
- **No Wind**
- **2008 Wind**

Boundary conditions include: observed 2011 tides, observed 2011 winds (apart from two of the wind scenarios), typical (1996) monthly average net evaporation, 2008 waves, automated barrage operations and a target lake water level (five different scenario conditions), 1996 catchment inflows, 10 GL/year Salt Creek (Morella) inflows, observed Lock 1 river inflows.

All simulations were of 3 month duration from 1st May to 1st August, 2011.

A.4.4 Results of Scenario Simulations

Results of the scenario simulations are presented in the following five figures.

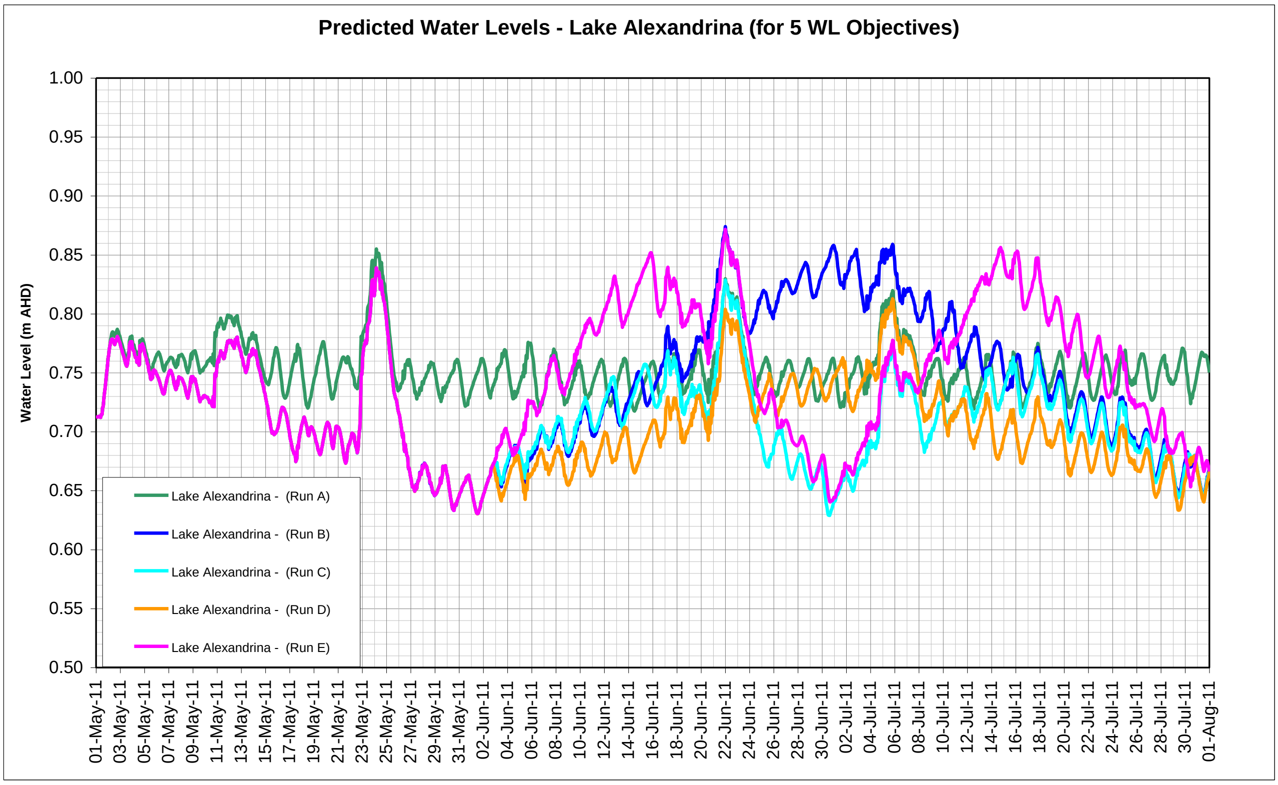

Figure A-8 Predicted Water Levels in Lake Alexandrina for 5 WL Objectives

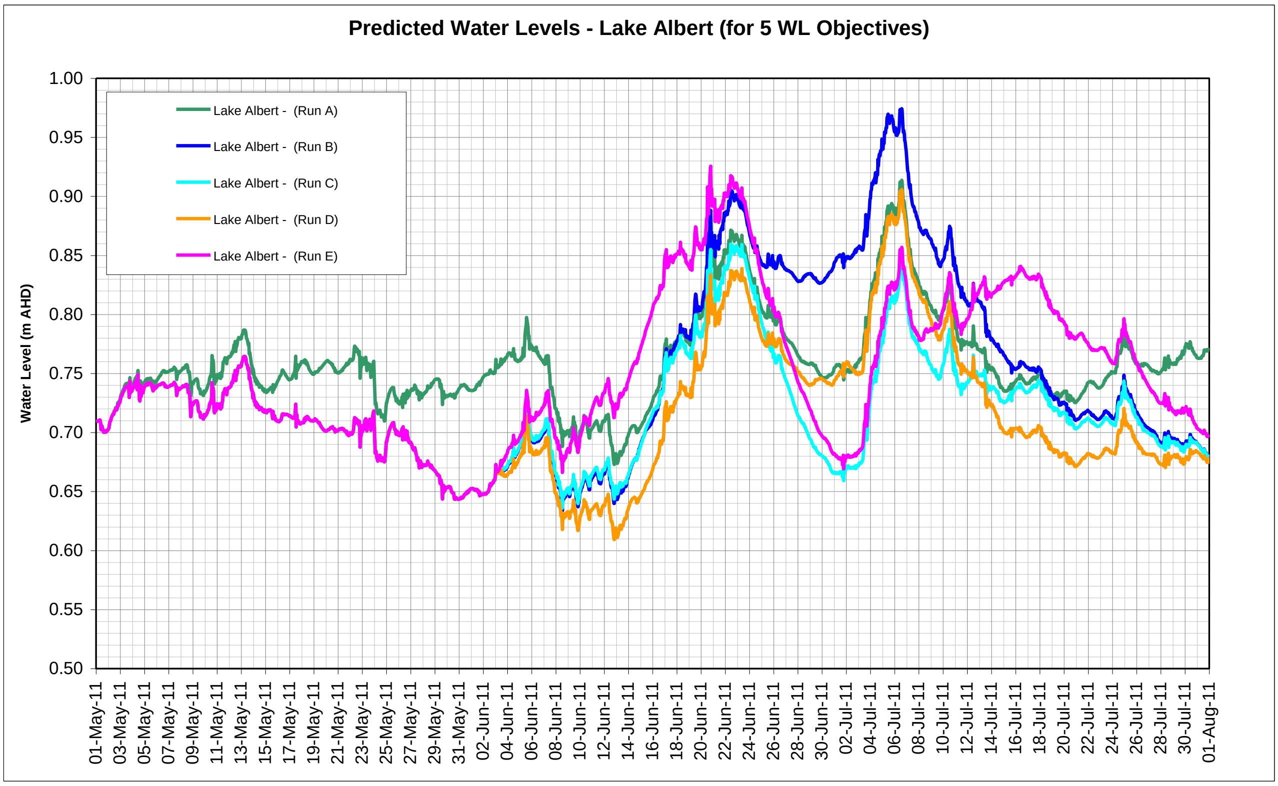

Figure A-9 Predicted Water Levels in Lake Albert for 5 WL Objectives

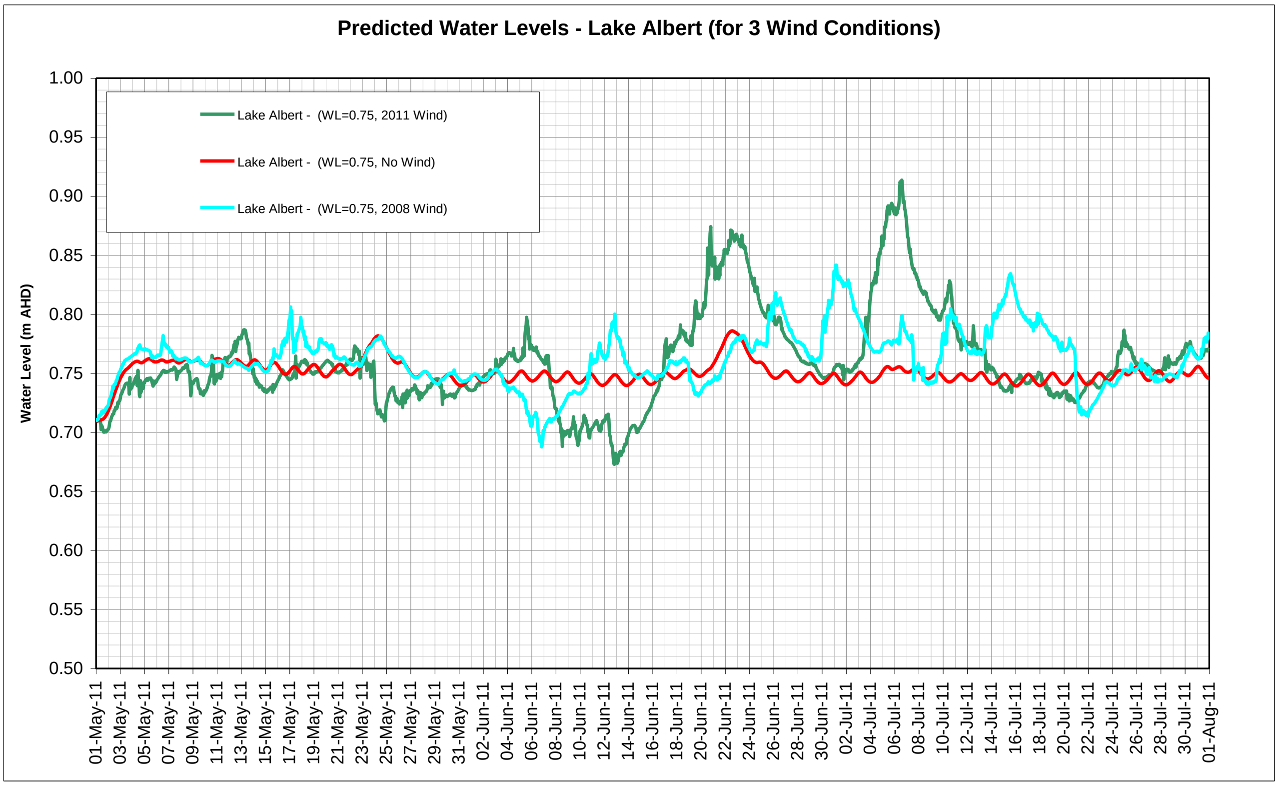

Figure A-10 Predicted Water Levels in Lake Albert for 3 Wind Conditions

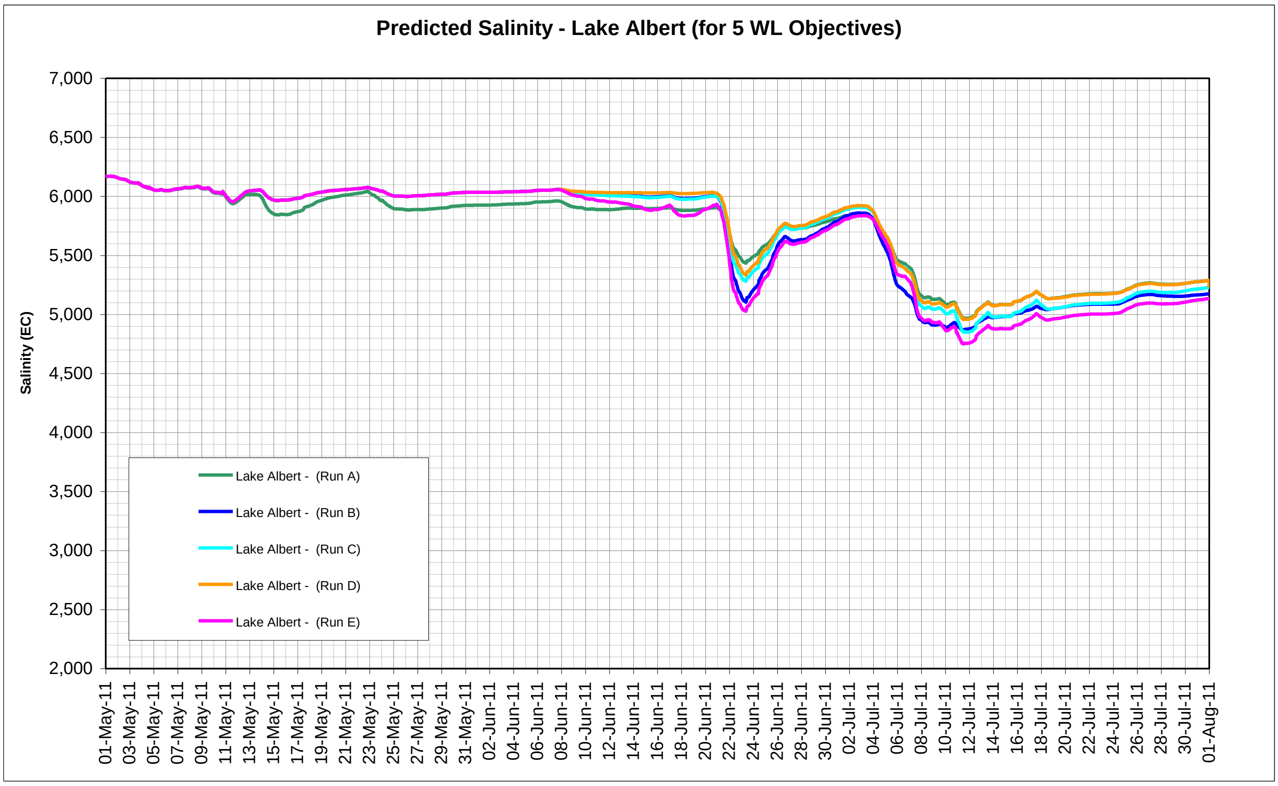

Figure A-11 Predicted Salinity in Lake Albert for 5 WL Objectives

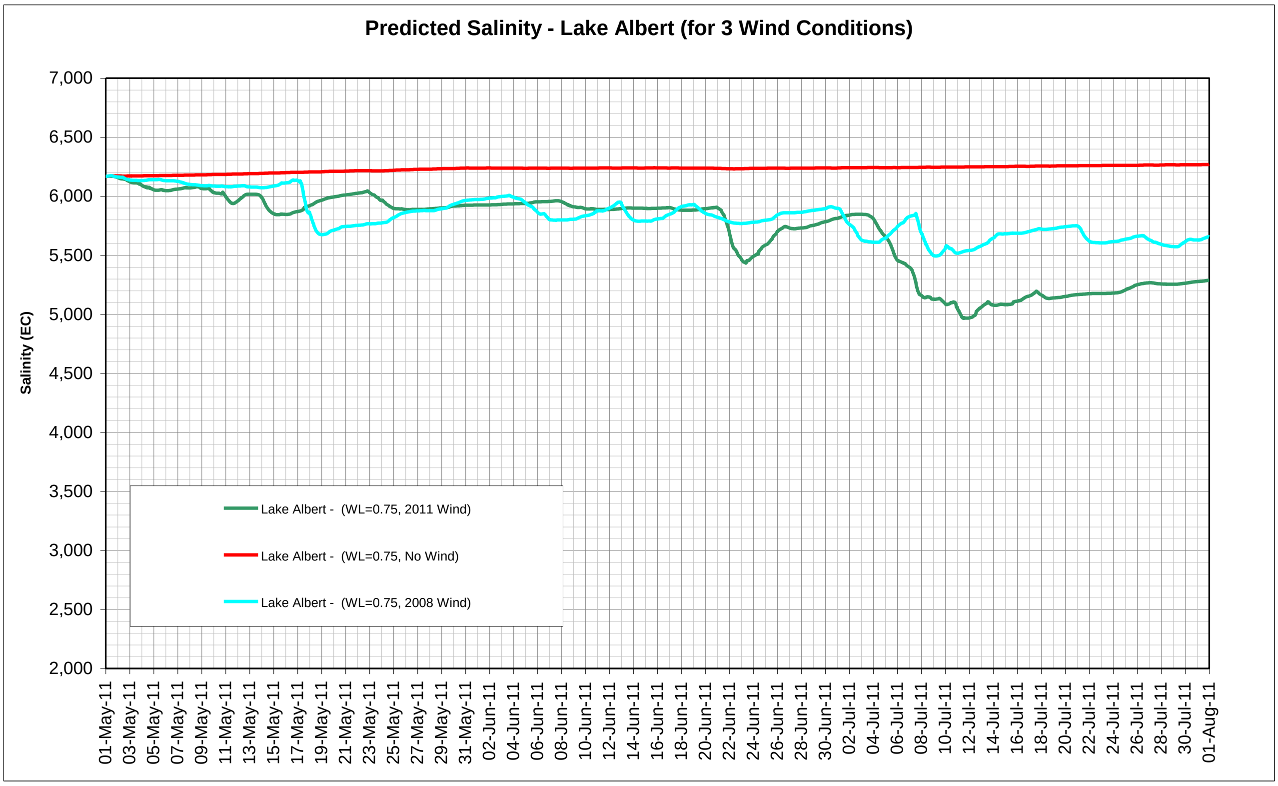

Figure A-12 Predicted Salinity in Lake Albert for 3 Wind Conditions

A.4.5 Salt Mass Change (Flux) Results

Lake Albert

Changes to the mass of salt residing in Lake Albert are presented in Figure A-13 and Figure A-14. At the start of the simulation on the 1st May 2011 the total salt mass content of Lake Albert is some 949,200 tonnes. Model results predict that if Lake Alexandrina is maintained at an approximately constant 0.75 m AHD, wind mixing using observed 2011 conditions would remove some 80,000 tonnes of salt during the three month simulation period. This equates to a reduction in salt mass of 8.6%. For similar lake management conditions but with winds observed in 2008 only approximately 40,000 tonnes (4.4%) of salt would be removed. If the Lower Lakes were maintained at a near constant level and there was no wind mixing, then no salt would be exported from Lake Albert.

Table A-2 Summary of Salt Mass Percentage Change - 1st August

Location	Run A / 2011 Wind	Run B	Run C	Run D	Run E	No Wind	2008 Wind
Lake Albert	-8.6	-14.8	-14.1	-13.4	-15.5	0.9	-4.4

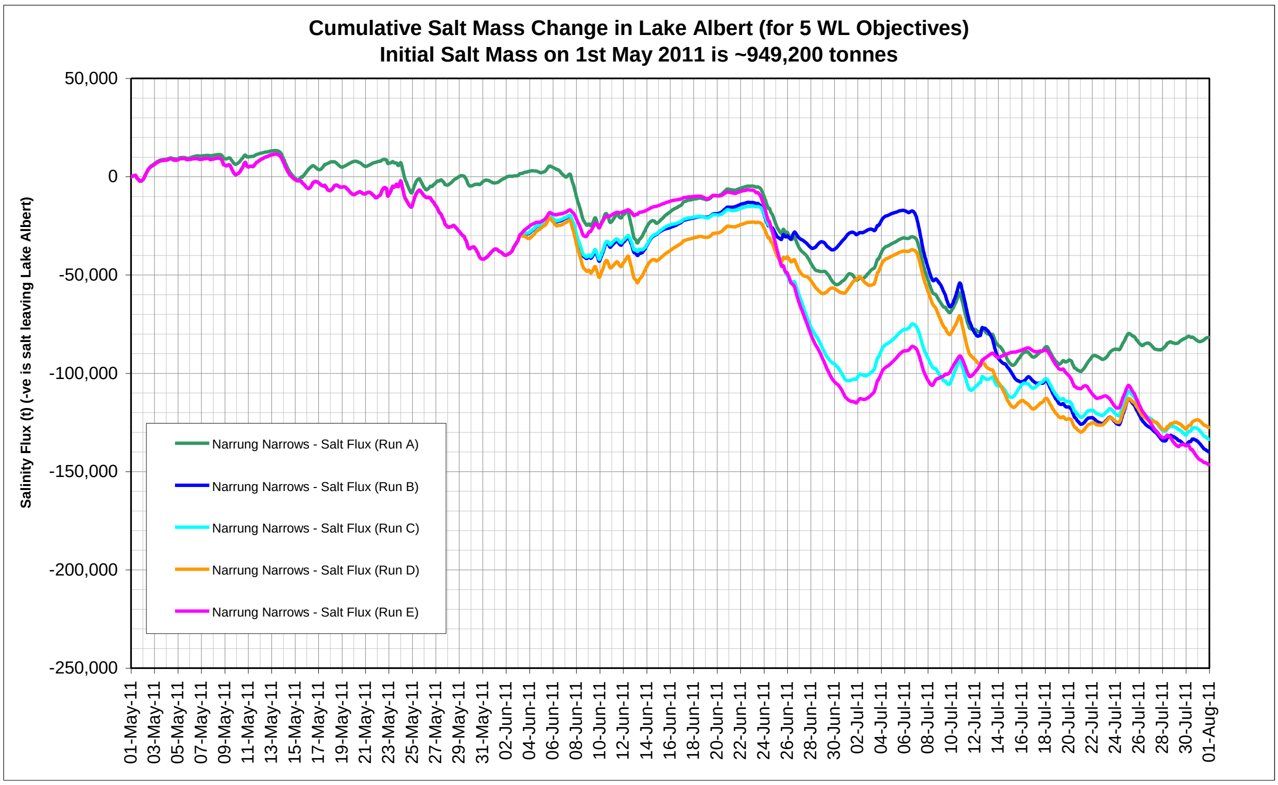

Figure A-13 Changes in Lake Albert Salt Mass for Five Water Level Management Scenarios

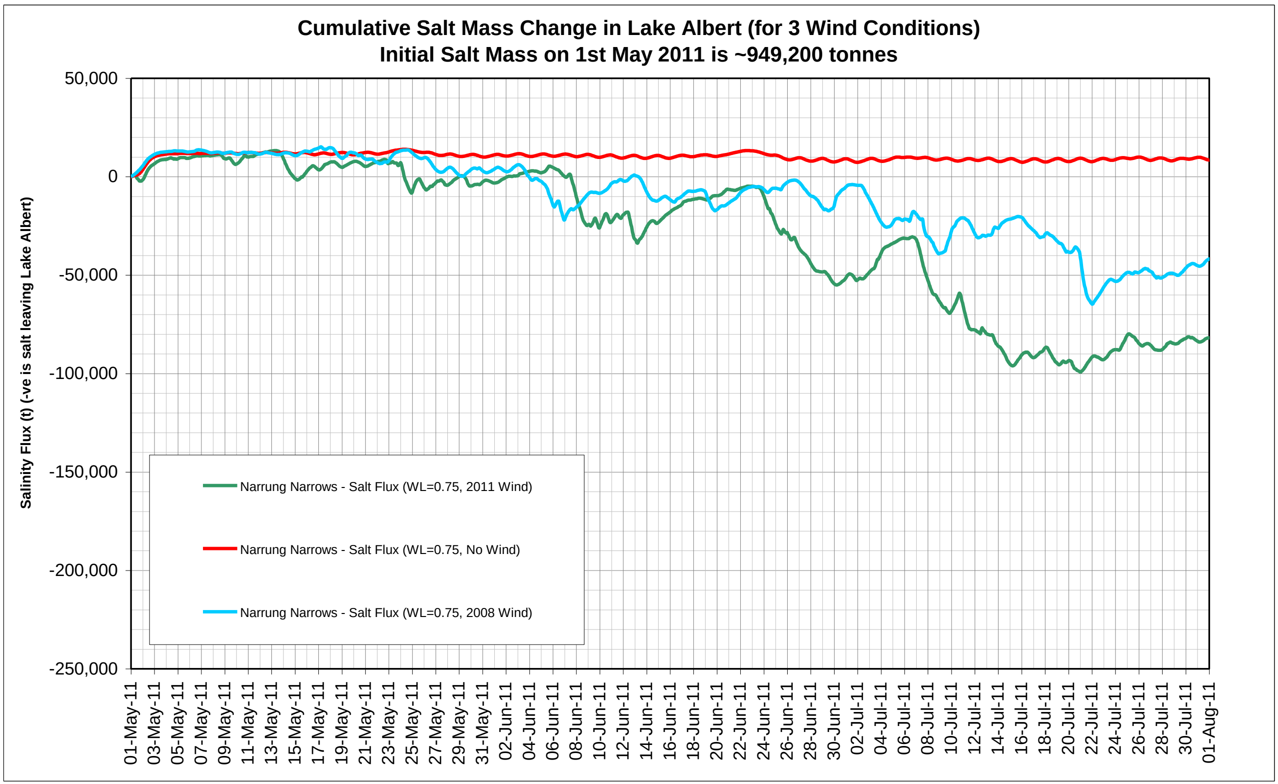

Figure A-14 Changes in Lake Albert Salt Mass for Three Wind Conditions

A.4.6 Conclusions

Seven scenario simulations of the Lower Lakes and Coorong have been completed for the period 1 May to 1 August 2011. Five simulations investigated the influence of a range of varying magnitude and duration water level manipulations, on salinity levels within Lake Albert and the Coorong. The results of three model scenario simulations which have varying wind conditions applied allow us to determine the significance of wind mixing and transport on salt dynamics within the study area.

Finding from this investigations include:

- Actual wind conditions appear to have a significant influence on salinity levels within Lake Albert.
- The frequency and magnitude of managed water level fluctuations in the Lower Lakes appears to have only a minor influence on the removal of salt from Lake Albert. However, the use of higher magnitude, more frequent water level fluctuations do appear to be the most effective at removing salt from Lake Albert. However, in the absence of significant wind events, managed water level fluctuation are likely to still be important.
- At these lower flows and open mouth conditions, tidal anomaly appears to significantly influence water and salinity levels in the Coorong North Lagoon.
- At these lower flows and under typical winter conditions, the barrage operations undertaken to target a specific water level in the Lower Lakes appear to have minimal impact on water levels or salinity changes within the North or South Lagoon. However, an evaluation of salt load does indicate that barrage releases can influence the amount of salt retained in the Coorong following

from a storm surge event. It is possible that by opening gates along Tauwitchere Barrage to increase discharge, both immediately prior and during a storm surge event, fresh lake water instead of sea water could be transported into the North Lagoon. Further model testing is recommended to check and refine this recommendation.

- Wind mixing and transport appears to have a significant role in salinity dynamics of the South Lagoon.

A.5 Model Investigations and Scenario Runs (BMT WBM, 2011f)

A.5.1 Introduction

This report was the final in a series of six reports commissioned by the SA Department of Environment and Natural Resources (DENR). This report discusses a range of model simulations aimed at improving the understanding of key environmental hydraulic processes in the Coorong, Lower Lakes and Murray Mouth (CLLMM) system.

A.5.2 Summary of Base Case and Scenario Simulations

A broad range of simulations were undertaken to determine the potential influences on salt migration from Lake Albert and the Coorong.

Description of Base Case Scenario

The adopted base case simulation is from 1 May to 1 August, 2011 and uses predominantly observed boundary conditions data sets. This period was adopted as the model is known to perform well under these conditions (BMT WBM, 2011c) and the period is broadly representative of typical non-drought inflow conditions.

The base case scenario is used as the basis for all the scenario simulations. This means that for each scenario simulation nearly all the boundary conditions from the base case were used with the exception of the variable that is being tested in the scenario. A description of the scenario simulations is provided below.

The below series of simulations have a minimal direct influence on salt transport from Lake Albert:

- Murray Mouth Bathymetry
- Wave Conditions
- Barrage Release Distribution
- Lake Inflow

While the following investigations have a more significant influence on salinity dynamics in Lake Albert and hence have been described in greater detail.

Impact of Winds and Tides (including seasonality) Investigation

Most scenarios in this investigation focus on only minor variations in boundary conditions used in the base case (i.e. observed: winds, tides, and inflows for 1st May to 1st August 2011). Longer simulations were not included in the scope of this study, so to determine the influence of running the model during different seasons (when wind, tides and evaporation can be considerably different) and also to determine the impact of running with boundary conditions recorded from different years an additional four scenarios were simulated. The five scenarios (including the base case) used to examine the influence of seasonality and inter-annual variability of winds and tides included:

- Base Case - Observed 2011 (1/5 – 1/8/11)
- Observed 2008 (1/5 – 1/8/08)

- Observed 2010 (1/5 – 1/8/10)
- Observed Summer 2010/2011 (Dec 2010, Jan & Feb 2011)
- Observed Spring 2010 (Sept, Oct & Nov 2010)

Sensitivity Testing and Other Investigations

To test the sensitivity of the base case results to a range of possible model changes, four additional model scenarios were simulated. The additional four runs included:

- Run the model using observed evaporation. The base case uses a design time series of monthly averaged, typical (i.e.1996) net evaporation;
- Run the model using a higher Mannings Roughness at the Murray Mouth;
- Remove the remaining bund at Narrung Narrows
- Remove both the remaining bunds at Narrung Narrows and Clayton (Goolwa Channel)

A.5.3 Key Results of Base Case & Scenario Simulations

Base Case and Generic Findings:

- It is important to consider salt mass in addition to salt concentration when evaluating the scenario runs.
- Given short term events (i.e. the small storm surge event in late-July) can significantly change model results (in particular salt flux calculations), longer period simulations (preferably a year or more) are likely to provide a better indication of scenario outcome.
- For the base case simulation the ~153,000 tonnes of salt exported from Lake Albert over the three month simulation period (1/5/2011 to 1/8/2011) represents a 16% reduction in total salt mass compared to the initial salt mass of 949,200 tonnes at the start of the simulation. Observed salt reduction (see Section 2.4) over this approximate period was approximately 160,000 tonnes indicating a good model performance.

Findings and Implications of Winds and Tides (including seasonality))

- Increased Summer and Spring evaporation can reduce total barrage discharge due to evaporative loss in the Lower Lakes. It also reduces water levels in Lake Albert and increases salt concentrations in Lake Albert and the South Lagoon.
- Inter-annual differences in wind may influence predicted salt export from Lake Albert, although it is important to consider short term events near the end of the simulation when interpreting results.

Variation in predicted salinity in Lake Alexandrina between the five scenarios is due to differences in evaporation, the mass of salt ingress that occurs during backflow events and variations in wind mixing and transport. In Lake Albert (Figure A-15) there is a greater difference in predicted salinity, with different winds producing different rates of flushing through Narrung Narrows. The impact of evaporation causes the Summer and Spring scenarios to have the highest salinity levels within Lake Albert at the end of the three month simulation. While there is some difference in simulated concentrations between the base case (Observed 2011), 2008 and 2010 scenarios, total salt mass change to provide a more accurate assessment of flushing than salinity at a single point in the lake.

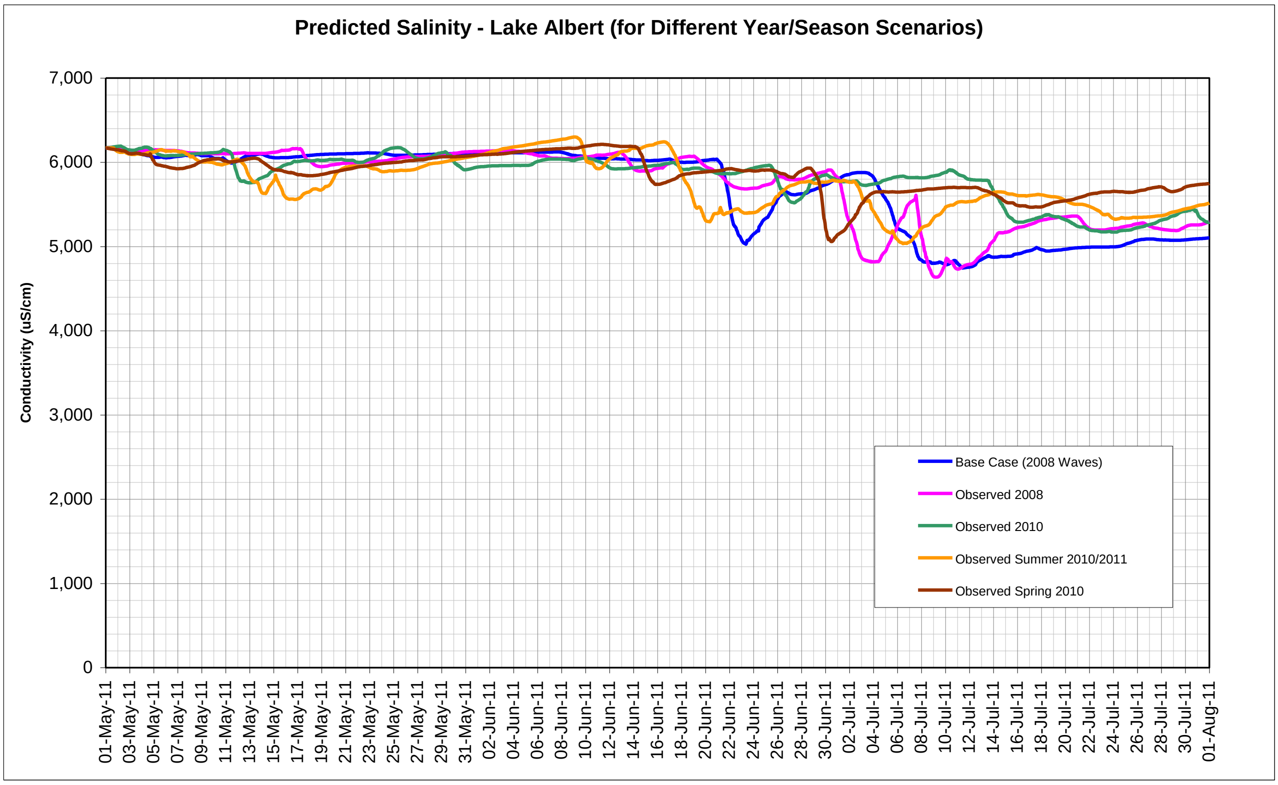

Figure A-15 Predicted Salinity in Lake Albert for Wind and Tide Scenarios

A summary of changes in salt mass (i.e. salt flux) at a number of important locations throughout the model is presented in Table A-3. Fluxes between Lake Albert and Lake Alexandrina are calculated at Narrung Narrows. The results show that with the exception of the 2010 scenario, there is less than 10% variation between the simulations. For the 2010 scenario, a strong south westerly in the final few days of the simulation pushes water (and salt) from Lake Alexandrina into Lake Albert, increasing the water level by nearly 0.1 m by the end of the simulation. For the Spring and Summer scenarios, the evaporative demand will have reduced the potential export of salt into Lake Alexandrina, however, wind mixing results in only a minor difference in total salt export.

Table A-3 Summary of Salt Fluxes for Wind and Tide Scenarios

Salt Summary (Tonnes)	Base Case (Observed 2011)	Observed 2008	Observed 2010	Observed Summer 2010/2011	Observed Spring 2010
Narrung Narrows	-152,831	-139,251	-113,741	-147,331	-144,486

Findings and Implications of Sensitivity Testing and Other Investigations (Narrung Bund Removal)

A summary of changes in salt mass (i.e. salt flux) at a number of important locations throughout the model is presented in Table A-4. Fluxes between Lake Albert and Lake Alexandrina are calculated at

Narrung Narrows. The results indicate that by completely removing the Narrung bund, salt export could be increased by nearly 10%. However, the results appear to be more sensitive to the applied evaporation boundary data.

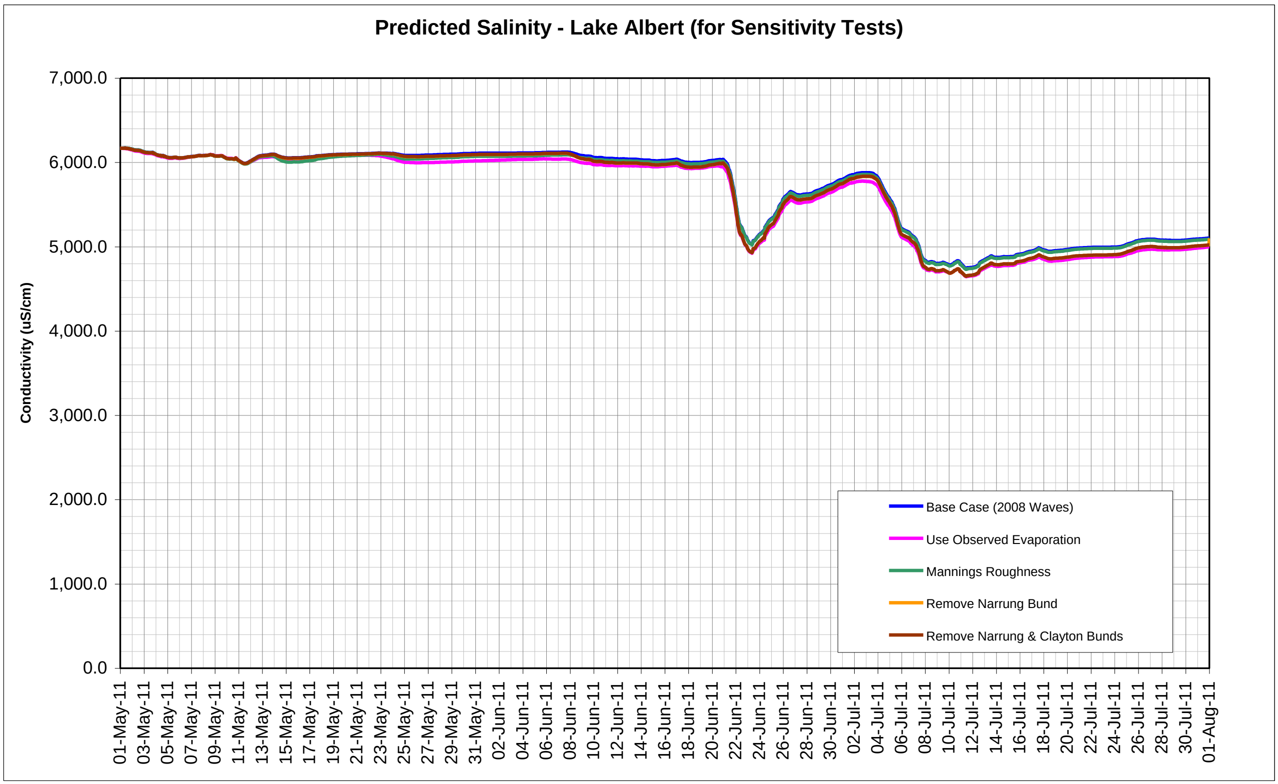

Figure A-16 Predicted Salinity in Lake Albert for Sensitivity Tests

Table A-4 Summary of Salt Fluxes for Sensitivity Tests

Salt Summary (Tonnes)	Base Case (Design Evap)	Use Observed Evaporation	Mannings Roughness	Remove Narrung Bund	Remove Narrung & Clayton Bunds
Narrung Narrows	-152,831	-170,310	-154,331	-166,604	-166,523

A.6 CLLMM Forecast Modelling – 12 Month Forecast Report (BMT WBM, 2012b)

A.6.1 Introduction

BMT WBM was commissioned by the South Australian Department of Environment and Natural Resources (DENR) to provide an estimate of predicted salinity and water levels based on a range of forecast River inflows and target lake levels over a 12 month period 18/4/2012 to 18/4/2013.

The study involved producing a base case forecast using average/typical boundary conditions to produce a reasonable estimate of water level and salinity. Following on from the base case forecast a range of additional model scenarios were used to determine error bands associated with the base case forecast. The additional scenarios investigated the sensitivity of the base case forecast to different: lake inflows, evaporation, wind and tide conditions, target lake levels and changes to barrage release distributions.

The model utilized in the study was the full CLLMM TUFLOW-FV model including: hydrodynamics (including waves and morphology), salt transport and automated barrages as previously discussed in Sections 0, 0 & 0.

A.6.2 Summary, Results and Findings of Base Case and Scenario Simulations

Description of Base Case Scenario

The adopted base case simulation models the 12 month period from 18th April, 2012 to 18th April, 2013 and uses a mix of forecast, design and historic boundary condition data sets. The base case simulation is designed to be a forecast run that should give a reasonable indication of changes to water level and salt concentrations over the next 12 months in the Coorong and Lower Lakes. Key boundary conditions for the base case simulation include:

- 50% AEP (median) forecast lake inflows;
- DfW average monthly net evaporation (975 mm/year);
- Observed 2008/09 winds and tides;
- Standard target lake water levels; and
- Typical barrage operating rules.

The base case scenario is used as the basis for all the scenario simulations. This means that for each scenario simulation nearly all the boundary conditions from the base case were used with the exception of the variable that is being tested in the scenario. A description of the scenario simulations is provided below.

Relevant Findings

Using the base case assumptions which include the use of observed 2008/2009 wind and tide conditions, the salt mass in Lake Albert is expected to fall by 91,400 tonnes in 12 months. This represents a 12% reduction compared to the mass of salt in Lake Albert at the start of the simulation (757,820 tonnes). This would reduce salinity from in the centre of the lake from ~5000 µS/cm to

~4600 µS/cm over the 12 months.

Impact of Different Lake Inflows Scenarios

Changes to Lake inflow have a direct influence on the magnitude of barrage discharge which influences water level and salinity dynamics within the Coorong and Lower Lakes and also potentially the morphology of the Murray Mouth. Four model runs were used to evaluate the impact of a range of different magnitude River flows, including:

- 50% AEP (base case)
- 50% AEP + environmental flows (e-flows)
- 90% AEP (i.e. a low flow condition)
- 90% AEP + environmental flows (e-flows)

Relevant Findings

The four inflows scenarios tested resulted in only a minor difference (< 1%) in salt export from Lake Albert as the differing inflows caused only a minor change to lake levels.

Table A-5 Summary of Salt Fluxes for Lake Inflow Scenarios

Salt Summary (Tonnes)	50% AEP (base case)	50% AEP + e-flow	90% AEP (low flow)	90% AEP + e-flow
Narrung Narrows	-91,434 (-12.1%)	-92,277 (-12.2%)	-90,260 (-11.9%)	-89,909 (-11.9%)

Impact of Wind and Tide Scenarios

Four different annual series of winds and tides have been modelled to determine the sensitivity of model predictions to different wind and tide conditions. Due to the complex interaction between wind and tides and also the effect of wind stress on hydrodynamics, it is difficult to characterise the influence of a given wind and tide time series on the resulting water levels and salt dynamics in the Coorong and Lower Lakes. Therefore in order to examine the likely range of future salt and water level conditions in the system a total of four different wind and tide conditions were examined, including;

- 2008/2009 (as presented in the base case);
- 2009/2010;
- 2010/2011; and
- 2007/2008.

Relevant Findings

Wind conditions have a significant influence on the salt dynamics of Lake Albert. In the base case (2008/09 winds) scenario the model predicts the export of 91,400 tonnes (a 12% reduction compared to the initial salt mass in Lake Albert). The other three scenarios predict between 126,300 tonnes (-19%) (for the 2007/08 simulation) and 173,650 tonnes (-23%) (for the 2009/10 scenario) of salt would leave Lake Albert over the 12 month simulation. This means that the use of the 2008/09 may under predict salt loss from Lake Albert by up to 50% over a year.

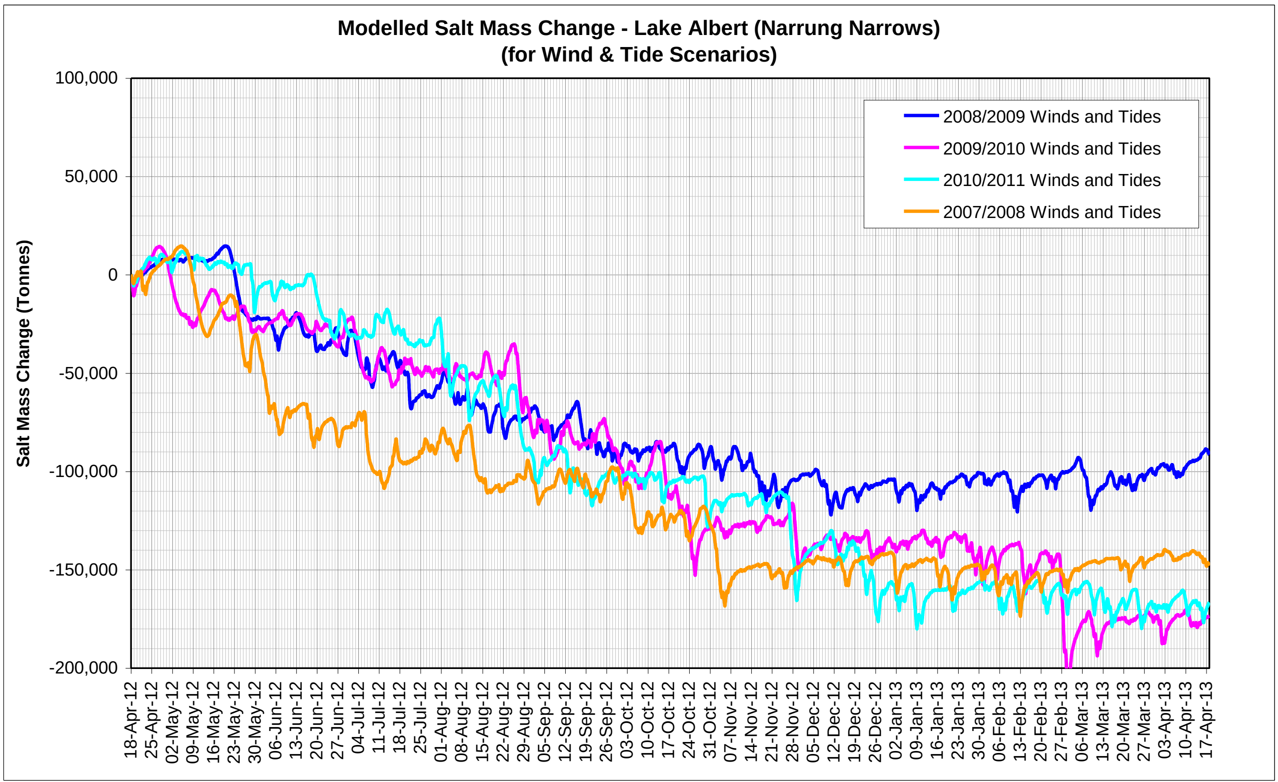

Figure A-17 Lake Albert Salt Mass Change for Wind and Tide Scenarios

Table A-6 Summary of Salt Fluxes for Wind and Tide Scenarios

Salt Summary (Tonnes)	2008/2009 Wind & Tide (base case)	2009/2010 Wind & Tide	2010/2011 Wind & Tide	2007/2008 Wind & Tide
Narrung Narrows	-91,434 (-12%)	-173,654 (-23%)	-166,520 (-22%)	-146,317 (-19%)

Impact of Lake Level Manipulation Scenario

The influence of manipulating barrage discharge and lake levels to enhance flushing salt from Lake Albert has been investigated using an alternate series of target lake water levels to that adopted in the base case. The additional scenario is the same as the median forecast flow (with additional environmental water) (50% AEP + e-flow) scenario, though instead of gradually drawing down the lake levels over summer, water levels are deliberately lowered (to 0.55 m AHD), raised (to 0.8 m AHD) before being lowered to 0.6 m AHD over the final 4 months of the simulation.

Relevant Findings

The deliberate raising and lowering of lake levels can cause a significant increase in the flushing of salt from Lake Albert. Using the standard series of target lake levels the model predicts 92,277 tonnes (a 12.2% reduction in mass compared to the initial salt mass in Lake Albert) of salt would be exported from Lake Albert. However, using the manipulated target lake level series, 142,000 tonnes (-18.7%) would be exported from the lake. This is a near 50% increase in salt mass removal compared to the non-manipulated scenario.

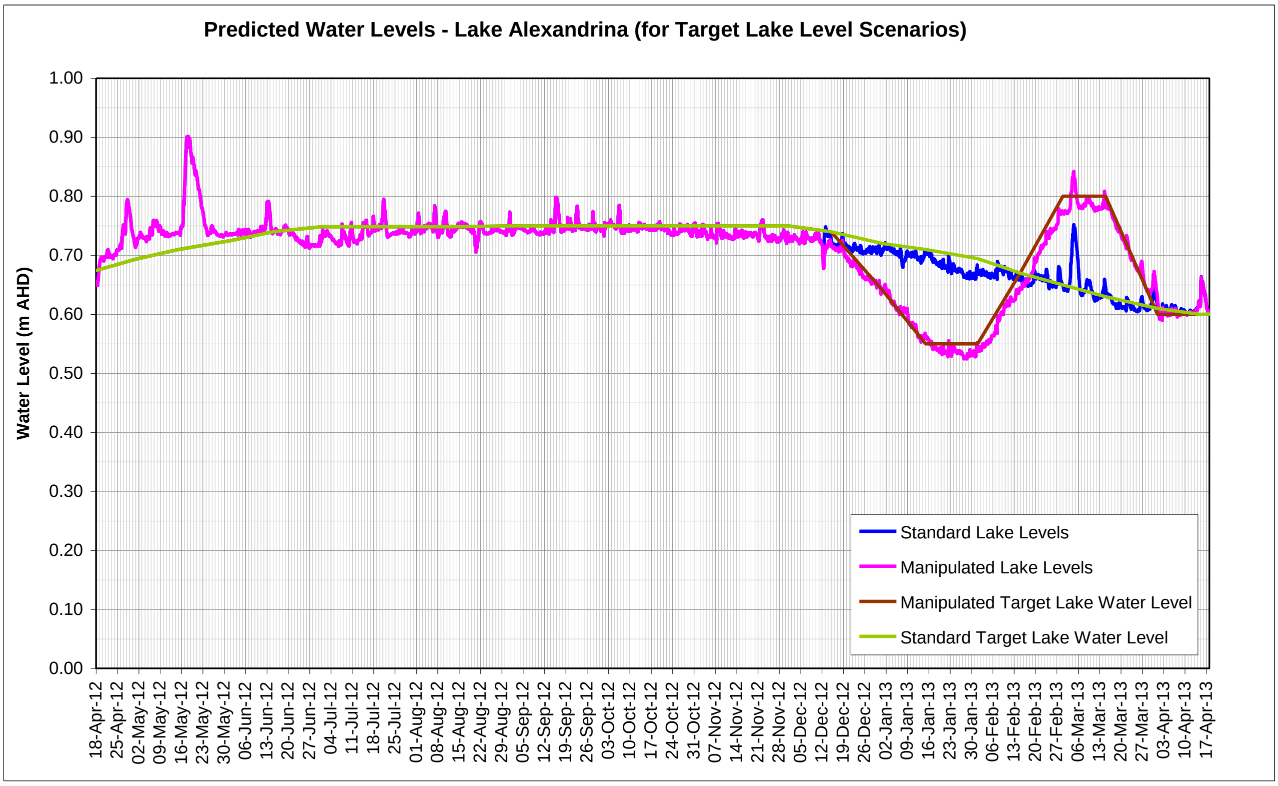

Figure A-18 Predicted Water Levels in Lake Alexandrina for Target Lake Level Scenarios

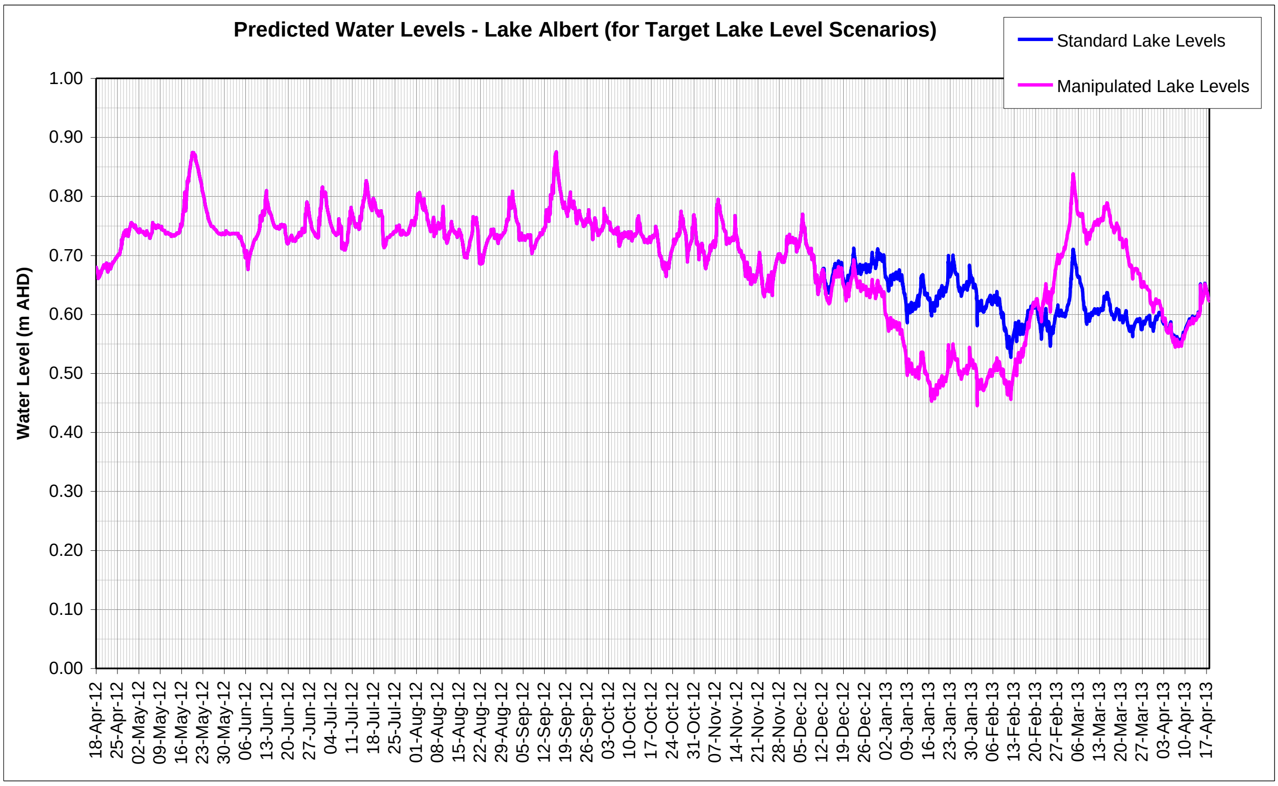

Figure A-19 Predicted Water Levels in Lake Albert for Target Lake Level Scenarios

Table A-7 Summary of Salt Fluxes for Target Lake Level Scenarios

Salt Summary (Tonnes)	Standard Target Levels (50% AEP + e-flow)	Manipulated Target Levels (50% AEP + e-flow)
Narrung Narrows	-92,277 (-12.2%)	-142,001 (-18.7%)

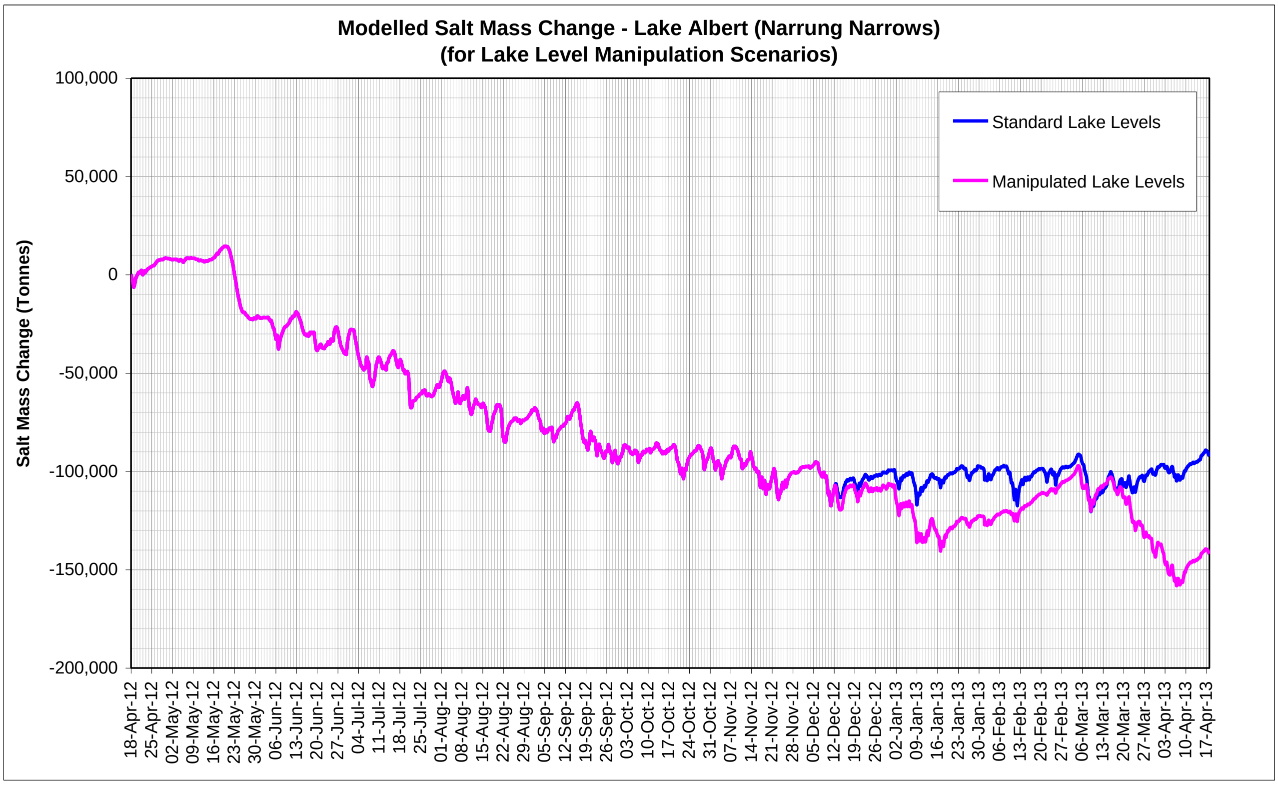

Figure A-20 Lake Albert Salt Mass Change for Target Lake Level Scenarios

Impact of Barrage Distribution Investigations

The influence of manipulating barrage discharge distribution was examined to determine if favouring releases into Tauwitchere Channel would reduce salt ingress into the Coorong, or if favouring releases into Goolwa Channel would result in greater salt ingress to the Coorong. Three model runs were used to evaluate the impact of a range of different barrage release distribution, including:

- Typical distribution (base case);
- Tauwitchere favoured;
- Goolwa favoured.

Relevant Findings

The results show that changes to barrage discharge distribution result in only very minor changes to predicted salt export from Lake Albert with all scenarios predicting the loss of ~ 90,000 tonnes of salt which is approximately a 12% reduction in salt mass compared to the initial mass of salt in Lake Albert.

Table A-8 Summary of Salt Fluxes for Barrage Distribution Scenarios

Salt Summary (Tonnes)	Typical Barrage Distribution Rules (base case)	Tauwitchere Favoured Barrage Rules	Goolwa Favoured Barrage Rules
Narrung Narrows	-91,434 (-12.1)	-90,433 (-11.9)	-89,469 (-11.8)

Impact of Evaporation Investigations

The influence of the net evaporation time series applied to the model forecasts was investigated by running three different net evaporation time series to the 50% AEP inflow scenario. The three applied evaporation time series include:

- DfW average monthly net evaporation (975 mm/year) as used in the base case
- Daily 1996 SILO evaporation data for Lake Alexandrina (834 mm/year)
- Daily 1996 SILO evaporation data for the South Lagoon (Woods Well) (605 mm/year)

Relevant Findings

The selection of net evaporation time series can have a significant influence on predicted salinity levels within Lake Albert. In Lake Albert a final salinity of ~4600 µS/cm is predicted for the DfW (975 mm/year) evaporation series compared to ~4000 µS/cm predicted using the SILO South Lagoon (605 mm/year) evaporation series. In Lake Albert, the base case DfW (975 mm/year) scenario produces a loss of 91,434 tonnes of salt (which is a 12.1% reduction in salt mass compared to the initial mass of salt in Lake Albert). Using the SILO daily Lake Alexandrina (834 mm/year) series ~30% more salt (120,752 tonnes) is exported, while the SILO daily South Lagoon (605 mm/year) scenario predicts the export of 167,972 tonnes, which is 84% more than the base case.

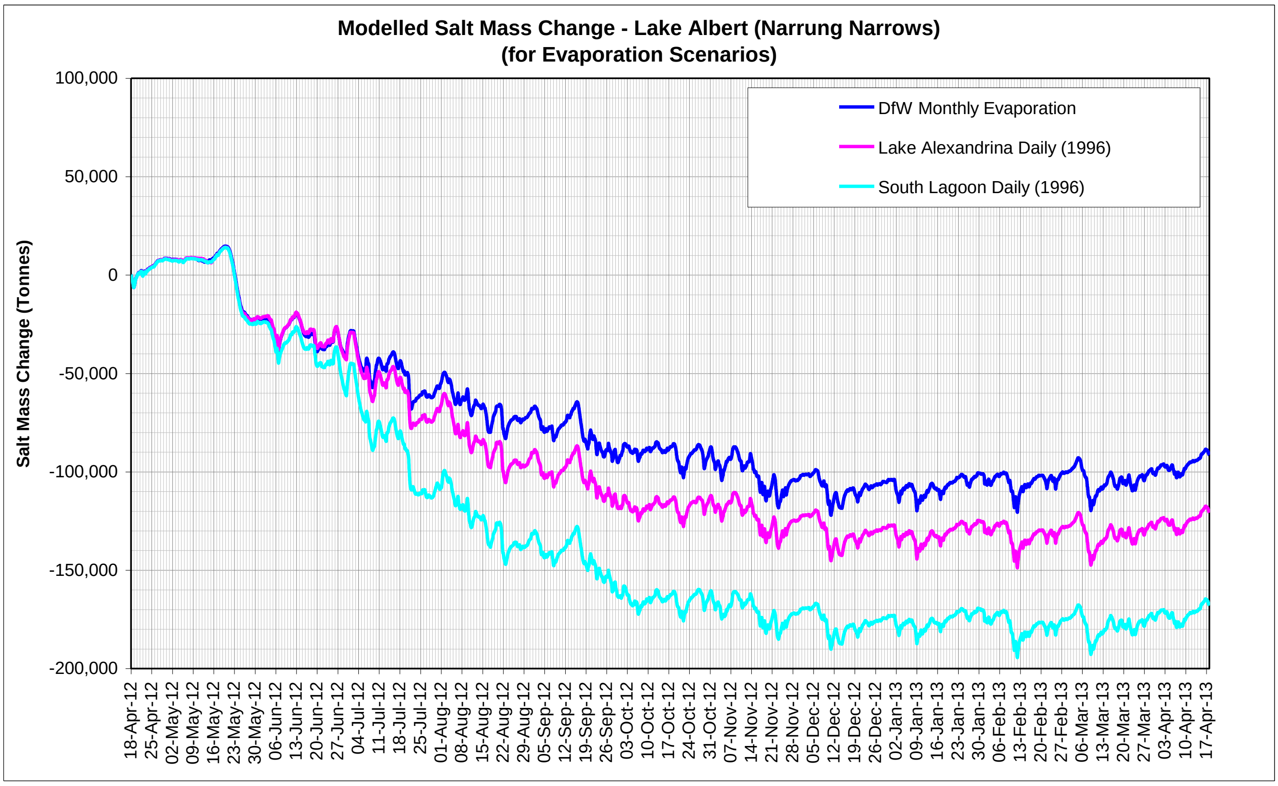

Figure A-21 Lake Albert Salt Mass Change for Evaporation Scenarios

Table A-9 Summary of Salt Fluxes for Evaporation Scenarios

Salt Summary (Tonnes)	DfW Monthly Evaporation (975 mm/year)	Lake Alexandrina Daily (1996) (834 mm/year)	South Lagoon Daily (1996) (605 mm/year)
Narrung Narrows	-91,434 (-12.1%)	-120,752 (-15.9%)	-167,972 (-22.2%)

A.6.3 Conclusions

- Differences in adopted wind conditions may result in significant (up to 100%) differences in the predicted annual salt transport from Lake Albert.
- The deliberate raising and lowering of lake levels can cause a significant increase in the flushing of salt from Lake Albert.
- The selection of evaporation conditions can significantly influence the prediction of salt transport and salinity within Lake Albert and the Coorong. This is likely to be a very important consideration especially for long term simulations.
- Forecast predictions of salt mass change may differ significantly from those observed if there is a significant difference between the boundary conditions and hence water level variations within Lake Albert.

A.7 Modelling Of Lake Albert Flushing Scenarios (BMT WBM, 2012c)

A.7.1 Introduction

BMT WBM was commissioned by the South Australian Department of Environment and Natural Resources (DENR) to undertake ten hydrodynamic model simulations of the Lower Lakes, Coorong and Murray Mouth to predict if changes to lake water levels may improve the flushing of salt from Lake Albert. Five different water level management options and two different wind and tide conditions were modelled. Model simulations covered the approximate 3 month period from the 1/6/2012 to the 7/9/2012.

The five different lake water level management options (as detailed in Figure A-22) were:

- 0.7 m AHD
- 0.8 m AHD
- 0.9 m AHD
- 0.1 m cycled
- 0.2 m cycled

The two different wind and tide data sets used in the scenario simulations are:

- 1/6/2008 – 7/9/2008
- 1/6/2010 – 7/9/2010

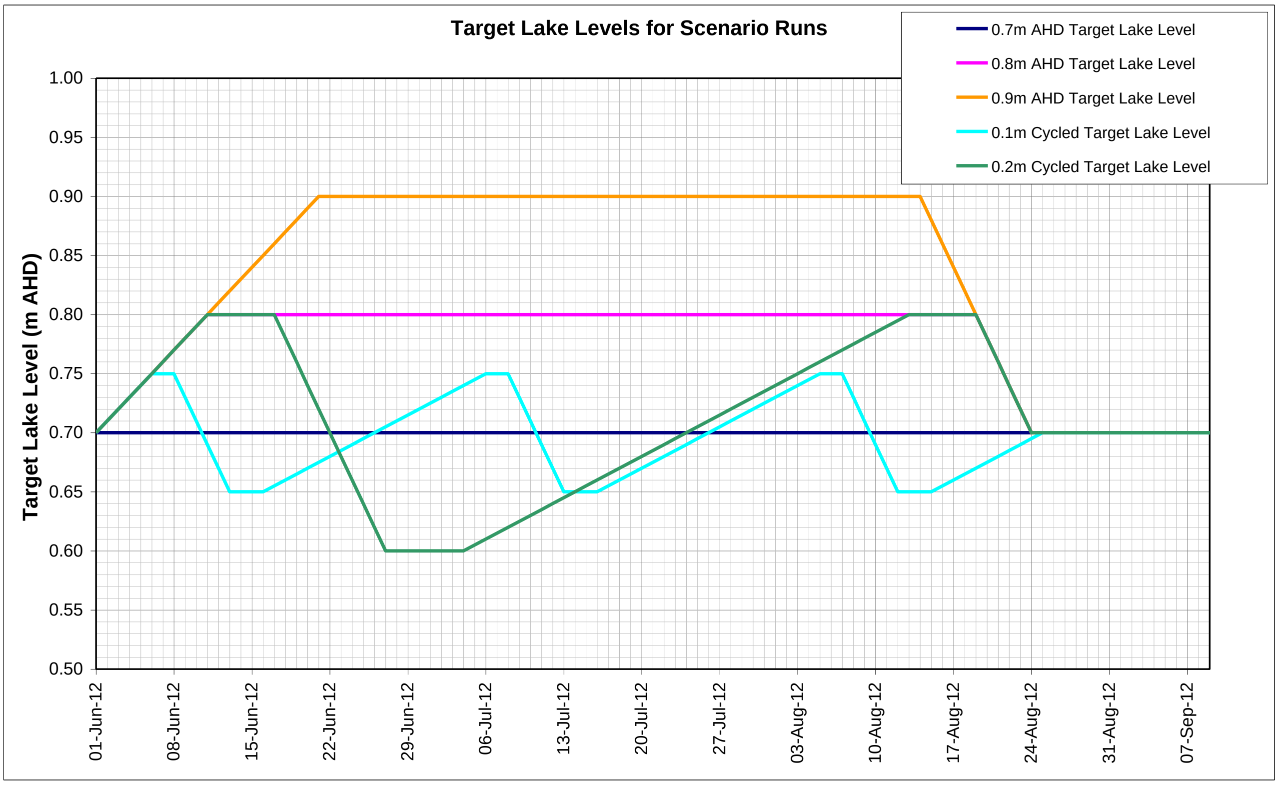

Figure A-22 Target Lake Levels for Five Scenarios

A.7.2 Results of Simulations

Lake Albert Salinity Change

Predicted changes to Lake Albert salinity for the ten scenarios are presented in Figure A-24 (2008 winds) and Figure A-25 (2010 winds) and are summarised in Table A-10.

Salinity at the start of the simulations at the approximate centre of Lake Albert was 4700 µS/cm. By the end of the approximately 3 month simulation a minimum of 7.5% salinity reduction is predicted, bringing salinity levels to below 4350 µS/cm by the 7th September, 2012. The greatest reduction in salinity (for a location at the centre of Lake Albert) occurred under the 0.2 m cycled water levels with 2010 winds scenario, which predicts a salinity level of 3808 µS/cm by the 7th September 2012. This is a reduction of 19% compared to the initial salinity at the start of the simulation.

Lake Albert Salt Flux

Consideration of salt mass changes in Lake Albert provides a more effective comparison than examining differences in salinity at a single point in the lake. However, as can be seen in Table A-10 there is a reasonably close correlation between changes in salinity at the centre of Lake Albert and salt flux at Narrung.

Modelled changes to Lake Albert salt mass for the ten scenarios are presented in Figure A-26 (2008 winds) and Figure A-27 (2010 winds) and are summarised in Table A-10. The initial salt mass in Lake Albert at the start of the simulation (1/6/2012) is 740,000 tonnes. The model predicts a reduction in salt mass over the 3 month simulation ranging from 83,433 tonnes to 142,749 tonnes. Compared to the initial mass of salt in Lake Albert this represents a -11.3% to -19.3% change. An examination of the results indicates that the selection of applied winds can cause a considerable difference to total net salt export (see Table A-11). An average of the five water level simulations using the 2010 winds predicts an average salt loss of 118,293 tonnes. This is ~23% greater than if the 2008 wind series is used which predicts an average salt loss of 95,933 tonnes.

To determine the potential benefit of adopting either a higher static lake level or the deliberate raising and lowering (cycling) of lake levels, changes in salt mass should be compared to the 0.7 m AHD (do nothing) scenario. Using 2008 wind conditions the 0.9 mAHD water level scenario results in 24,145 tonnes (28.9%) more salt being exported compared to the “do nothing”, 0.7 m AHD scenario. While under 2010 wind conditions, the 0.2 m cycled water level scenario results in 36,859 tonnes (35.2%) more salt being exported compared to the “do nothing”, 0.7 m AHD scenario.

Further examination of the results indicate that water level manipulations typically increase the mass of salt exported and that the change is typically related to the magnitude of the water level variation. However, it is also apparent that the relative timing of bulk water level changes when compared to wind events can significantly influence that amount of net salt export. A comparison of the two, 0.2 m cycled water level scenarios indicate that in the 2008 simulation, approximately 50,000 tonnes of salt is exported in the final month of the simulation, whereas in the equivalent 2010 simulation, only ~20,000 tonnes is exported over the same period. The interaction between wind driven transport and water level manipulations is also likely to be why in the 2010, 0.1m cycled water level scenario, less salt is exported during the simulation than in the “do nothing”, 0.7 m AHD scenario.

Influence of Lake Level on Salt Export

The influence of increases to static Lower Lake water levels on salt export rates from Lake Albert has also been examined. In order to remove the influence of bulk salt mass transport (due to changes in long term water levels), only salt mass changes in the six weeks from the 1st July to the 12th August were examined (see Table A-12). During this six week period the water level in each of the three 0.7, 0.8 and 0.9 m AHD simulations was constant. The results show that over this period there is less than a ~5% difference in the mass of salt exported between the three scenarios, and that increases in lake water levels appear to slightly reduce the magnitude of salt export. This reduction in salt transport at higher water levels is likely to be due to fresher water residing near Narrung Narrows as a result of rising lake levels in the first month of the simulation in the 0.8 and 0.9 m AHD scenarios. However, as increased water depths are known to result in a reduced magnitude of wind setup, it is possible that increases in lake levels may actually reduce the efficiency of salt export in Lake Albert.

Table A-10 Summary of Salinity and Salt Flux

	0.7m AHD Lake Level 2008 Winds	0.8m AHD Lake Level 2008 Winds	0.9m AHD Lake Level 2008 Winds	0.1m Cycled Lake Level 2008 Winds	0.2m Cycled Lake Level 2008 Winds
Final Lake Albert* Salinity (Percentage Change)	4346.3 (-7.5%)	4225.1 (-10.1%)	4060.5 (-13.6%)	4268.3 (-9.2%)	4150.3 (-11.7%)
Total Lake Albert Salt Loss (tonnes) (Percentage Salt Loss)	83,433 (-11.3%)	85,291 (-11.5%)	107,578 (-14.5%)	106,013 (-14.3%)	97,650 (-13.2%)
Difference in Salt Flux Compared to 0.7mAHD (% Difference)	0	-1,858 (-2.2%)	-24,145 (-28.9%)	-22,580 (-27.1%)	-14,217 (-17.0%)

	0.7m AHD Lake Level 2010 Winds	0.8m AHD Lake Level 2010 Winds	0.9m AHD Lake Level 2010 Winds	0.1m Cycled Lake Level 2010 Winds	0.2m Cycled Lake Level 2010 Winds
Final Lake Albert* Salinity (Percentage Change)	4044.0 (-14.0%)	3986.2 (-15.2%)	3957.6 (-15.8%)	4055.7 (-13.7%)	3808.1 (-19.03%)
Total Lake Albert Salt Loss (tonnes) (Percentage Salt Loss)	105,890 (-14.3%)	115,788 (-15.6%)	122,465 (-16.5%)	104,575 (-14.1%)	142,749 (-19.3%)
Difference in Salt Flux Compared to 0.7mAHD (% Difference)	0	-9,898 (-9.3%)	-16,575 (-14.3%)	+1,315 (+1.1%)	-36,859 (-35.2%)

Table A-11 Comparison of 2008 to 2010 Scenarios

	2008 Winds Five Scenario Average	2010 Winds Five Scenario Average
Final Lake Albert Salinity (Percentage Change)	4210.1 (-10.4%)	3970.3 (-15.5%)
Total Lake Albert Salt Loss (tonnes) (Percentage Salt Loss)	95,993 (-13.0%)	118,293 (-16.0%)

Table A-12 Predicted Lake Albert Salt Export (tonnes) (1/7 to 12/8)

Target Lake Level (m AHD)	2010 Winds	2008 Winds
0.7	49,569	47,865
0.8	47,951	45,429
0.9	46,962	44,962

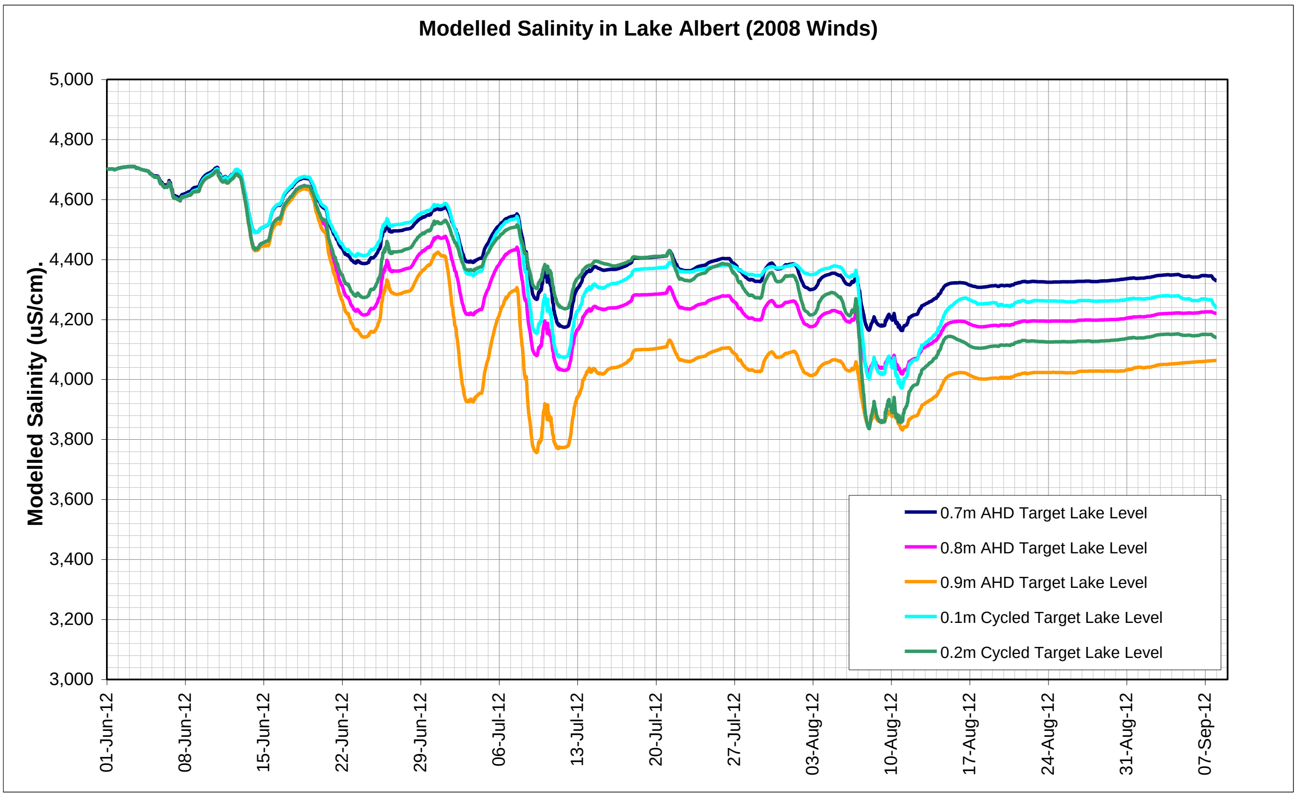

Figure A-23 Modelled Salinity Centre Lake Albert (2008 Winds)

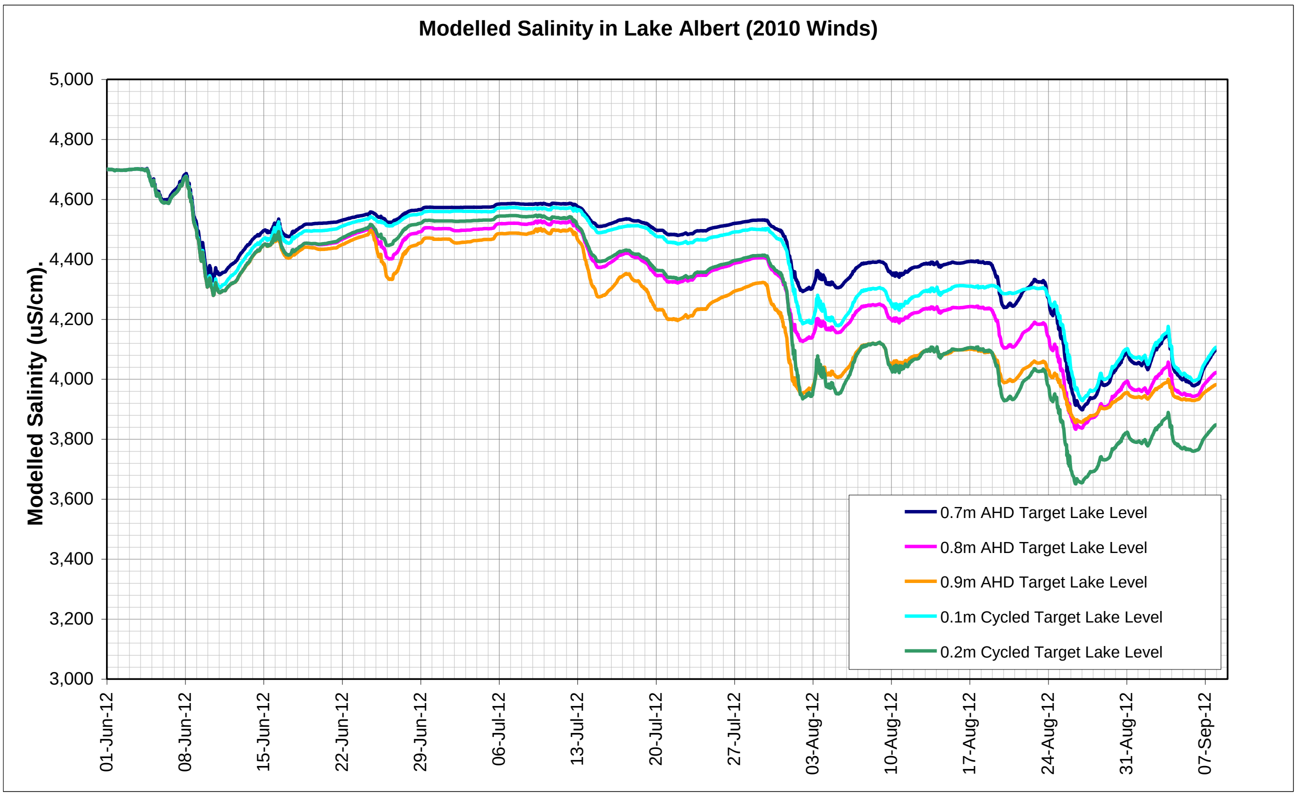

Figure A-24 Modelled Salinity Centre Lake Albert (2010 Winds)

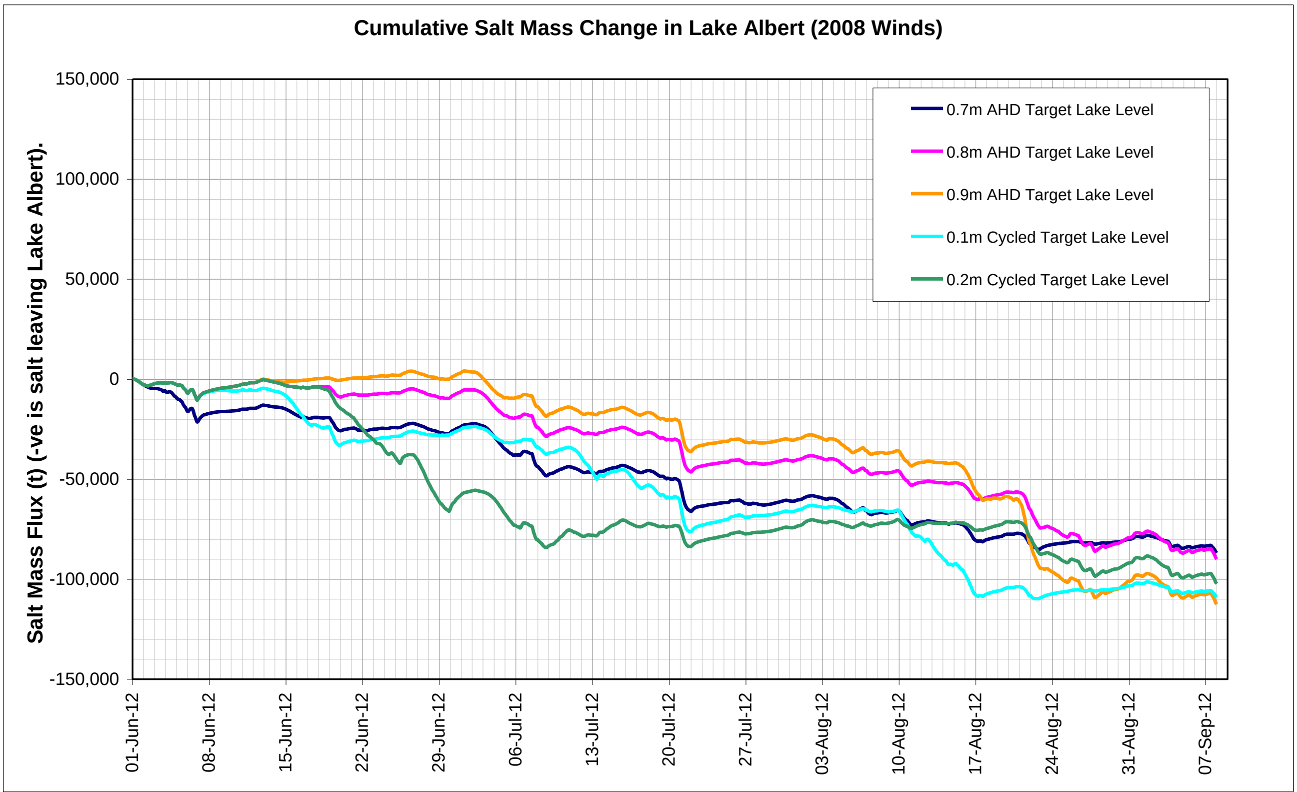

Figure A-25 Modelled Lake Albert Salt Mass Change (2008 Winds)

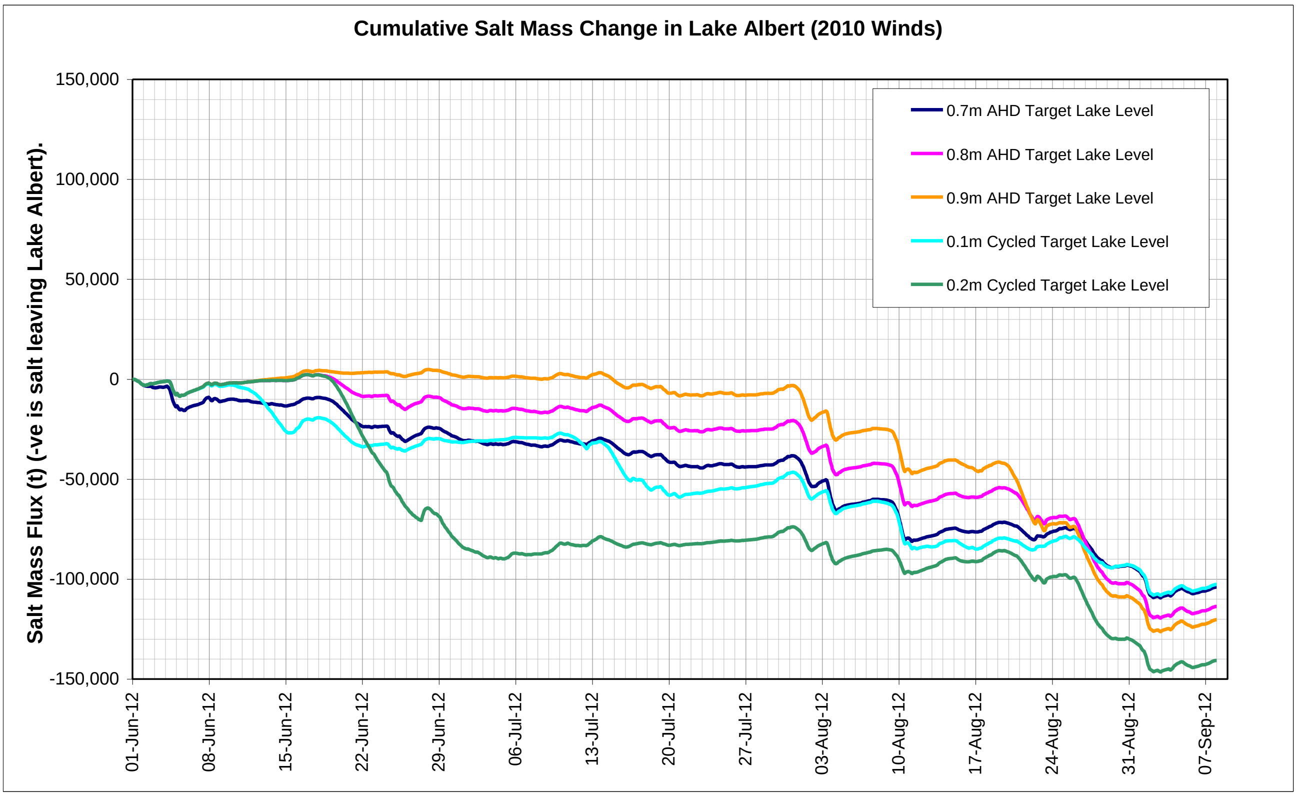

Figure A-26 Modelled Lake Albert Salt Mass Change (2010 Winds)

A.7.3 Discussion & Conclusions

Ten model scenario runs have examined predicted changes to Lake Albert salt dynamics under the influence of five different management lake water level options and two different climatic (wind) conditions. The results indicate that during winter, wind mixing alone is able to cause significant salt export from Lake Albert. The model simulations indicate that during the simulation period, the use of 2010 wind conditions result in an increase in salt export of 20% compared to the equivalent 2008 simulation.

The model scenarios also indicate that by deliberately raising and lowering lake levels, up to 35% more salt could be exported from Lake Albert than if a static 0.7 m AHD lake level was adopted. However, the results also indicate that the timing of lake level fluctuations significantly influence the magnitude of salt export and deliberate lake level manipulation could actually slightly reduce salt export compared to the "do nothing" scenario. However, this only occurred in one of the eight water level manipulation scenarios and is likely to be a rare event.

The model results also indicate that no increases to salt export are likely to occur if lake water levels were deliberately raised above typical operating levels. The increases to salt export that occur in the 0.8 and 0.9 m AHD scenarios occur due to the bulk transport that happen during actual water level changes and not during the static period of increased water levels.

The model results indicate that large lake level fluctuations are likely to enhance salt export from Lake Albert. However, adaptive management should be used to ensure that targeted water level changes do not reduce impact of wind driven salt export events.

A.8 Development of Flow Regimes to Manage Water Quality in the Lower Lakes (Heneker, 2010)

A.8.1 Introduction and Summary

This report presents the results of an investigation into the development of inflow and outflow regimes required for the Lower Lakes in South Australia, for the purpose of maintaining a desired ecological character, which was described using threshold water quality (defined in terms of salinity) and water level targets. This work formed an integral component of the Department of Environment and Natural Resources' Coorong, Lower Lakes and Murray Mouth program for determining the environmental water requirements to manage the Coorong, Lake Alexandrina and Lake Albert Ramsar Wetland of International Importance. The environmental water requirements recommended through this program have been presented by the South Australian Government to the Murray–Darling Basin Authority (MDBA) for use during the development of their Basin Plan.

Salinity in Lake Alexandrina is primarily controlled by lake inflows and outflows through the barrages located at Goolwa, Tauwitcherie, Ewe Island, Mundoo and Boundary Creek. The nature of Lake Albert, as a terminal wetland with its narrow connection with Lake Alexandrina, means that flow into and out of this lake is controlled by water level, wind and evaporation. It is not practical to manage salinity levels within Lake Albert independently. As such, the salinity targets evaluated are defined in terms of thresholds solely for Lake Alexandrina and, based on ecological sensitivities, were examined for targets of 700, 1000 and 1500 EC.

Historically, the magnitude of lake inflows and barrage outflows have been highly variable, with a resulting substantial variation in salinity. An initial analysis of historical barrage outflows and the salinity variation in Lake Alexandrina was undertaken with the objective of understanding how the magnitude of outflows affect in-lake salinity. This analysis showed that there is a marked increase in salinity as annual barrage outflows fall below 2000 GL and three year cumulative outflows fall below 4000 GL.

Hydrological modelling provided the most appropriate and effective means of exploring a range of flow regimes to develop operational rules to achieve the various salinity threshold targets. The MDBA model BIGMOD (MDBC 2002) was used as the primary flow and salinity modelling tool in a number of recent studies and was used here. In order to objectively develop operational rules to deliver a flow regime to meet each of the three salinity threshold targets, input data was modified to remove the inter-annual influence from variables such as system losses, diversions and groundwater salt inflows as well as the intra-annual variability of lake inflows.

A.3.2 Description of Model

BIGMOD (MDBC 2002) is a computer model that conceptualises and simulates the River Murray system by dividing the river into a number of river reaches. In each river reach, the major processes modelled include the routing of flow and salinity, losses, inflows, extractions, the operation of storages and weirs based on specified rules and the diversion of water into branches. It has been calibrated to available data and is regularly re-calibrated as new data or information becomes available or operating rules are changed.

At the Lower Lakes, *BIGMOD* maintains a continuous water and salt balance and the key requirements from this component of the model was to provide a good representation of water levels and salinities as well as an ability to estimate the flow over the Barrages. The major components of the water balance are inflows (surface flows from the River Murray and Eastern Mount Lofty Ranges (EMLR) tributaries and groundwater inflows), barrage outflows, rainfall, evaporation, seepage, water supply and irrigation extractions.

A.8.3 Representation of Lake Levels

It was not possible to calibrate the model over the entire period of record, primarily because barrage releases are not recorded. In addition, while the management of water levels in the lakes and any required barrage releases may follow general rules to maximise water retention and minimise unwanted flooding, it is difficult to formulate actual operations into model rules that can replicate historical actions.

Figure A-27 shows observed levels in Lake Alexandrina for period 2003 to mid-2007, together with the modelled levels using *BIGMOD*. As can be seen, the model provides a reasonable representation of the rise and fall of lake levels over this period. However, given the importance of water level fluctuations in the Lower Lakes for Lake Albert salinity dynamics, the inability of BIGMOD to better match observed water levels means it is likely to have significant limitation in assessing short term salinity dynamics in Lake Albert.

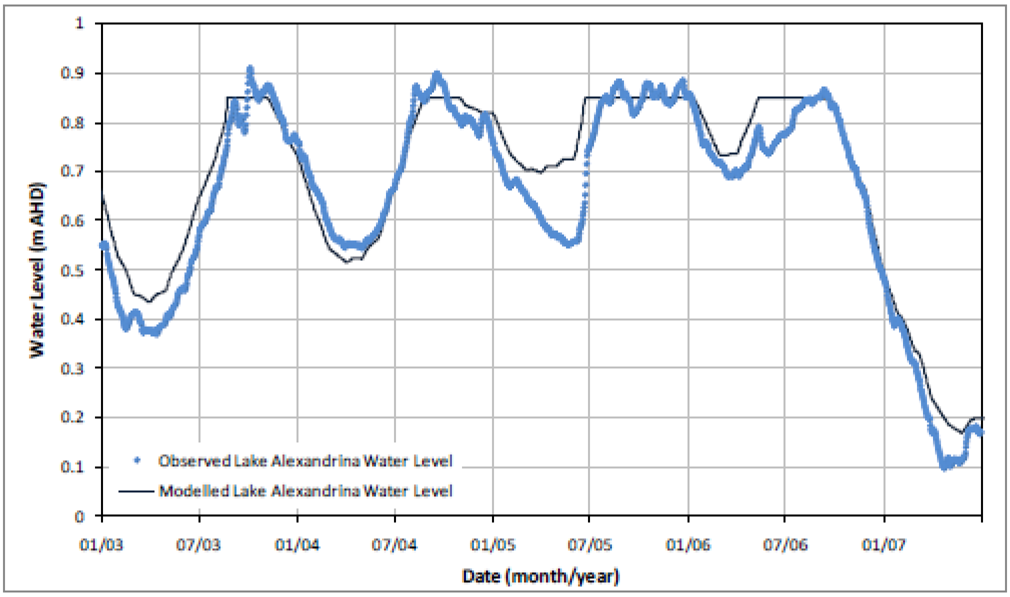

Figure A-27 BIGMOD Representation of Observed Lake Levels

A.8.4 Model Calibration & Lake Albert Salinity Statistics

The model (BIGMOD) was calibrated for salinity for the period 1975 to 2007. The overall correlation between model predictions and observed data was 0.93 for Lake Alexandrina and 0.8 for Lake Albert. The model appears to typically under predict Lake Albert salinity between 1975 and 1995 and slightly over-predict salinity from 1995 – 2007. A summary of salinity statistics for Lake Albert is presented in Table A.12. In order to represent the exchange of salt between Lake Albert and Lake Alexandrina a calibrated constant exchange of 600 ML/day was assumed with no intra- or inter-annual variation considered. This 600 ML/Day represents the exchange due to wind seiche and dispersive processes.

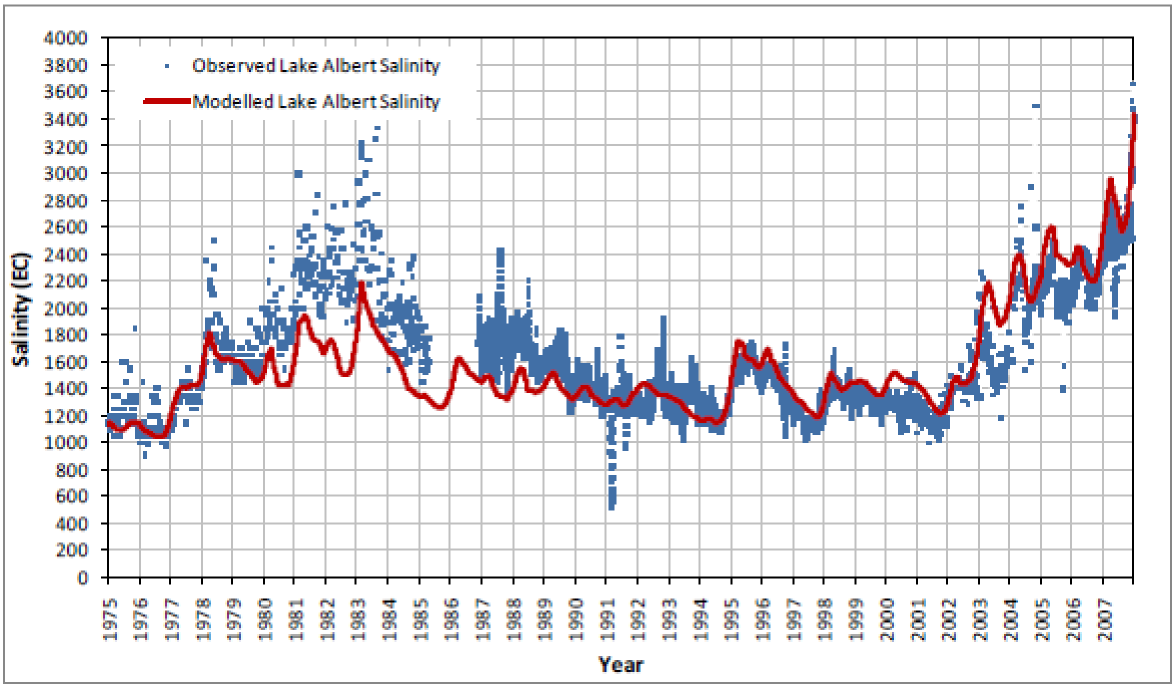

Figure A-28 Observed and Modelled Historical Lake Albert Salinity

Table A-13 Historical Lake Albert Salinity Statistics (1975/76 to 2006/07)

Statistics	Lake Albert Salinity (EC)	
	Observed	Modelled
Mean	1475	1560
Median	1440	1450
Minimum	965	1045
Maximum	2800	2960
10th Percentile	1200	1220
90th Percentile	2155	2150

APPENDIX B: REVIEW OF DATA REQUIREMENTS FOR ADDITIONAL MODELLING

B.1 Introduction

A review and initial quality check of the available data has be undertaken to determine if adequate data is available to support the suggested modelling approaches and simulation periods. Important data sets that if not available could delay further investigations include: wind, water level, electrical conductivity, flow, evaporation, rainfall, tide, barrage openings, irrigation extraction, and bathymetry data. A summary of the availability of the data is given below.

B.2 Tidal Data

Victor Harbour tidal water level data is a key boundary condition used by the numerical model. An accurate offshore tidal boundary is required to be able to simulate water levels in the Coorong. During periods of high barrage discharge an accurate tidal boundary condition data is also required to accurately predict water levels in the Lower Lakes.

A review of available tidal data from the Victor Harbour water level gauge indicates that the gauge failed twice in 2011 and 2012 as detailed in Table B-.

Table B-1 Summary of missing Victor Harbour Tidal Data

Date Fail	Date Re-instated	Days Missing
19/09/2011	29/12/2011	101
6/02/2012	13/05/2012	97

Due to the importance of this boundary condition an estimate of actual tide levels was required as the use of predicted tides alone was found to be unacceptable in model validation exercises presented in BMT WBM (2012a).

A reasonable estimate of storm surge was calculated using the below equation:

Estimate of Storm Surge / Tidal Anomaly = Average Daily Barker Knoll WL x 1.2 – 0.25

The above estimate was reasonable because daily average water levels tend to be a good estimate of tidal anomaly. This estimate was compared to observed tidal anomaly prior to 19th September, 2011 and was found to provide a reasonable estimate of observed tides. However, maximum errors ranging between 0.1 to 0.2m were noted.

It is hoped that the above estimate of tidal anomaly combined with predicted tide levels will provide a sufficient estimate of the tidal boundary condition to produce an acceptable level of calibration. If it isn't the use of a regional scale offshore hydrodynamic model could potentially be used to provide a better estimate of tidal anomaly or offshore tidal water levels required to increase the accuracy of model calibration to an acceptable level.

B.3 Wind Data

The applied wind field is another key driver of short term hydrodynamics (water levels and currents) within the study area. The wind field creates a shear stress on the surface of the water body that pushes the water downwind potentially causing wind setup (and set-down). Wind driven currents and setup can influence circulation between the Coorong's North and South Lagoon and also between Lake Albert and Lake Alexandrina.

Suitable wind speed and direction data for use as a model boundary is collected by DEWNR at the Pelican Point automatic weather station (AWS) and at the Waltowa gauge in Lake Albert. The AWS is located just to the east of Tauwitchere Barrage between the Coorong North Lagoon and the southern part of Lake Alexandrina. A time-series of wind speed and direction from 1/1/2010 to March 2013 for both gauges has been reviewed and a number of spurious readings were corrected by hand.

The Pelican Point guage is missing wind direction data from 8/1/2010 to 20/1/2010, while the Waltowa gauge produced spurious data from 8/10/2011 to 25/11/2011. As the gauges generally give very similar readings of wind speed and direction a complete set of wind conditions is available.

B.4 DEWNR WL and EC Data

Water level (WL) and electrical conductivity (EC) data collected is collected a number of locations throughout the Lower Lakes and Coorong as presented in Figure 2-1. Data from January 2010 to mid-March 2013 has been obtained and over 100 individual data files graphed. An initial check of data quality (i.e. QA) of the data shows that a number of sites have periods of missing data or experience periods of datum drift. However, the datum drift can be corrected based on comparison to nearby sites and model results and there is a sufficient number of available sites across the entire system to allow for a model calibration exercise based on this data to be undertaken.

B.5 Salinity Transect Data and Salt Mass Calculations

Salinity transect data for the Lower Lakes (i.e. including Lake Albert) has been collected at approximately monthly intervals from the 27/4/2011. The nineteen salinity data sets that were collected (up to the end of February 2013) and supplied by the SA EPA have been analysed to help determine changes in the total mass of salt contained within Lake Albert over the past two years as presented in Section 2.4and Table 2-3. The salt mass data and the digital surface maps (DSM) of salinity will be very useful for the model calibration exercise.

Prior to April 2011 salinity transect data was limited to Lake Alexandrina. On the 28/6/2011 a salinity transect of Lake Alexandrina and Narrung Narrows but not Lake Albert was collected. Transect data for Lake Alexandrina has also been provided for the 31/3/2011. BMT WBM has already been given a number of previous transects for including 18/2/2010, 11/5/2010, 10/6/2010, 7/7/2010, 6/8/2010, 30/9/2010 and 26/10/2010. The September and October 2010 transects should provide indication of the salinity of Lake Alexandrina water that would have flowed into Lake Albert when the Narrung Bund was removed in late-September 2010.

An initial condition of salinity for Lake Alexandrina has been previously been based a salinity transect survey of Lake Alexandrina collected on the 23rd and 24th of November 2010.

A number of salinity transect runs along the Coorong have also been collected on the following dates:

- 25th and 26th November 2010 (North and South Lagoon);
- 25th October 2011 (North Lagoon (to Long Point) only);
- 18th April 2012 (this transect missed the final 7 km to Snipe Island);
- 11th September 2012 (North and South Lagoon);
- 12th December 2012 (North Lagoon only).

B.6 Murray Mouth Bathymetry Survey Data

It is understood that Murray Mouth bathymetry data has been collected at approximately 6 week intervals since 2002 to assess changes in mouth morphology and evaluate the dredging operations that were required between 2002 and 2010 to ensure an open Murray Mouth. The availability of recent data provided by SA Water is presented in Table B-. This data will be used to provide an initial bed level for the Murray Mouth and will also be used to assess the numerical models ability to reproduce observed changes to morphology at the Murray Mouth.

Table B-2 Summary of Recent Murray Mouth Bathymetry Data

2010	2011	2012	2013
Feb 2010	18/1/2011	12/1/2012	5/2/2013
June 2010	10/3/2011	20/2/2012	
July 2010	1/5/2011	3/4/2012	
15/9/2010	15/6/2011	29/5/2012	
25/10/2010	12/7/2011	3/7/2012	
15/11/2010	9/8/2011	7/8/2012	
14/12/2010	5/10/2011	18/9/2012	
	7/11/2011	30/10/2012	
	12/12/2011	11/12/2012	

B.7 Barrage Openings

A recording of daily barrage (number of gates) openings has been provided by SA Water. Actual invert data for Goolwa Barrage stop log levels is not collected.

B.8 Lake Inflows

An estimate of Lake Inflow data up to 12/2/2013 has been provided by DEWNR. It is understood that this estimate includes most bulk extractions and an appropriate lag is applied to Lock 1 inflows to determine approximate flow rates at Wellington. The appropriateness of this data will be assessed during model calibration. During periods of low flow, it may be necessary to include a representation of the river between Wellington and Lock 1 to more accurately account for losses along the River and the additional storage contribution of the River.

The MDBA records river flow data at Lock 1 and can be downloaded from the internet.

Data on major river extraction (if required) will be sought from SA Water prior to ongoing modelling.

B.9 Wave Data

Offshore spectral wave data is required to accurately determine the hydrodynamics and morphology of the Murray Mouth. It will be purchased from BMT ARGOSS. An indicative cost for extending the existing data set (that finished on 1/11/2011) to 1/4/2013 is $2,000.

B.10 Net Evaporation Data

Rainfall and evaporation data is a key driver of hydrodynamic in the Lower Lakes and Coorong. It will be purchased from SILO (BoM) when required. An estimate of cost of data for 3 - 4 locations is $200.

B.11 Irrigation Extraction Volumes

Information on the total licensed extraction volume for Lake Albert has been provided by DEWNR. It indicates that since 2010 approximately 6 GL/year of extractions have been sought. However, no information on the temporal scale (i.e. time-series data) or spatial location of these extractions has been provided. Given the relatively small volume of these extractions they are unlikely to significantly influence saline dynamics. The model calibration exercise would be required to check this assumption.

B.12 Bathymetry Data Following Regulator Removal

Three water level regulators (bunds) were installed during 2008 and 2009 (see Figure 1-1) in the Lower Lakes to either reduce the threat of acidification or provide ecological refuge. A brief summary of regulator removal and available bathymetry is presented below.

B.12.1 Narrung

The Narrung Regulator was constructed in April 2008 and was breached in September 2010. By the time Lake Albert had filled (~2 weeks) the breach width was approximately 80 m with an assumed channel invert of -1m AHD (BMT WBM, 2011f).

Work to remove the remaining section of the bund began in March 2011, with excavation works to remove Narrung Bund being completed in July 2011. A bathymetric survey was collected in January 2011 (as used in BMT WBM, 2012b) and a further survey was carried out on 13 October 2011. This October, 2011 (or any subsequent) survey data will be required to update the model.

B.12.2 Clayton (Goolwa Channel)

The Clayton Regulator in Goolwa Channel was constructed in April 2009 and was partially opened in September 2010. On 25 September 2010, 170 metres of the Clayton Regulator was removed due to improved water levels allowing 15,000 ML/day to pass through the regulator to the Goolwa Barrage.

Excavation of the remaining regulator commenced on Monday 14 November 2011 and was completed by the end of February 2012

Final dredging to restore the channel to its original bathymetry occurred in 2012 and was completed by October 2012. A final survey of the channel was collected on the 4th October 2012 and will be required to update the model.

B.12.3 Currency

The Currency regulator was constructed in April 2009. The regulator appeared to become partially breached sometime in late 2010 or early 2011. Removal of the Currency Creek regulator started in March 2013. The regulators condition will have minimal influence on salinity dynamics of Lake Albert so will have limited significance (apart from a local influence on mixing) in the proposed modelling.

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