Lower Barwon Wetlands Hydraulic Modelling for the Environmental Entitlement

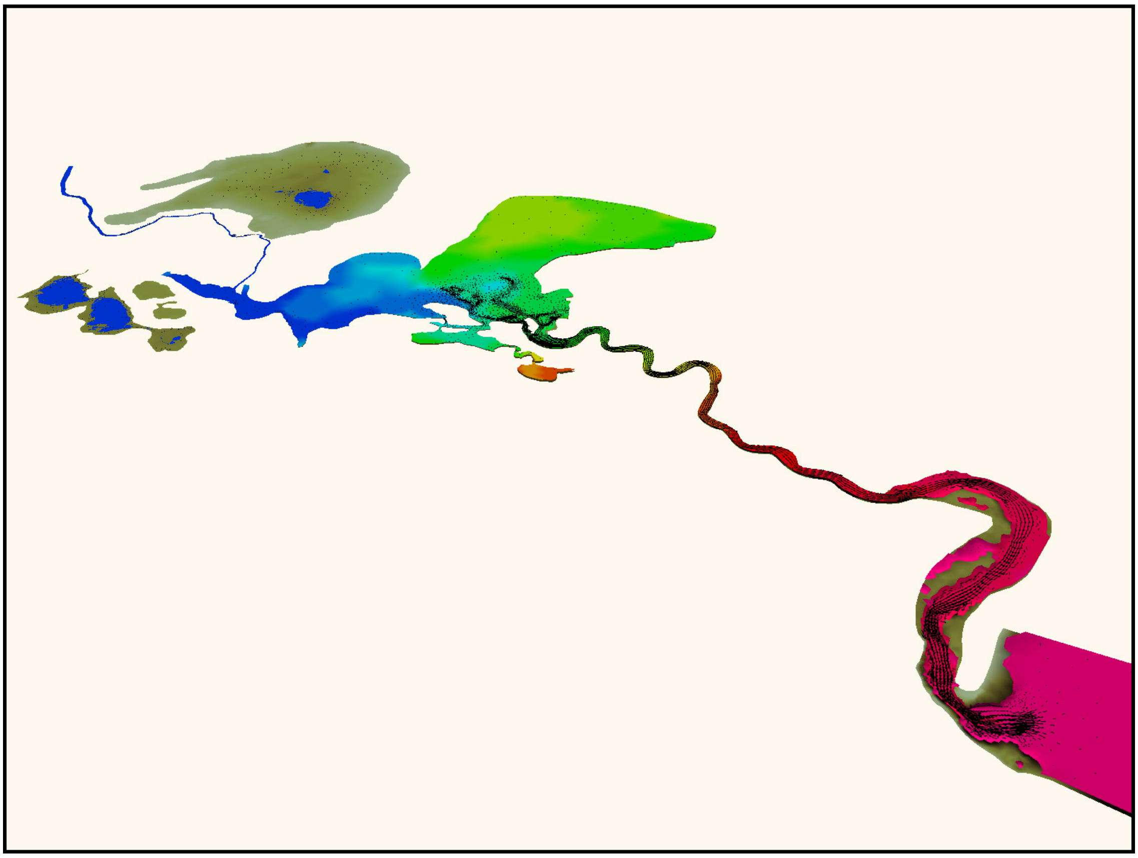

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Water Technology was commissioned by the Corangamite Catchment Management Authority (CCMA) to develop a hydrodynamic model of the Lower Barwon Wetlands (LBW). The hydrodynamic model is to be used to allow scenarios for future management and changes to the annual watering plan of these wetland systems to be modelled to facilitate the development of a more robust and legally supported watering regime for the LBW.

The LBW are located on the lower reaches of the Lower Barwon River and include the following main physical components listed below and displayed in Figure 1-1:

- Lake Connewarre
- Reedy Lake
- Hospital Swamp
- Barwon River
- Salt Swamp

The field data collection program undertaken to support the hydrodynamic model development is documented in Appendix A.

The development of the continuous digital elevation model for the study area is documented in Appendix B.

The hydrodynamic model development and calibration is documented in Appendix C.

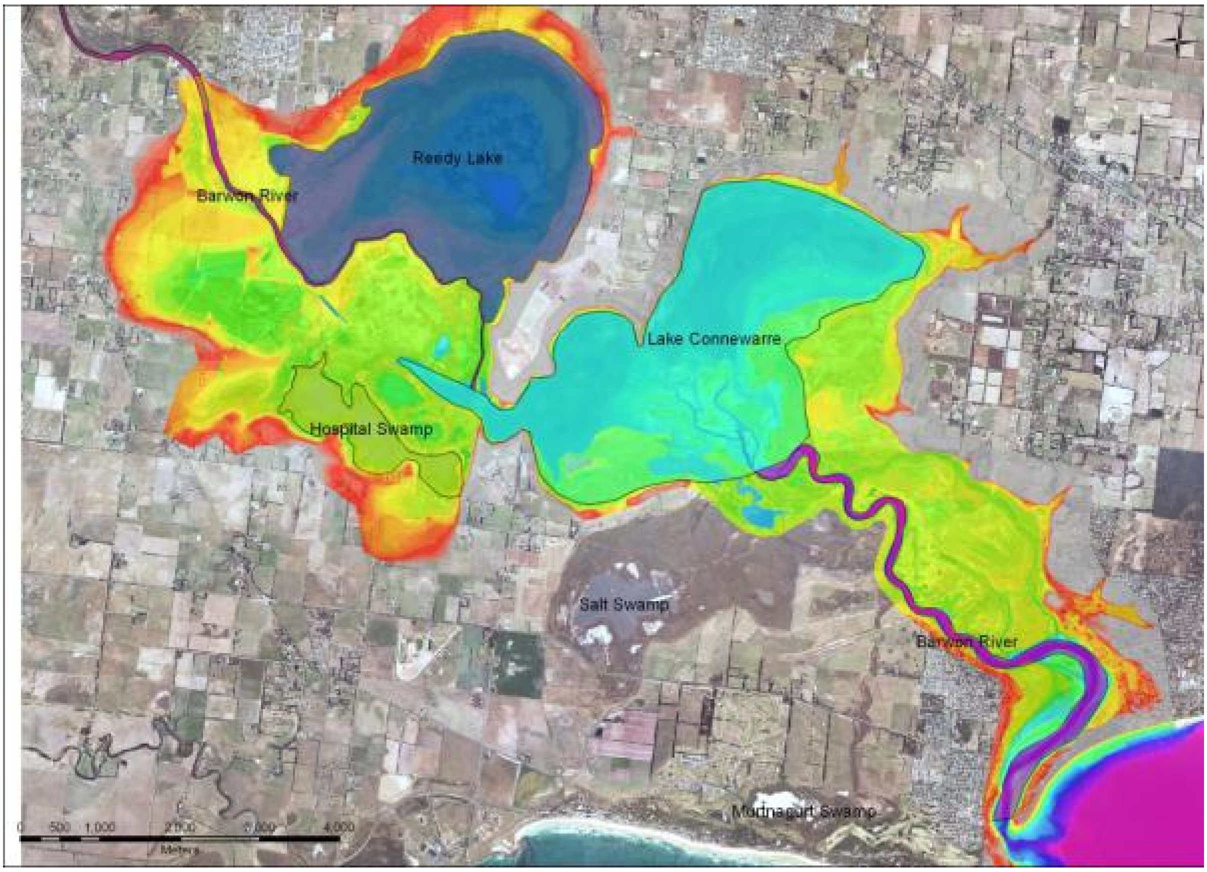


Figure 1-1 Lower Barwon Wetlands

2. LOWER BARWON WETLAND SYSTEM OVERVIEW

2.1 Barwon River & Lower Barrage

The Barwon River channel flows from north-west to south-east on the southern margin of Reedy Lake. The river channel is confined by natural levees and silt jetties that extend into Lake Connewarre into which the river discharges.

Prior to European settlement, saline water originating in Lake Connewarre could encroach upstream along the Barwon River channel, in the form of a salt wedge, to as far as South Geelong. To prevent the saline water moving upstream and enable the river to be used for irrigation and water supply, a tidal breakwater weir was constructed in 1898. The weir prevented the incursion of saline water upstream and raised water levels in the river channel upstream, promoting more frequent overbank inflow events into Reedy Lake.

In the 1950s flood waters from Lake Corangamite were diverted into the river via the Woady Yaloak Diversion Scheme with a resulting increase in flows down the Barwon River. To minimise the flooding impact from the increased flow, a floating gate arrangement was designed and installed. The gates were designed to maintain the functionality of the breakwater by preventing the saline water incursion up the river, whilst also increasing the volume of water that is able to pass through the structure during high flows.

The existing Lower Barrage structure is displayed in Figure 2-1 and the components of the structure can be summarised as follows:

- **A fixed crest weir** - The fixed crest weir is comprised of steel sheet piling with reinforced concrete. The component of the weir extends from the southern embankment across the river until it intersects the twin gate weir structure. The crest height of the weir is 0.85 m AHD.
- **An adjustable weir structure, consisting of two floating steel gates –** The gates each comprise a door of 1.65 m height and 4.9 m wide hinged at the bottom edge and supporting a steel drum at the full width of the gate and 760 mm in diameter. The steel drum floats on the tail water pool (the downstream pool).
- **A counterweight** - The counterweight is a cylinder located at the head of each of the weir gates.

A 2008 refurbishment of the structure exposed that the counterweight assemblies need replacing and that significant volumes of water can leak past the sides of the weir gates. (This has a significant impact on the maintenance of the weir pool during prolonged low flow periods) At present, the gates are permanently closed during times of dry weather and one gate is manually opened upon wet weather. The second gate is inaccessible due to the lack of safe access and occupational health and safety requirements.

Figure 2-1 Lower Barrage

2.2 Reedy Lake

Reedy Lake is a large wetland located adjacent to the northern bank of the Barwon River. Inundation of Reedy Lake can be generated by overbank flooding from the Barwon River, local catchment runoff and groundwater discharges.

Before European settlement, the spill of Barwon River floodwaters into Reedy Lake was controlled by natural levees. The construction of the lower barrage in 1898 raised levels along the Barwon River promoting more frequent overbank flow events into Reedy Lake (Lloyd et al, 2005).

The construction of the floating gate structures on the Lower Barrage to mitigate flooding impacts reduced the frequency of overbank flooding into Reedy Lake. A regulated channel was therefore cut between the Barwon River and Reedy Lake, upstream of the lower barrage to provide a regular inflow of freshwater to Reedy Lake.

Inflows into Reedy Lake are currently controlled via the operation of a hydraulic structure consisting of a series of box culverts and associated penstocks at the head of the cut channel connecting Reedy Lake to the Barwon River within the Lower Barrage weir pool. The inlet regulator structure to Reedy Lake is displayed in Figure 2-2.

The water levels in Reedy Lake can be controlled via the operation of a hydraulic structure consisting of a series of box culverts and associated penstocks located near the exit of a cut channel connecting Reedy Lake to Lake Connewarre. The outlet regulator structure to Reedy Lake is displayed in Figure 2-3.

The following flow and water level thresholds are considered relevant to Reedy Lake:

- The natural levees separating the Barwon River, upstream of the Lower Barrage, from Reedy Lake are overtopped by levels in the Barwon River of approximately 1.7m AHD. Hydrodynamic modeling of the Lower Barwon and Reedy Lake undertaken as part of the

Barwon River Lower Breakwater Management Options study (Water Technology, 2010) found that flows in the Barwon River of approximately 3,500ML/d were required to initiate significant overbank flooding into Reedy Lake above the Lower Barrage.

- The natural levees separating Lake Connewarre from Reedy Lake are overtopped by levels of approximately 0.9m AHD .

Figure 2-2 Reedy Lake Inlet Regulator Structure

Figure 2-3 Reedy Lake Outlet Regulator Structure

2.3 Hospital Swamp

Hospital Swamp comprises 5 basins that can potentially receive water from the overbank flooding of the Barwon River, local catchment runoff associated with Armstrong Creek, potentially elevated water levels in Lake Connewarre and shallow groundwater discharges.

Hospital Swamp can be regulated through diversions from the Barwon River via a regulated channel through Sparrowvale Farm. The regulator has an invert of 0.3m AHD. The Hospital Swamp inlet penstock is displayed in Figure 2-4. Overbank flooding into Hospital Swamp from the Barwon River commences at levels of approximately 1.4m AHD.

Banks separating Hospital Swamp and Lake Connewarre are overtopped at a level of approximately 0.5m AHD. The wetland can be drained using a regulated pipe with an invert of 0.2m AHD. The Hospital Swamp regulated pipe outlet is displayed in Figure 2-5.

Figure 2-4 Hospital Swamp Inlet Regulator Structure

Figure 2-5 Hospital Swamp Outlet Regulator Structure

2.4 Lake Connewarre

Lake Connewarre is a shallow (<2m) tidal lagoon that is connected to the ocean at Barwon Heads via a sinuous tidal channel. Lake Connewarre is separated from the tidal channel by a flood tide delta system that extends into the lake. The tidal range reduces from approximately 2m at Barwon Heads to approximately 0.3m in Lake Connewarre. Due to the lagoon's shallow depths, wind driven mixing is an important process operating in Lake Connewarre.

The salinity in Lake Connewarre shows a relatively high degree of spatial and temporal variation. Salinity varies in response to freshwater inflows from the Barwon River and local run-off, tidal and surge driven marine flows and evapo-concentration.

3. HYDROLOGY

3.1 Barwon River

Analysis of a historical streamflow series for the Barwon River at Geelong has been undertaken to quantify, at a relatively broad scale, the historical magnitude, duration, frequency and timing of overbank flows into Reedy Lake and Hospital Swamp from the Barwon River.

The historic daily streamflow series was derived from a REALM model of the Barwon River catchment developed by SKM (2005). The streamflow series from this model was utilised as part of the Environmental Flow Determination for the Barwon River study (Lloyd et al, 2005). This streamflow series covers the period 1st January 1955 to 30th June 2004. To extend the timeseries up to present day, the McIntyre Bridge gauged streamflow data was appended to the timeseries to provide a continuous daily streamflow series through to 1st January 2010.

The historic daily streamflow series has been analysed to specifically provide an indication of the following components of the LBW hydrology:

- The historical frequency of significant overbank flooding and inundation of Reedy Lake and Hospital Swamp from the Barwon River.
- The annual duration of significant overbank flooding into Reedy Lake and Hospital Swamp
- The historic monthly distribution of overbank flooding events into the wetlands.

- The historic frequency and duration of low streamflow periods that would not have resulted in overbank flooding and inundation of Reedy Lake and Hospital Swamp.

3.1.1 Overbank Flow Spells Analysis

The historic daily streamflow series has been analysed to determine the number of events (spells) in which the mean daily Barwon River flows equalled or exceeded 3,500ML/d. Previous hydrodynamic analysis undertaken as part of the Barwon River Lower Breakwater Management Options study (Water Technology, 2010) determined this streamflow threshold for initiating significant overbank flooding into Reedy and Hospital Swamp. It is however recognized that a degree of uncertainty exists around the precise flow magnitude at which overbank flooding would be initiated into these wetlands. To provide an indication of the sensitivity that the overbank flow threshold estimate has on the number of overbank flow spells calculated, the spells analysis has considered streamflow thresholds approximately 15% higher and lower than the best estimate of 3,500ML/d. Overbank flow spells were considered independent if they were greater than 7 days apart. In addition to the determination of the number overbank flow threshold flow spells, the total annual duration of overbank flows into these wetlands has been calculated.

Figure 3-1 displays the results of the overbank flow spells analysis in relation to the historic daily streamflow series as follows:

- The second timeseries displays the annual number of independent overbank flow spells. The upper and lower whiskers display the sensitivity of the overbank streamflow threshold estimate when it was decreased and increased by 15% respectively.
- The third timeseries displays the total annual duration of overbank flows into the wetlands. The upper and lower whiskers display the sensitivity of the overbank streamflow threshold estimate when it was decreased and increased by 15% respectively.

The following comments are provided based on the results of the overbank flow spells analysis displayed in Figure 3-1.

- The median number of annual overbank flow events into Reedy Lake and Hospital Swamp has been estimated at approximately 3 historically.
- Uncertainty in the precise flow magnitude at which overbank flooding commences into these wetlands is not considered to significantly affect the estimation of the annual overbank flow spells.
- The total annual duration of overbank flows into Reedy Lake and Hospital Swamp has been estimated as 10 days historically.

The distribution of days in which the streamflows exceeded the overbank flow threshold of 3,5000ML/d has been determined from the streamflow series and is displayed in Figure 3-2. Figure 3-2 shows that overbank flows are concentrated over the months of July through to October.

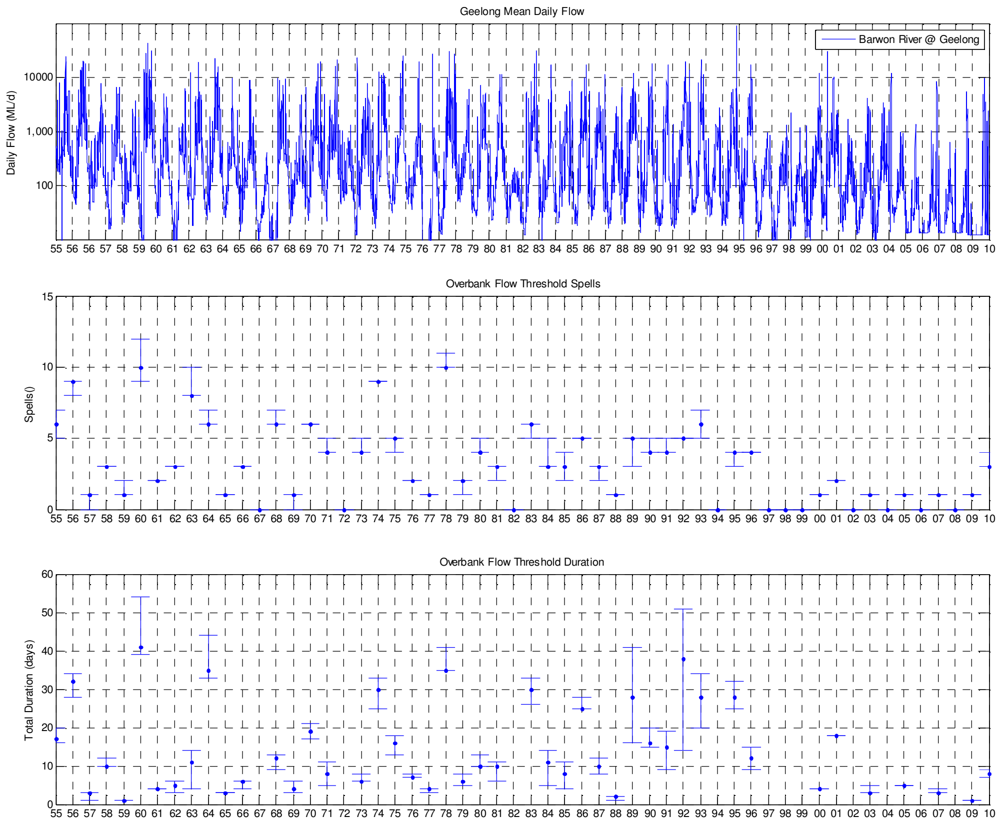


Figure 3-1 Overbank Flow Spells Analysis (1955 – 2010)

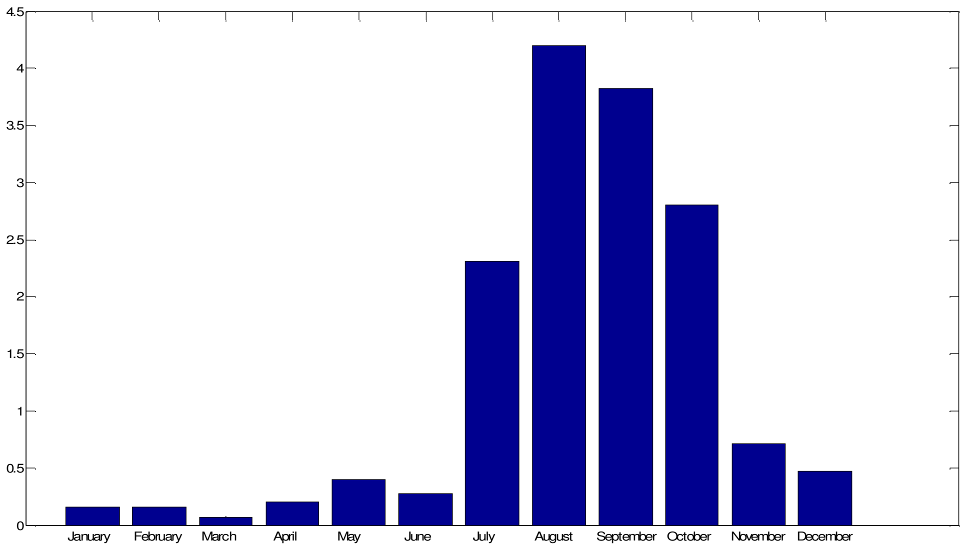


Figure 3-2 Mean Number of Overbank Flow Days (1955-2010)

3.1.2 Low Flow Spells Analysis

The historic daily streamflow series has been analysed to determine the number of events (spells) in which the consecutive mean daily Barwon River flows were less than 3,500ML/d for 365 days or greater. These prolonged low flow periods are considered to provide an indication of potential historical dry phases of Reedy Lake and Hospital Swamp, where Barwon River streamflows were not significant enough to cause overbank flooding into these wetlands. Figure 3-3 displays the temporal distribution of the 365 day or greater, sub-overbank flow spells over the historic daily streamflow series. Table 3-1 displays the start and end date and length of the longest sub-overbank flow spells greater than 365 days.

Based on the analysis of the sub-overbank flow spells, it is considered that on average, dry or partially dry phases may naturally occur in Reedy Lake and Hospital Swamp on average once every 5 years.

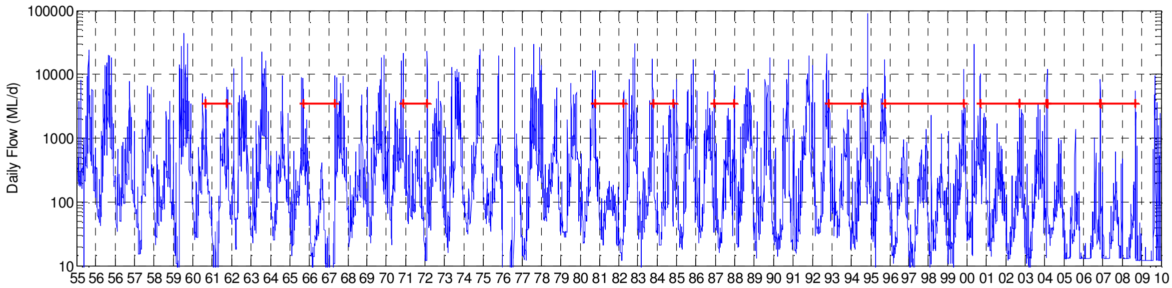


Figure 3-3 Temporal distribution of sub-overbank flow spells greater than 365 days (1955 – 2010)

Table 3-1 Longest sub-overbank flow spells greater than 365 days (1955 -2010)

Start Date	End Date	Duration (Days)
7-Oct-96	26-Oct-00	1480
9-Feb-05	28-Oct-07	991
28-Aug-01	27-Aug-03	729
10-Nov-07	27-Aug-09	656
11-Nov-93	18-Jul-95	614
19-Sep-66	30-Apr-68	589
9-Oct-81	26-Mar-83	533
30-Aug-03	4-Feb-05	524
12-Nov-71	6-Feb-73	452
26-Aug-61	25-Sep-62	395
8-Oct-84	27-Oct-85	384
8-Dec-87	12-Dec-88	370

3.2 Estuarine Storm Surge & Tidal Water Levels

The relative elevations of the wetland complexes in the study area and their proximity to tidally connected Lake Connewarre provides the potential that the natural hydrology of the wetlands could be influenced by inundation associated with storm surge and/or astronomical tidal water level variations in Bass Strait propagating into Lake Connewarre. This mechanism of inundation of Hospital Swamp and Reedy Lake is potentially significant as the inundation from Lake Connewarre is likely to be of brackish or even potentially marine salinity, depending on the antecedent conditions in Lake Connewarre.

Storm surges are meteorologically induced coastal water level variations caused by atmospheric pressure fluctuations and frictional action of wind on the ocean surface. Storm surges generally have periods of approximately 24-48 hours in Bass Strait. The combination of storm surge and the astronomical tide gives rise to the observed coastal water level variations.

To provide an understanding of the relevant storm surge and astronomical water level variations and probabilities in Lake Connewarre, the instantaneous water level records at Lorne and in Lake Connewarre have been compared over an approximate 2 month period from June to July 2008. The comparison is displayed in Figure 3-4. Note that this period includes a significant storm surge event in Bass Strait that occurred in the first week of July. The second timeseries comparison in Figure 3-4 displays the instantaneous residual water level at these two locations after the astronomical tidal component has been removed from the two water level signals. These two water level timeseries comparisons are considered to highlight the following aspects of the estuarine water level variations in Lake Connewarre compared to the open coast:

- The higher frequency astronomical tidal component of the coastal water level variations on the open coast at Lorne is significantly attenuated within the estuarine reach of the Lower Barwon such that the astronomical tidal range in Lake Connewarre is only approximately 15% (0.2m) of the range on the coast at Barwon Heads.
- The low frequency storm surge component of the coastal water level variations with periods of 24-48 hours are able to propagate into Lake Connewarre with minimal attenuation such that the storm surge component of the coastal water level variations are essentially fully transmitted into Lake Connewarre.
- Mean water levels within Lake Connewarre are generally 0.2m above mean sea level due to shallow water hydrodynamic effects associated with the propagation of the astronomical tide along the Lower Barwon estuary.

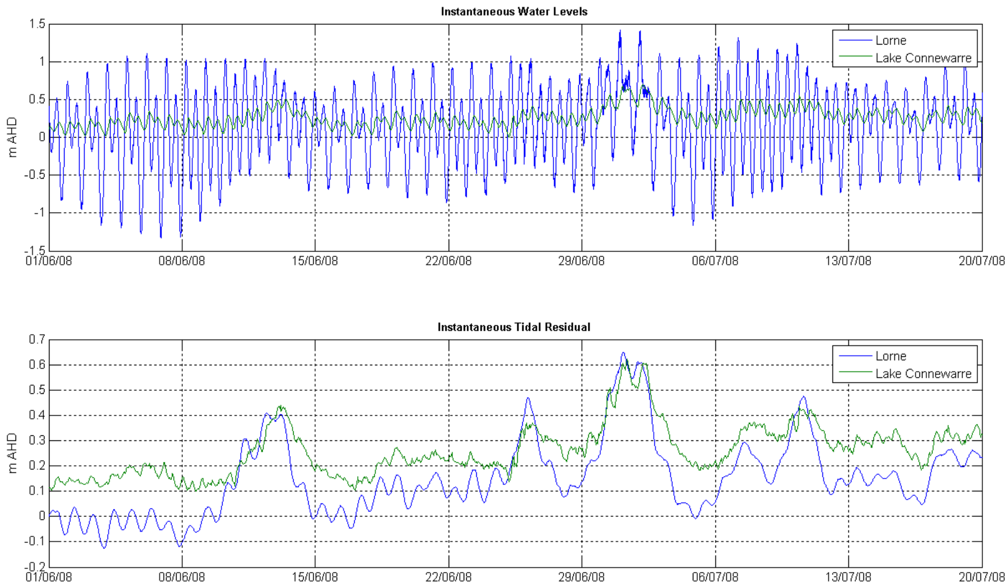


Figure 3-4 Comparison of Lorne and Lake Connewarre instantaneous and tidal residual water levels

Estimates of the exceedance probability of different storm surge levels at Lorne have been developed by CSIRO (2009. The estimates provided for Lorne are considered applicable to Lake Connewarre, based on the analysis of the water levels displayed previously in Figure 3-4. To provide an estimate of peak storm tide levels in Lake Connewarre, an additional 0.1m has been added to the storm surge estimates based on the observed tidal range within Lake Connewarre. An estimate of mean high water in Lake Connewarre has also been provided in Table 3-2.

Table 3-2 Relevant Storm Surge and Tidal Water Level Planes for Lake Connewarre

Relevant Water Level	Lake Connewarre Water Levels (m AHD)
MHW	0.40
100% AEP	0.60
10% AEP	0.76
5% AEP	0.78
2% AEP	0.8
1% AEP	0.81

The following comments are provided in relation to the potential for storm surge and/or astronomical tidal water level variations to cause inundation of Reedy Lake and Hospital Swamp:

- The height of the natural banks separating Lake Connewarre and Hospital Swamp are approximately 0.5m AHD. Based on the analysis of the storm surge planes for Lake Connewarre displayed in Table 3-2, these banks would be overtopped on average once per year or greater to a depth of 0.1m. This would potentially enable significant inundation of these wetlands and in particular the northern most two basins of Hospital Swamp from Lake Connewarre.
- The natural banks separating Lake Connewarre from Reedy Lake are at their lowest point approximately 0.9m AHD. Based on the levels summarised in Table 3-2, significant overbank

inundation from Lake Connewarre into Reedy Lake is considered unlikely and would be an extremely rare occurrence.

- The outlet channels and regulator sill levels of both Reedy Lake and Hospital Swamp are below mean high water in Lake Connewarre and inundation to a level of approximately 0.4m AHD in these wetlands could theoretically be achieved by operation of the regulators to allow the ingress of estuarine water from Lake Connewarre into these wetlands.

4. KEY ECOLOGY/FLOW RELATIONSHIP WATERING SCENARIO MODELLING

In order to improve the understanding of the potential ecological responses within the LBW to different water management regimes, a number of water management scenarios were simulated in the hydrodynamic model. The watering scenario simulations were largely focused on options to manage inundation in Reedy Lake through changes to the operation of the existing regulating structures. Following an all day workshop involving a number of technical specialists and land manager representatives, a range of 3 potential water management scenarios were identified for Reedy Lake.

These key ecology/flow relationship water management scenarios relate to the main characteristics of the inundation that would occur within Reedy Lake following their implementation. The 3 water management scenarios are presented in Table 4-1 and discussed in more detail in the following sections.

Table 4-1 Key Ecology/Flow Relationship Water Scenarios

Water Management Scenario	Inlet Regulator Operation	Outlet Regulator Operation
Wet	Permanently Open	Permanently Closed
Maximum Variation	Open winter/spring Close summer/autumn	Close winter/spring Open summer/autumn
Dry/Salty	Permanently Closed	Open whenever water enters Reedy lake

A 12 month sequence of streamflows, ocean water levels, rainfall, evaporation and wind forcing conditions derived 2008-2009 observed data sources was simulated in the model under 3 different Reedy Lake regulator operation conditions representing the Wet, Maximum Variation and Dry/Salty water management scenarios. The Barwon River inflows to the LBW over the 12 month period used in the scenario modelling are displayed in Figure 4-1. As can bee seen from Figure 4-1, inflows in the Barwon River were very low for extensive periods over the 12 month scenario. Additionally, temperatures and evaporation rates were also considered relatively high compared to long term average conditions. The 12 month period tested in the model therefore provides an indication of the response of the system to various different water management options under drought type conditions and this should be considered when evaluating the results of the water management option scenarios.

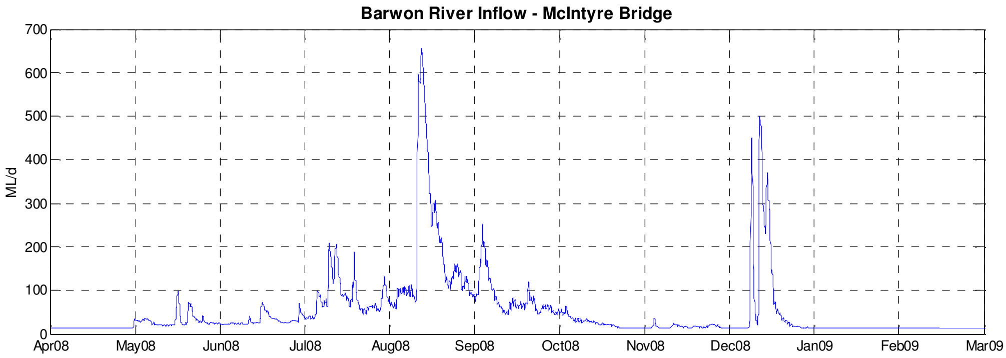


Figure 4-1 Barwon River Inflows of the Water Management Scenario

The model results from each of the water management scenarios simulations have been processed to provide a range of temporal and spatial outputs describing the predicted flows, volumes, levels and inundation extents and durations resulting from the different water management scenarios. The results from the water management scenario simulations are presented in Section 4.4.

4.1 'Wet' Watering Scenario Modelling

The intent of the wet watering scenario modelling is to improve the understanding of the inundation, flow and water level conditions that could be expected to occur within Reedy Lake under a wet as possible water management regime for this wetland.

The boundary conditions and regulator structure operations adopted for the Wet watering scenario are discussed in Section 4.1.1.

The results of the Wet watering scenario simulation are presented in Section 4.4.

4.1.1 Regulator Settings

Reedy Lake Regulator Operations

The following regulator operation logic was incorporated into the Reedy Lake regulators for the Wet watering scenario:

- Reedy Lake inlet regulator was permanently open over the 12 month scenario
- Reedy Lake outlet regulator was permanently shut over the 12 month scenario.

Hospital Swamp Regulator Operations

The following regulator operation logic was incorporated in the Hospital Swamp regulators for the Wet watering scenario:

- Hospital Swamp inlet regulator was opened on 1st September
- Hospital Swamp was filled to 0.5m AHD and the regulator was operated to maintain a water level no greater than 0.5m AHD until 1st November
- Hospital Swamp inlet regulator was closed on 1st November.
- Hospital Swamp outlet regulator remained closed and Hospital Swamp was allowed to dry via evaporation over summer.

4.2 'Maximum Variation' Watering Scenario Modelling

The intent of the maximum variation watering scenario modelling is to improve the understanding of the degree of variation in the inundation, flow and water level conditions that can be manipulated within Reedy Lake with the present regulating structures for this wetland.

The boundary conditions and regulator structure operations adopted for the maximum variation watering scenario are discussed in Section 4.2.1.

The results of the maximum variation watering scenario simulation are presented in Section 4.4.

4.2.1 Regulator Settings

Reedy Lake Regulator Operations

The following regulator operation logic was incorporated into the Reedy Lake regulators for the maximum variation scenario:

- Reedy Lake inlet regulator was opened on 1st May to commence filling of Reedy Lake
- Reedy Lake was allowed to be filled to between 0.5 – 0.9m AHD until 1st November
- Reddy Lake outlet regulator opened on 1st November to enable drawdown and drying over summer

Hospital Swamp Regulator Operations

The following regulator operation logic was incorporated in the Hospital Swamp regulators for the maximum variation scenario:

- Hospital Swamp inlet regulator was opened on 1st September
- Hospital Swamp was filled to 0.5m AHD and the regulator was operated to maintain a water level no greater than 0.5m AHD until 1st November
- Hospital Swamp inlet regulator was closed on 1st November.
- Hospital Swamp outlet regulator remained closed and Hospital Swamp was allowed to dry via evaporation over summer.

4.3 'Dry' Watering Scenario Modelling

The intent of the dry watering scenario is to improve the understanding of the degree in which flows and resulting inundation can be excluded from Reedy Lake with the existing regulating structures on this wetland.

The boundary conditions and regulator structure operations adopted for the maximum variation watering scenario are discussed in Section 4.3.1.

The results of the maximum variation watering scenario simulation are presented in Section 4.4.

4.3.1 Regulator Settings

Reedy Lake Regulator Operations

The following regulator operation logic was incorporated into the Reedy Lake regulators for the dry scenario:

- Reedy Lake inlet regulator was permanently closed over the 12 month scenario
- Reedy Lake outlet regulator was opened only if Reedy Lake water levels were greater than Lake Connewarre water levels.

Hospital Swamp Regulator Operations

The following regulator operation logic was incorporated in the Hospital Swamp regulators for the maximum variation scenario:

- Hospital Swamp inlet regulator was opened on 1st September
- Hospital Swamp was filled to 0.5m AHD and the regulator was operated to maintain a water level no greater than 0.5m AHD until 1st November
- Hospital Swamp inlet regulator was closed on 1st November.
- Hospital Swamp outlet regulator remained closed and Hospital Swamp was allowed to dry via evaporation over summer.

4.4 Scenario Modelling Results

The following sections document the comparisons between the different watering scenario simulations in terms of the following;

- Reedy Lake water levels and inflows and outflows
- Hospital Swamp water levels and inflows
- Hospital Swamp and Reedy Lake Water Use
- Lake Connewarre Salinity Impact
- Inundation Extent and Durations

4.4.1 Reedy Lake Water Levels and Flows

Figure 4-2 displays the predicted water levels Reedy Lake for each water management option over the duration of the 12 month scenario. The following observations regarding the comparisons of the Reedy Lake water levels displayed in Figure 4-2 are provided:

- At times during the Scenario, inflows in the Barwon River were insufficient to maintain the weir pool above the lower Barwon Barrage. The reduced inflows into Reedy Lake limited the ability to maintain fully inundated conditions in Reedy Lake over the course of the Wet scenario due to the relatively high evaporation losses that occur from this wide and shallow water body, particularly in the warmer months. The potential inability to maintain fully inundated conditions in Reedy Lake during dry years should be considered in the development of the water management plan for Reedy Lake.

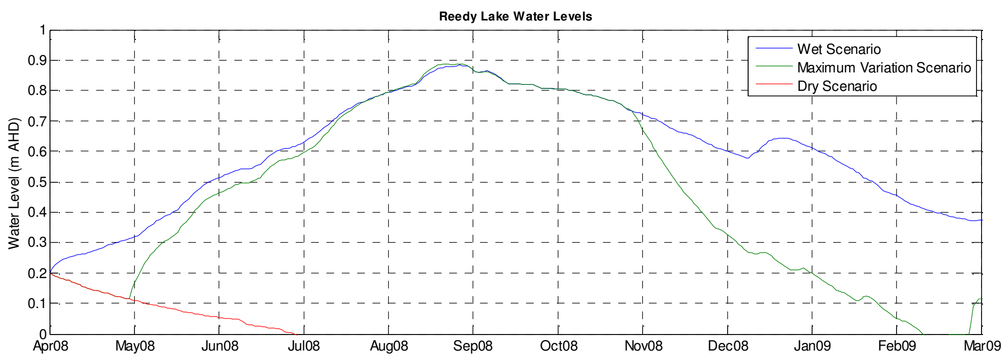


Figure 4-2 Comparison of Predicted Reedy Lake Water Levels

Figure 4-3 displays the predicted inflow and outflow timeseries in Reedy Lake for each water management option over the duration of the 12 month scenario. The following observations regarding the comparisons of the Reedy Lake water levels displayed in Figure 4-3 are provided:

- The difference between the Reedy Lake inlet regulator inflows under the Wet and Maximum Variation Scenario were relatively minor over the 12 month scenario. This is largely due to the small Barwon River inflows which were insufficient to maintain the weir pool above the Lower Barrage at times.
- The Reedy Lake outlet regulator can experience periodic flow reversals due to tidal variations in Lake Connewarre when water levels in Reedy Lake are low. The tidal influence from Lake Connewarre on Reedy Lake water levels is however not significant as the tidal signature is significantly attenuated along the outlet channel.

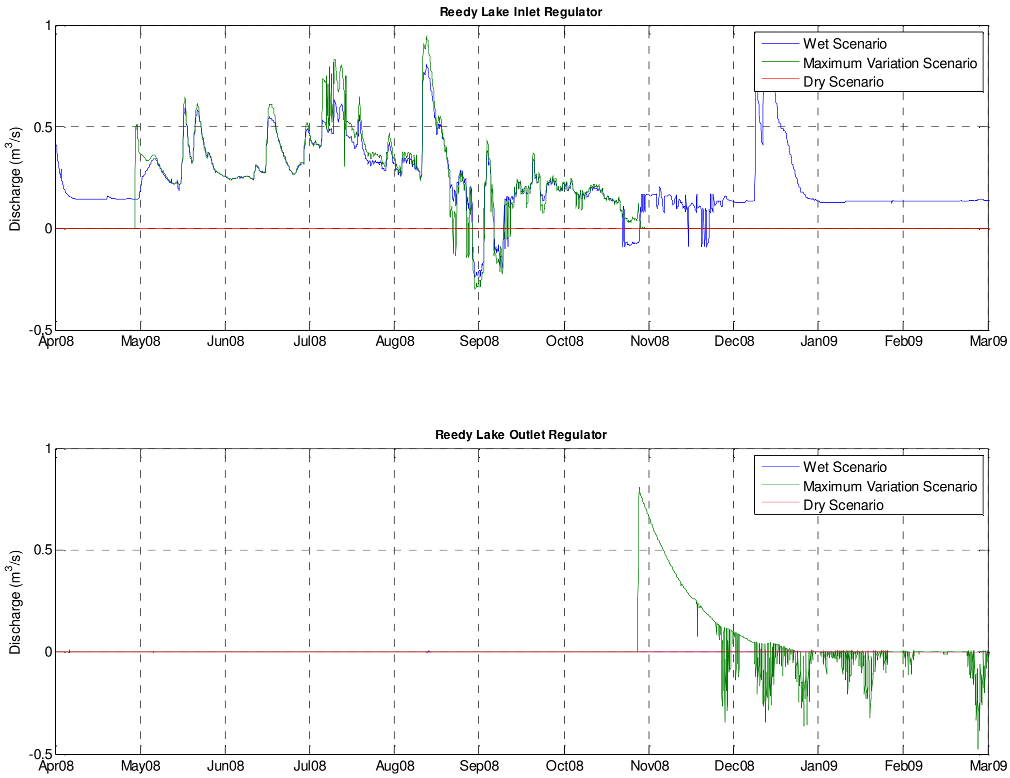


Figure 4-3 Comparison of Predicted Reedy Lake Inflows and Outflows

4.4.2 Hospital Swamp Water Levels and Flows

Figure 4-4 displays the predicted water levels Reedy Lake for each water management option over the duration of the 12 month scenario. The following observations regarding the comparisons of the Reedy Lake water levels displayed in Figure 4-4 are provided:

- No significant difference in the water level variation or flows into Hospital Swamp are predicted in the model between the various water management regime scenarios simulated in the model for Reedy Lake. It is therefore considered that changes to the Reedy Lake water management regime will not significantly impact Hospital Swamp.

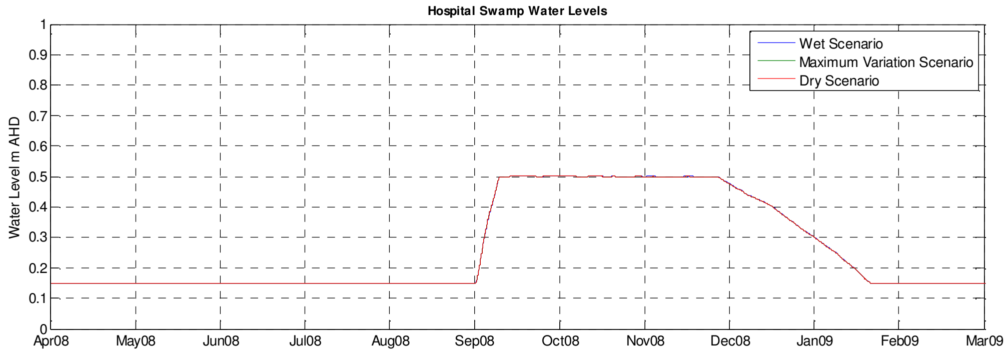


Figure 4-4 Comparison of Predicted Hospital Swamp Water Levels

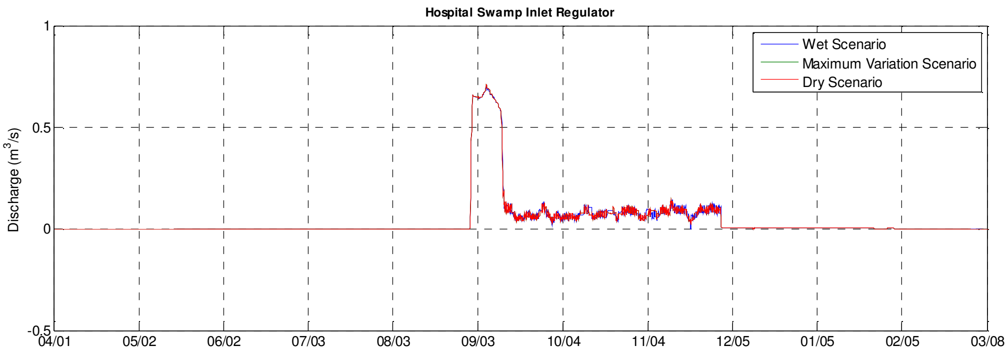


Figure 4-5 Comparison of Predicted Hospital Swamp Inflows

4.4.3 Hospital Swamp and Reedy Lake Water Use

Figure 4-6 displays the predicted cumulative inflows to Reedy Lake and Hospital Swamp for each water management option over the duration of the 12 month scenario. The following observations regarding the comparisons of the Reedy Lake cumulative inflows displayed in Figure 4-6 are provided:

- The cumulative inflows into Reedy Lake under the Wet Scenario are predicted at approximately 6,900ML over the 12 month period.
- The cumulative inflows into Reedy Lake under the Maximum Variation Scenario are predicted at approximately 4,700ML over the 12 month period
- The cumulative inflows into Reedy Lake under the Dry Scenario are 0ML over the 12 month period

The following observations regarding the comparisons of the Hospital Swamp cumulative inflows displayed in Figure 4-6 are provided:

- The different water management scenarios for Reedy Lake are not predicted to affect the Hospital Swamp water use.
- The cumulative inflow to Hospital Swamp under all scenarios is predicted at approximately 1,150ML over the 12month period.

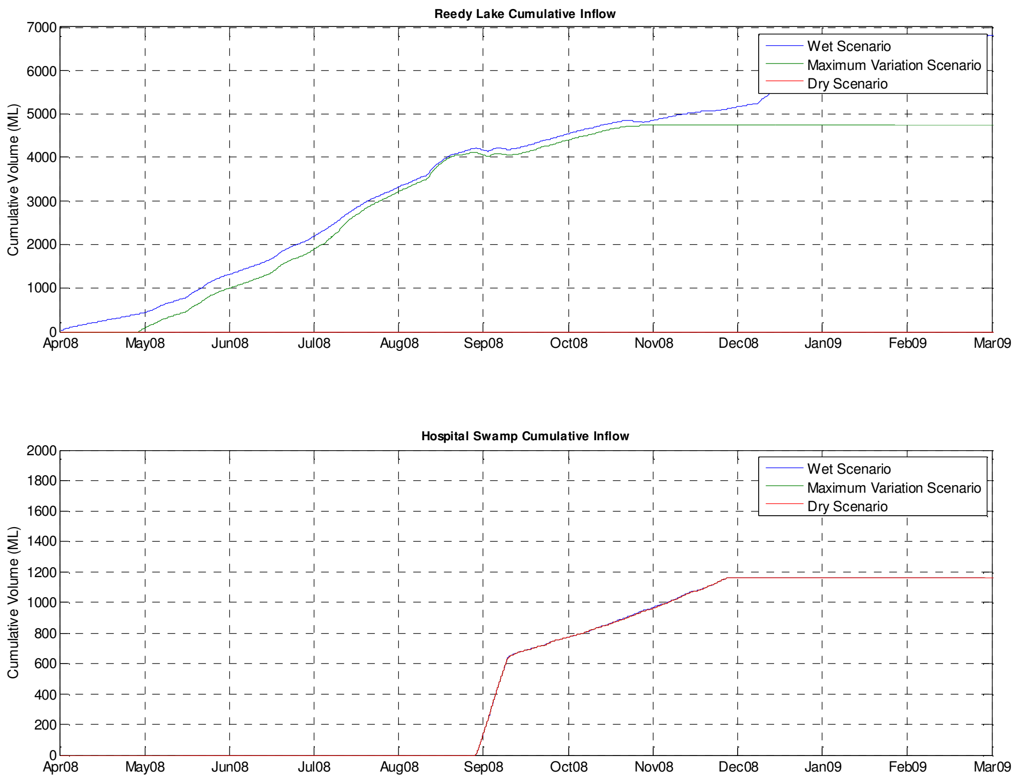


Figure 4-6 Comparison of Predicted Reedy Lake and Hospital Swamp Water Use

4.4.4 Lake Connewarre Salinity Impact

Figure 4-7 displays the predicted impact on salinity at locations representative of western and eastern sections of Lake Connewarre for each of the different Reedy Lake water management regimes scenarios over the duration of the 12 month scenario.

It should be noted that the limited long term salinity data was available with which to calibrate the hydrodynamic model. The accuracy of the salinity predictions from the model are therefore not considered particularly reliable. However, the model precision is such that relative changes in salinity between different scenarios are considered to be relatively reliably predicted.

The following observations regarding the relative comparisons of the Lake Connewarre salinities displayed in Figure 4-7 are provided:

- Only minimal differences between predicted salinities in the western and eastern sections of Lake Connewarre are predicted between the Wet and Maximum Inundation scenarios.
- The Dry scenario is however expected to result in a significant reduction in relative salinities in both the western and eastern sections of Lake Connewarre.
- The model results indicate that the diversions into Reedy Lake from the Barwon River under the wet and maximum variation scenario are potentially significant to salinity in Lake Connewarre, particularly when Barwon River inflows are very low. Under the 2008 scenario tested in the model, diversions into Reedy Lake exceeded the Barwon River inflows at times, resulting in the lower breakwater weir pool lowering below the weir crest. During these periods, the only freshwater inflows into Lake Connewarre were due to leakage around the breakwater structure. Under these conditions the impact of the flow diversions into Reedy

Lake appears to be particularly significant to the salinity in the western section of Lake Connewarre.

- The model indicates that importance of the Barwon River inflows in maintaining the estuarine character of Lake Connewarre, particularly over dry and warm periods when evapo-concentration of salinity is high and hyper saline conditions can persist for multiple months within Lake Connewarre.

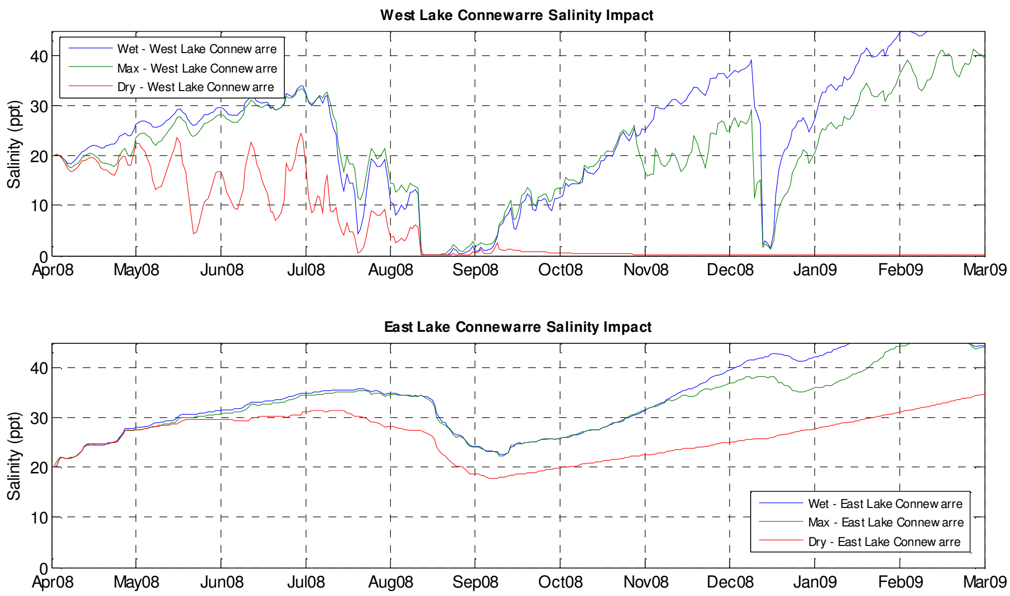


Figure 4-7 Comparison of Predicted Lake Connewarre Salinity

4.4.5 Inundation Extents and Durations

The predicted extents of inundation and the depth/duration characteristics of the inundation have been processed from the scenario simulation results. The following summaries of the inundation characteristics have been provided:

- The total extent and duration of inundation
- The extent and duration of inundation greater than 0.5m depth.

The summaries of the inundation characteristics for each scenario are provided in the following figures.

The following observations regarding the comparisons of the predicted inundation depth and duration characteristics presented in following figures are provided:

- The Wet scenario increases the duration of flooding greater than 0.5m depth in the deepest sections of Reedy Lake by up to approximately 90 days compared to the Maximum Variation scenario.
- The Wet scenario increases the total duration of flooding in shallower areas by up to approximately 60 days compared to the Maximum Variation scenario.

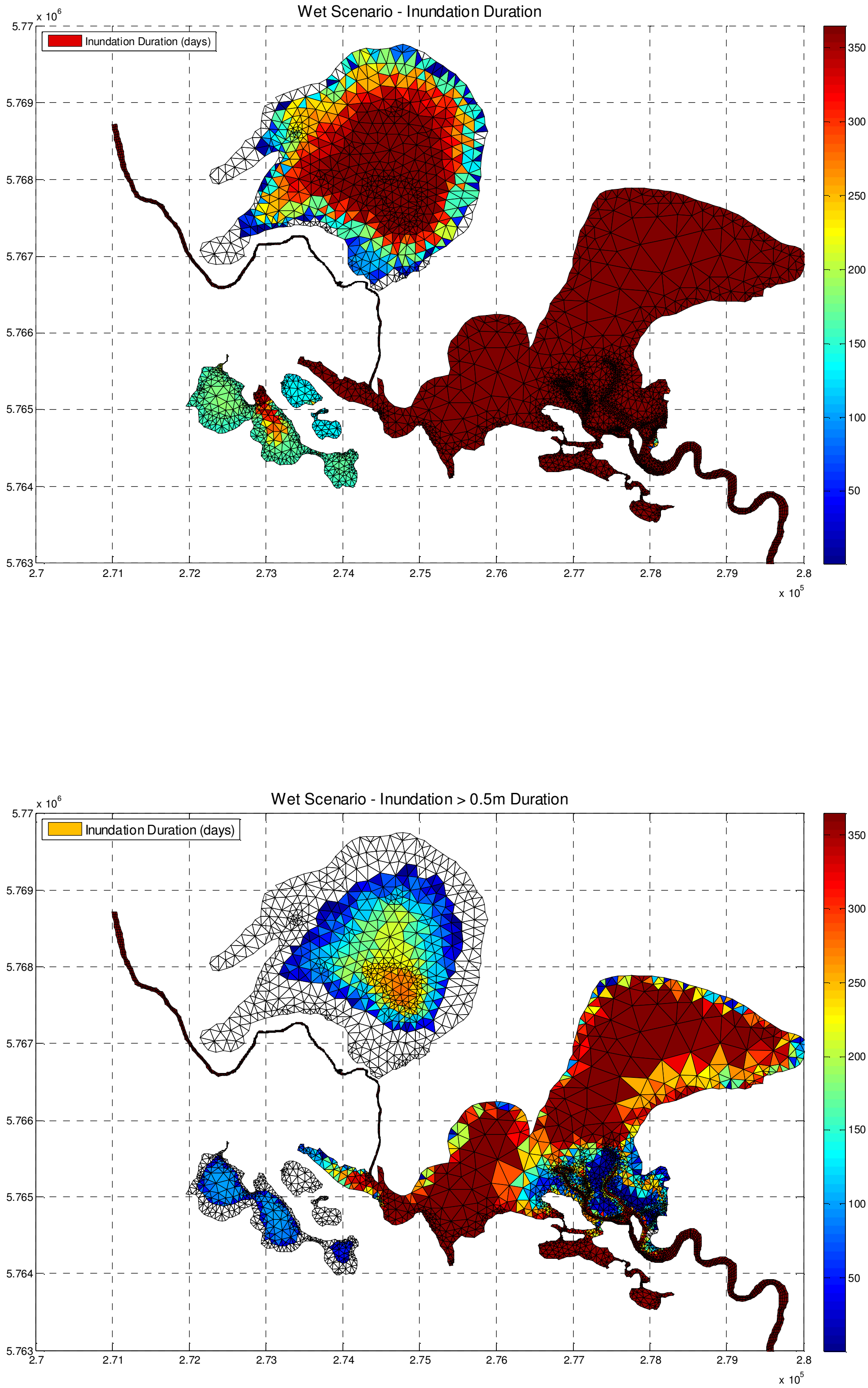
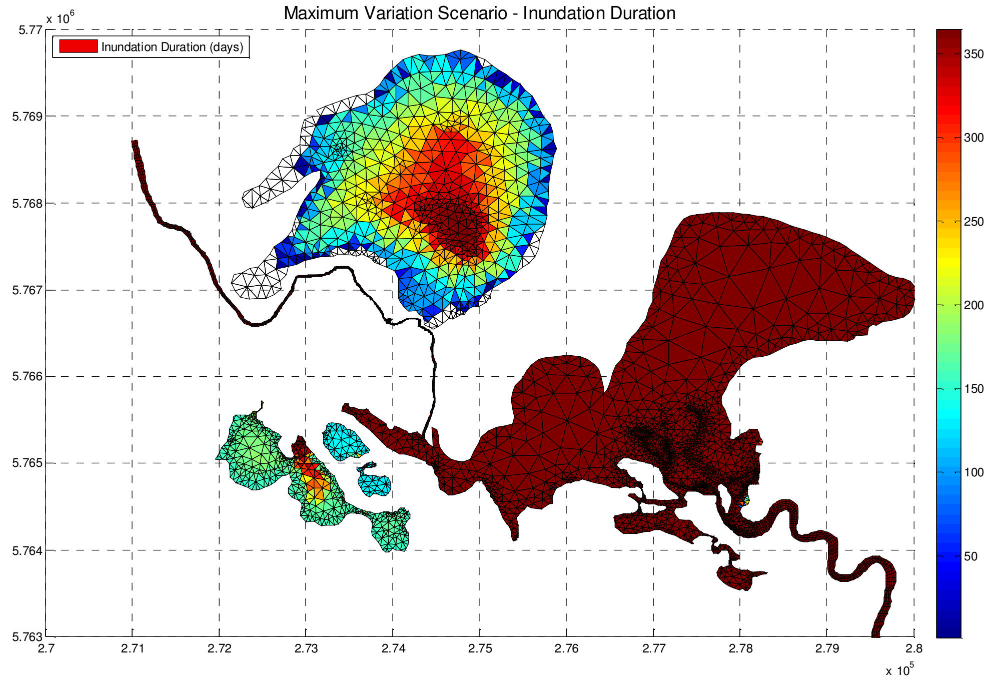


Figure 4-8 Wet Scenario Predicted Inundation Characteristics



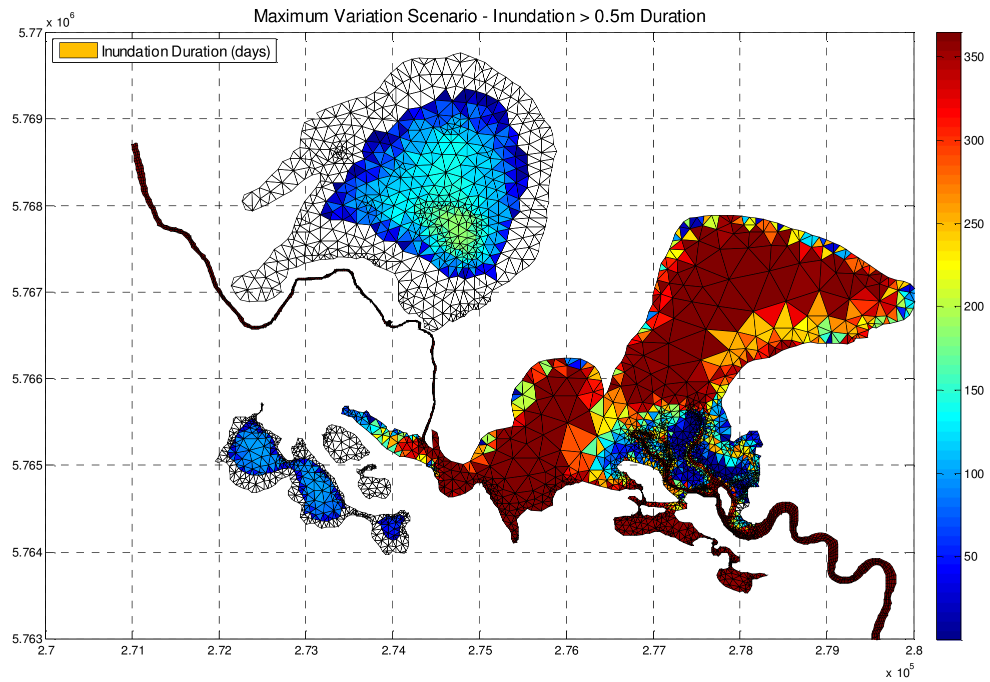
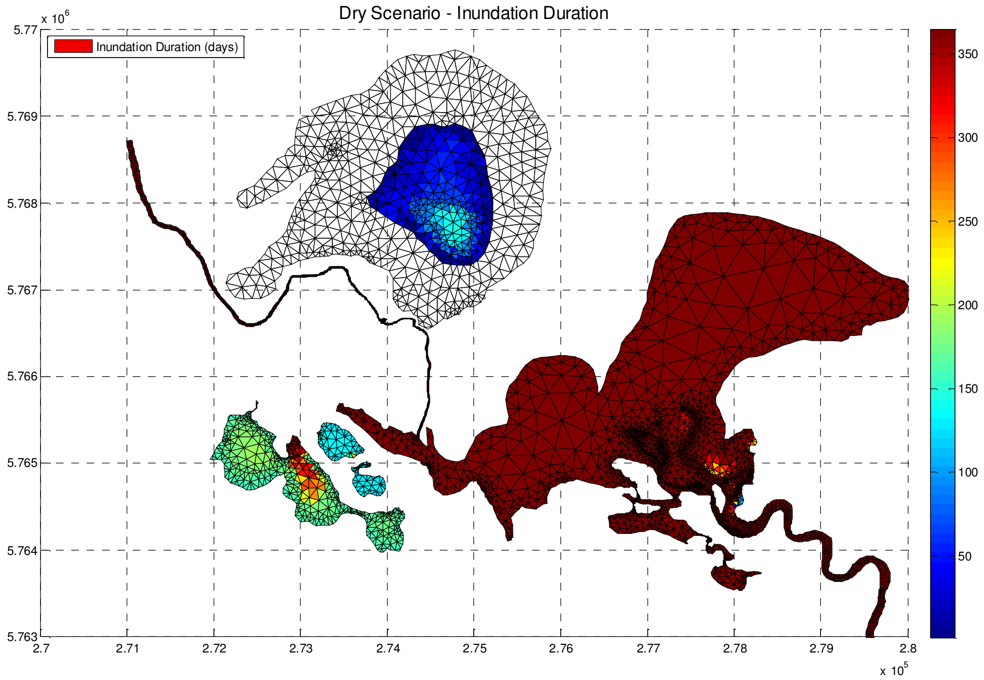


Figure 4-9 Maximum Variation Scenario Predicted Inundation Characteristics



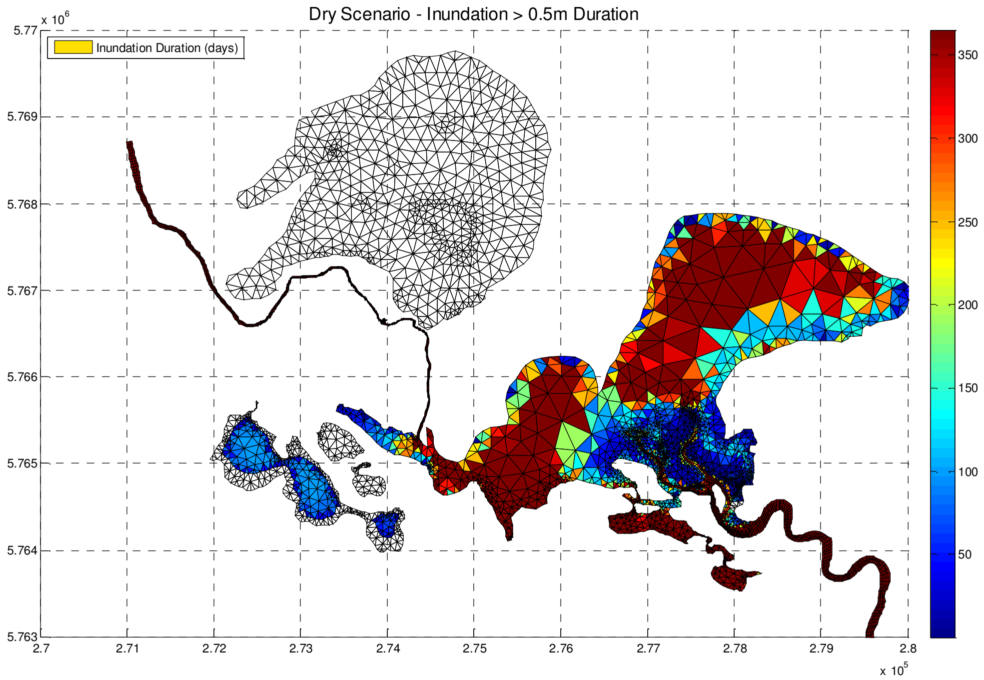


Figure 4-10 Dry Scenario Predicted Inundation Characteristics

5. CONCLUSION

The following summarises the main conclusions from the LBW modelling for the Environment Entitlement:

- Hydrodynamic modelling and subsequent validation from water level records available during an overbank flooding event that occurred in January 2011, determined that a flow rate of approximately 3,500ML/d initiated sustained overbank flooding into Reedy Lake and Hospital Swamp.
- Analysis of long term historical streamflow time series for the Barwon River at Geelong provided estimated annual overbank flow frequencies of approximately 3 events per year. The frequency of overbank flow events over the last approximate 10 years has however been well below the long term average.
- The total annual duration of overbank flows into Reedy Lake and Hospital Swamp has been estimated as 10 days historically. Overbank flow events are strongly concentrated over the months of July through to October.
- Historically, sub-overbank flow spells greater than 365 days occur on average, once every 5 years.
- The height of the natural banks separating Lake Connewarre and Hospital Swamp are approximately 0.5m AHD. Based on the analysis of the storm surge planes for Lake Connewarre, these banks would be overtopped on average once per year or greater to a depth of 0.1m. This would potentially enable significant inundation of these wetlands and in particular the northern most two basins of Hospital Swamp from Lake Connewarre.
- The natural banks separating Lake Connewarre from Reedy Lake are at their lowest point approximately 0.9m AHD. Significant overbank inundation from Lake Connewarre into Reedy Lake is considered unlikely and would be an extremely rare occurrence.
- The outlet channels and regulator sill levels of both Reedy Lake and Hospital Swamp are below mean high water in Lake Connewarre and inundation to a level of approximately 0.4m AHD in these wetlands could theoretically be achieved by operation of the regulators to allow the ingress of estuarine water from Lake Connewarre into these wetlands.

A number of water management scenarios were simulated in the hydrodynamic model to improve the understanding of the potential ecological responses within the LBW to different water management regimes in Reedy Lake. ‘Wet’, ‘Maximum Variation’ and ‘Dry’ water management scenarios for Reedy Lake were simulated in the hydrodynamic model over a 12 month sequence of Barwon River streamflows, tidal water level variations, rainfall, wind and evaporation. The following main observations from the results of the scenario modelling are provided:

- The scenario modelling results indicate that fully inundated conditions in Reedy Lake may not be achieved consistently during periods of low Barwon River streamflows. Relatively high evaporation losses occur from Reedy Lake due its large surface area and shallow depths during the warmer months.
- No significant difference in the water level variation or flows into Hospital Swamp are predicted in the model between the various water management regime scenarios simulated in the model for Reedy Lake. It is therefore considered that changes to the Reedy Lake water management regime will not significantly impact the existing Hospital Swamp water management regime.
- The cumulative inflows into Reedy Lake under the Wet Scenario are predicted at approximately 6,900ML over a 12 month period. The cumulative inflows into Reedy Lake under the Maximum Variation Scenario are predicted at approximately 4,700ML over a 12 month period
- The cumulative inflow to Hospital Swamp under all scenarios is predicted at approximately 1,150ML over a 12month period.

- The Wet scenario can potentially increase the duration of flooding greater than 0.5m depth in the deepest sections of Reedy Lake by up to approximately 90 days on average compared to the Maximum Variation scenario. The Wet scenario potentially increases the total duration of flooding in shallower areas by up to approximately 60 days on average compared to the Maximum Variation scenario.
- The scenario modelling results indicate that the diversions into Reedy Lake from the Barwon River under the Wet and Maximum Variation scenarios during low flow/drought type conditions in the Barwon River are potentially significant to the salinity of Lake Connewarre. The scenario modelling results highlight the importance of the Barwon River inflows in maintaining the estuarine character of Lake Connewarre, particularly over dry and warm periods when evapo-concentration of salinity is high and hyper saline conditions can persist for multiple months within Lake Connewarre.
- Longer term, continuous salinity data in Lake Connewarre is required to assist in calibrating the hydrodynamic model and to enable analysis of the long term salinity regime of Lake Connewarre. This analysis is required to allow the impact of the water management options on the salinity in Lake Connewarre to be more definitively assessed.

APPENDIX A FIELD DATA COLLECTION

To support the development of the hydrodynamic model and provide a monitoring date set for model calibration and validation, a range of field data was collated from existing sources and/or collected as part of this project. The main components of the field data collection program were the following:

- Topographic and Hydraulic Structure Survey
- Water Level and Water Quality Monitoring

The details of the field data collection program are discussed in more detail in the following sections.

Topographic and Hydraulic Structure Survey

Survey data was available from a range of different sources and previous projects in the study area. Available survey data was collated and reviewed in order to identify gaps and subsequently prepare a survey scope to fill these gaps. Additional field and hydraulic structure survey was undertaken for this project to fill the identified survey gaps. The additional field survey undertaken for this project included details of Hospital Swamp bed, the constructed inlet and outlet channels to Hospital Swamp and details of the culverts and penstocks used to control flows through these channels.

Table 5-1 lists the main topographic and structural survey data sources collated as part of this project used to assist in the model development. Figure 5-2 displays the location of these topographic and structural field survey data sources.

Table 5-1 Summary of Topographic and Structural Field Survey Data Sources

Data	Source	Note
VICMAP Future Coast Elevation LiDAR	DSE	1m LiDAR Survey
Upper Barwon River Channel Survey	Water Technology	Survey commissioned previously
Lower Barwon River Channel Survey	Barwon Water	Hydrographic and field survey
Lake Connewarre Spot Level Survey	Barwon Water	Hydrographic and field survey
As constructed Channel Dimensions	Ian McLachlan, Barwon Water, Field and Game	Field survey, construction drawings
Hospital Swamp Spot Level Survey	Ian McLachlan	Field survey
Reedy Lake Spot Level Survey	CCMA	CCMA's Barwon Barrage assessment

Water Level and Water Quality Monitoring Data

Suitable hydrologic and water quality monitoring data was collated from previous and ongoing project work in the study area. This data was reviewed to identify historical periods with the most extensive and up to date monitoring datasets of the LBW to ensure the most rigorous calibration of the hydrodynamic model possible was undertaken.

From this review, the following main suitable monitoring datasets and sources were identified.

- Lake Connewarre Values Hydrodynamic Modelling Project

- University of Ballarat Groundwater Monitoring Project

Monitoring 2008

From these data sources, the most extensive and complete series of suitable measurements for model calibration were identified as occurring from a period beginning June 2008 to March 2009. Over parts of this period, concurrent tidal water levels, Lake Connewarre salinity, Reedy Lake and Barwon River water level data was available. This period also includes a flooding and partial drying of Reedy Lake and is considered to provide a good test of the hydrodynamic models ability to reproduce this aspect of the Reedy Lake hydrology.

The relevant data collated from these monitoring sites over this period is displayed in Figure 5-1.The locations of the monitoring sites from these two main data sources are displayed in Figure 5-3.

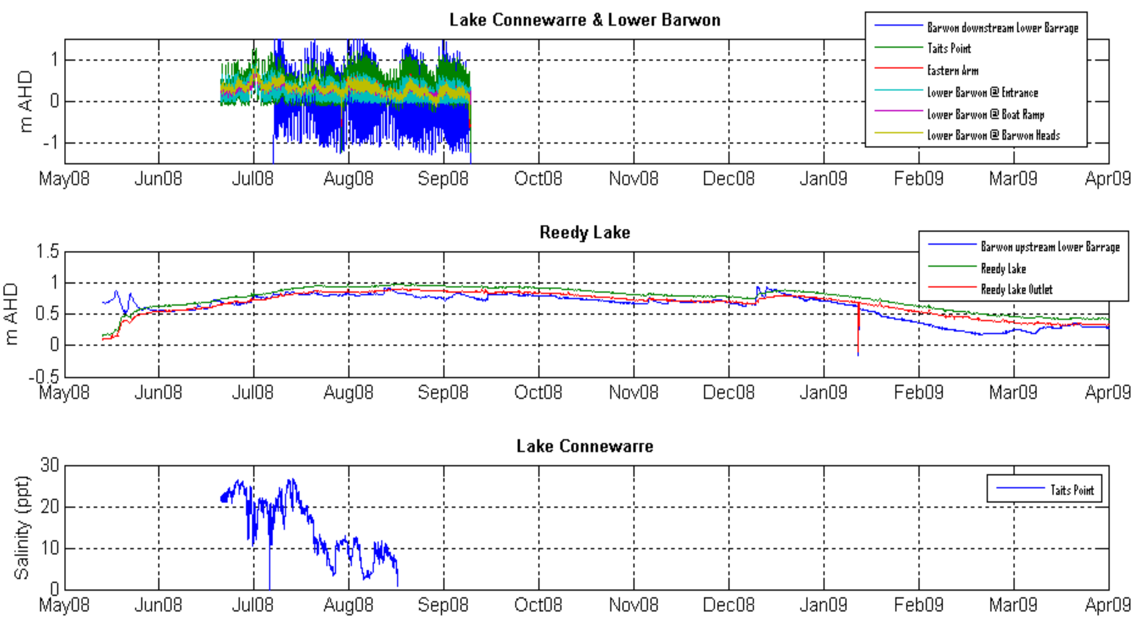


Figure 5-1 2008 Monitoring Data

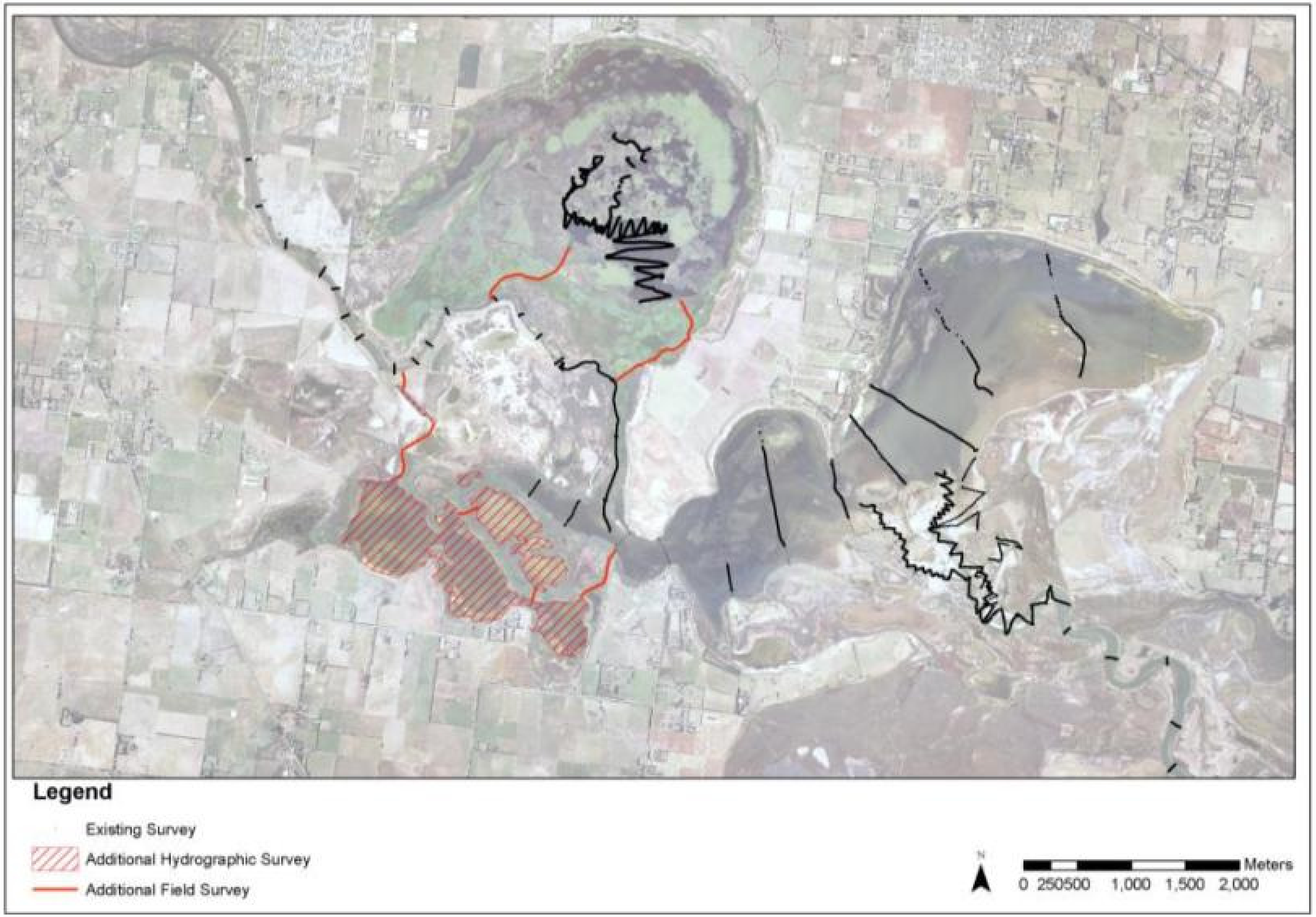


Figure 5-2 Overview of Extent of Topographic and Structural Field Survey

Figure 5-3 Hydrologic Monitoring Locations

Monitoring 2010 – 2011

Continuous (6-10 min) pressure observations were logged at 2 locations within Lake Connewarre during the summer of 2010 – 2011. The locations are displayed in Figure 5-3. Where required, the pressure observations were adjusted for barometric pressure variations based on the Geelong AWS recorded barometric pressures, and the adjusted pressures converted to water depths.

The loggers were deployed on the 23rd November 2010 and retrieved on the 4th February 2011. An interim data download was undertaken on 23rd December 2010. Water level loggers in the first deployment were drowned and returned no usable results; however two continuous records were obtained for the salinity monitoring at the Lake Connewarre entrance to the Lower Barwon.

Figure 5-4 and Figure 5-5 display the recorded water level and salinity respectively at the monitoring locations.

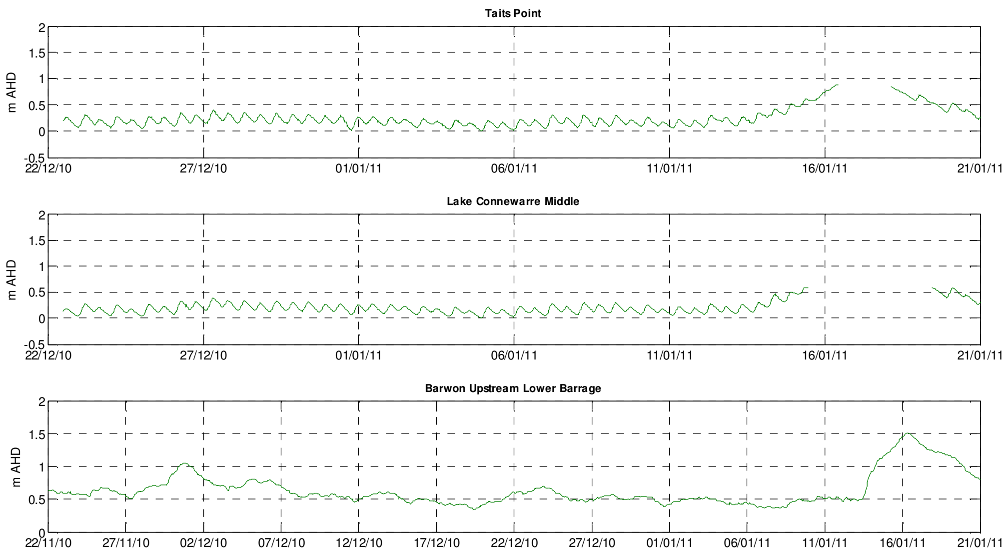


Figure 5-4 Logged Water Levels 2010 – 2011

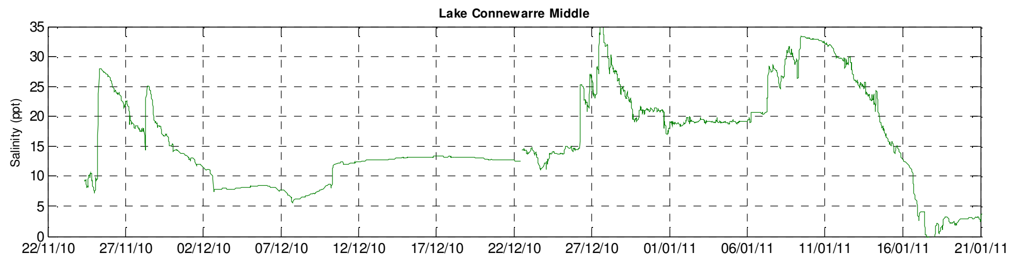


Figure 5-5 Logged Salinity Level, Lake Connewarre Entrance to Lower Barwon River 2010 - 2011

APPENDIX B DIGITAL ELEVATION MODEL

To support the hydrodynamic model development, a continuous digital terrain model (DTM) of the LBW has been constructed by combining the various sources of terrain information discussed in Appendix A.

The main objective of the DTM development was to ensure the various tidal channels and small constructed channels into Reedy Lake and Hospital Swamp were properly resolved as these features are considered critical to the hydrodynamic behaviour of the LBW.

Figure 5-6 displays an overview of the continuous DTM including the bathymetry of Lake Connewarre, Reedy Lake and Hospital Swamp.

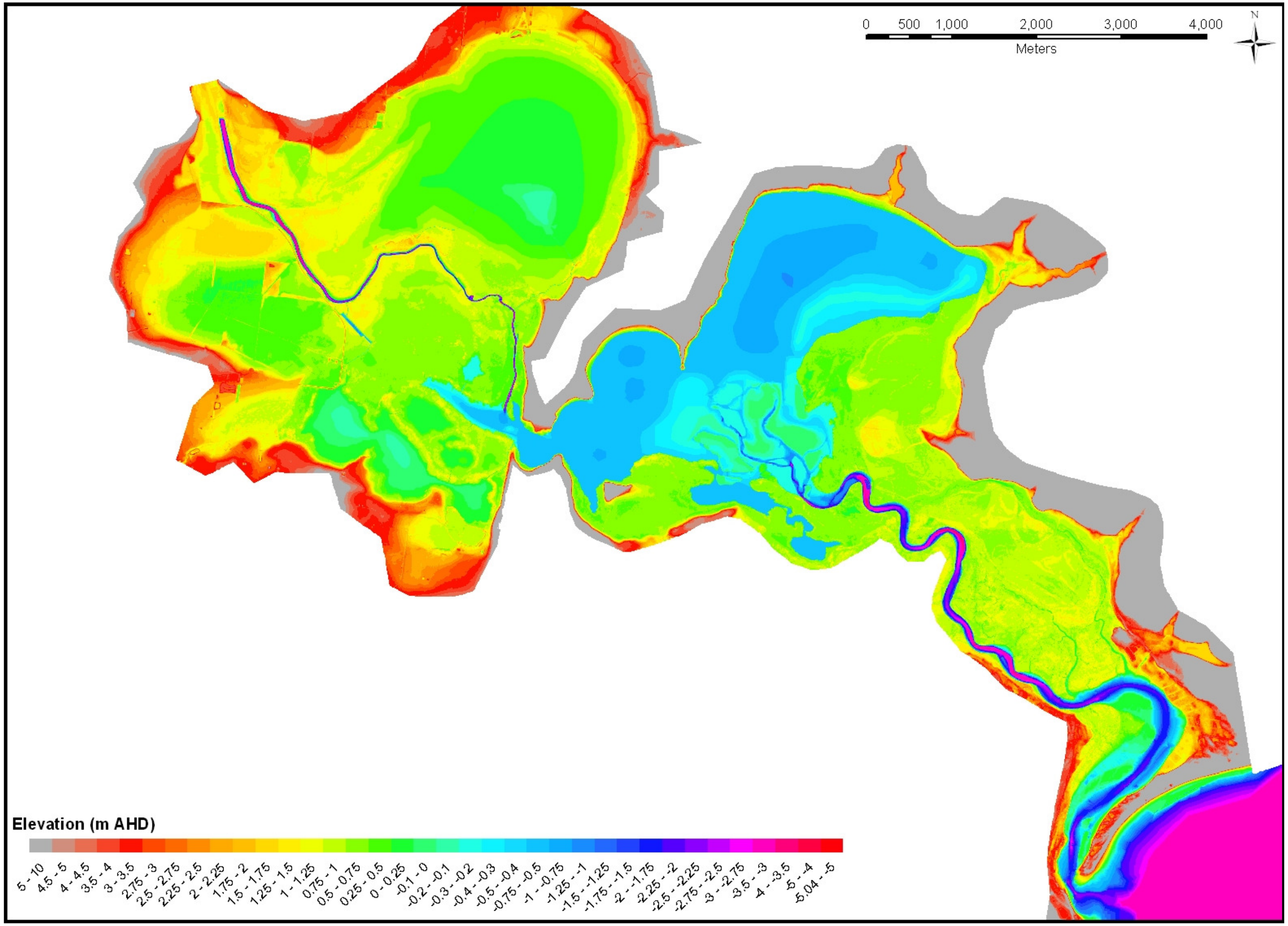


Figure 5-6 Digital Elevation Model of the Lower Barwon Wetland Complex

APPENDIX C HYDRODYNAMIC MODEL DEVELOPMENT AND CALIBRATION

Introduction

Numerical modelling is the process of creating an equation or system of equations that describes or predicts, with an appropriate degree of accuracy, some physical situation.

The governing equations for the flow and transport of scalar variables (salinity) in an estuary can be achieved by combining the Reynolds form of the Navier Stokes equations, the volume continuity equation, the advection diffusion equation for salinity and an equation of state relating water density to salinity.

The model supports a range of boundary conditions including spatially and temporally varying tide, river inflow, wind, rainfall and evaporation. The model allows use of a range of eddy viscosity formulations including the Smagorinsky closure methodology.

Model Topography

The horizontal spatial domain of the model is comprised of quadrilateral and triangular elements. Linear features such as the Lower Barwon Estuary channel and the Barwon River were resolved as quadrilateral elements to improve computational efficiency and numerical resolution of the hydrodynamics of these features. The wetlands and other topographic features are resolved as triangular elements of varying size to adequately resolve areas of high hydraulic gradients and minimise unnecessary computational points in other areas. The two dimensional computational mesh of the entire model is displayed in Figure 5-7.

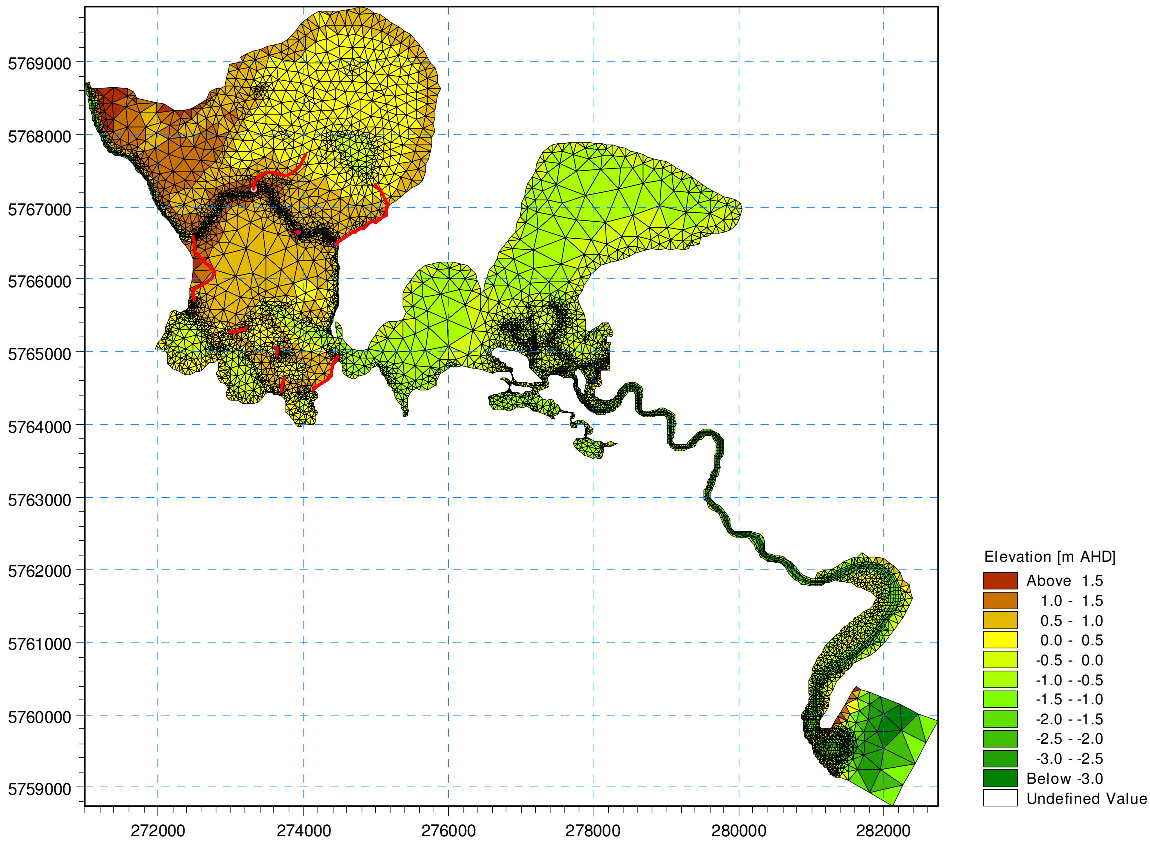


Figure 5-7 Hydrodynamic Model Domain

Boundary Conditions

Tidal Boundary

A tidal water level boundary is specified offshore of the entrance to the Lower Barwon at Barwon Heads. Water level variations at this boundary are a function of astronomical and meteorological forcing conditions.

From the results of previous analysis of the comparison of the astronomical tide between Lorne and Barwon Heads (Water Technology, 2008) it was found that the observed water level record at Lorne provided a suitable description of the ocean boundary condition at Barwon Heads after a slight adjustment of the amplitude of the diurnal M2 component of the tide.

The tidal boundary was specified with a constant ocean salinity of 35ppt.

Barwon River

Freshwater inflows in the Barwon River are specified at a location approximately 6 kilometres upstream of the Lower Barrage. The closest available streamflow gauge on the Barwon River is at the McIntyre Bridge gauge in Geelong. The gauge is however approximately a further 4 kilometres upstream of the model boundary location and uncertainty remains in the estimation of the flows at the models upstream boundary.

Wind

Wind driven circulation and mixing is an important component of the hydrodynamic behaviour of Lake Connewarre in particular. 10 minute average, hourly wind speed and direction observations were derived from the Geelong AWS and applied to the modelled water surface.

Evaporation

The air–sea exchange of heat and water across the surface of the LBW determines changes in temperature and salinity in wetlands and estauries. For the purposes of this study, the impact of evaporation on salinities and water levels has been simply accounted for by applying a time varying (negative) fresh water flux from the model surface area based on appropriately factored daily pan evaporation rates sourced from the Bureau of Meteorology.

Rainfall

Direct rainfall is applied to the surface layer of the model as a time varying fresh water flux. Observed rainfall data has been derived from the Geelong AWS and was uniformly applied spatially across the model domain.

One Dimensional Elements and Hydraulic Structures

Sub element scale features and structures on the floodplain not efficiently resolved in the two dimensional computational mesh were incorporated within the model schematisation by the incorporation of one dimensional, cross sectional elements and structures which were then dynamically linked to the two dimensional mesh. This approach reduces the computational overhead, flexibility and numerical stability of the model. One dimensional elements and structures were used to define the inlet and outlet channels to Reedy Lake and Hospital Swamp and associated regulating structures on these channels as well as to define the Lower Barwon Barrage.

Bed Resistance

Bed resistance was specified as a Manning's n, roughness coefficient that was varied spatially over the model domain to reflect changes in bed roughness within the LBW and as a fine tuning parameter for the model calibration.

Eddy Viscosity

The transfer of momentum through sub-grid scale turbulence was modelled through the inclusion of horizontal eddy viscosity. The horizontal eddy viscosity is given by the Smagorinsky formulation. This expresses the effects of sub-grid scale turbulence by an effective eddy viscosity related to a characteristic length scale and the local spatial current variations.

Dispersion Coefficients

The transport of salinity is a function of molecular and other flow processes that are not explicitly resolved in the finite volume flow model. The effects of non-resolved processes on the transport of salinity in the model has been incorporated by adoption of dispersion coefficients that were derived as part of the model calibration process.

Hydrodynamic and Salinity Model Calibration

Overview

The development of a hydrodynamic model of the LBW requires a rigorous calibration process to ensure the model accurately reproduces observed hydrodynamic behaviour of the study area. The calibration process consists of systematically comparing observed hydrodynamic behaviour within the study area against the hydrodynamic models reproduction of that behaviour. This process generally incorporates comparisons between observed water level variations and other available water quality measurements i.e. salinity. Where the model does not adequately represent the observed behaviour, reasons for the discrepancies are identified and inputs to the model adjusted. This process is repeated until a satisfactory result is achieved.

Calibration Period

The hydrodynamic model has been calibrated to the observed water level and salinity variations captured by the field monitoring program in Lake Connewarre and Lower Barwon between the 21/06/2008 and 10/09/2008. Following calibration of the tidal components of the LBW, the model was calibrated to the Barwon River and Reedy Lake water level timeseries provided by Peter Dalhaus and the University of Ballarat over the period June 2008 through May 2009.

2008 Calibration Results

Tidal Water Level Variation

Tidal water levels within the model have been compared to those observed within the LBW. The comparisons presented below in Figure 5-8 and Figure 5-9 are considered to indicate that the model provides a good reproduction of the tidal dynamics within Lake Connewarre and the Lower Barwon estuary.

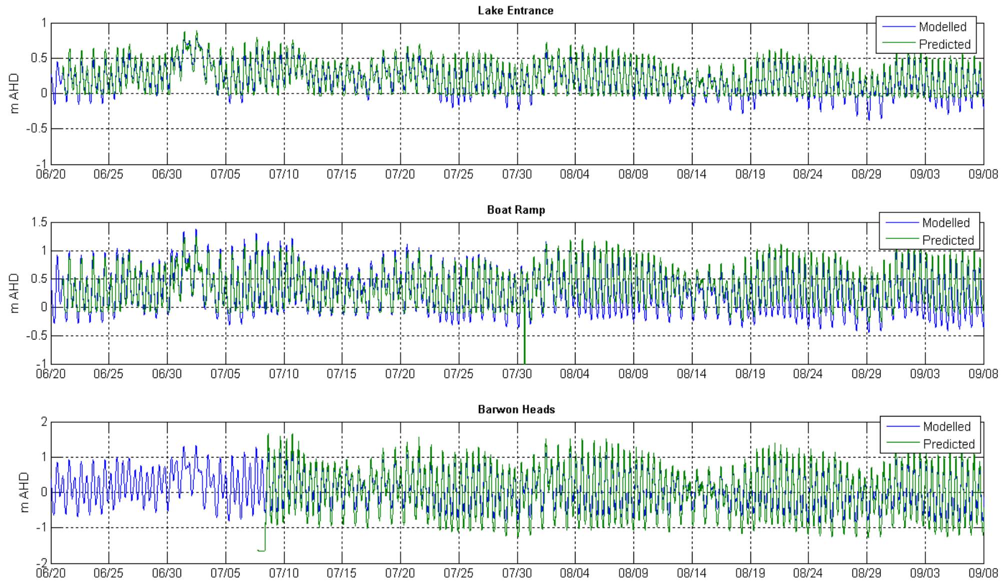


Figure 5-8 Calibrated Water Level Comparisons on the Lower Barwon

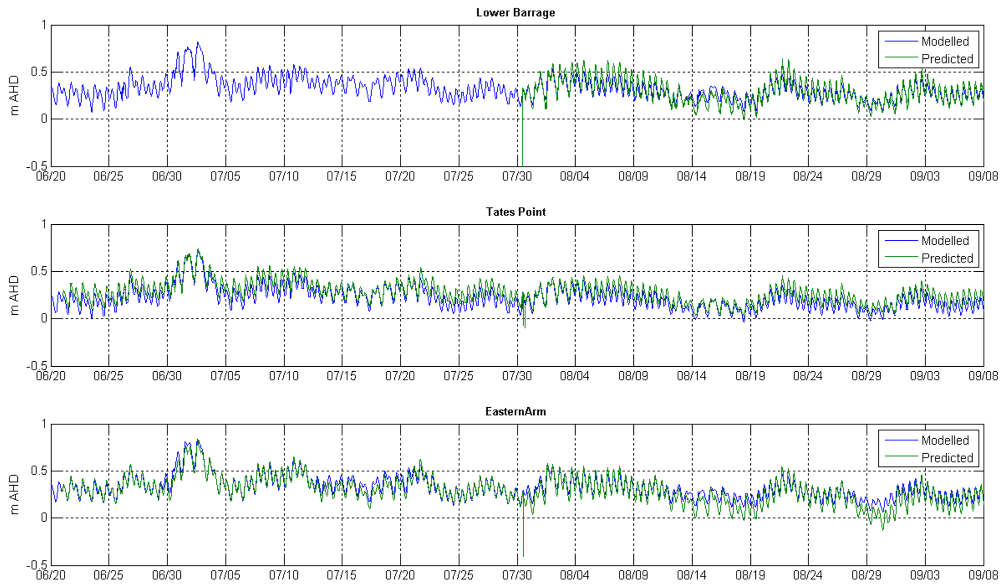


Figure 5-9 Calibrated Water Level Comparisons in Lake Connewarre

Reedy Lake and Barwon River Calibration

Figure 5-10 shows the water level measured in the Barwon River at a location approximately 1 km upstream of the Lower Barrage compared with those simulated in the model at the same location.

The results are considered to indicate that in general the model accurately reproduces water levels within the Barwon River upstream of the barrage in response to varying Barwon River inflows. Towards the end of the calibration period over the summer months, the modelled weir pool above the Lower Barrage does not fall to the same extent as was observed. This discrepancy is attributed to leakage past the floating gates on the Lower Barrage which is difficult to define accurately within the hydrodynamic model.

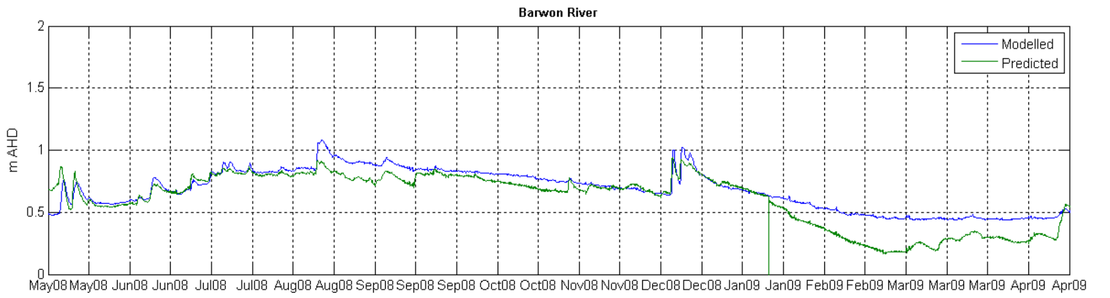


Figure 5-10 Calibrated Water Level Comparisons on the Barwon River upstream of the Lower Barrage

The comparison of the observed Reedy Lake water level timeseries and the model prediction is displayed in Figure 5-11. The comparison displayed in Figure 5-11 is considered to show the model is in excellent agreement with observed filling and drying sequence observed in Reedy Lake.

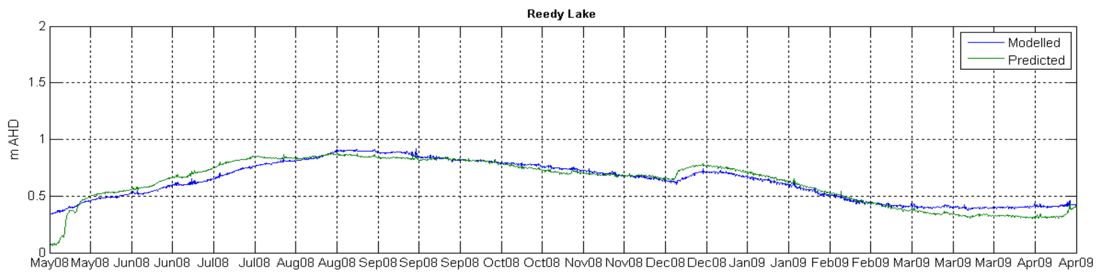


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Figure 5-11 Calibrated Water Level Comparison in Reedy Lake

Lake Connewarre Salinity

The observed variation in salinity in Lake Connewarre at Taits Point has been compared to the modelled results over an approximate 2 month period during 2008 in Figure 5-12.

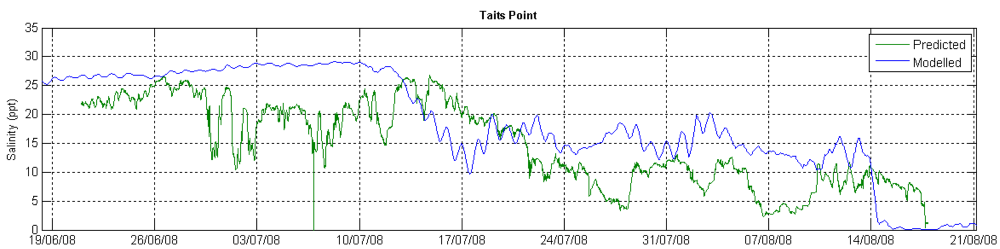

Figure 5-12 Calibrated Salinity Comparison in Lake Connewarre at Taits Point

Discussion

The following broad observations are made regarding the level of agreement achieved between the modelled and observed water level variations in the Lower Barwon wetlands:

- The attenuation of the tide and shift in phase along the length of the Lower Barwon is considered to be well resolved in the model.
- The attenuation of the tide and impact on mean water levels in Lake Connewarre associated with the passage of the tide across the flood tide delta is considered to be reproduced quite well in the model.

- The influence of the large storm surge event in Bass Strait around the 1st July on water levels in Lake Connewarre is accurately reproduced by the model.
- The influence of small freshes on water levels in the Barwon River upstream of the barrage is reproduce well by the model.
- Evaporation within Reedy Lake is reproduced well within the model.

Validation Period

The hydrodynamic model has been validated to observed water level and salinity variations captured by an additional field monitoring program in Lake Connewarre and Lower Barwon between December 2010 and January 2011. The period is noteworthy in that it includes two high flow events, the second of which occurred in mid January and resulted in significant overbank flooding into Reedy Lake and Hospital Swamp. Figure 5-15 displays the simulated overbank flooding into Reedy Lake close to the peak of the January flood event.

2010 Validation Results

Tidal Water Level Variation

Tidal water levels within the model have been compared to those observed within the LBW. The water level comparisons are presented below in Figure 5-13. It should be noted that due to the magnitude of the flood in January, the atmospheric pressure correction breather on the water level loggers in Lake Connewarre was overtopped and the instrument did not record meaningful data during the peak of this flood event.

The water level comparisons displayed in Figure 5-13 are considered to validate the hydrodynamic model configuration and demonstrate the ability of the model to reproduce overbank flooding from the Barwon River into Reedy Lake and Hospital Swamp.

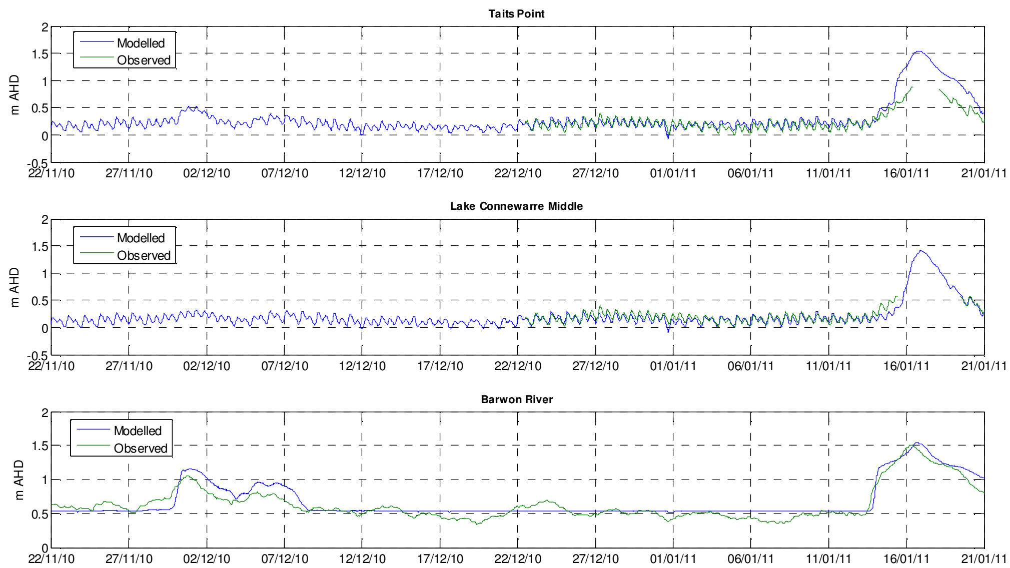

Figure 5-13 Lake Connewarre and Barwon River Water Level Validation

Lake Connewarre Middle Salinity

The observed variation in salinity in Lake Connewarre has been compared to the modelled results over an approximate 2 month period between December 2010 and January 2011 in **Error! Reference source not found.**.

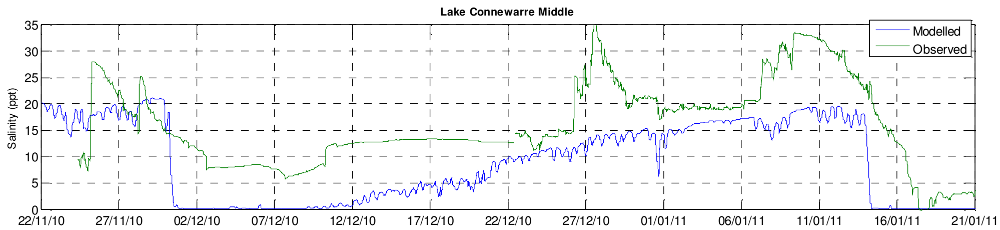

Figure 5-14 Lake Connewarre Salinity Validation

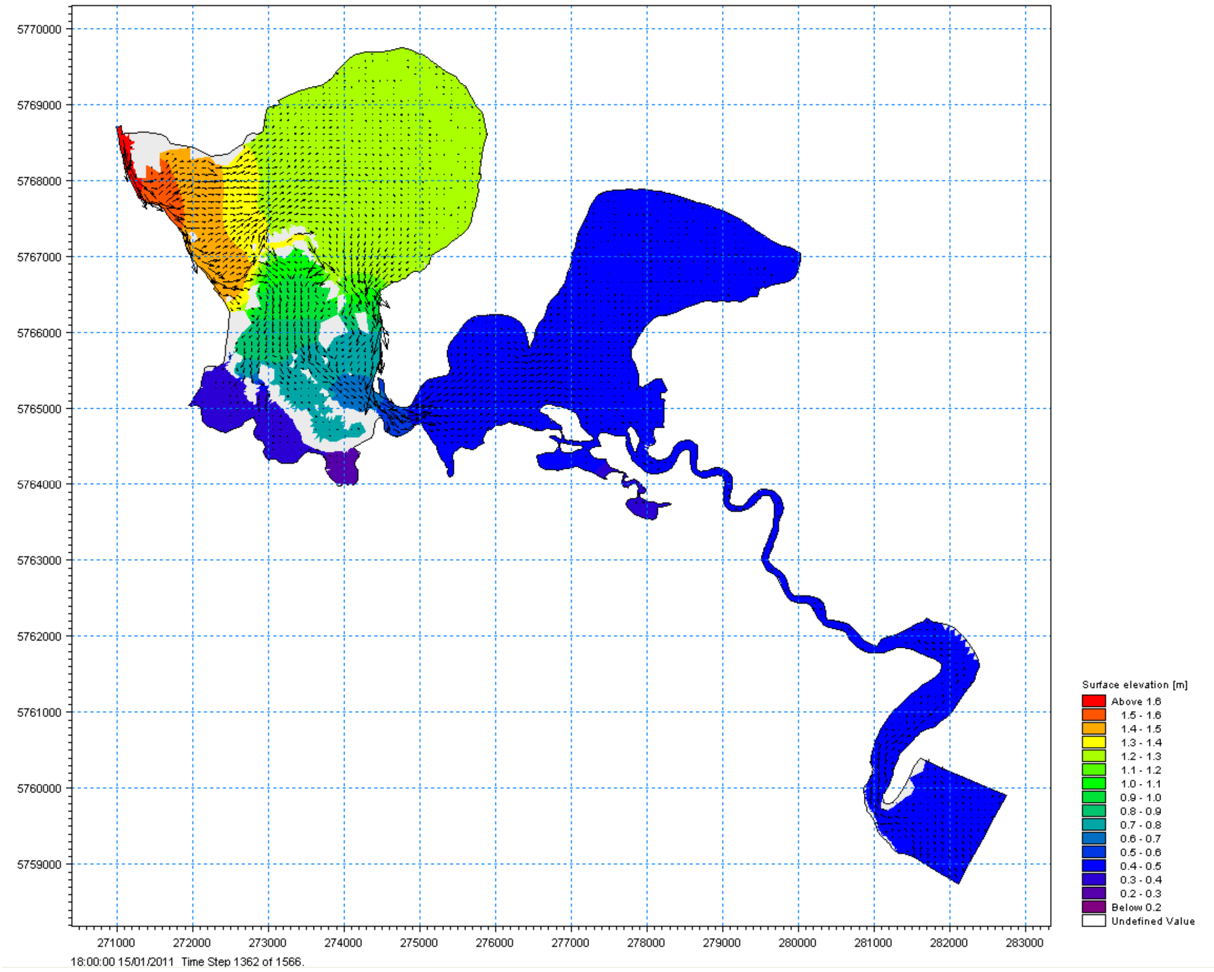

Figure 5-15 Predicted Overbank Flooding Extent into Reedy Lake during January 2011 Flood Event