A part of BMT in Energy and Environment

Lake Albert Salinity Reduction Study - Scenario Schematisation and Testing

Reference: R.N20056.003.02_LakeAlbert_Meshing&1yrScenarios.docx
Date: March 2014
Confidential

Lake Albert Salinity Reduction Study – Scenario Schematisation and Testing

Prepared for:	South Australian Department of Environment, Water and Natural Resources
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

Offices

Brisbane
Denver
London
Mackay
Melbourne
Newcastle
Perth
Sydney
Vancouver

Document Control Sheet

BMT WBM Pty Ltd 126 Belford Street BROADMEADOW NSW 2292 Australia PO Box 266 Broadmeadow NSW 2292 Tel: +61 2 4940 8882 Fax: +61 2 4940 8887 ABN 54 010 830 421 www.bmtwbm.com.au	**Document:**	R.N20056.003.02_LakeAlbert_Meshing&1yrScenarios.docx
	Title:	Lake Albert Salinity Reduction Study - Scenario Schematisation and Testing
	Project Manager:	Rohan Hudson
	Author:	Rohan Hudson
	Client:	South Australian Department of Environment, Water and Natural Resources
	Client Contact:	Theresa Andrew (nee Myburgh)
	Client Reference:	n/a
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. A numerical model capable of simulating salinity dynamics of the Lower Lakes and Coorong was used to evaluate the effectiveness of six potential management options designed to reduce salinity levels in Lake Albert.	

VERSION/CHECKING HISTORY

Version Number	Date	Checked by		Issued by	
1 (draft)	31/1/2014	LJK	Luke Kidd	RMH	31/1/2014
2 (final)	6/3/2014			RMH	6/3/2014

DISTRIBUTION

Destination	VERSION										
		1	2	3	4	5	6	7	8	9	10
BMT WBM File		pdf									
BMT WBM Library											
SA DEWNR		pdf									

Contents

1 Introduction 1

1.1 Summary of Associated Studies and Reports 1

1.1.1 Lake Albert Salinity Reduction Study - Preliminary Investigations (BMT WBM, 2013a) 1

1.1.2 Lake Albert Salinity Reduction Study – Model Setup and Calibration Report (BMT WBM, 2013b) 2

1.1.3 Lake Albert Salinity Reduction Study – Wind Mixing Investigation 2

1.1.4 Lake Albert Salinity Reduction Study – Model Scenario Schematisation and Initial Testing 3

1.1.5 Lake Albert Salinity Reduction Study – Three Year Scenario Model Investigations 3

1.2 Structure of Report 4

2 Model Setup and Description of Scenario Simulations 5

2.1 Model Configuration 5

2.2 Model Schematisation of Six Management Options 5

2.3 Description of One Year Forecast Scenario Simulations 6

2.4 Boundary Conditions for Scenario Simulations 6

2.4.1 River Murray Inflows 7

2.4.2 Net Rainfall – Evaporation 8

2.4.3 Pelican Point Wind Data 9

2.4.4 Victor Harbour Tides 10

2.4.5 Offshore Wave Data (BMT ARGOSS) 11

2.4.6 Salt Creek Inflows 11

2.4.7 Catchment Inflows 12

2.4.8 Use of Automated Barrage Opening Logic and Target Lake Water Levels 12

2.4.9 Adopted Model Barrage Structures 13

2.4.10 Target Management Lake Water Levels (Barrage Openings) 13

2.4.11 Adopted Barrage Operating Rules 14

2.5 Model Initial Conditions 15

2.5.1 Initial Water Levels 15

2.5.2 Initial Salinity and Salt Mass 15

2.5.3 Murray Mouth Bathymetry 16

2.6 Model Scenario Schematisation for Initial Assessment 19

2.6.1 Model Mesh Development for Scenarios 19

2.6.2 Details of Narrung Narrows Dredging Scenario 21

2.6.3 Details of Coorong Connector Scenario 21

2.6.4 Details of Permanent Narrung Control Structure 25
3 Model Output and Results 27
3.1 Description of Model Output 27
3.1.1 Water Level Output 27
3.1.2 Salinity Outputs 27
3.1.3 Water Volume and Salt Mass Change 27
3.2 Comparison of Management Option Results 29
3.2.1 Water Levels 29
3.2.2 Salinity (Salt Concentration) 29
3.2.3 Cumulative Salt Mass Change 35
3.2.4 Narrung Flows and Cumulative Volume Change 36
3.2.5 Coorong Connector Flow Summary 36
3.3 Sensitivity Testing of Scenarios 40
3.3.1 Coorong Connector Channel Conveyance 40
3.3.2 Quarterly Lake Cycling Performance 41
3.3.3 Permanent Narrung Structure Options 41
4 Conclusion 44
5 References 45

List of Figures

Figure 2-1 Wellington Inflow Data 7
Figure 2-2 Lower Lakes Rainfall and Evaporation Data 8
Figure 2-3 Pelican Point Wind Speed and Direction 9
Figure 2-4 Victor Harbour Tidal Water Level Data 10
Figure 2-5 Salt Creek Inflow Data 11
Figure 2-6 Finniss and Currency Creek Inflow Data 12
Figure 2-7 Standard and Cycled Target Lake Water Levels 14
Figure 2-8 Initial Model Salinity (ppt) and Transect Locations 17
Figure 2-9 Initial Murray Mouth Model Bathymetry, 18th April 2012 18
Figure 2-10 TUFLOW-FV Management Scenario Mesh 20
Figure 2-11 Base Case Mesh Narrung Narrows Bathymetry 22
Figure 2-12 Dredged Scenario Mesh Narrung Narrows Bathymetry 23
Figure 2-13 Schematisation of Coorong Connector 24
Figure 2-14 Proposed Location of Permanent Narrung Control Structure (Source: SKM) 25
Figure 2-15 Narrung Control Structure One Week Gate Closure Sequence 26
Figure 2-16 Narrung Control Structure Two Week Gate Closure Sequence 26

Figure 3-1 Map of Model Output Locations 28
Figure 3-2 Modelled Water Levels in Lake Alexandrina for Proposed Scenarios 31
Figure 3-3 Modelled Water Levels in Lake Albert for Proposed Scenarios 31
Figure 3-4 Modelled Water Levels in the North Lagoon for Proposed Scenarios 32
Figure 3-5 Modelled Water Levels in the South Lagoon for Proposed Scenarios 32
Figure 3-6 Modelled Salinity in Lake Albert for Proposed Scenarios 33
Figure 3-7 Modelled Salinity in Lake Alexandrina for Proposed Scenarios 33
Figure 3-8 Modelled Salinity in the North Lagoon for Proposed Scenarios 34
Figure 3-9 Modelled Salinity in the South Lagoon for Proposed Scenarios 34
Figure 3-10 Modelled Lake Albert Salt Mass Change (Tonnes) for Six Scenarios 37
Figure 3-11 Modelled Lake Albert Percentage Salt Mass Change for Six Scenarios 37
Figure 3-12 Modelled Lake Albert Volume Change for Six Scenarios 38
Figure 3-13 Modelled Narrung Flows for Six Scenarios 38
Figure 3-14 Modelled Narrung Flows for Six Scenarios (six weeks) 39
Figure 3-15 Applied Wind Data (six weeks) 39
Figure 3-16 Coorong Connector Channel Modelled Flow Time series 40
Figure 3-17 Modelled Lake Albert Salt Mass Change (Tonnes) Sensitivity Test Results 42
Figure 3-18 Standard and Cycled Target Lake Water Levels 43
Figure 3-19 Target and Modelled Lake Water Levels (Quarterly Cycling) 43

List of Tables

Table 2-1 Adopted Hydraulic Properties for Barrages 13
Table 2-2 Adopted Gate Opening Rules for Barrages 14
Table 2-3 Initial Water Levels (18th April, 2012) 15
Table 2-4 Initial Salinity Assumptions 16
Table 2-5 Approximate Initial Salt Mass (18th April, 2012) 16
Table 3-1 Summary of Output Locations 27
Table 3-2 Summary of Lake Albert Salinity Results 30
Table 3-3 Summary of Lake Albert Salt Mass Change Results 35
Table 3-4 Summary of Lake Albert Sensitivity Test, Salinity Results 41
Table 3-5 Summary of Lake Albert Sensitivity Test, Salt Mass Change Results 42

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 investigation is to increase understanding of salinity dynamics within Lake Albert and to provide an assessment of the proposed management options.

1.1 Summary of Associated Studies and Reports

This report is associated to a number of other reports prepared as part of the broader study for Lake Albert. The associated studies and reports should be consulted as necessary when referred to throughout this document. A summary of associated reports is given below.

1.1.1 Lake Albert Salinity Reduction Study - Preliminary Investigations (BMT WBM, 2013a)

This report provides details of 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 were examined to 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 was also used to help better understand salt dynamics in Lake Albert and provide an initial evaluation of the proposed management options.

The report contains:

- 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.

- 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 of the report.
- 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.
- A description of important features of a numerical model that would be required to accurately quantify the five management options. The report 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.
- A summary of key investigation outcomes and relevant conclusions and recommendations.
- Further relevant details of previous reports (including figures and summary tables).
- A review of the data available for future model scenarios and calibration exercises.

An initial assessment of the proposed management options indicated that:

- 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.

The report and a number of the references included in the report provide good background to the key hydrodynamic processes and environmental drivers of the Lower Lakes and Coorong system.

1.1.2 Lake Albert Salinity Reduction Study – Model Setup and Calibration Report (BMT WBM, 2013b)

The report details the model setup and also the achieved model calibration. The report shows that the model is capable of simulating observed salt exchange processes from Lake Albert and provides details of the TUFLOW-FV model software used in this study which should be referred to as necessary.

1.1.3 Lake Albert Salinity Reduction Study – Wind Mixing Investigation

As part of a broader study into potential management options (BMT WBM, 2013a) that can reduce salinity levels in Lake Albert, BMT WBM completed six hydrodynamic modelling simulations of the Murray Mouth, Lower Lakes and Coorong, to simulate the exchange of salt between Lake Alexandrina and Lake Albert due to wind mixing. Each run adopted a different wind and tide data series corresponding to the following water years (a water year was defined as the 12 months from 1st July):

- 2007-2008
- 2008-2009
- 2009-2010

- 2010-2011
- 2011-2012
- 2012-2013

By running the hydrodynamic model using wind and tidal conditions experienced in six different years, the variability in expected natural (baseline) lake water mixing was assessed. The complexity of system hydrodynamics and mixing meant that correlations between wind statistics and salt export from Lake Albert could not be made without the use of a hydrodynamic model. By assessing six recent years of wind data against the level of modelled salt (tracer) export and understanding of the variability of wind mixing and exchange was possible. The results showed that:

- 2008/09 winds and tides produced a low degree of salt export from Lake Albert; and
- 2010/11 winds and tides produced a high degree of salt export from Lake Albert.

1.1.4 Lake Albert Salinity Reduction Study – Model Scenario Schematisation and Initial Testing

This document details the model setup for the six different scenarios and also provides results of an initial 12 month simulation. An outline of the report is provided below in Section 1.2.

1.1.5 Lake Albert Salinity Reduction Study – Three Year Scenario Model Investigations

The report (BMT WBM, 2013c) details the evaluation of six proposed management options to reduce Lake Albert salinity, over a broad range of environmental conditions over a three year period.

The six management options evaluated in the study include:

a) **Base-Case** (i.e. do nothing)

b) **Lake Cycling Option 1** (a single +/- 0.25m Lake Level variation in November/December)

c) **Lake Cycling Option 2** (a single +/- 0.15m Lake Level variation in November/December)

d) **Dredge Narrung Narrows and Remove Causeway**

e) **Coorong Connector**

f) **Permanent Water Level Control Structure at Narrung**

The report provides a brief description of the model setup, base case and scenarios simulations. It includes detail of all the model boundary conditions including a description of the automated barrage approach and the models initial conditions (including 2 different initial salinity conditions). A brief description of the six different management options is also provided.

The report also details of the model results for 12 base case simulations used to gain an appreciation of the range of environmental conditions and outcomes that may occur. The 12 different base case simulations include a matrix of: 2 wind, 3 inflow and 3 evaporation conditions.

The report also provides details of the model results for the additional 30 scenario simulations used to evaluate the non “base case” scenario options. The 30 different scenario simulations are for a matrix of: 5 management options, 2 wind, 2 inflow and 2 evaporation conditions.

1.2 Structure of Report

An outline of the remainder of the report includes:

Section 2: provides a brief description of the model setup, base case and scenarios simulations. It includes detail of all the model boundary conditions including a description of the automated barrage approach and the model initial conditions. A description of the six different management options and how they were implemented/schematised by the model is also provided.

Section 3.1: provides a description of the available model results.

Section 3.2: provides details of the model results for the six scenario simulations.

Section 3.3: provides details of the model results for the additional sensitivity simulations. This includes an assessment of an additional Quarterly Lake Cycling options, a larger Coorong Connector and a number of different Permanent Narrung Structure options.

Section 4: provides a summary and discussion of the study findings.

2 Model Setup and Description of Scenario Simulations

2.1 Model Configuration

The model comprises a combination of hydrodynamics (TUFLOW-FV), waves (SWAN) and morphology (TUFLOW-MORPH) components as described in the model calibration report (BMT WBM, 2013b). The calibration report describes the extents, configuration and interactions between the model components as well as how the barrages are numerically represented by the model.

The use of automated barrage logic, which allows a target Lake water level to be specified instead of a pre-defined sequence of barrage openings, has been used in these scenario simulations. This is an important feature of the model simulations and is further discussed in Section 2.4.8.

2.2 Model Schematisation of Six Management Options

The model was used to evaluate the influence of six potential management options on salinity reduction in Lake Albert.

The six management options included in the study include:

a) **Base-Case –** This represents the “do nothing” option and assumes typical lake operations.

b) **Lake Water Cycling/Manipulation –** This option involves no capital expense or physical structure but involves the deliberate manipulation (lowering and raising) of water levels to enhance the natural export of salt from Lake Albert. In this lake cycling option there is a single large (+/-0.2 m) deliberate change in lake levels that occurs in December through March.

c) **Dredge Narrung Narrows –** This option involves increasing the channel conveyance of the narrow straight (Narrung Narrows) between Lake Alexandrina and Lake Albert. This scenario involves significant dredging of the channel, including the removal of 5-6 million m^3 of sediment to create a channel that is a minimum 200 m wide, with an invert of -2 m AHD that runs for approximately 12 km between the two Lakes.

d) **Remove Narrung Causeway –** This option involves the removal of the causeway at the ferry crossing at Narrung.

e) **Coorong Connector –** This option involves constructing a channel connecting the southern part of Lake Albert to the Coorong North Lagoon. The channel assessed in this scenario is approximately 2 km long, 15 m wide with an invert of -1 to -1.5 m AHD and is able to convey approximately 1000 ML/day.

f) **Permanent Water Level Control Structure at Narrung –** This option involves the construction of a gated barrage structure across the Narrung Narrows so that flow between the lakes is able to be controlled.

More details of how the different management options were represented by the model is provided in Section 2.6.

2.3 Description of One Year Forecast Scenario Simulations

The adopted simulation period is a one year duration nominally defined as 18th April, 2012 to 18th April, 2013 though the use of "design" conditions mean that it is just a one year simulation using a "design" boundary conditions and initial conditions observed on the 18th April, 2012. The adopted "design" boundary condition is considered to be a fairly typical environmental condition that should give a reasonable indication of what water level and salt concentrations are likely to be over a twelve month period in the Coorong and Lower Lakes if a given management option is adopted.

A "design" condition is often used by engineers or scientists to help evaluate and quantify a potential outcome. The "design" condition is often a synthetic dataset that has similar characteristics to observed data.

2.4 Boundary Conditions for Scenario Simulations

Boundary conditions are used to "drive" model simulations. A range of "design" conditions and historically observed datasets were used in the scenario simulations. The "design" conditions are the same as used in BMT WBM (2012b) allowing us to compare these simulations with those already examined in the previous study.

Boundary condition data used for the model scenario runs included:

- 50% AEP Lake inflows (refer Section 2.4.1);
- Average "typical" (1996) direct net rainfall – evaporation (refer Section 2.4.2);
- Pelican Point wind speed and direction data for 2008/09 (refer Section 2.4.3);
- Offshore (Victor Harbour) water levels (tides) for 2008/09 (refer Section 2.4.4);
- Offshore wave data for 2008/09 (refer Section 2.4.5);
- Observed 2011/12 Salt Creek flows (refer Section 2.4.6);
- Average (1996) Finniss and Currency Creek catchment inflows (refer Section 2.4.7); and
- Target lake water levels and barrage opening rules (refer Section 2.4.10 & 2.4.11).

2.4.1 River Murray Inflows

Forecast flow data for Wellington was applied as an inflow just upstream of where the River Murray flows into Lake Alexandrina. The flow forecast uses a hydrologic model (BIGMOD) to predict inflows based on current forecast conditions and 50% AEP forecast flows (Figure 2-1). A total of 7088 GL inflow to the Lakes occurs in the 12 month base case scenario. An assumed constant salinity of 0.25 ppt (416 µS/cm) was adopted at the boundary.

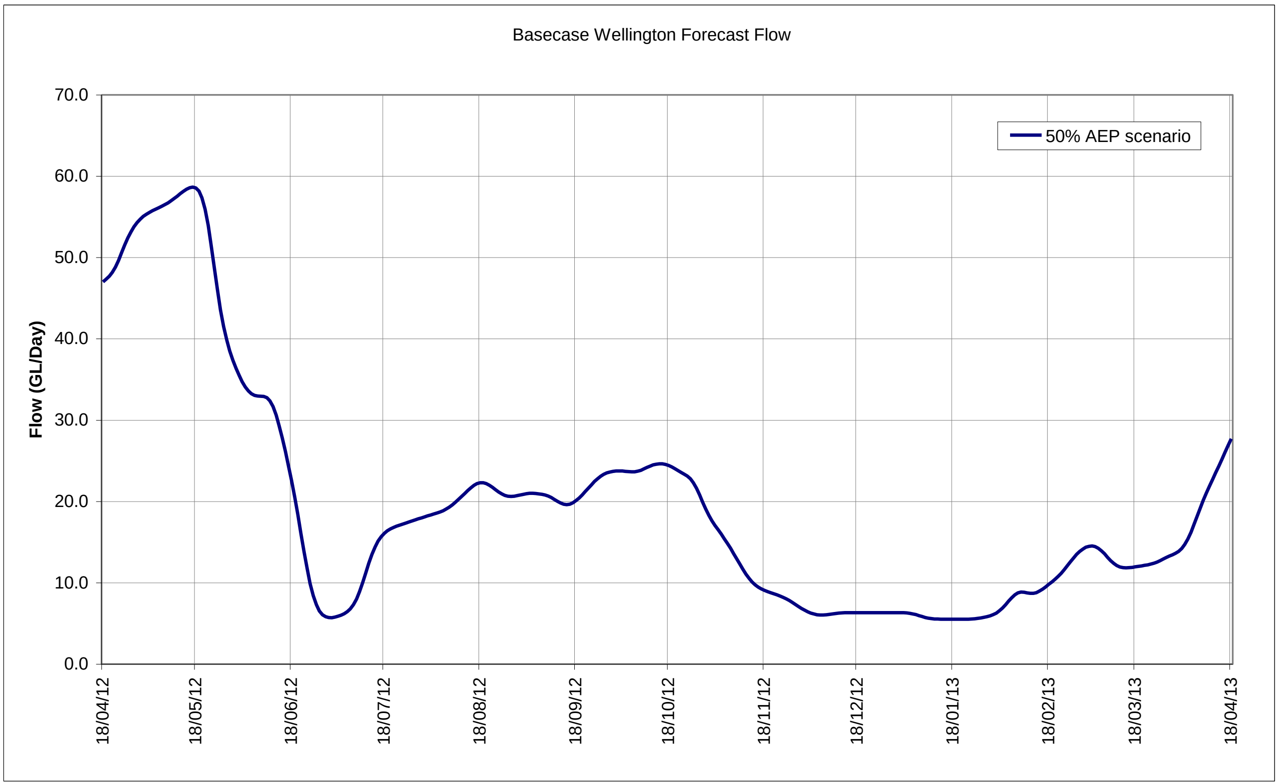


Figure 2-1 Wellington Inflow Data

2.4.2 Net Rainfall – Evaporation

Net evaporation is a key driver of salt dynamics in the Lower Lakes and Coorong. For the scenario simulations, typical, average monthly net evaporation rates (as supplied by DfW (now part of DEWNR) and described in BMT WBM (2011i)) were applied to the surface of the model.

The net evaporation data used in the scenario model simulations can be seen in Figure 2-2. Positive values represent net evaporation and indicate a removal of water from the system. Using the South Australian Department for Water (DfW) monthly averaged time-series a total of 975 mm of evaporative loss occurs over the year.

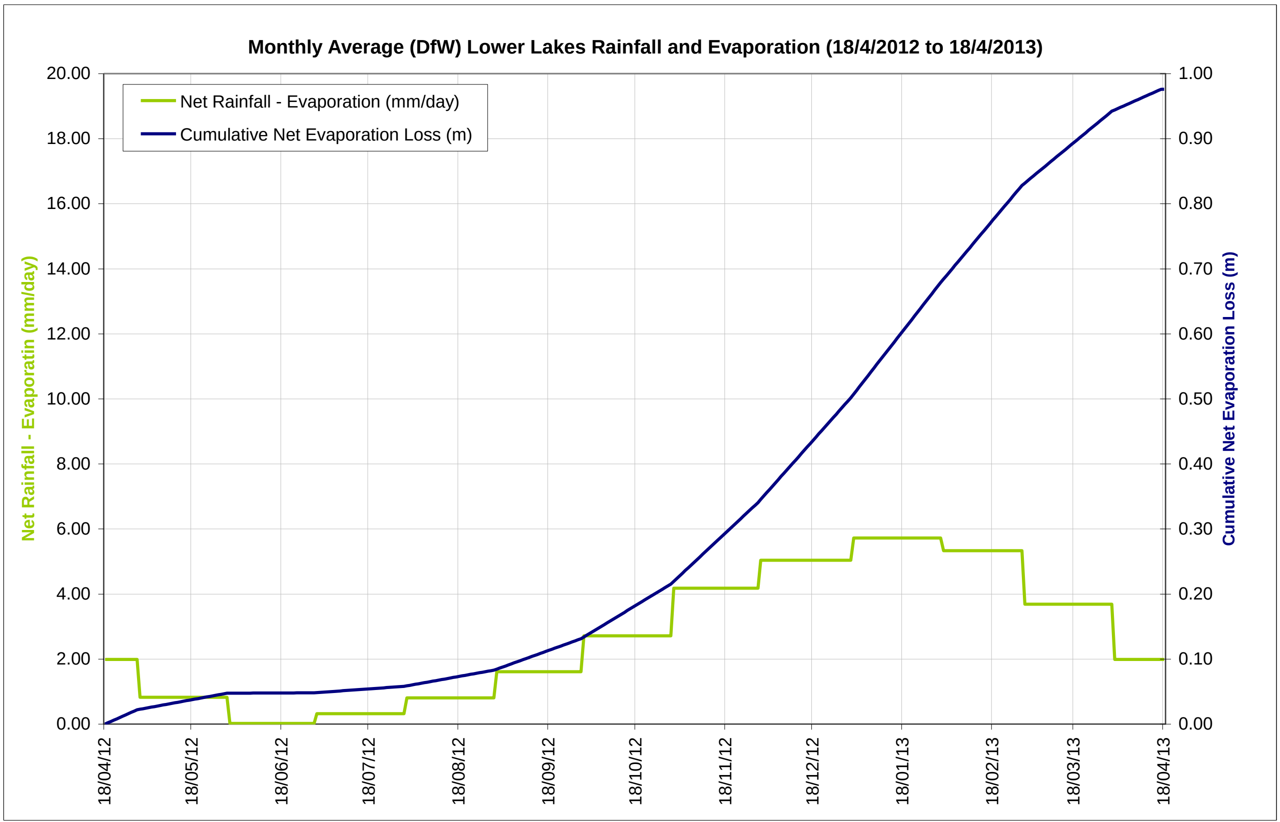


Figure 2-2 Lower Lakes Rainfall and Evaporation Data

2.4.3 Pelican Point 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 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). The gauge is located just to the east of Tauwitchere Barrage between the North Lagoon and the southern part of Lake Alexandrina.

For base case scenario simulations, actual wind data recorded during between 18/4/2008 and 18/4/2009 was used as presented in Figure 2-3.

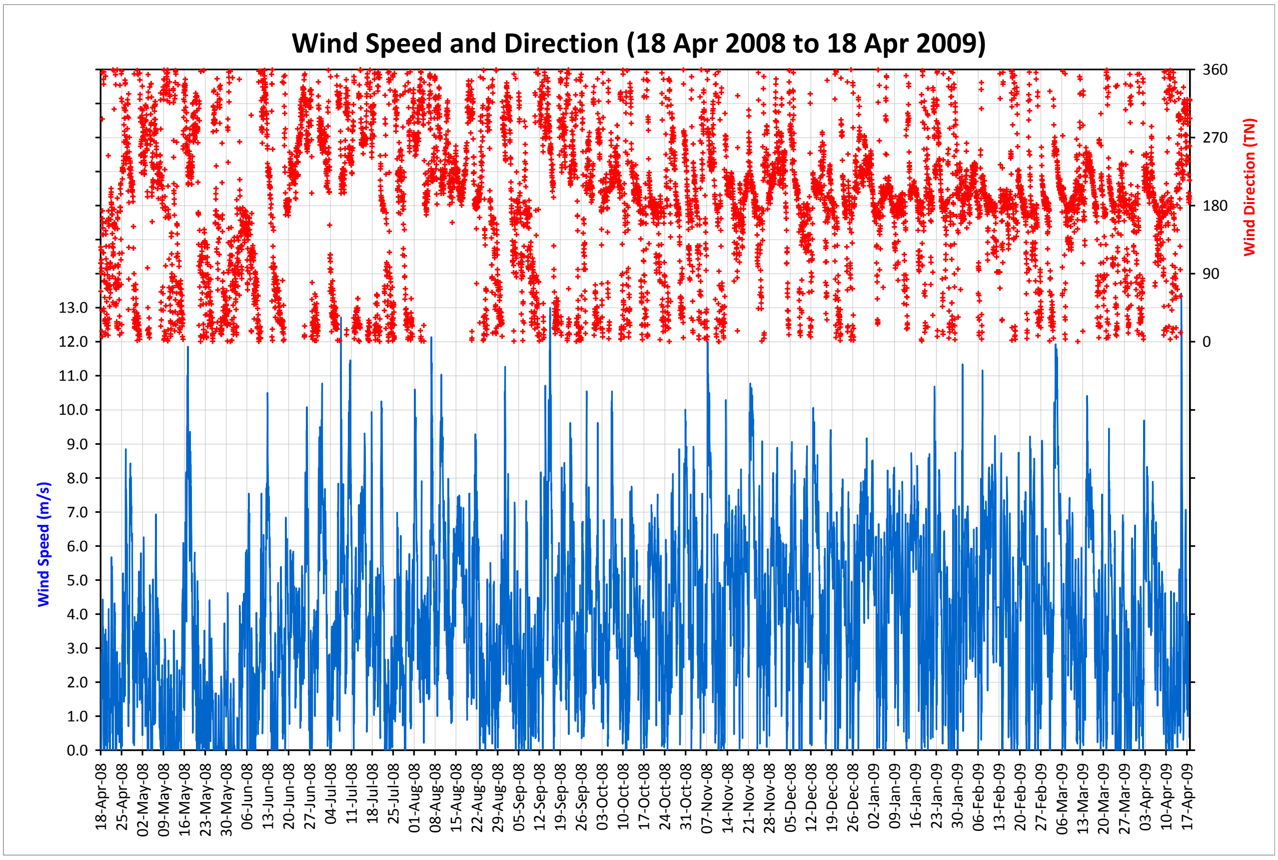


Figure 2-3 Pelican Point Wind Speed and Direction

2.4.4 Victor Harbour Tides

A time-series of tidal water levels is required to drive the offshore water level boundary of the hydrodynamic model. The observed Victor Harbor tidal water levels for 18/4/2008 to 18/4/2009 were used in the base case scenario simulation and are presented in Figure 2-4. During the simulation period a number of significant tidal anomaly events were observed. A comparison of the observed tidal anomaly to observed wind data shows a strong correlation between high wind events and tidal anomaly.

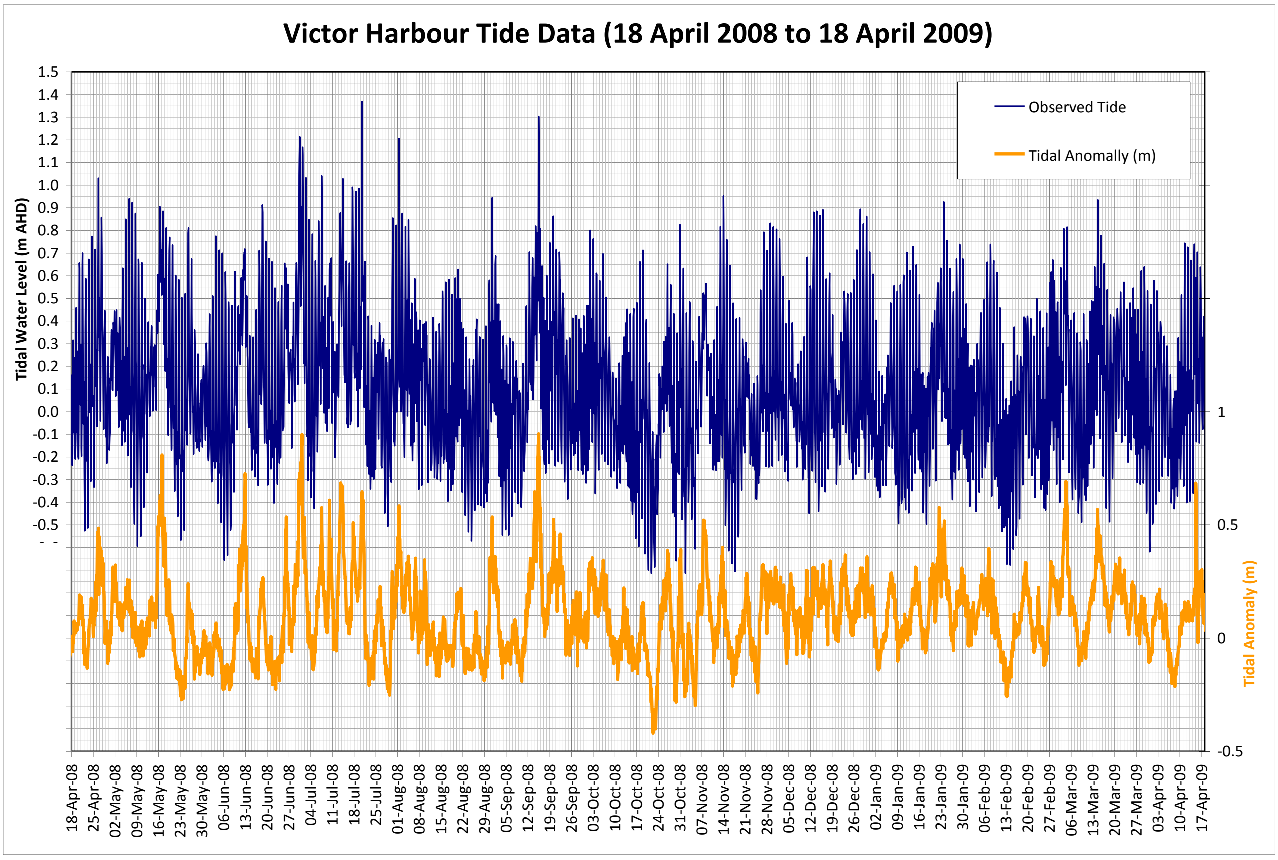


Figure 2-4 Victor Harbour Tidal Water Level Data

2.4.5 Offshore Wave Data (BMT ARGOSS)

Modelled wave information for a location offshore of Kangaroo Island (37° S, 136° 15' E) some 280 km south-west from the Murray Mouth was obtained from BMT ARGOSS for 1/7/2008 to 1/7/2013 at a 3-hour time interval. The BMT ARGOSS modelled wave data was extracted from a regional WAM III wave model with a grid resolution of 1.25° (longitude) x 1.00° (latitude) driven by wind fields from the NCEP final analysis.

These wave data were used as input to a SWAN wave model as described in BMT WBM (2013b). The wave model calculates characteristics of the wave field near the mouth, including wave heights, directions, periods and forces.

Wave conditions at the Murray Mouth provide a relatively minor direct contribution to overall hydrodynamics for the Coorong and Lower Lakes. Waves have a significant role in affecting bathymetric change at the Murray Mouth which can significantly influence hydrodynamics within the Coorong (especially the Mouth area and North Lagoon). However, given the reasonable flows present during the simulation period, the Murray Mouth was not at risk of significant constriction or closure.

2.4.6 Salt Creek Inflows

Base case salt creek inflow data was provided by DEWNR and is based on observed data from 18/4/2011 to 18/4/2012 as presented in Figure 2-5. Total inflow over this period is 24.97 GL which carries 167,085 tonnes of salt into the South Lagoon. The majority (~22 GL) of this flow occurs in August and September while a further 3 GL occurs between mid-February to mid-March.

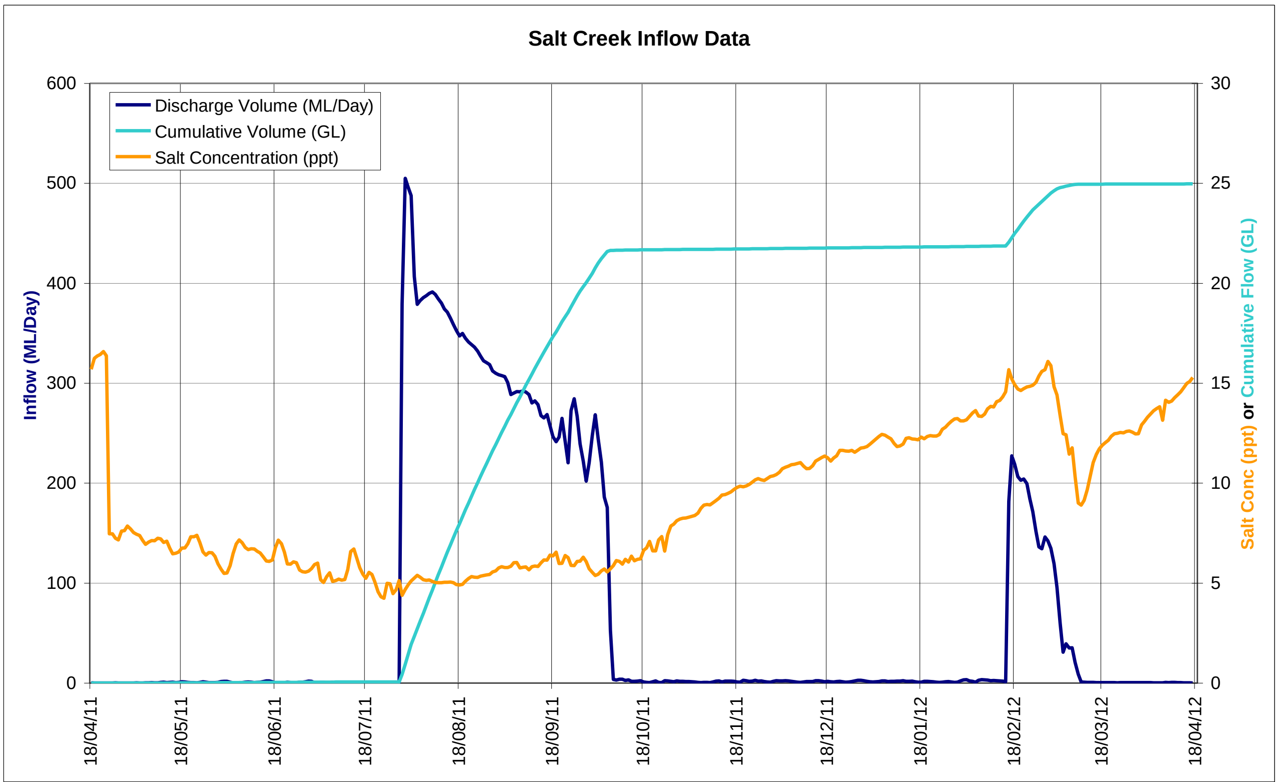


Figure 2-5 Salt Creek Inflow Data

2.4.7 Catchment Inflows

The daily time series of flow rates for Finniss and Currency Creeks were extracted from the existing catchment (E2) model of the Murraylands region, which was developed for the EPA by BMT WBM. Average (1996) rainfall conditions were applied to the catchment model to calculate a daily time series of catchment inflows. The time series of inflow and salinity into the Finniss River and Currency Creek are presented in Figure 2-6. The time-series correspond to a total annual inflow of 53.7 GL and 8.2 GL for the Finniss and Currency catchments respectively.

Due to the moderate River inflows during the simulation period, catchment inflows will have a negligible influence on model results.

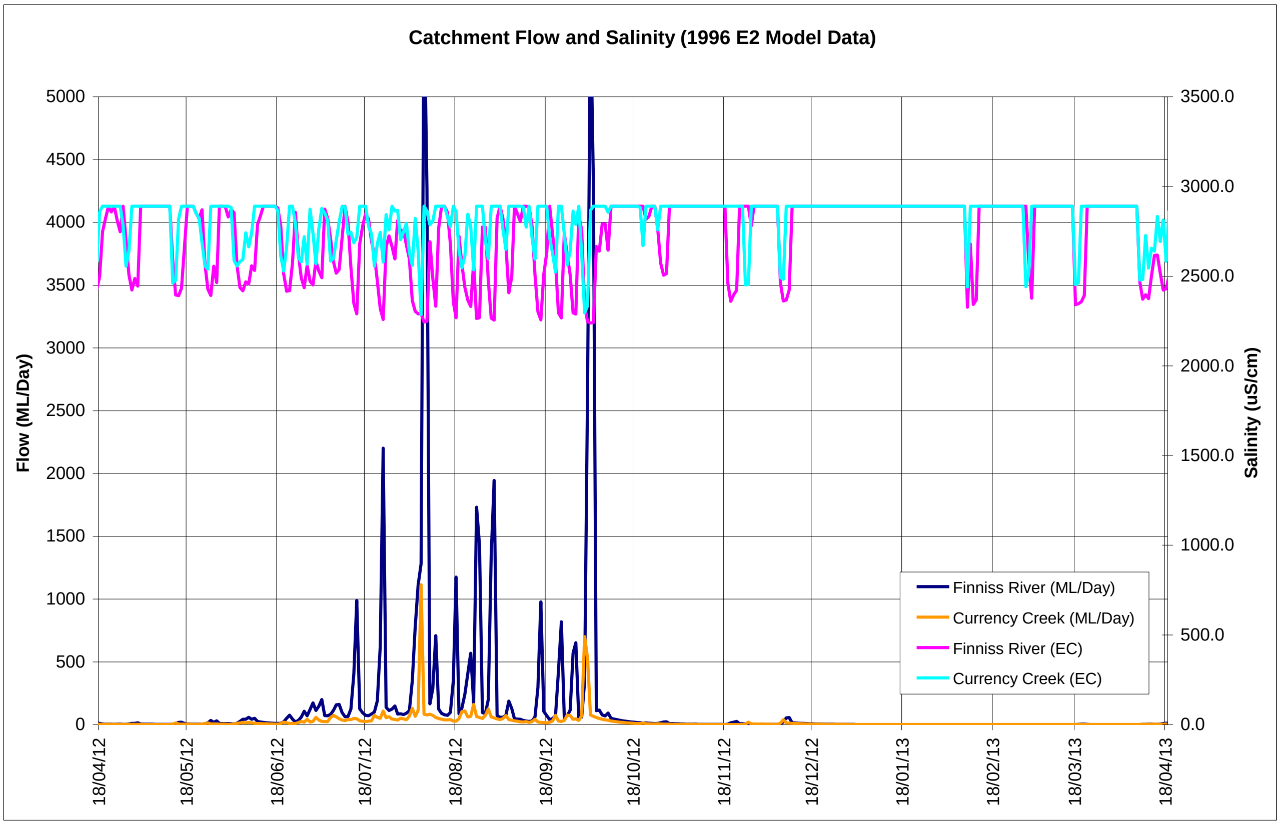


Figure 2-6 Finniss and Currency Creek Inflow Data

2.4.8 Use of Automated Barrage Opening Logic and Target Lake Water Levels

It is important to recognise the use of automated barrage / gate management logic in these scenario simulations. 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 to 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.

For the scenario simulations it may have been possible to calculate and apply a specified flow rate at the barrages, however, such an approach does not consider the impact of downstream water levels blocking barrage discharge and cannot simulate periods of reverse flow across the barrages.

The use of automated barrage logic (a relatively new feature in TUFLOW-FV) and a time-series of target lake water levels allows for more realistic scenario simulations to be modelled. The automated barrages work by comparing modelled water levels through the simulation in the Lake to a time-series of target lake water levels (see Section 2.4.10). Every 6 hours, the model calculates what the predicted water level in the Lake is, compares it to the time-series of target lake water levels and calculates a water level deficit (see Equation 1). This water level deficit is then compared to a set of rules for each of the barrages, which instruct the model how many gates at each barrage should be opened for a given water level deficit (see Section 2.4.11).

Water Level Deficit = Predicted Model Lake Level – Target Lake Level (Equation 1)

Some examples of how the automated barrage logic works are given below:

- If the water level deficit increases (i.e. the predicted model lake level starts to rise above the target lake level), then more barrage gates are opened up, which should increase barrage discharge and reduce the lake level back towards the target lake level.
- If the water level deficit begins to decrease (i.e. the predicted model lake level starts to approach the target lake level), then barrage gates are closed, reducing barrage discharge so that the modelled water level begins to approach the target water level.
- If the modelled lake level is below the target water level, then eventually all the barrage gates will be closed so that the lake level should rise until the target lake level is achieved.

2.4.9 Adopted Model Barrage Structures

Table 2-1 summarises the adopted hydraulic properties used in the model. A description of the numerical implementation of the barrage discharge calculations are provided in BMT WBM (2013b).

The management target water levels used in the scenario simulations are presented in Section 2.4.10, while the adopted barrage operation rules are presented in Section 2.4.11.

Table 2-1 Adopted Hydraulic Properties for Barrages

Barrage	Full Opening Width	Sill Level
Goolwa	458.4m (128 gates)	-0.45 m AHD (two logs removed)
Mundoo	90m (26 gates)	-1.0 m AHD
Boundary Creek	21.5m (6 gates)	-1.0 m AHD
Ewe Island	431.35m (121 gates)	-0.05 m AHD
Tauwitchere	1251.3m (322 gates)	-0.05 m AHD

2.4.10 Target Management Lake Water Levels (Barrage Openings)

A time-series of target management lake water levels is required for use with the automated barrage opening logic, which was adopted for use in the scenario simulations. The time-series of target water levels was provided by DEWNR for use in BMT WBM (2012b) and is presented in

Figure 2-7. It was used in conjunction with barrage operating rules (see Section 2.4.11) to determine actual barrage gate openings used by the model.

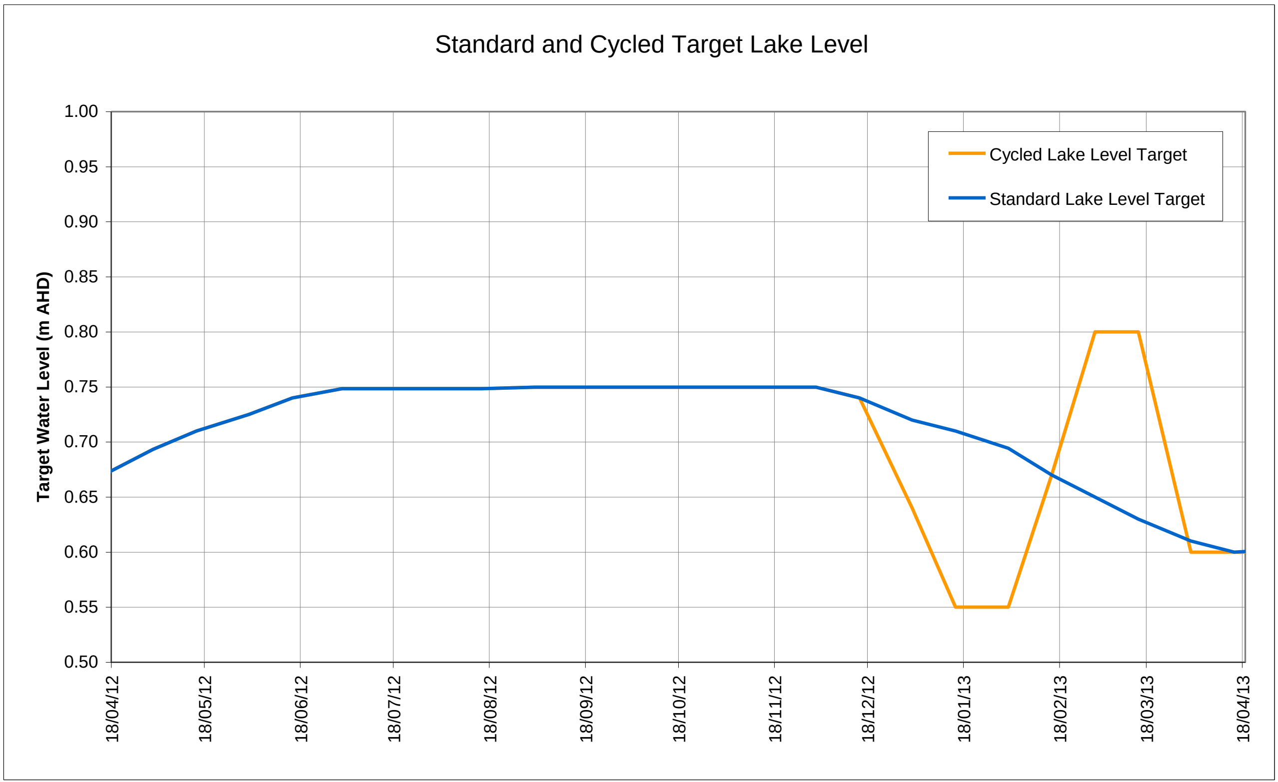


Figure 2-7 Standard and Cycled Target Lake Water Levels

2.4.11 Adopted Barrage Operating Rules

The use of the automated barrage logic requires a target water level (as defined above) and a set of gate operational rules that relate a water level deficit to a number of gates that should be open. The gate opening logic as defined in Table 2-2 was adopted for the base case scenario simulation. The table defines the proportion of total gates that should be opened for a given water level deficit (see definition provided in Section 2.4.8). These gate opening rules were used for all scenario simulations.

Table 2-2 Adopted Gate Opening Rules for Barrages

	Proportion of Total Structure Length Open				
WL Deficit (m)	**Goolwa**	**Mundoo**	**Boundary Creek**	**Ewe Island**	**Tauwitchere**
-0.05	0	0	0	0	0
-0.02	0.05	0.05	0	0.05	0.05
0.00	0.1	0.1	0	0.1	0.1
0.01	0.2	0.2	0.167	0.2	0.2
0.05	0.5	0.5	0.167	0.55	0.6
0.10	0.7	1	0.167	0.55	0.6
0.20	1	1	1	0.8	0.8
0.30	1	1	1	1	1

2.5 Model Initial Conditions

Initial conditions required by the model include:

- Water level;
- Salinity; and
- Murray Mouth bathymetry.

Details and assumptions for the derivation of initial conditions used for model scenarios are provided in the following sections.

2.5.1 Initial Water Levels

The initial water levels adopted in the base case scenario are based on an examination of DEWNR water level data for the 18th April 2012, as presented on the River Murray Data website, which provides water levels and salinity data in the Lower Lakes and Coorong. A degree of engineering judgement was applied to determine a representative water level for each water body as presented in Table 2-3.

Table 2-3 Initial Water Levels (18th April, 2012)

Water Body	Level (m AHD)
Lake Alexandrina	0.65
Lake Albert	0.68
North Lagoon	0.52
South Lagoon	0.51

2.5.2 Initial Salinity and Salt Mass

The initial salinity adopted for the base case and scenario simulations was based on:

- Salinity transect data collected in the Coorong on the 18th April, 2012;
- Salinity transect data collected in Lake Alexandrina and Albert on the 13th April, 2012; and
- DEWNR salinity data as presented on the River Murray Data website.

The model transect data (as presented in Figure 2-8) was used to generate a continuous digital surface of salinity using an inverse distance weighted (IDW) extrapolation method. In areas where no transect data was available, assumed salinities (based on DEWNR gauge data) were used to complete the initial conditions for the model. A map of the initial model salinity for the start of the simulation period (18th April, 2012) is presented in Figure 2-8.

Table 2-4 Initial Salinity Assumptions

Water Body	Salt Concentration (ppt)
Goolwa Channel	0.3
Murray Mouth Area	1.0
Offshore	35
End of South Lagoon	90 - 102

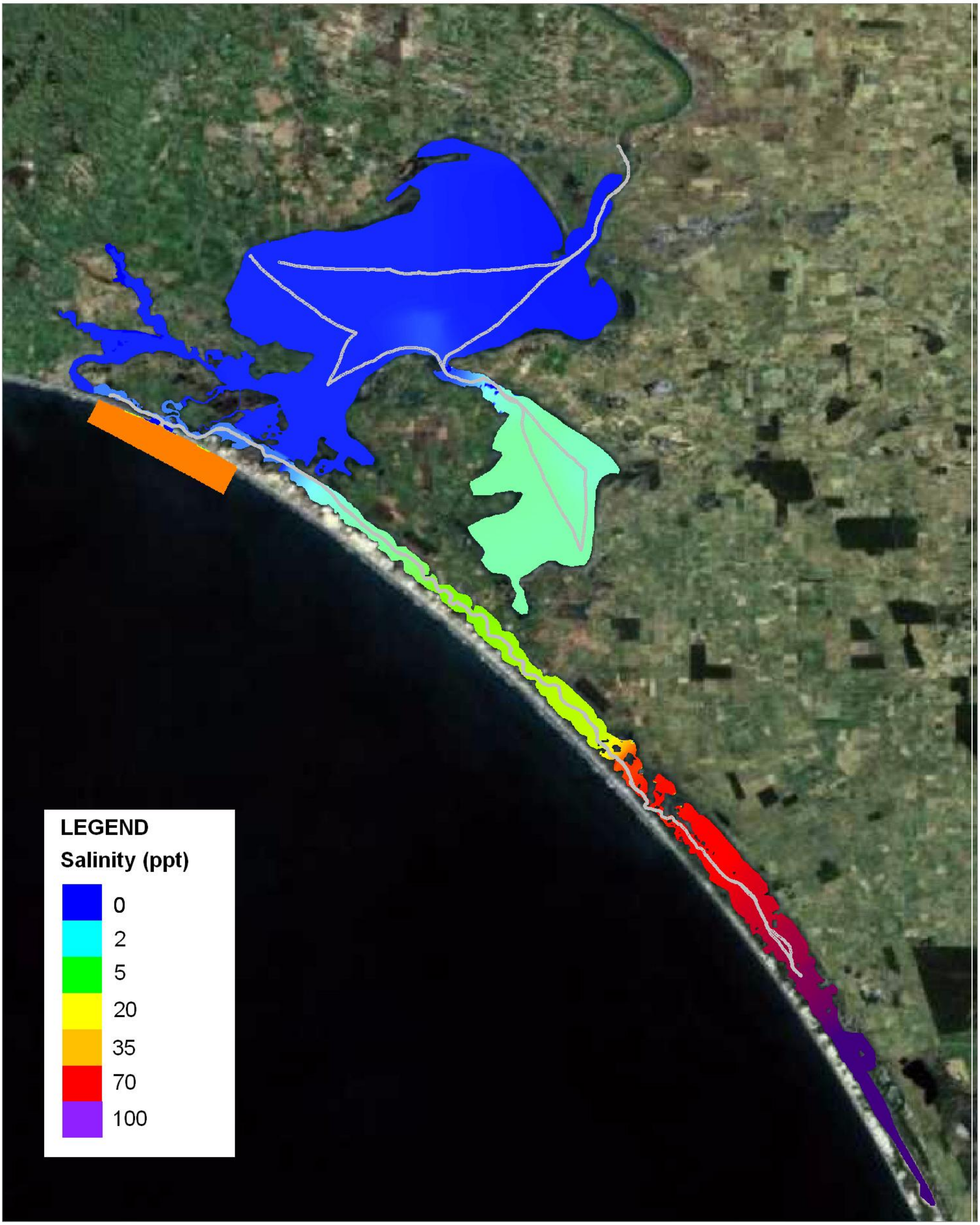
The initial mass of salt at the start of the simulation (18th April, 2012) is provided in Table 2-5. The mass was calculated by multiplying the concentration of each cell by the average cell depth and integrating the mass over each region. It shows that a significant mass of salt still resides in the South Lagoon.

Table 2-5 Approximate Initial Salt Mass (18th April, 2012)

Area	Salt Mass (Tonnes)
Lake Alexandrina	459,160
Lake Albert	757,820
Coorong (Total – Combined North and South Lagoon)	15,487,780
North Lagoon	1,189,710
South Lagoon	14,298,070

2.5.3 Murray Mouth Bathymetry

The model's initial Murray Mouth bathymetry for the base case and scenario runs are based on a bathymetric survey data collected by SA Water on the 3rd of April, 2012. As the bathymetry data does not extend offshore beyond the mouth, these data were combined with model predictions of offshore bathymetry taken from the latest model calibration run (see BMT WBM, 2012a), which provide indicative bathymetry for the 1st November 2011. A map of starting bed levels (for 18th April, 2012) for the Murray Mouth area is presented in Figure 2-9.



Title:
Initial Model Salinity (18 April, 2012) and Transect Locations

Figure: **2.8**

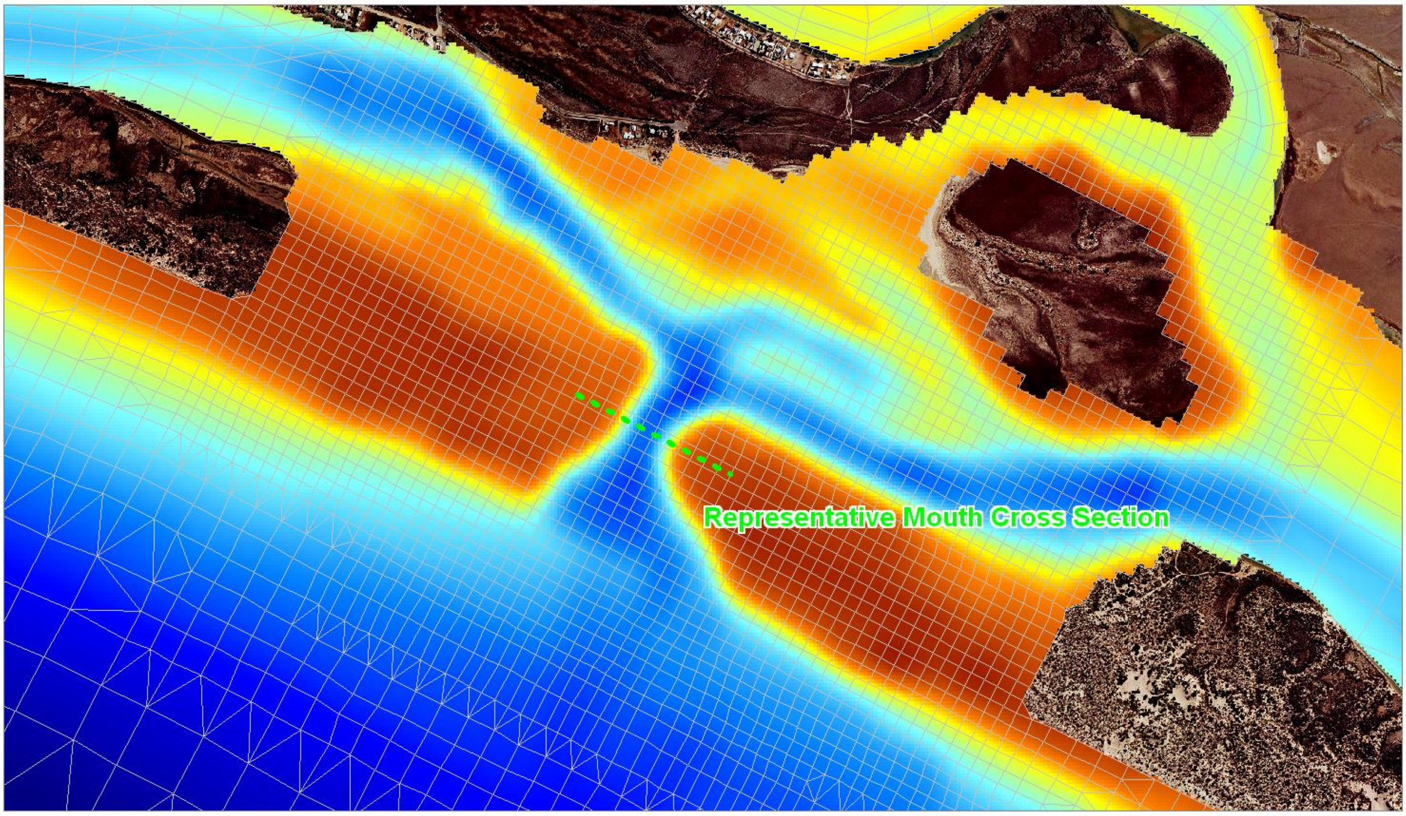
Rev: **A**

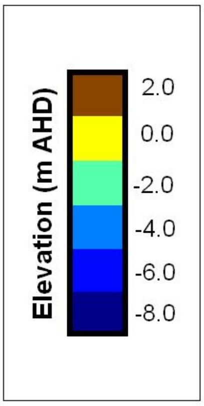
N

0 10 20km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N1874_CLLMM_FullyOpenedBarrageAssessment\docs\Figures\Base2012\Fig2_8_InitialModelSalinity18April2012.WOR





Title:

Initial Murray Mouth Model Bathymetry, 18 April 2012

Figure: **2.9**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N1874_CLLMM_FullyOpenedBarrageAssessment\docs\Figures\Base2012\Fig2_9_InitialMurrayMouthBathy18April2012.wor

2.6 Model Scenario Schematisation for Initial Assessment

Six different management options were schematised (represented by the model) including:

a) **Base-Case –** This represents the "do nothing" option and assumes typical lake operations.

b) **Lake Water Cycling/Manipulation –** This was represented in the model by applying a different target lake level time-series (see Figure 2-7). This time-series used in conjunction with the automated barrage logic (refer Section 2.4.8, 2.4.10 & 2.4.11) which would then close or open barrages so that the target lake level is realised in the model.

c) **Dredge Narrung Narrows –** This option involves increasing the channel conveyance of the narrow straight (Narrung Narrows) between Lake Alexandrina and Lake Albert. This scenario was represented in the model by applying a different (typically deeper) bathymetry along Narrung Narrows as presented in Section 2.6.2.

d) **Remove Narrung Causeway –** This option involves the removal of the causeway at the ferry crossing at Narrung, it was implemented in the model by altering the bathymetry in the vicinity of the Causeway.

e) **Coorong Connector –** This option involves constructing a channel connecting the southern part of Lake Albert to the Coorong North Lagoon. It was implemented in the model by altering the mesh to allow a connection between Lake Albert and the Coorong's North Lagoon. A barrage control structure was also specified to simulate a gate structure that could prevent backflow from the Coorong in Lake Albert. Channel and control structure details are presented in Section 2.6.3.

f) **Permanent Water Level Control Structure at Narrung –** This option involves the construction of a gated barrage structure at Narrung Narrows so that flow between the lakes is able to be controlled. It was implemented in the model using a range of nodestring structure elements as described in Section 2.6.4.

The scenarios were defined based on information provided in an email from DEWNR on 5th July, 2013 and include advice from SKM.

2.6.1 Model Mesh Development for Scenarios

The modular setup of TUFLOW-FV inputs enabled a single model mesh (see Figure 2-10) to be used for all model scenarios. Any of the six management scenarios can be developed with only minor changes to some of the model input files. The use of a single mesh also facilitates the comparison of results within SMS or EXCEL and only a single set of model initial conditions and boundary conditions was required.

The means that even though the mesh has elements that are used to represent the Coorong Connector channels (in this case to alternative locations have been included in the base mesh), the use of separate cell centre mesh elevation files can be used to specify which (or neither) channel is open as required.

Title:

TUFLOW-FV Management Scenario Mesh

Figure: **2.10**

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:\n20056_lakeAlbertFlushingStudy\docs\report_figures\1yrScenarios\Fig2_10_TuflowMesh.WOR

2.6.2 Details of Narrung Narrows Dredging Scenario

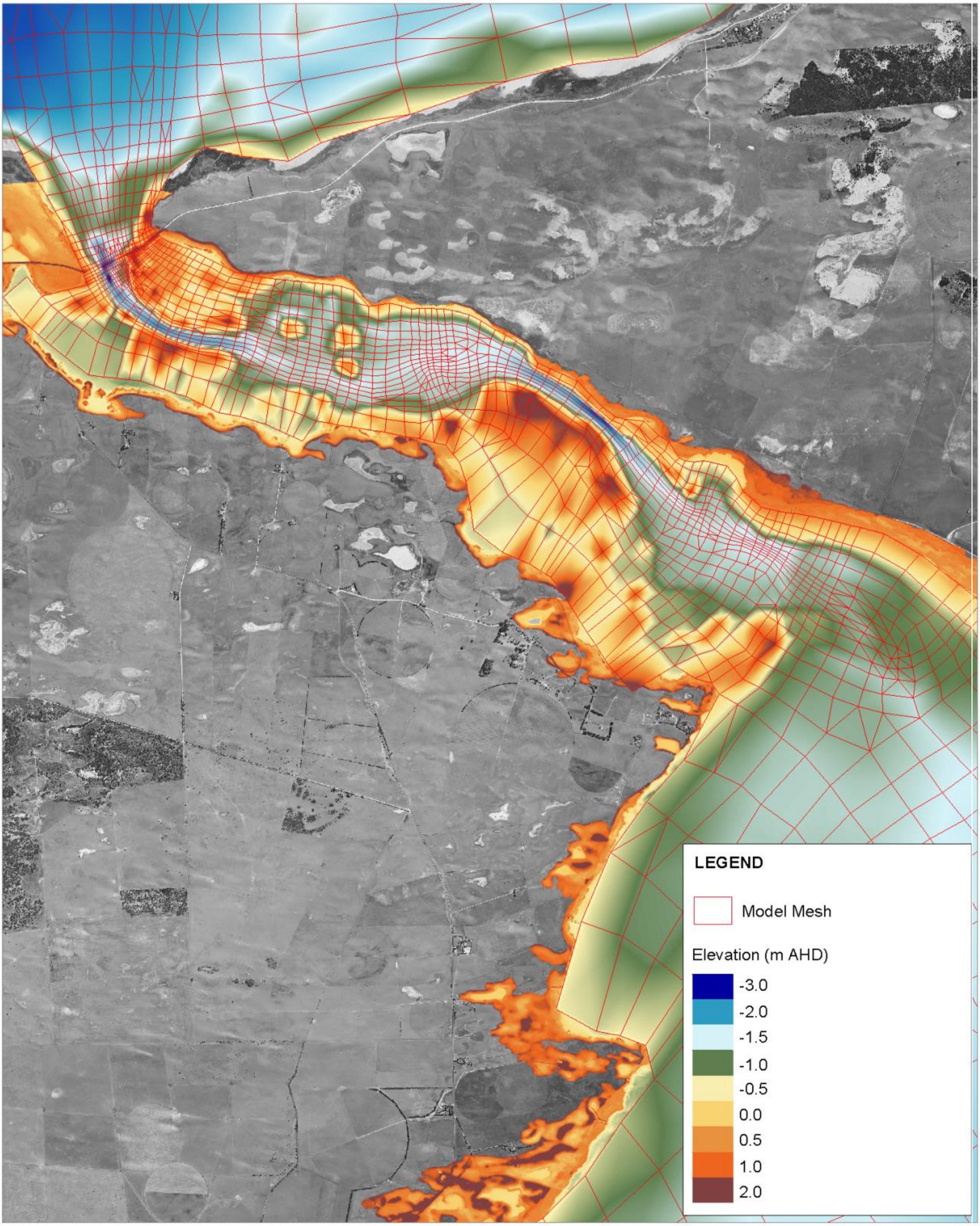
This option involves increasing the channel conveyance of the narrow straight (Narrung Narrows) between Lake Alexandrina and Lake Albert. This scenario involves significant dredging of the channel, including the removal of 5-6 million m^3 of sediment to create a channel that is a minimum 200 metres wide, with an invert of -2 m AHD that runs for approximately 12 km between the two Lakes. The existing bathymetry of the Narrung Narrows adopted in the Base Case (and other) simulation is presented in Figure 2-11, while the changed bathymetric data used in the Dredging scenario is presented in Figure 2-12.

2.6.3 Details of Coorong Connector Scenario

This option investigates the benefits of constructing a channel between the southern part of Lake to the Coorong North Lagoon. The channel assessed in this scenario is approximately 2 km long, 15 metres wide with an invert of -1 (Lake Albert) to -1.5 m AHD (North Lagoon) and is able to convey approximately 1000 ML/day. The adopted channel location is from Kennedy Bay in Lake Albert to Noonameena in the North Lagoon (see Figure 2-13).

A barrage control structure located midway along the channel was specified to simulate a gate structure that could prevent backflow from the Coorong in Lake Albert. The gate structure uses a nodestring, automated weir structure object (similar to that used for the Coorong Barrages (see Sections 2.4.8) with a -1.25 m AHD sill. The structure has been implemented to automatically (instantaneously) close to prevent reverse flow (i.e. flow from the Coorong into Lake Albert) occurring. The gate control is also implemented to stop lake levels falling significantly (currently set to -0.011 m) below target lake levels (as defined in Section 2.4.10).

Details of the achieved channel discharge are presented in Section 3.2.5.



Title:

Base Case Mesh Narrung Narrows Bathymetry

Figure: **2-11**

Rev: **A**

N

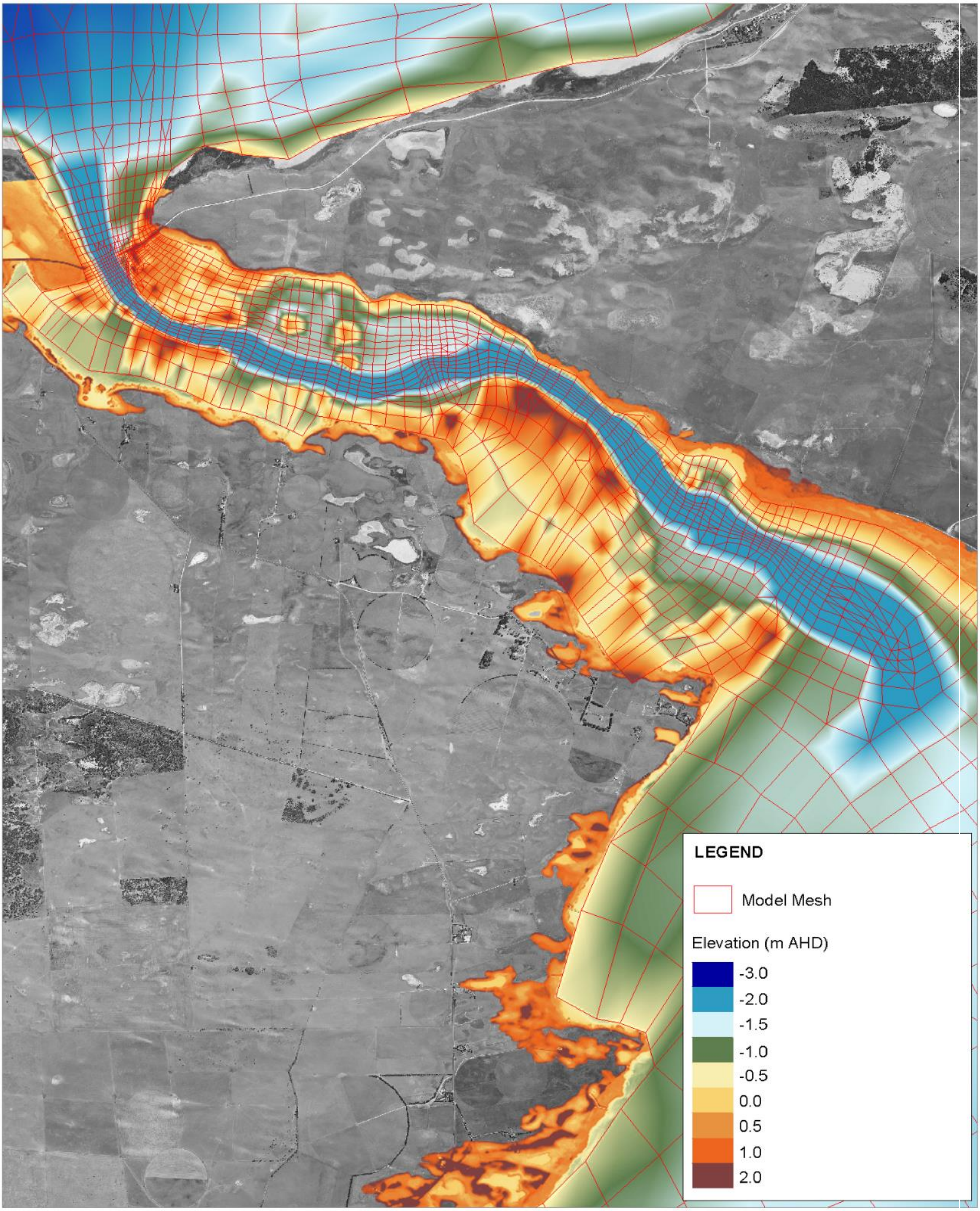
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\n20056_lakeAlbertFlushingStudy\docs\report_figures\1yrScenarios\Fig2_11_BaseCaseNarrungDEM.WOR



Title:

Dredged Mesh Narrung Narrows Bathymetry

Figure: **2-12**

Rev: **A**

N

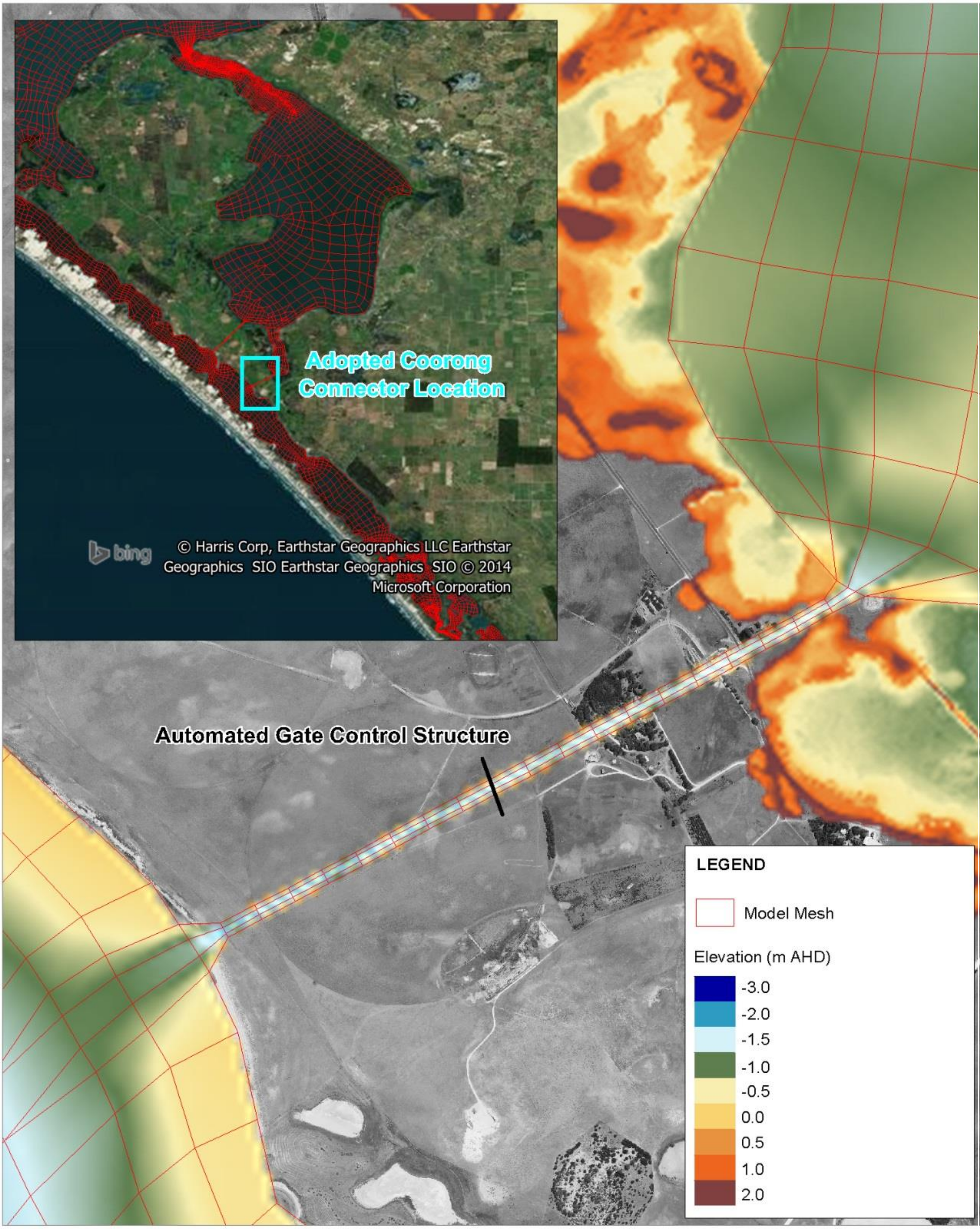
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\n20056_lakeAlbertFlushingStudy\docs\report_figures\1yrScenarios\Fig2_12_NarrungDredgingDEM.WOR



Title:
Schematisation of Coorong Connector

Figure: **2-13**

Rev: **A**

BMT WBM
www.bmtwbm.com.au

Filepath : K:\n20056_lakeAlbertFlushingStudy\docs\report_figures\1yrScenarios\Fig2_13_SchematisationOfCoorongConnector.WOR

2.6.4 Details of Permanent Narrung Control Structure

Advice from DEWNR/SKM indicated that the location of the permanent Narrung Control Structure would be an approximate 230 metre opening that is the route of the current car ferry service at Narrung. The control structure was considered to be similar to the existing automated hydraulic barrages at Tauwitchere with a sill level of between -2 to -1.5 m AHD. The proposed structure was implemented in the model using three nodestring structures including:

1) The existing causeway to the east of the channel;
2) A short ramp to the west of the channel; and
3) The 230 m long gated control structure with a -2 m AHD sill and a time series (see Figure 2-15 and Figure 2-16) specifying when the gates were open or closed.

The derivation of the gate opening, closure sequence is described in Section 3.3.3.

Figure 2-14 Proposed Location of Permanent Narrung Control Structure (Source: SKM)

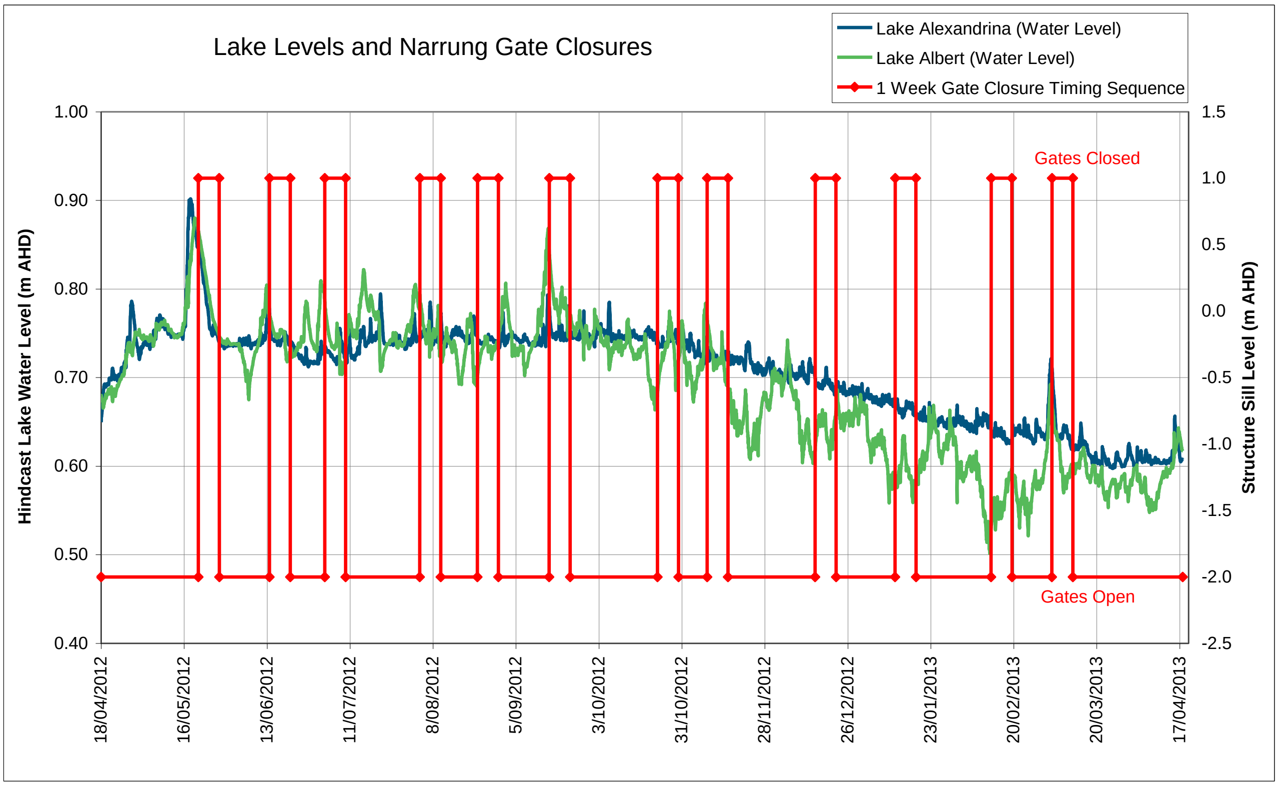


Figure 2-15 Narrung Control Structure One Week Gate Closure Sequence

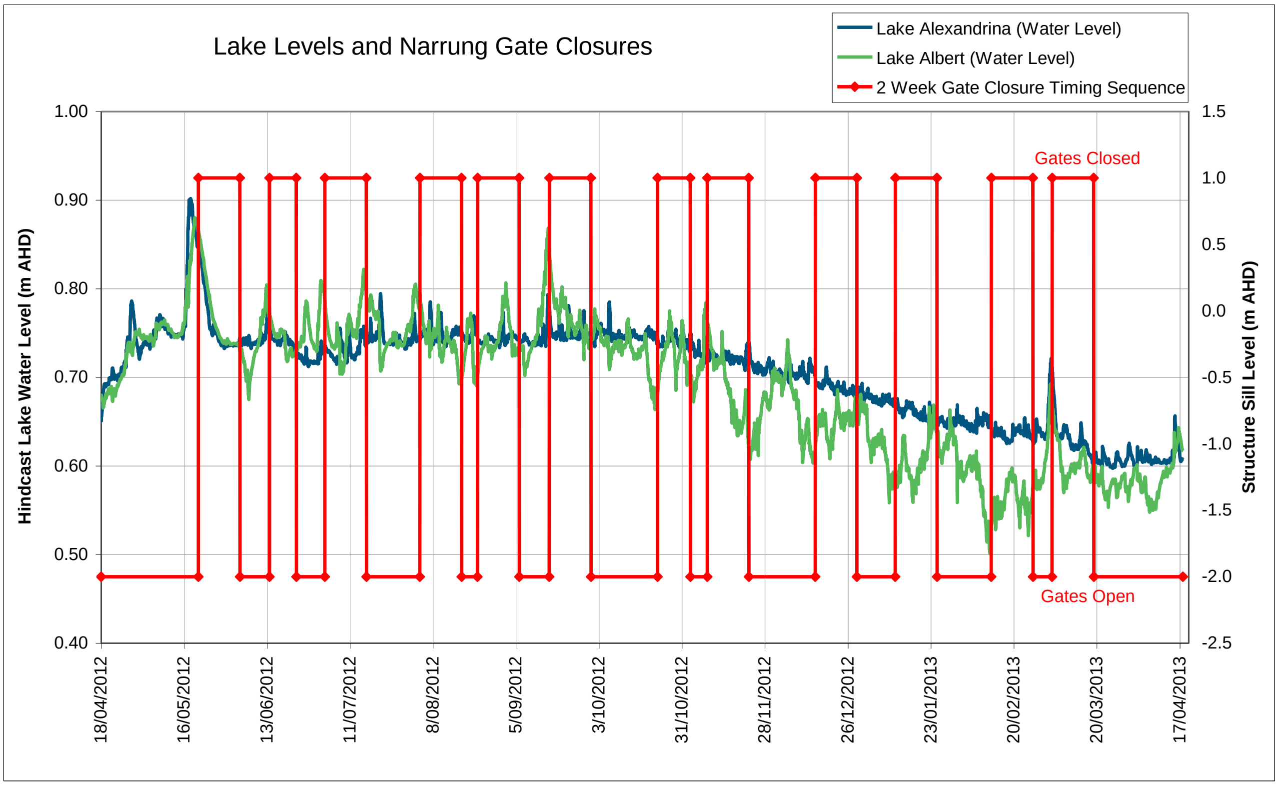


Figure 2-16 Narrung Control Structure Two Week Gate Closure Sequence

3 Model Output and Results

3.1 Description of Model Output

3.1.1 Water Level Output

Representative water levels for each of the four water bodies in the study region predicted by the model are presented below. The locations adopted for each of the water bodies are summarised in Table 3-1 and presented in Figure 3-1. By selecting locations near the centre of each of the water bodies the influence of wind setup is minimised. It is important to note that wind setup could create water level differences across the lakes of up to ±0.2 m in very strong (>10 m/s) winds.

Table 3-1 Summary of Output Locations

Water Body	Location
Lake Alexandrina	Centre (see Figure 3-1)
Lake Albert	Centre (see Figure 3-1)
Coorong – North Lagoon	Long Point (see Figure 3-1)
Coorong – South Lagoon	Woods Well (see Figure 3-1)

3.1.2 Salinity Outputs

Salinity results for the four key water bodies in the Coorong and Lower Lakes system are presented at the same output locations summarised above. The locations are broadly representative for salinity in each of the water bodies, although the presence of high longitudinal salinity gradients in the North Lagoon should be noted and results at the chosen location should be interpreted with caution. The locations adopted are fairly representative for each of the water bodies are summarised in Table 3-1 and displayed in Figure 3-1.

3.1.3 Water Volume and Salt Mass Change

TUFLOW-FV is capable of tracking the volume and mass (salt) flux between any cell in the model domain. This allows the presentation of flow (water movement) data and also the calculation of the total volume or salt mass change with time to be calculated.

Figure 3-1 Map of Model Output Locations

3.2 Comparison of Management Option Results

The following sections describe the results of the six different lake configurations or management options, which include:

a) Base Case (i.e. do nothing);

b) Remove Causeway;

c) Dredge Narrung Narrows;

d) Permanent Water Level Control Structure at Narrung;

e) Summer Lake Water Level Cycling; and

f) Coorong Connector.

The results presented in this Section for the Permanent Water Level Control Structure at Narrung Scenario adopt the -2 m AHD and always open sill configuration, which (as discussed in Section 3.3.3) is the most effective configuration for that scenario.

3.2.1 Water Levels

Modelled water levels for the six proposed management scenarios are presented in Figure 3-2 (Lake Alexandrina), Figure 3-3 (Lake Albert), Figure 3-4 (the North Lagoon (Long Point)) and Figure 3-5 (South Lagoon (Woods Well)).

Overall, modelled water levels in Lake Alexandrina (Figure 3-2) for the six scenarios closely match the target lake level, though during periods of low flow, the current barrage rules allow lake level to fall up to 10 cm below the target levels. Also, the influence of storm surges blocking barrage discharge and increasing lake levels can be observed in mid-May, 2012 and early-March, 2013. Lake levels for the five management options that use the same "standard" lake level target are nearly the same, while the influence of the summer lake cycle option is obvious.

In Lake Albert (Figure 3-3) modelled water levels are similar to those in Lake Alexandrina; however, the influence of wind seiche results in a greater water level fluctuation (up to 10 to 15 cm), and the differences in water levels between the management scenarios is more apparent. Water levels in Lake Albert for the Coorong Connector option are 1 to 2 cm below the base case water levels as slightly more water is transported into the Coorong than in the other options. The impact on water levels due to increase conveyance at Narrung for the Dredging scenario is apparent, and the influence of wind on water levels for the summer lake cycle can also be observed in the water level signal.

Water levels in the North Lagoon (Figure 3-4) and South Lagoon (Figure 3-5) are primarily driven by tides, winds and barrage discharge. The influence of the Coorong Connector option in raising water levels in the Coorong is marginally apparent, likewise the changes to barrage discharge required to implement the summer lake cycle option also influences Coorong water levels.

3.2.2 Salinity (Salt Concentration)

Modelled salinity levels for the six scenarios are presented in Figure 3-6 (Lake Albert), Figure 3-7 (Lake Alexandrina), Figure 3-8 (the North Lagoon (Long Point)) and Figure 3-9 (South Lagoon (Woods Well)).

The effectiveness of the six potential management options for salinity reduction in Lake Albert is presented in Figure 3-6 and summarised in Table 3-2. The results shows that the Coorong

Connector options is by far the most effective at reducing salinity in Lake Albert, with salinity levels dropping by approximately 60% from 4935 µS/cm to below 2000 µS/cm over a 12 month period. This compares favourably to the Base Case in which there is only an 8.1% reduction in salinity over the same simulation period. The Summer Lake Cycle scenario is the only other management option that results in a significant salinity reduction compared to the Base Case, with the single water level fluctuation being able to reduce salinity by 64% above the Base Case scenario.

The causeway removal option has minimal impact on lake system hydrodynamics or the salt dynamics of Lake Albert, i.e. it reduces the change to salt concentration relative to the Base Case (i.e. “Do Nothing”) scenario by less than 3%. A somewhat surprising outcome of the study is that dredging Narrung Narrows would be less effective in terms of salinity reduction in Lake Albert than the Base Case. Further discussion of the processes responsible for that result is presented in Section 3.2.4. The construction of a permanent gate structure with a -2 m AHD sill would reduce the salinity reduction potential of the Lake Albert by 25% compared to the Base Case. Any closure of the structure’s gates would further reduce the ability for salt to be exported (refer Section 3.3).

Table 3-2 Summary of Lake Albert Salinity Results

Scenario	Final Salinity (µS/cm)	Salinity Reduction (µS/cm)	Salinity Reduction (%)	% Comparison to Base Case
Base Case	4533.1	401.7	8.1	0.0
Remove Causeway	4522.7	412.1	8.4	2.6
Dredge Narrung	4575.2	359.6	7.3	-10.5
Permanent Structure (-2 m AHD Sill, Always Open)	4634.6	300.2	6.1	-25.3
Summer Lake Cycle	4274.8	660.0	13.4	64.3
Coorong Connector	1988.6	2946.2	59.7	633.4

There are minor differences in predicted salinity in Lake Alexandrina (Figure 3-7) between the six scenarios; with the Coorong Connector achieving a moderate reduction in Lake Alexandrina salinity as saltier water from Lake Albert is transported into the Coorong instead of mixing into Lake Alexandrina. The impact of a Summer Lake Water Level Cycle is also evident with salinity increasing in Lake Alexandrina as lake levels fall and saltier water from Lake Albert is transported into Lake Alexandrina.

The model predicts minor differences in salinity levels in the North Lagoon (Figure 3-8) and South Lagoon (Figure 3-9) for four of the six scenarios. For the Coorong Connector scenario, there is a significant reduction in peak salinity levels in the North Lagoon due to dilution and also a change to the water balance of the Coorong. In the South Lagoon, the impact of the Coorong Connector in reducing salinity is also evident as the reduced salt load results in a considerable drop in South Lagoon salinity by the end of the 12 month simulation. The Summer Lake Level scenario also changes salinity levels in the Coorong, due to changes in barrage discharge. That option can influence water levels and hence the salinity gradient along the Coorong, however, it will only have a minor impact on the overall salt load to the Coorong.

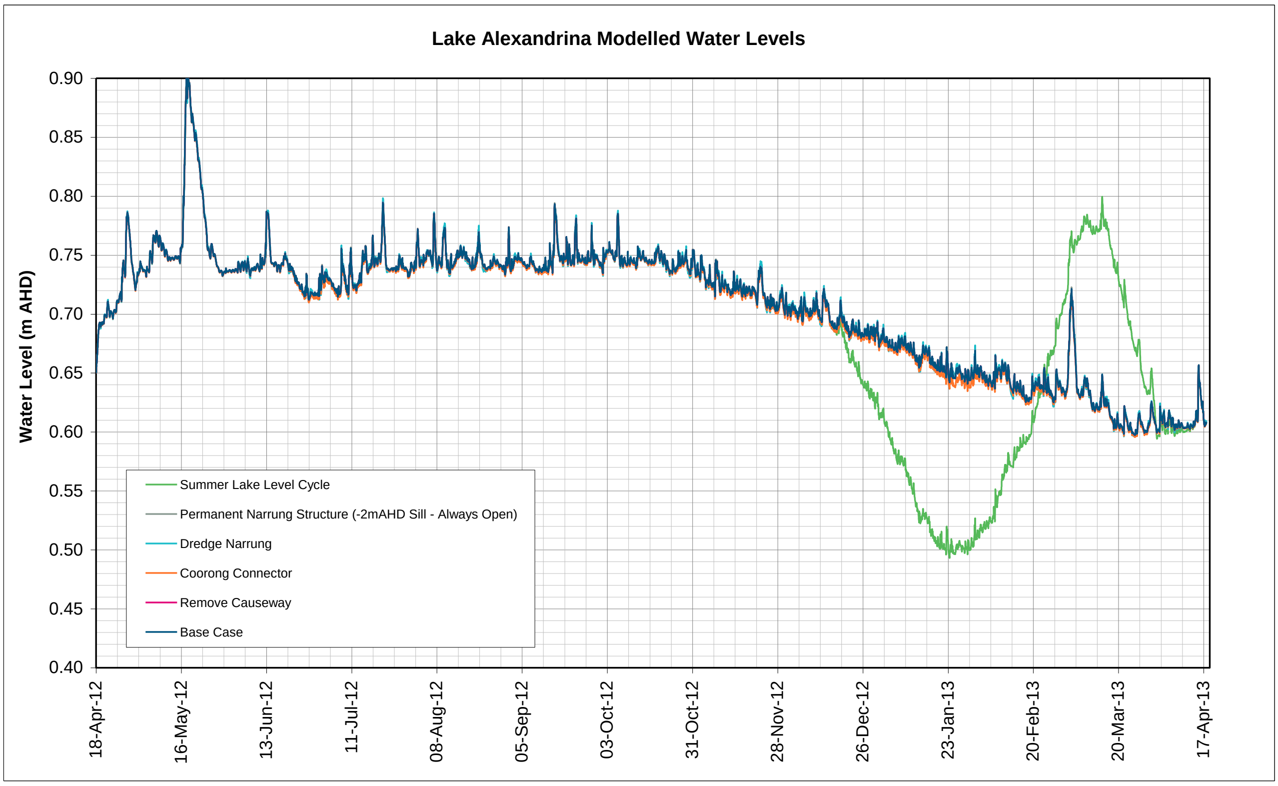


Figure 3-2 Modelled Water Levels in Lake Alexandrina for Proposed Scenarios

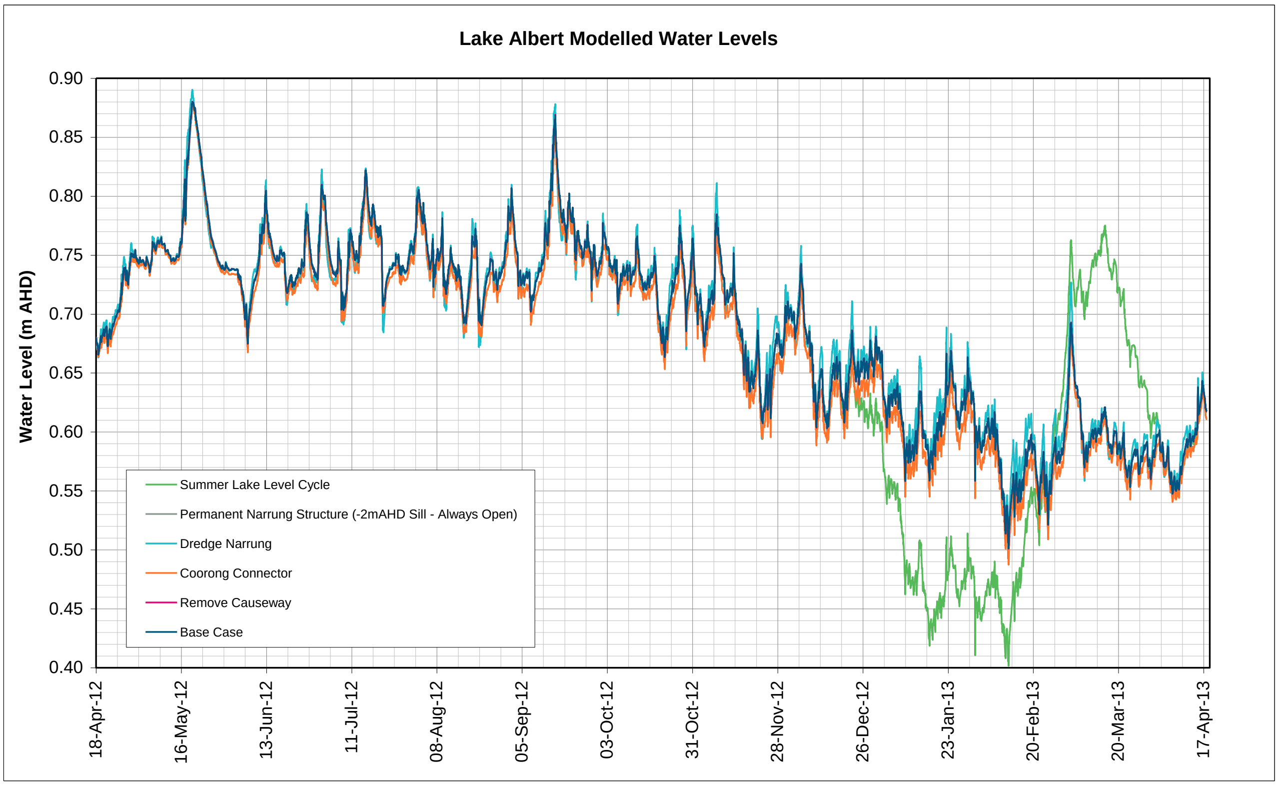


Figure 3-3 Modelled Water Levels in Lake Albert for Proposed Scenarios

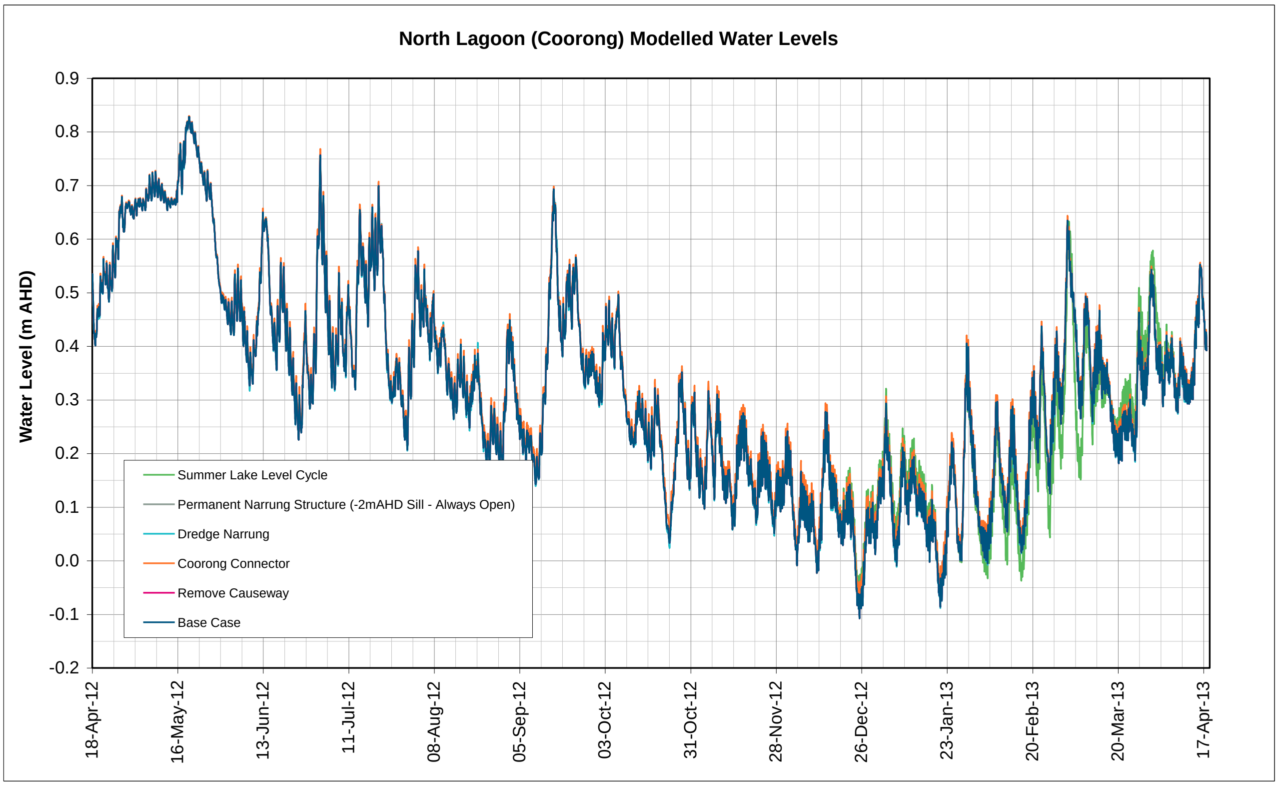


Figure 3-4 Modelled Water Levels in the North Lagoon for Proposed Scenarios

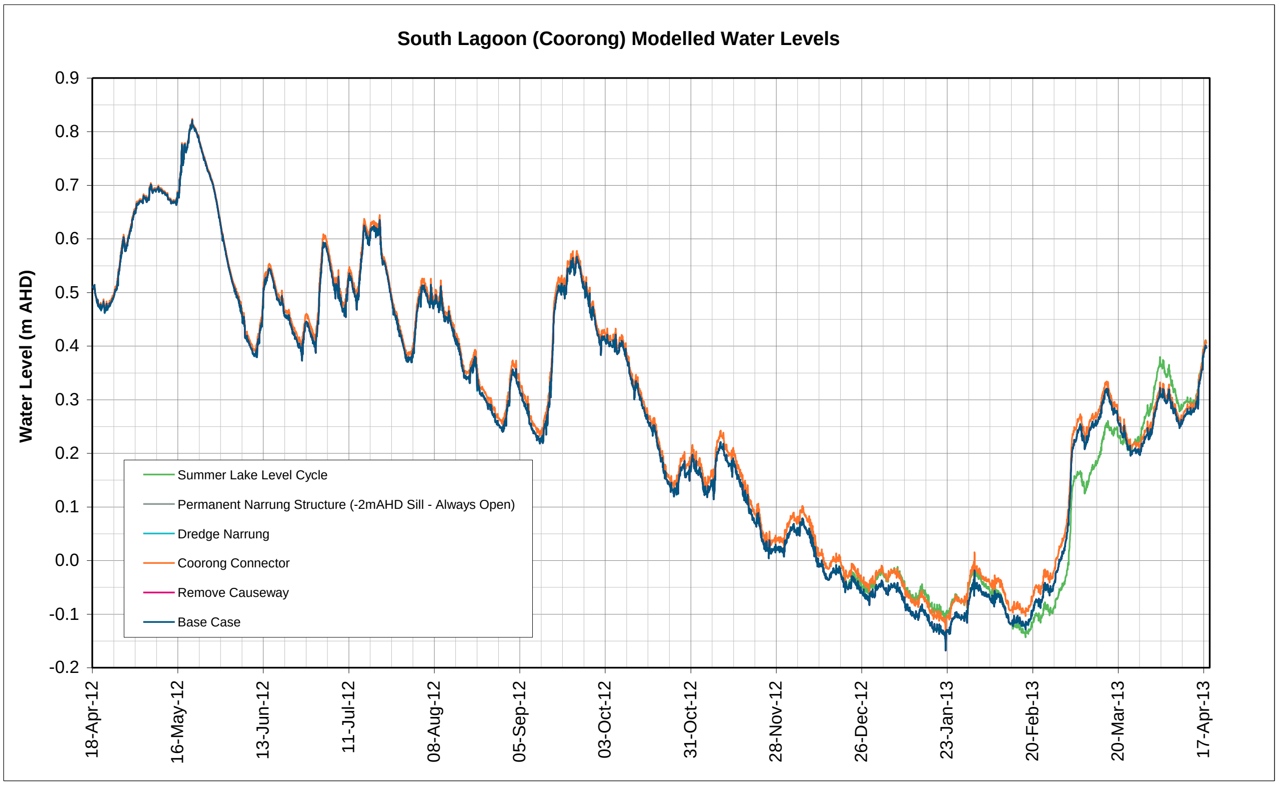


Figure 3-5 Modelled Water Levels in the South Lagoon for Proposed Scenarios

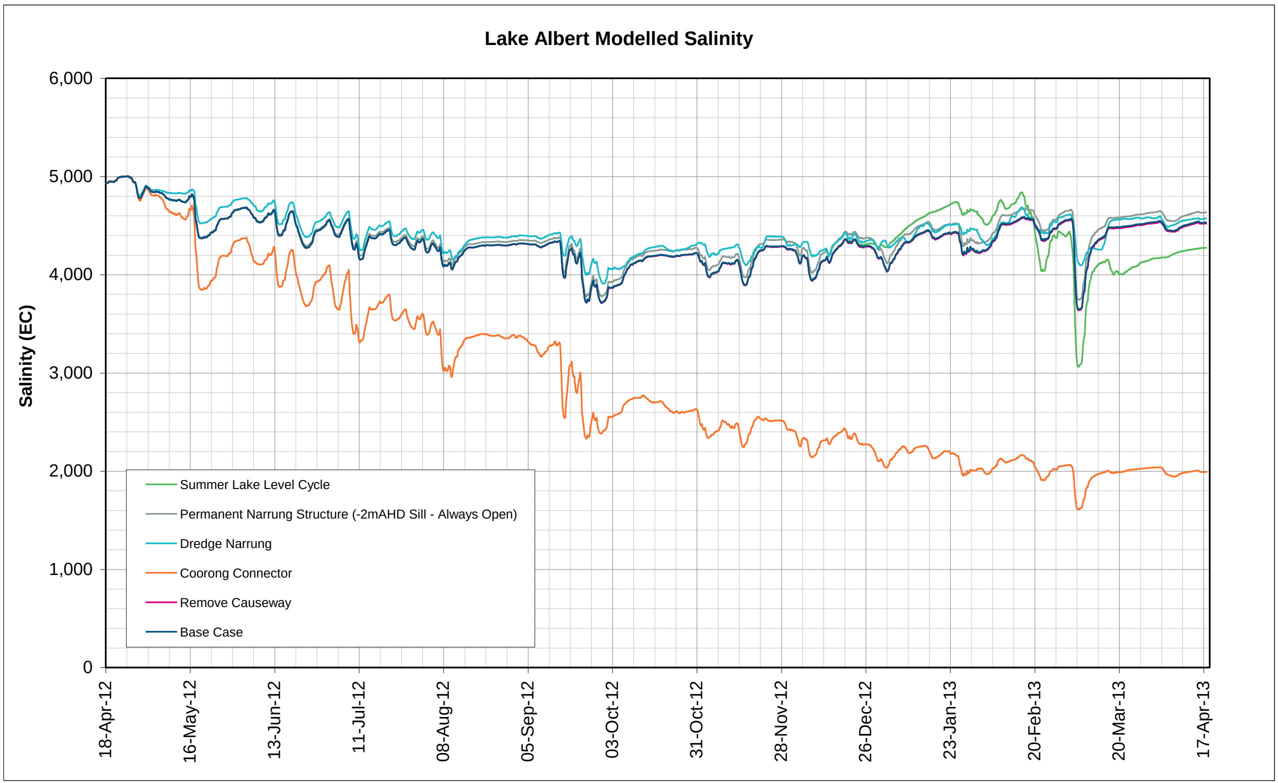


Figure 3-6 Modelled Salinity in Lake Albert for Proposed Scenarios

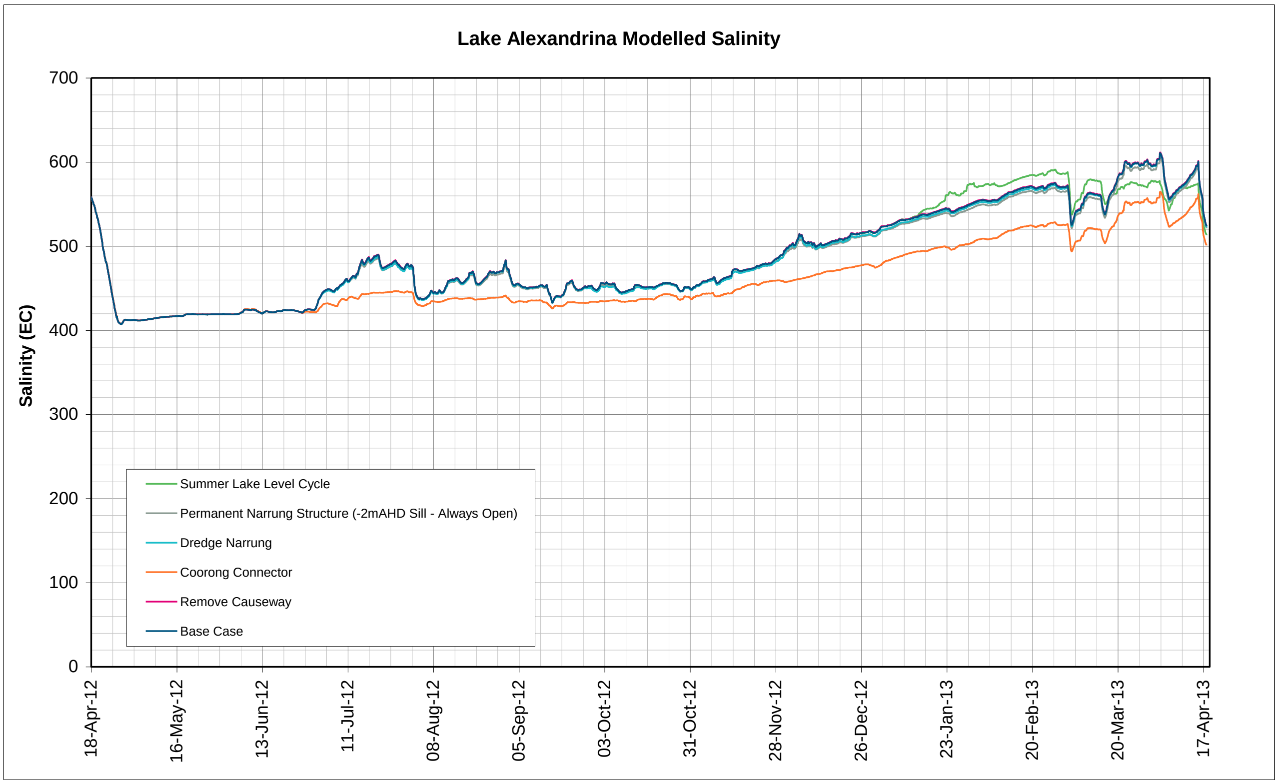


Figure 3-7 Modelled Salinity in Lake Alexandrina for Proposed Scenarios

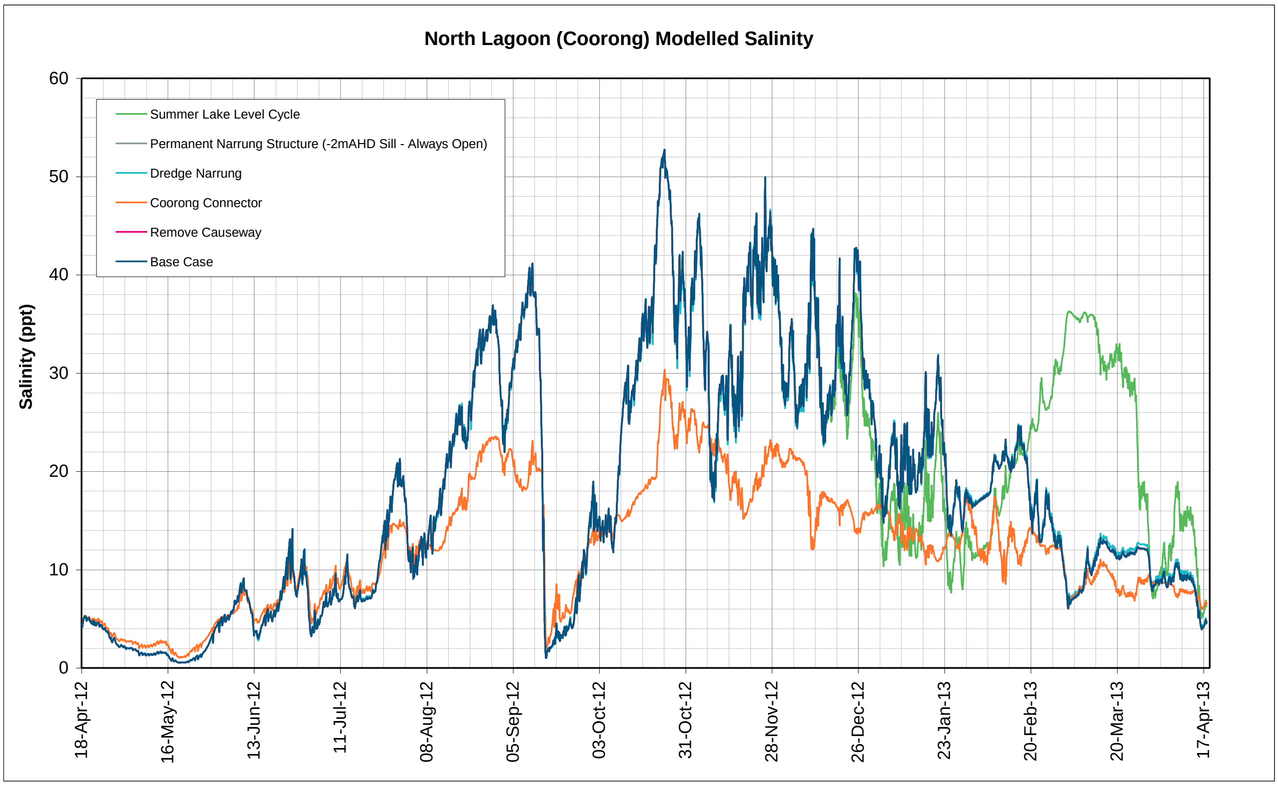


Figure 3-8 Modelled Salinity in the North Lagoon for Proposed Scenarios

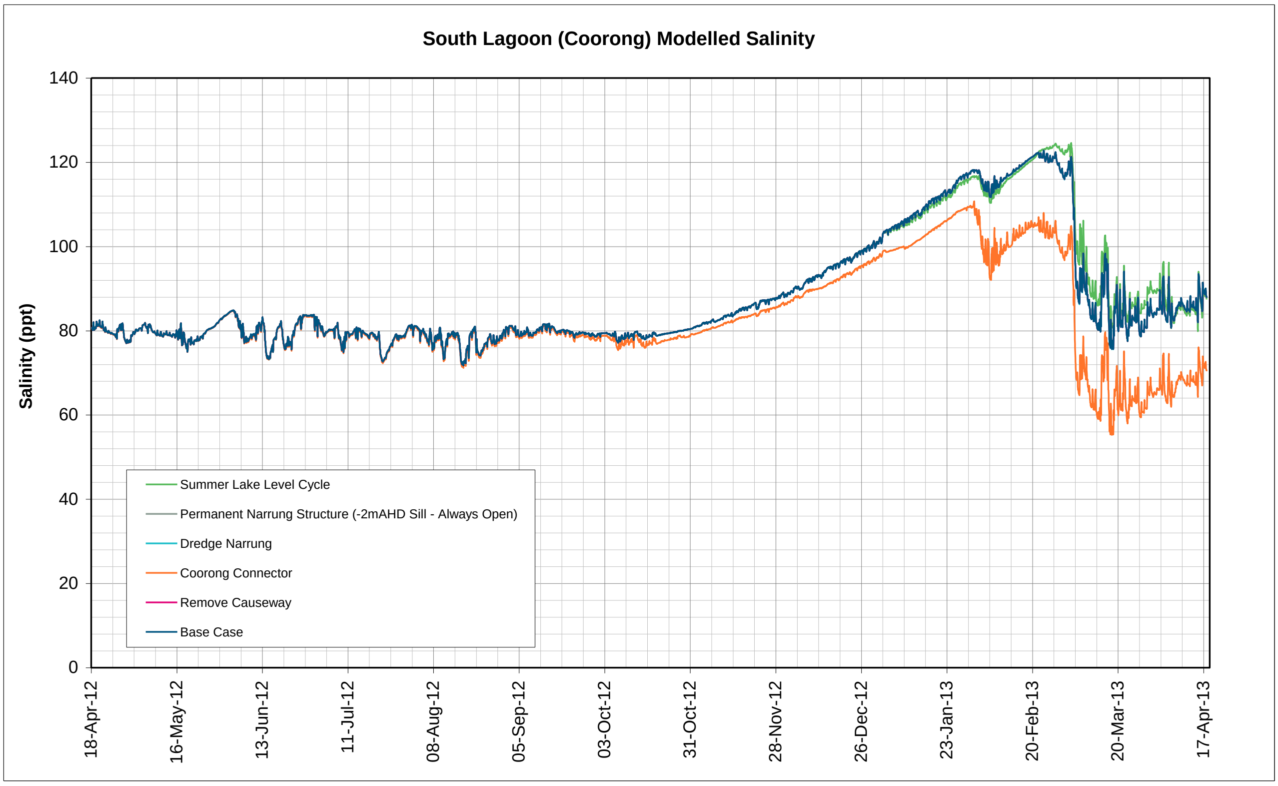


Figure 3-9 Modelled Salinity in the South Lagoon for Proposed Scenarios

3.2.3 Cumulative Salt Mass Change

Modelled Lake Albert salt mass change is presented in Figure 3-10 (expressed in Tonnes of salt), Figure 3-11 (expressed in percentage change from initial salt mass) and summarised in Table 3-3 for the six scenarios. The percentage salt mass reduction is based on an initial Lake Albert salt mass of 757,820 tonnes (see Section 2.5.2.).

Table 3-3 Summary of Lake Albert Salt Mass Change Results

Scenario	Salt Mass Reduction (tonnes)	Salt Mass Reduction (%)	% Comparison to Base Case
Base Case	98,678	13.0	0.0
Remove Causeway	100,213	13.2	1.6
Dredge Narrung	91,546	12.1	-7.2
Permanent Structure (-2 m AHD Sill, Always Open)	84,324	11.1	-14.5
Summer Lake Cycle	136,882	18.1	38.7
Coorong Connector	465,655	61.4	371.9

The results show that in the Base Case (i.e. do nothing) scenario 98,678 tonnes of salt would be transported from Lake Albert during the 12 month simulation period (a decrease in salt mass of 13.0%). The decrease to the salt mass is higher than the change in concentration as the water level (and hence lake volume) has fallen. Since the salt concentration is reported in the centre of Lake Albert it does not account for the possibility that fresher water may be present in the north-western segment of the lake.

A comparison of the effectiveness of the six management options in reducing salt mass is similar to that for reducing salt concentration (see Section 3.2.2). The results show that the Coorong Connector option is able to remove the most salt from Lake Albert, transporting a net salt mass of 465,655 tonnes from the lake. This includes 590,792 tonnes of salt transported into the Coorong through the connector channel and 125,137 tonnes of (lower concentration) salt flows from Lake Alexandrina into Lake Albert, to balance the flow out of the connector channel (see Section 3.2.5.). This Coorong Connector is able to reduce the Lake Albert salt mass by 61% which is nearly 4 times as much as the Base Case scenario.

The Summer Lake Cycle scenario is the next most efficient option removing 40% more salt than the Base Case in a single lake cycle event. All other scenarios behave in a similar manner to the Base Case, with the exception of the Remove Causeway option which removes marginally (2%) more salt. The Dredge Narrung scenario actually removes 7% less salt than the Base Case scenario, while the Permanent Structure with a -2 m AHD sill with gates open removes approximatley15% less salt than the Base Case scenario.

An examination of the timing of the salt mass change (Figure 3-10) shows that there is a small increase in salt mass in Lake Albert at the start of the simulation as the lake level is increased over an approximate 2 month period (see Figure 2-7). From June to October the lake levels are held relatively constant and wind driven transport and mixing is able to remove nearly 100,000 tonnes of salt from Lake Albert. As evaporation increases in Spring and Summer, the transport of salt into Lake Albert to satisfy evaporation demand is close to the wind driven mixing of salt out of Lake Albert (which is slightly assisted by a lowering of Lake water levels through Summer), with minimal salt mass change occurring in December through April.

For the Summer Lake Cycle option, the salt mass change is the same as the Base Case until December. During December, water levels are deliberately lowered, and additional salt is exported from Lake Albert to Lake Alexandrina. As the water level is raised again during February, there is an increase of salt mass which is marginally greater than the Base Case amount; however, as the water level falls again in March, additional salt is removed from Lake Albert.

3.2.4 Narrung Flows and Cumulative Volume Change

Cumulative Lake Albert volume change presented in Figure 3-12 and shows that the overall water balance is driven by evaporation and lake level change, and hence there is insignificant difference between the six management options, though the influence of the lake cycle option on lake volume is evident. Evaporative demand in Lake Albert accounts for a volume of 170 GL (assuming a loss of 0.975 m and surface area of approximately 175 km^2), while each 1 cm change in water level in Lake Albert equates to a volume change of -1.7 GL. Over the 1 year simulation, the net change in Lake Albert water level is about 8cm (a decrease from 0.68 m AHD to 0.60 m AHD) which is a volume change of -14 GL. Adding these volume changes together results in a net volume change of 156 GL which agrees with the cumulative Lake Albert volume change presented in Figure 3-12.

While there is insignificant difference between the six options in terms of long-term cumulative volume change in Lake Albert, there is a difference in instantaneous flows at Narrung in a number of the options as presented in Figure 3-13 and Figure 3-14 (6 weeks only). The graphs show positive flows as those entering Lake Albert, while negative flows are discharges from the Lake. Comparison of the Narrung flow data to wind data (Figure 2-3 and Figure 3-15 (6 weeks only)) reveals that the majority of flow events are due to wind setup. An examination of Figure 3-14 and Figure 3-15 shows that in the week following the 9th May, conditions are mostly calm with a south to south-easterly sea-breeze forming during the day, and then dropping in the evening. This produces a day time flow of water out of Lake Albert, which then flows back into Lake Albert as the wind speed drops and the water levels in the lake return to an equilibrium (i.e. flat) position.

The results show that dredging at Narrung increases the channel conveyance (and hence magnitude of peak flow exchanges) but as shown in Figure 3-12 it does not alter the overall water balance, though in summer it does allow the evaporative demand to be more quickly met (and hence may allow salt to penetrate further into Lake Albert). The flow results also show that there is slightly higher inflow in the Coorong Connector option than is required to satisfy the discharge (as quantified in Section 3.2.5) through the Coorong Connector channel. Further examination of Figure 3-14 shows that there is no difference in flows at Narrung between the Base Case and Remove Causeway scenario; however, the Permanent Structure scenario slightly reduces peak flows for a number of wind events.

3.2.5 Coorong Connector Flow Summary

For the Coorong Connector simulations, the total discharge from Lake Albert into the Coorong for the 1 year simulation period is 315 GL. The discharge represents an average flow of 862 ML/day, however, actual daily discharge varies seasonally (mostly due to difference in lake water levels) with predicted daily flow varying from between ~500 ML/day and ~1100 ML/day as presented in Figure 3-16. It is assumed that the channel gates would automatically close if reverse flow is about to occur (i.e. when the Coorong water level is higher than Lake Albert water level), which is why the flow is occasionally 0 ML/day.

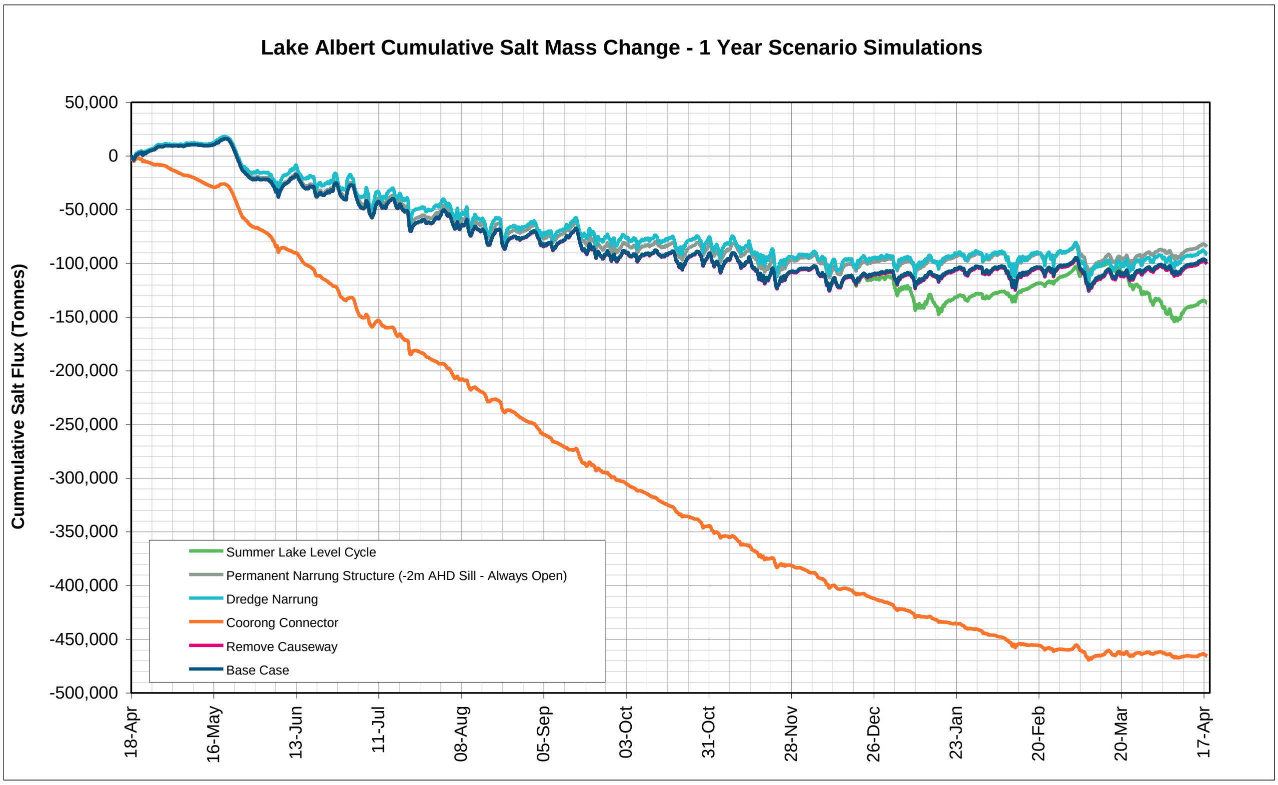


Figure 3-10 Modelled Lake Albert Salt Mass Change (Tonnes) for Six Scenarios

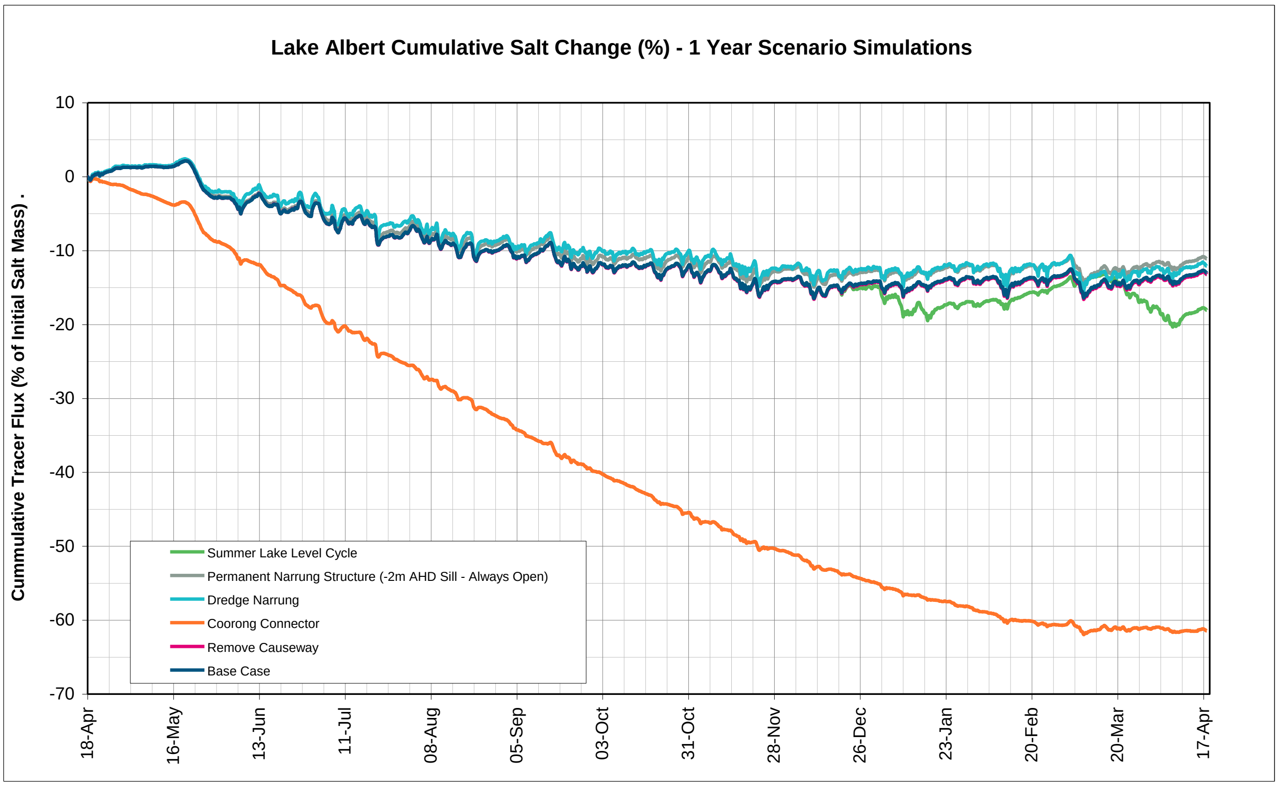


Figure 3-11 Modelled Lake Albert Percentage Salt Mass Change for Six Scenarios

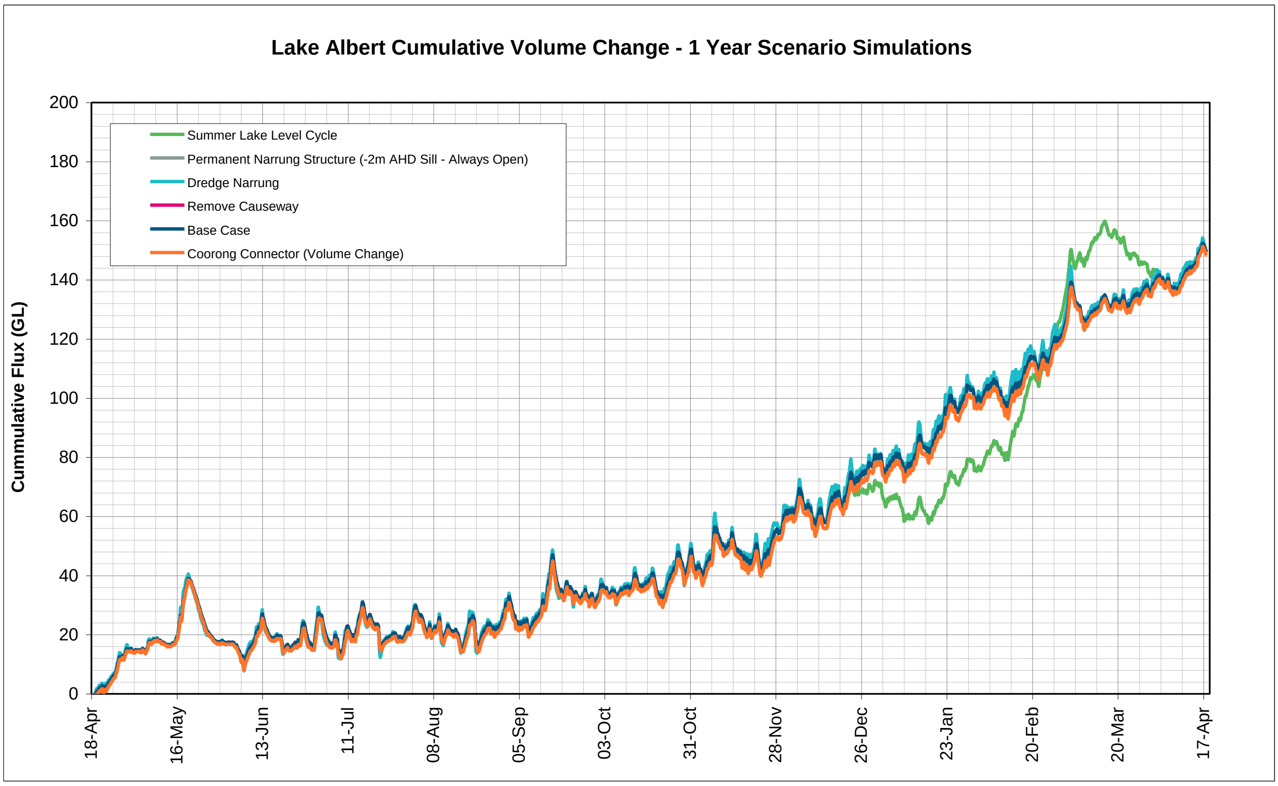


Figure 3-12 Modelled Lake Albert Volume Change for Six Scenarios

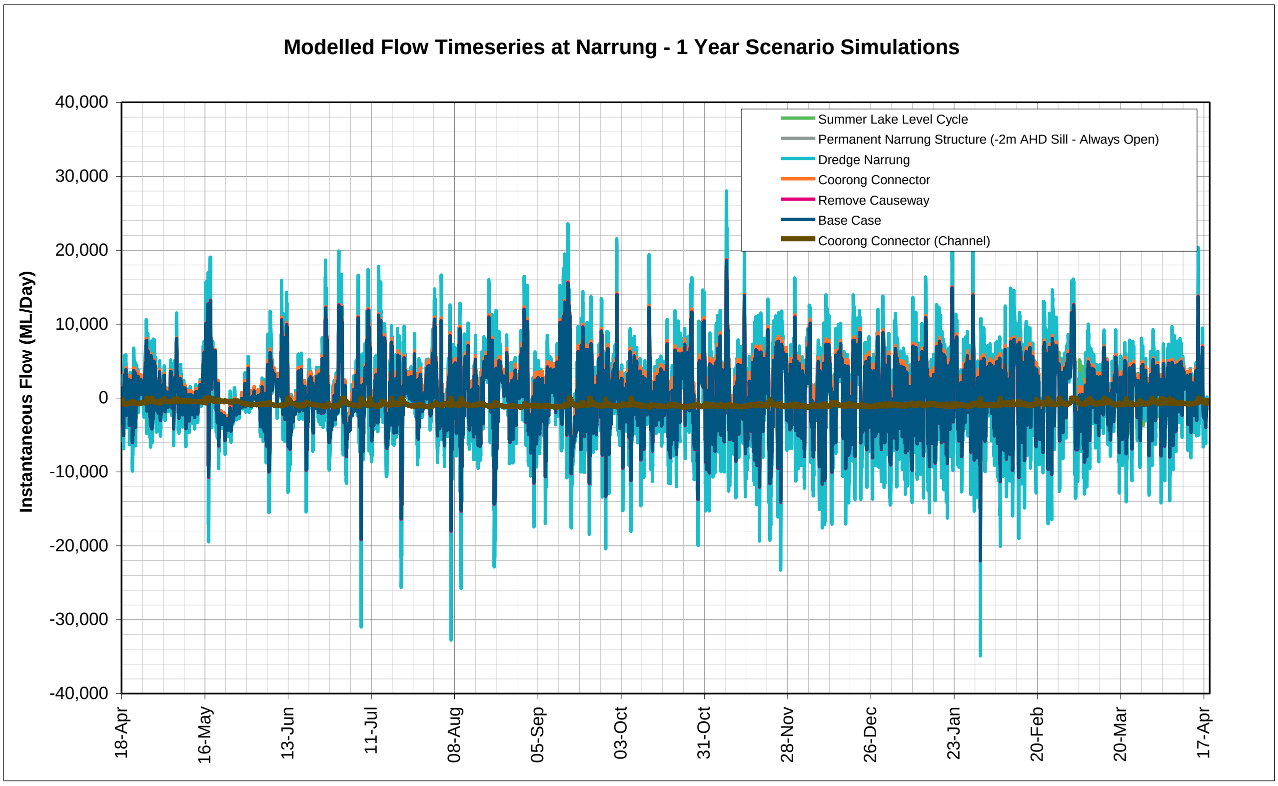


Figure 3-13 Modelled Narrung Flows for Six Scenarios

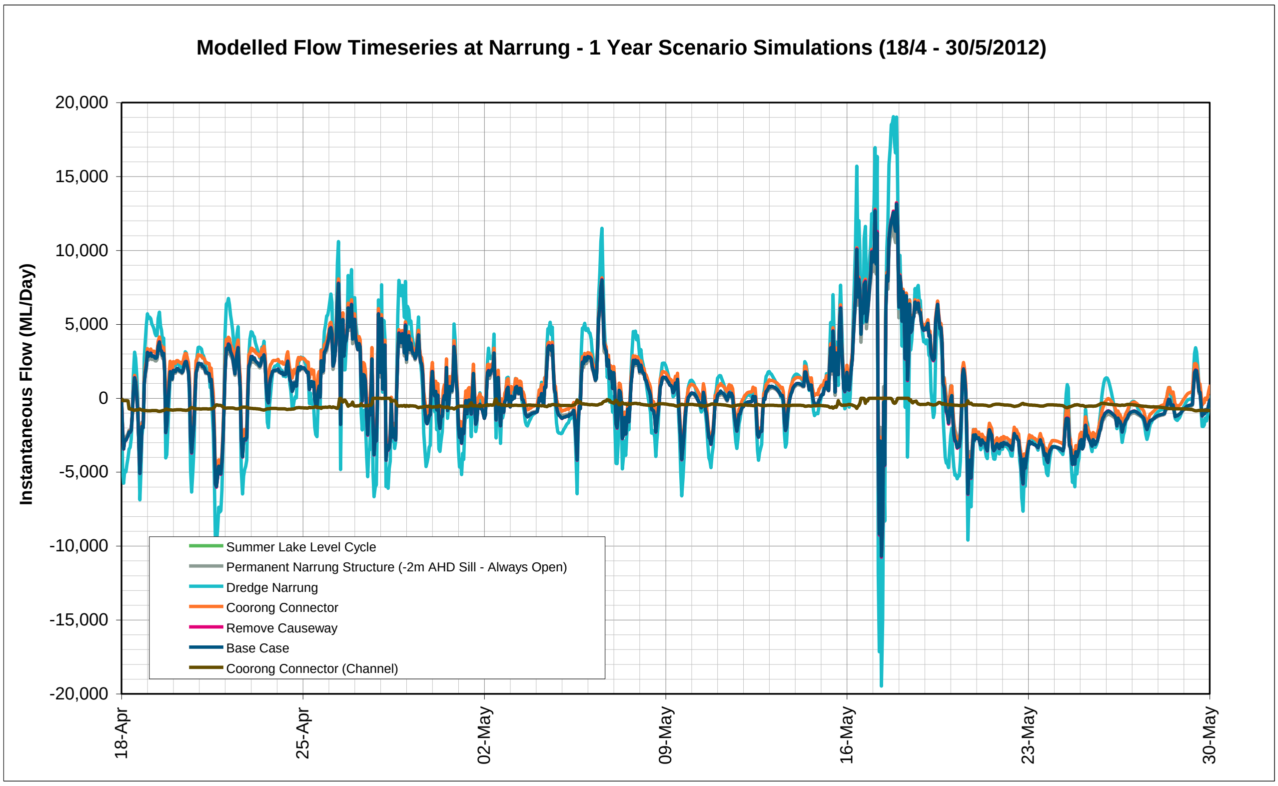


Figure 3-14 Modelled Narrung Flows for Six Scenarios (six weeks)

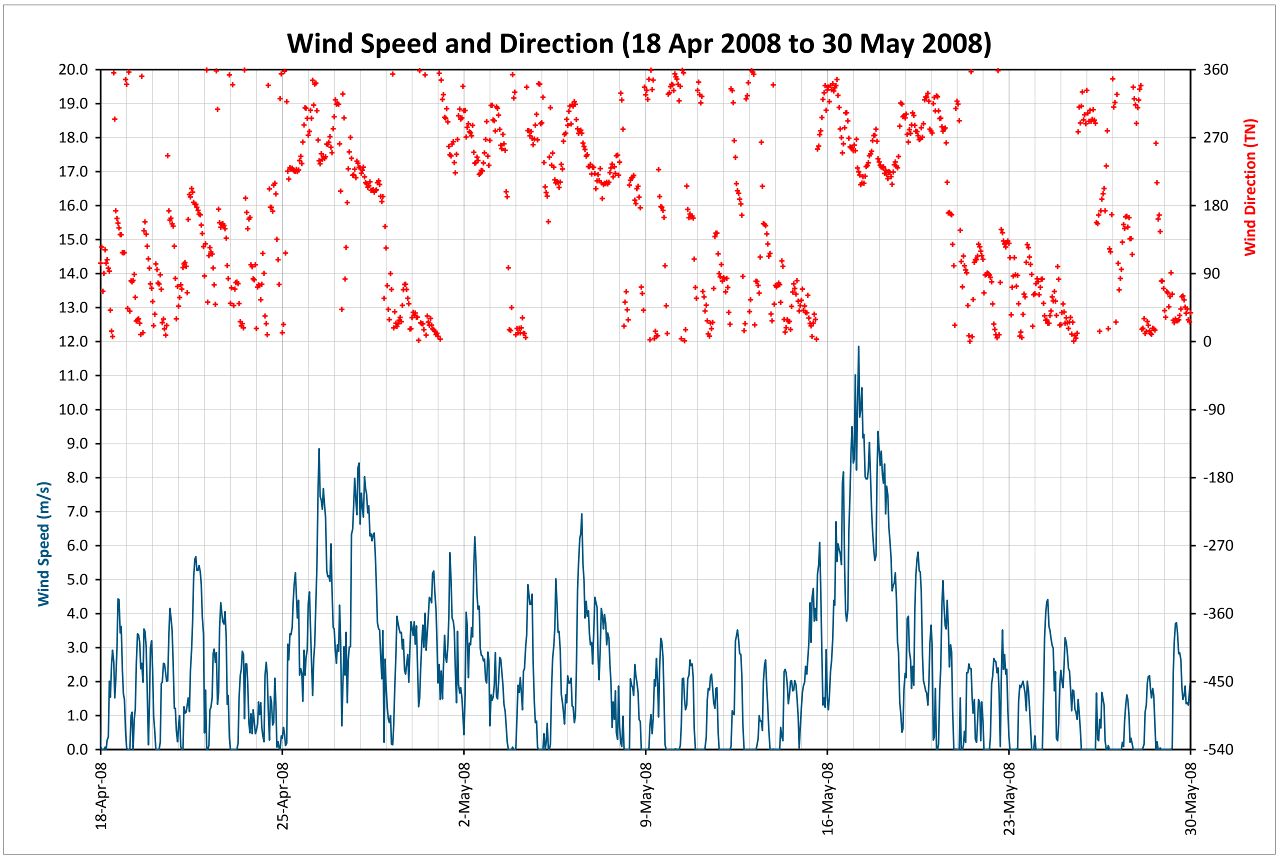


Figure 3-15 Applied Wind Data (six weeks)

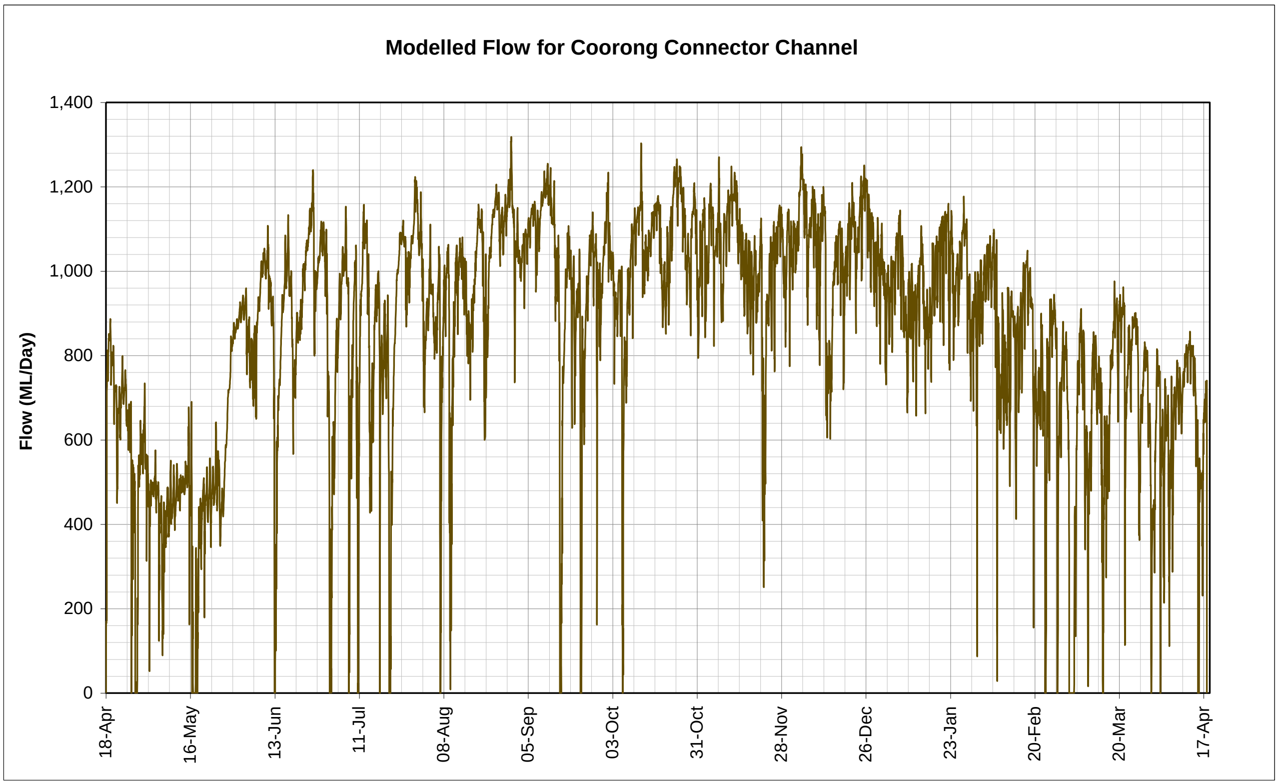


Figure 3-16 Coorong Connector Channel Modelled Flow Time series

3.3 Sensitivity Testing of Scenarios

The following sections describe the results of a number of sensitivity tests undertaken to provide further information regarding a number of the management scenarios.

3.3.1 Coorong Connector Channel Conveyance

The performance of a larger channel (with increased channel conveyance) connecting Lake Albert to the Coorong was also assessed. The option is nearly identical to the Coorong Connector channel previously described although it uses a larger channel/gate, capable of higher discharge. The total flow predicted for a larger Coorong Connector Channel for the year was 461 GL compared with the 315 GL for the smaller channel. The discharge represents an average flow of 1263 ML/day compared to 862 ML/Day which is close to a 50% increase in discharge. Again actual daily discharge varies seasonally (mostly due to difference in lake water levels) with actual daily flow varying from between approximately 600 ML/day and approximatley1350 ML/day.

The results of the simulation of the larger channel are compared to the previous Coorong Connector and Base Case results in Table 3-4 (salinity), Table 3-5 (salt mass change) and Figure 3-17 (salinity time-series). The results show that the increased discharge further assists with the export of salt (an additional 80,000 tonnes) resulting in a final Lake Albert of salinity of 1410 µS/cm.

3.3.2 Quarterly Lake Cycling Performance

The performance of a quarterly lake level cycle option with lake levels fluctuating between 0.6 and 0.8 m AHD every three months (see Figure 3-18) was also assessed. While insufficient lake inflows or wind conditions result in target levels not always being achieved (see Figure 3-19), the results of the simulation as presented in Table 3-4 (salinity), Table 3-5 (salt mass change) and Figure 3-17 (salinity time-series) show that the additional water level fluctuations enhance salt export. The results show that the increased frequency of discharge is able to export an additional 42,000 tonnes (~30% more) of salt compared to the summer cycled option. This option is predicted to reduce salinity in Lake Albert from about 5000 µS/cm to below 4000 µS/cm within 12 month which is an almost 140% increase in salinity reduction compared to the Base Case scenario.

3.3.3 Permanent Narrung Structure Options

In order to better understand the performance of the Permanent Narrung Structure, a number of additional model simulations were required including: tests on the adopted structure sill level (-2, 1 or 0 m AHD), and also the duration of gate closures (either one or two weeks). The tests on the different sill level assumed that the structure was always open, while for the gate closure option a sequence of 12 closure events were selected (see Figure 2-15 and Figure 2-16). This involved selecting significant wind events that produced over a 10 cm water level difference between Lake Albert and Lake Alexandrina and the closing the structure for a period of either one or two weeks to prevent the immediate levelling of lake levels and potentially enhance mixing and hence salt export.

The results of the simulations of the five simulations are presented in Table 3-4 (salinity), Table 3-5 (salt mass change) and Figure 3-17 (salinity time-series). The results show that reducing the sill level of the gate on the structure reduces the level of salt export, and that any closures of the gate reduce the potential of export of salt from Lake Albert.

Table 3-4 Summary of Lake Albert Sensitivity Test, Salinity Results

Scenario	Final Salinity (µS/cm)	Salinity (µS/cm) Reduction	% Salinity Reduction	% Comparison to Base Case
Base Case	4533.1	401.7	8.1	0.0
Summer Lake Cycle	4274.8	660.0	13.4	64.3
Quarterly Lake Cycle	3975.8	959.0	19.4	138.7
Coorong Connector	1988.6	2946.2	59.7	633.4
Coorong Connector (Larger Channel)	1410.1	3524.8	71.4	777.4
Permanent Structure (-2mAHD Sill, Always Open)	4634.6	300.2	6.1	-25.3
Permanent Structure (-1mAHD Sill, Always Open)	4645.8	289.0	5.9	-28.1
Permanent Structure (0mAHD Sill, Always Open)	4920.2	14.6	0.3	-96.4
Permanent Structure (-2mAHD Sill, 1 week closures)	4766.9	167.9	3.4	-58.2
Permanent Structure (-2mAHD Sill, 2 week closures)	5034.0	-99.2	-2.0	-124.7

Table 3-5 Summary of Lake Albert Sensitivity Test, Salt Mass Change Results

Scenario	Salt Mass Reduction (tonnes)	% Salt Mass Reduction	% Comparison to Base Case
Base Case	98,678	13.0	0.0
Summer Lake Cycle	136,882	18.1	38.7
Quarterly Lake Cycle	178,866	23.6	81.3
Coorong Connector	465,655	61.4	371.9
Coorong Connector (Larger Channel)	545,999	72.0	453.3
Permanent Structure (-2 m AHD Sill, Always Open)	84,324	11.1	-14.5
Permanent Structure (-1mAHD Sill, Always Open)	82,692	10.9	-16.2
Permanent Structure (0mAHD Sill, Always Open)	44,697	5.9	-54.7
Permanent Structure (-2mAHD Sill, 1 week closures)	65,509	8.6	-33.6
Permanent Structure (-2mAHD Sill, 2 week closures)	28,047	3.7	-71.6

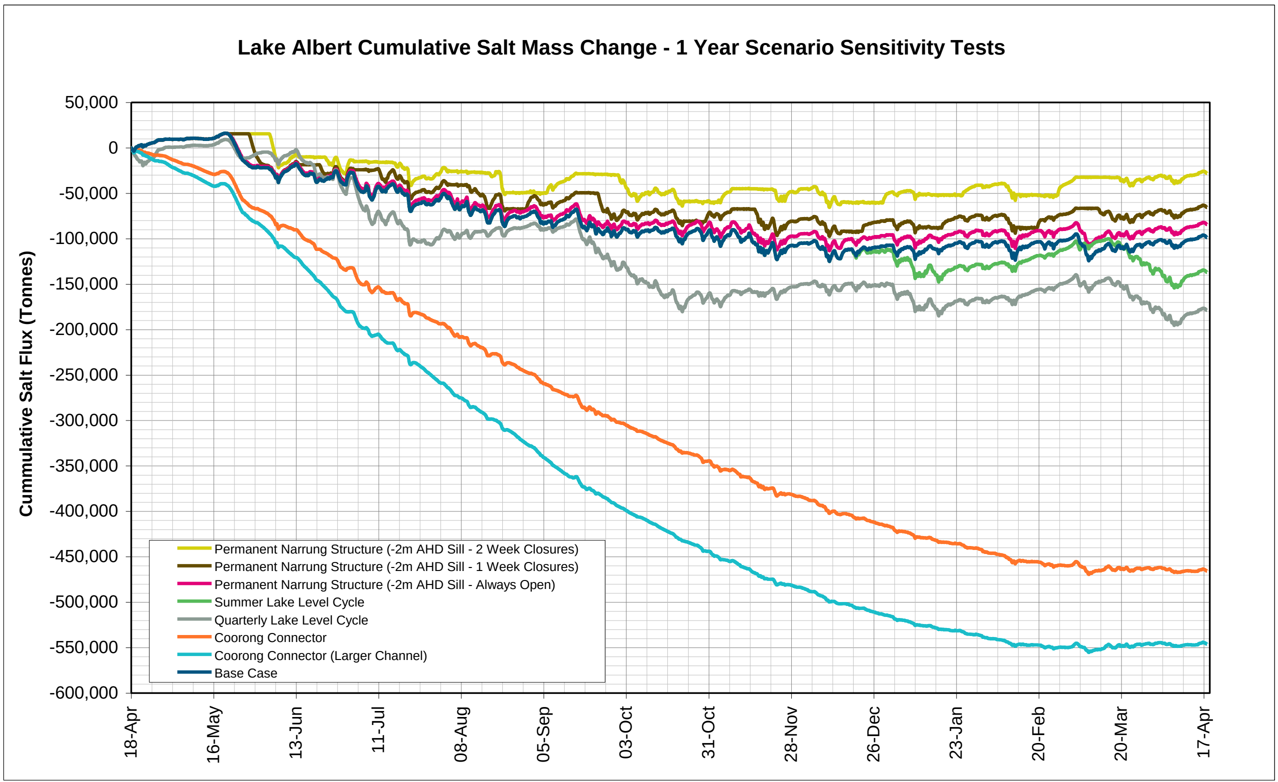


Figure 3-17 Modelled Lake Albert Salt Mass Change (Tonnes) Sensitivity Test Results

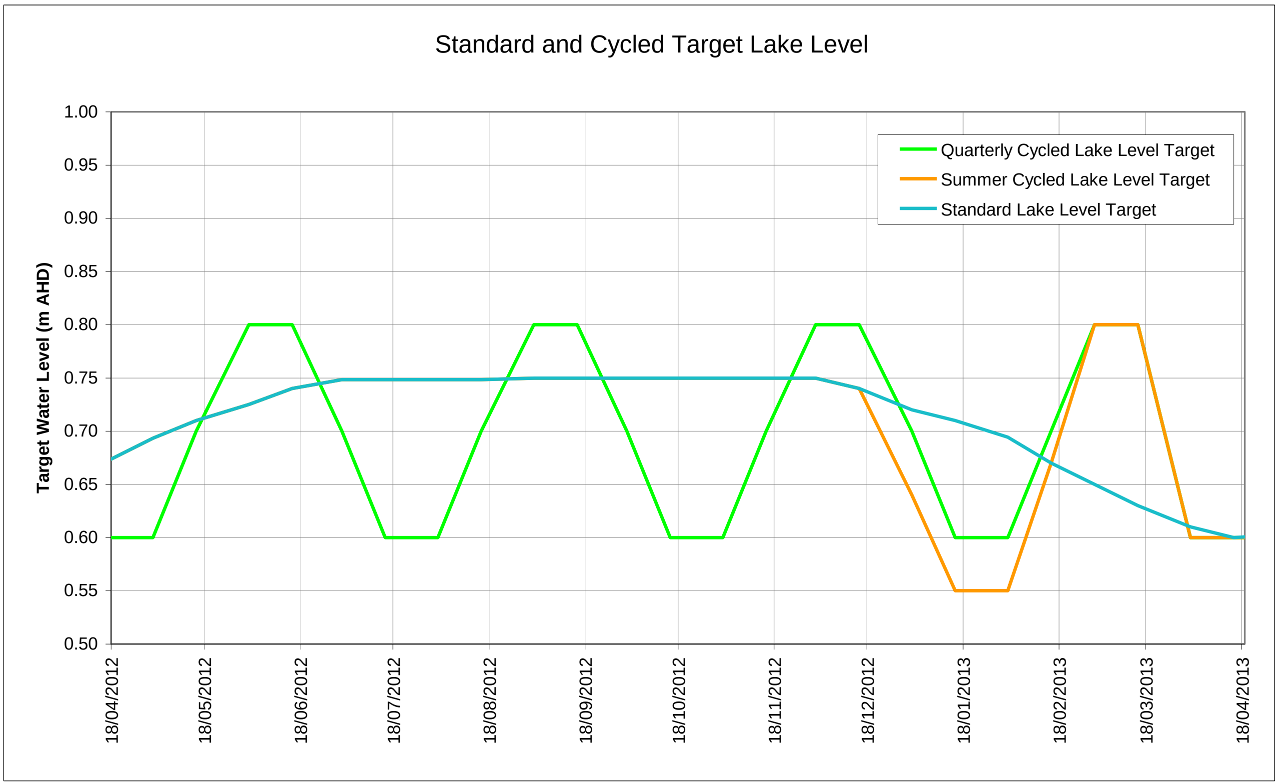


Figure 3-18 Standard and Cycled Target Lake Water Levels

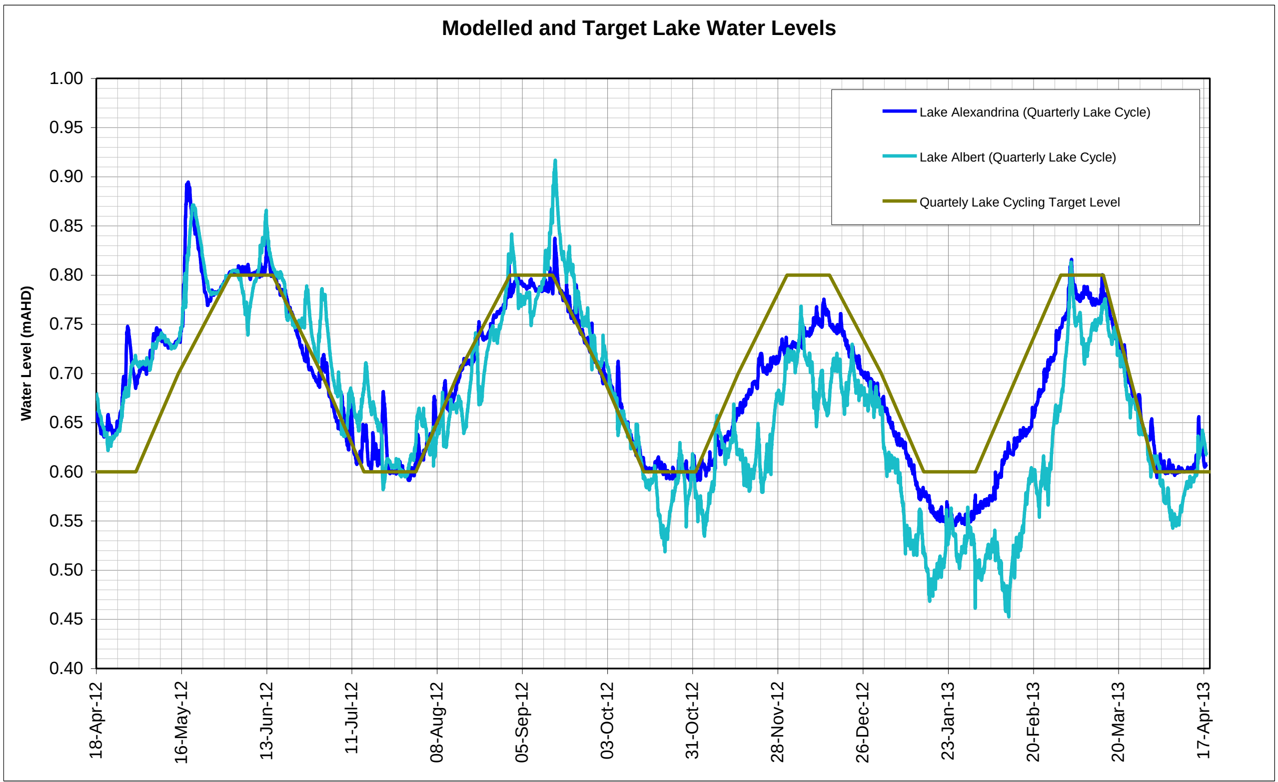


Figure 3-19 Target and Modelled Lake Water Levels (Quarterly Cycling)

4 Conclusion

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. A numerical model capable of simulating salinity dynamics of the Lower Lakes and Coorong was used to evaluate the effectiveness of six potential management options designed to reduce salinity levels in Lake Albert.

The six management options evaluated in the study included:

a) Base Case (i.e. do nothing);

b) Remove Causeway;

c) Dredge Narrung Narrows;

d) Permanent Water Level Control Structure at Narrung;

e) Summer Lake Water Level Cycling; and

f) Coorong Connector.

An initial investigation into the effectiveness of the six management options in reducing salinity in Lake Albert was undertaken using a 12 month model simulation. The calibrated model was successfully applied to demonstrate the potential benefits (or otherwise) of the management options considered.

An examination of the results indicates the following:

- Under the Base Case (i.e. “do nothing”) scenario condition, salinity in Lake Albert would decrease from approximately 5000 µS/cm to approximately 4500 µS/cm in a year.
- The Coorong Connector option is clearly the most efficient option for reducing salt concentration in Lake Albert. At the end of the 12 month simulation, the salt concentration in Lake Albert has been reduced from ~5000 µS/cm to below 2000 µS/cm.
- The Narrung Regulator option is the least efficient option for reducing salt concentration in Lake Albert with any gate closure reducing the likelihood for wind driven salt export to occur.
- The Summer Lake Cycle scenario is capable of removing nearly 40% more salt than the Base Case scenario and reduces salinity from ~5000 µS/cm to below 4275 µS/cm in a year. If a Quarterly Lake Cycle water level target was adopted 80% more salt than the Base Case would be exported over the 12 months with salinity in the centre of Lake Albert falling from ~5000 µS/cm to below 4000 µS/cm in a year.
- The “Dredge Narrung” option performs slightly worse than the “Base Case” scenario, while the “Remove Causeway” option performs slightly better.

This initial testing has only been undertaken for a single set of environmental conditions (i.e. inflow, evaporation, wind and tides). To gain a better understanding on the envelope of likely future salinity levels in Lake Albert further modelling was undertaken and presented in BMT WBM (2013c) and summarised in Section 1.1.5.

5 References

BMT WBM (2011a), Data Analysis for the Lower Murray Region – Tides, Winds and Waves, R.N1874.001.00_DataAnalysis.pdf, Produced for: DENR, June 2011.

BMT WBM (2011b), CLLMM Forecast Model Development – Model Calibration Report, R.N1874.003.00_ModelCalibration_FinalDraft.pdf, Produced for: DENR, September 2011.

BMT WBM (2011c), CLLMM Forecast Model Development – Development and Benchmarking of Automated Barrage Logic, R.N1874.006.00_AutoBarrages_Draft.pdf, Produced for: DENR, October 2011.

BMT WBM (2011i), Lower Lakes, Coorong and Murray Mouth - Modelling of Environmental Water Requirement and Fully Open Barrage Scenarios, R.N1874.002.01_16SimulationsFinalReport.pdf, Produced for: DENR, August 2011.

BMT WBM (2012a), CLLMM Forecast Model Development – Model Validation (May – November 2011) Report, R.N1874.008.01_OngoingCalibration_FinalDraft.pdf, Produced for: DENR, February 2012.

BMT WBM (2012b), CLLMM Forecast Modelling – 12 Month Forecast Report, R.N2228.003.01_12monthForecasts_Draft.docx, Produced for: DENR, June 2012.

BMT WBM (2013a), Lake Albert Salinity Reduction Study - Report on Preliminary Investigations, Report, R.N20056.001.02_LakeAlbertPrelimInvestigations_Final.docx, Produced for: DEWNR, June 2013.

BMT WBM (2013b), Lake Albert Salinity Reduction Study – Model Setup and Calibration Report, R.N20056.002.00_ModelCalibration_Draft_v1a.docx, Produced for: DEWNR, January 2014.

BMT WBM (2013c), Lake Albert Salinity Reduction Study - Three Year Scenario Model Investigations, R.N20056.004.01_LakeAlbert3yrScenarioModelling_Draft_wAppendixB_v2.1.docx, Produced for: DEWNR, November 2013.

BMT WBM Bangalow	6/20 Byron Street Bangalow 2479 Tel +61 2 6687 0466 Fax +61 2 66870422 Email bmtwbm@bmtwbm.com.au Web www.bmtwml.com.au
BMT WBM Brisbane	Level 8, 200 Creek Street Brisbane 4000 PO Box 203 Spring Hill QLD 4004 Tel +61 7 3831 6744 Fax +61 7 3832 3627 Email bmtwbm@bmtwbm.com.au Web www.bmtwml.com.au
BMT WBM Denver	8200 S. Akron Street, #B120 Centennial Denver Colorado 80112 USA Tel +1 303 792 9814 Fax +1 303 792 9742 Email denver@bmtwbm.com Web www.bmtwbm.com
BMT WBM London	1st Floor, International House St Katherine's Way London E1W1TW Email london@bmtwbm.co.uk Web www.bmtwbm.com.au
BMT WBM Mackay	Suite 1, 138 Wood Street Mackay 4740 PO Box 4447 Mackay QLD 4740 Tel +61 7 4953 5144 Fax +61 7 4953 5132 Email mackay@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Melbourne	Level 5, 99 King Street Melbourne 3000 PO Box 604 Collins Street West VIC 8007 Tel +61 3 8620 6100 Fax +61 3 8620 6105 Email melbourne@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Newcastle	126 Belford Street Broadmeadow 2292 PO Box 266 Broadmeadow NSW 2292 Tel +61 2 4940 8882 Fax +61 2 4940 8887 Email newcastle@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Perth	Suite 6, 29 Hood Street Subiaco 6008 Tel +61 8 9328 2029 Fax +61 8 9486 7588 Email perth@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Sydney	Level 1, 256-258 Norton Street Leichhardt 2040 PO Box 194 Leichhardt NSW 2040 Tel +61 2 8987 2900 Fax +61 2 8987 2999 Email sydney@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Vancouver	Suite 401, 611 Alexander Street Vancouver British Columbia V6A 1E1 Canada Tel +1 604 683 5777 Fax +1 604 608 3232 Email vancouver@bmtwbm.com Web www.bmtwbm.com