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PROJECT DETAILS

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1. INTRODUCTION

Water Technology in association with Kingfisher Research were engaged by the Corangamite Catchment Management Authority (CCMA) to undertake a study to identify modifications to existing infrastructure that could improve ecological outcomes through the use of unregulated water and improve the connectivity of Reedy Lake and Hospital Swamps to the Barwon River.

1.1 Scope of Works

The Lower Barwon Wetland Connectivity project has the following three main objectives:

- Objective 1 - Identify modifications that could be made to the Reedy Lake outlet channel and culvert to improve the ability to flush the wetland with tidal water from Lake Connewarre once Reedy Lake has been partially dried.
- Objective 2 - Identify modifications (and the need for modifications) to the outlet of Hospital Swamps that would improve the ability to drain increasing volumes of stormwater from the wetland and maintain a level of 0.5 to 0.6 m AHD over winter to help reduce flooding on private land (this could include a defined overflow point).
- Objective 3 - Identify options for both Reedy Lake and Hospital Swamps to improve fish passage at outlet structures, inlet structures and overflow points.

An existing numerical hydrodynamic model of Lake Connewarre, the Lower Barwon River, Hospital Swamps and Reedy Lake has been used to assist to undertake the hydraulic investigations for the study. Details of the hydrodynamic model development and calibration have been previously documented in Water Technology (2011).

The following sections detail the investigations undertaken and subsequent recommendations and concept designs developed with respect to the project objectives above.

2. REEDY LAKE ESTUARINE INUNDATION ASSESSMENT

2.1 Background

Previous investigations into options available to manage the abundance of tall reeds in Reedy Lake have identified periodic inundation with saline water from Lake Connewarre as a potential beneficial approach (Alluvium, 2013, Lloyd, 2012).

In 2006, Field and Game opened the Reedy Lake outlet for approximately two weeks to allow estuarine water from Lake Connewarre to flow into Reedy Lake. Localised dieback of reed vegetation was observed along the outlet channel and in the vicinity of the beginning of the outlet channel within Reedy Lake (pers comm. Ian Mclaughlin, 06/02/2014). The anecdotal observations provided by Field and Game are considered to indicate that the physical geometry of the Reedy Lake outlet channel and regulator, in terms of the sill levels and channel capacity, are such that inundation of Reedy Lake can potentially be manipulated to some extent from Lake Connewarre.

Figure 2-1 displays 0.1m elevation contours for Reedy Lake. These contours provide an initial estimate of the inundation extent within Reedy Lake for water levels between 0 and 0.7 m AHD.

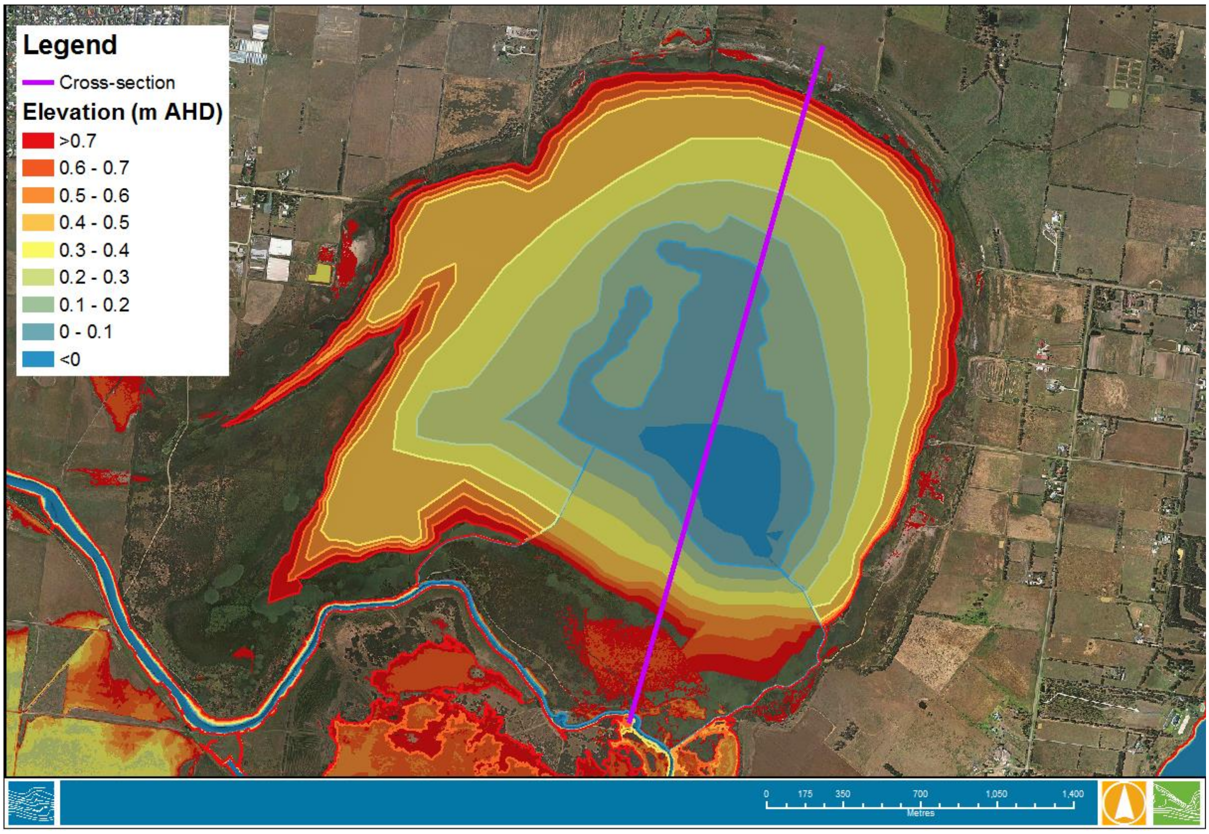

Figure 2-1 Elevation Contours (0.1m increments) for Reedy Lake
(The cross-section through Reedy Lake is displayed in Figure 2-2)

2.2 Estuarine Inundation Assessment

Previous water level monitoring campaigns in Lake Connewarre (Water Technology 2009 & Water Technology, 2011), are considered to provide a reasonable basis for estimating the approximate elevation of various components of the coastally generated water level variations observed in Lake Connewarre.

An overview of the coastal influences on water levels in Lake Connewarre is provided below:

- Mean water levels in Lake Connewarre are elevated above mean sea level in Bass Strait due to tidal pumping within the Lower Barwon River. This results in the mean water level in Lake Connewarre of approximately 0.27 m AHD;
- The astronomical tidal variations are significantly attenuated by the time they have propagated into Lake Connewarre. Peak water levels associated with spring tides are generally only approximately 5 cm, resulting in a spring tidal place of approximately 0.32 m AHD;
- Meteorological forcing associated with low pressure systems and wind along the southern margin of the Australian continent drive additional coastal water level variations that propagate into Lake Connewarre from Bass Strait. These meteorologically driven water level variations are frequently observed to result in increases in water levels up to approximately 0.4 m AHD every month or two on average for a period of 24-48 hours;
- Occasionally, during major storm events in the Southern Ocean and Bass Strait, large storm surges associated with meteorological forcing can increase water levels in Lake Connewarre up to approximately 0.6-0.7 m AHD for a period of 24-48 hours. These levels occur with a frequency of approximately once a year to once every few years.

A comparison of the available digital elevation model of Reedy Lake and the Lower Barwon and the typical coastal water level components in Lake Connewarre previously discussed is displayed in Figure 2-2 and provides a first order assessment of the potential ability to manipulate inundation in Reedy Lake from Lake Connewarre. The location of the cross-section in the figure is displayed in Figure 2-1. Based on Figure 2-2, the following observations regarding the potential depth and extent of inundation that could be achieved from coastal water levels in Lake Connewarre are provided:

- The available survey of Reedy Lake indicates that much of the wetland exists at an elevation at or below approximately 0.1 m AHD. As the mean water level of Lake Connewarre is approximately 0.27 m AHD, relatively extensive, though shallow inundation (<~0.2 m) could be expected to be routinely achieved from Lake Connewarre.
- More extensive and deeper inundation of Reedy Lake to levels greater than approximately 0.4 m AHD would be dependent on the occurrence of large storm surges which have relatively short durations of typically 24-28 hours. The potential ability to achieve more extensive and deeper inundation of Reedy Lake during storm surge events would be a function of the hydraulics of the regulator and channel capacity and time varying/duration characteristics of the storm surges.

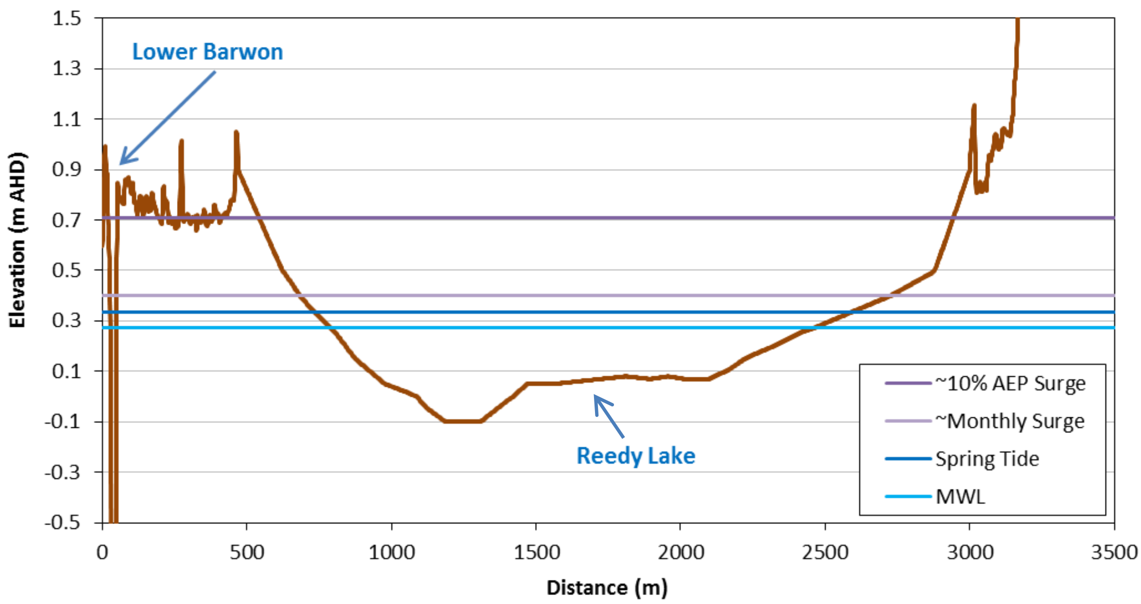

Figure 2-2 Comparison of Reedy Lake Topography and Typical Coastal Water Level Components of Lake Connewarre

To develop a more detailed understanding of the likely characteristics of inundation of Reedy Lake that can be manipulated from Lake Connewarre, a series of hydrodynamic modelling scenarios have been undertaken using the existing hydrodynamic model of this system. The modelling has also been undertaken to test the practicalities of augmenting gravity driven flows into Reedy Lake from Lake Connewarre via a pumping scenario.

The modelling scenarios extend over a representative 6 month period of coastal water level variations in Lake Connewarre. The period includes multiple small, meteorological induced water level increases to 0.4-0.5 m AHD, as well as a significant storm surge event to 0.7 m AHD, which has an annual exceedance probability of approximately 10% (i.e. 10yr average recurrence interval). Figure 2-3 displays the modelled water level variations in Lake Connewarre over the 6 month period simulation period.

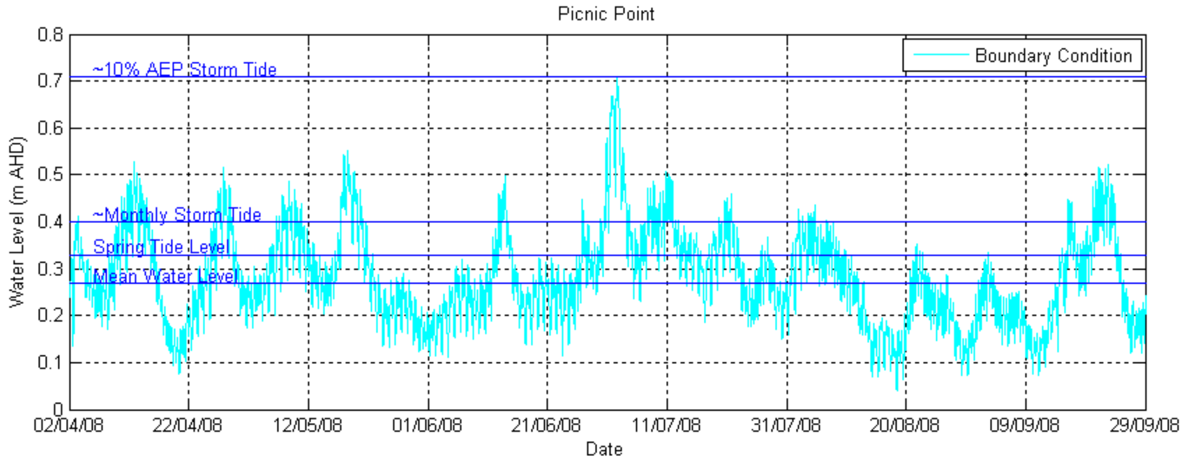

Figure 2-3 6 Month Representative Period of Lake Connewarre Water Level Variations

Three estuarine inundation scenarios have been simulated over the 6 month representative period in the hydrodynamic model to provide an understanding of the potential ability to manipulate inundation of Reedy Lake from Lake Connewarre. All three scenarios have been simulated with the following initial conditions and assumptions:

- Reedy Lake is partially dry at the start of each simulation, with a water level of 0.2 m AHD;
- Reedy Lake inlet is closed for the duration of the simulation;
- The influence of direct rainfall and evaporation on Reedy Lake has not been considered; and
- The salinity of the Lake Connewarre flows in Reedy Lake has not been modelled. Evaluation of the likely salinity of inundation of Reedy Lake from Lake Connewarre is considered separately in Section 2.3.

The three estuarine inundation scenarios simulated in the hydrodynamic model are outlined below:

Scenario 1 – Base Case

This scenario provides an assessment of the characteristics of the inundation of Reedy Lake that could be expected with the existing Reedy Lake outlet channel and regulator arrangement. The Reedy Lake outlet regulator remains opened for the duration of the simulation, allowing the two way exchange of flows between Reedy Lake and Lake Connewarre.

Scenario 2 – Enlarged Reedy Outlet Channel and Regulator

This scenario provides an assessment of the potential ability to increase the extent and depths of inundation of Reedy Lake from Lake Connewarre by increasing the size of the outlet channel and outlet regulators.

For this scenario, the width of the existing Reedy Lake outlet channel was increased by 50% and the outlet regulator capacity was also increased by approximately 50%. The Reedy Lake outlet regulator remains opened for the duration of the simulation, allowing the two way exchange of flows between Reedy Lake and Lake Connewarre.

Scenario 3 – Pumping Scenario

This scenario provides an assessment of the potential ability to augment gravity driven flows into Reedy Lake from Lake Connewarre with a pump. For this scenario, a pump was simulated at the Reedy Lake outlet that pumped at a rate of 100 l/s (0.1 m^3/s), 24 hours a day for the entire simulation period.

To prevent water that was pumped into Reedy Lake from flowing back out of the outlet regulator as the head increases in Reedy Lake compared to Lake Connewarre, the Reedy Lake outlet regulator was manipulated in the model such that it operated with a one-way valve, only allowing flows from Lake Connewarre into Reedy Lake.

The predicted results from the three scenarios detailed above over the 6 month representative period are summarised in Figure 2-4. The top panel displays the predicted water levels in Reedy Lake and the bottom panel displays the predicted instantaneous flows through the Reedy Lake outlet regulator including the pumping rate for Scenario 3 (Negative flow rates indicated flows from Lake Connewarre into Reedy Lake). Figure 2-5 displays the predicted maximum extent of inundation in Reedy Lake from estuarine inundation scenarios. The inundation extents have been generated by interpolating the maximum predicted water level in Reedy Lake from the hydrodynamic model scenarios onto a digital elevation model of Reedy Lake derived from LiDAR survey and local field survey. The accuracy of the predicted inundation extents of Reedy Lake is limited by the quality of the available survey but is considered to provide a reasonable indication of the broad extent of inundation that could be expected from the estuarine inundation scenarios.

From the predicted results presented in Figure 2-4 and Figure 2-5, the following comments on the likely characteristics of the estuarine inundation of Reedy Lake from these scenarios are provided:

Scenario 1 – Base Case

Moderate extents of inundation of Reedy Lake with water levels of typically around 0.3 m AHD are predicted to be readily achieved from Lake Connewarre. This level approximates the mean water level that is typically observed in Lake Connewarre. During the large storm surge event of 0.7 m AHD in Lake Connewarre, Reedy Lake levels are only predicted to increase slightly to approximately 0.35 m AHD. This reflects the relatively limited hydraulic capacity of the existing Reedy Lake outlet channel and regulator and the large surface area volume of Reedy Lake as well as the relatively short temporal duration of the large storm surges (24-48 hrs) in Lake Connewarre.

Scenario 2 – Enlarged Reedy Outlet Channel and Regulator

The approximate 50% increase in the Reedy Lake outlet channel and regulator capacity are predicted to result in only very minor differences in inundation levels from Lake Connewarre compared to the existing arrangement. The larger capacity of the outlet channel and regulator provides a greater capacity for flows to enter Reedy Lake from Lake Connewarre, however, when the coastally driven water levels in Lake Connewarre decline, flows are able to exit Reedy Lake more rapidly as can be seen from the discharge time series comparisons in Figure 2-4. The predicted result of this scenario is a slightly more variable but not significantly different level of inundation in Reedy Lake compared to the existing outlet channel and regulator configuration.

Scenario 3 – Pumping Scenario

The pumping scenario predicts that pumping at a rate of 100 l/s combined with natural inflows could achieve an inundation level of approximately 0.5 m AHD after 3 months. An additional 2-3 months of pumping at this rate is predicted to be required to achieve an additional 0.1 m of inundation to almost 0.6 m AHD. The extent of inundation at 0.6 m AHD water level is predicted to increase by approximately 50% the extent of inundation that can be achieved from gravity driven flows with water levels of approximately 0.3 m AHD. Over the course of the 6 month scenario a total of approximately 1,500 ML was pumped in addition to natural inflows from Lake Connewarre.

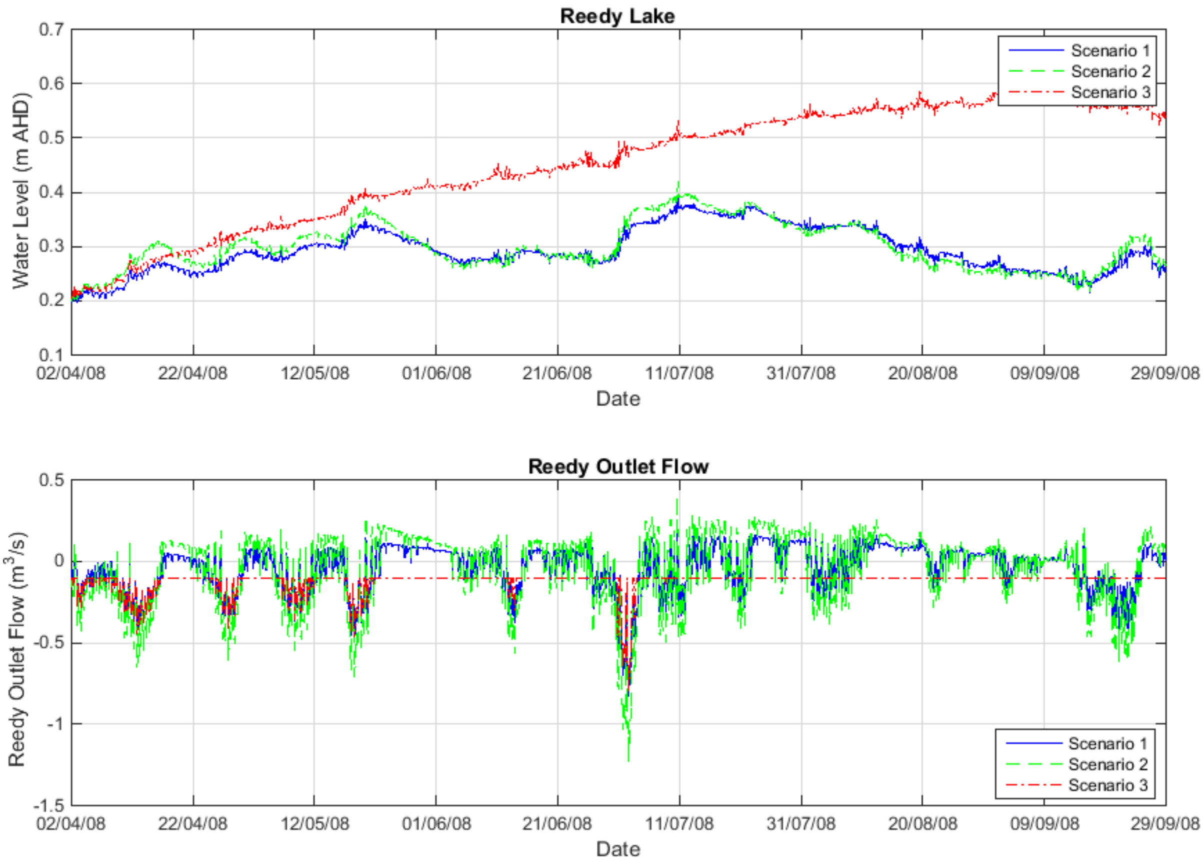

Figure 2-4 Summary of Estuarine Inundation Scenario Results for Reedy Lake

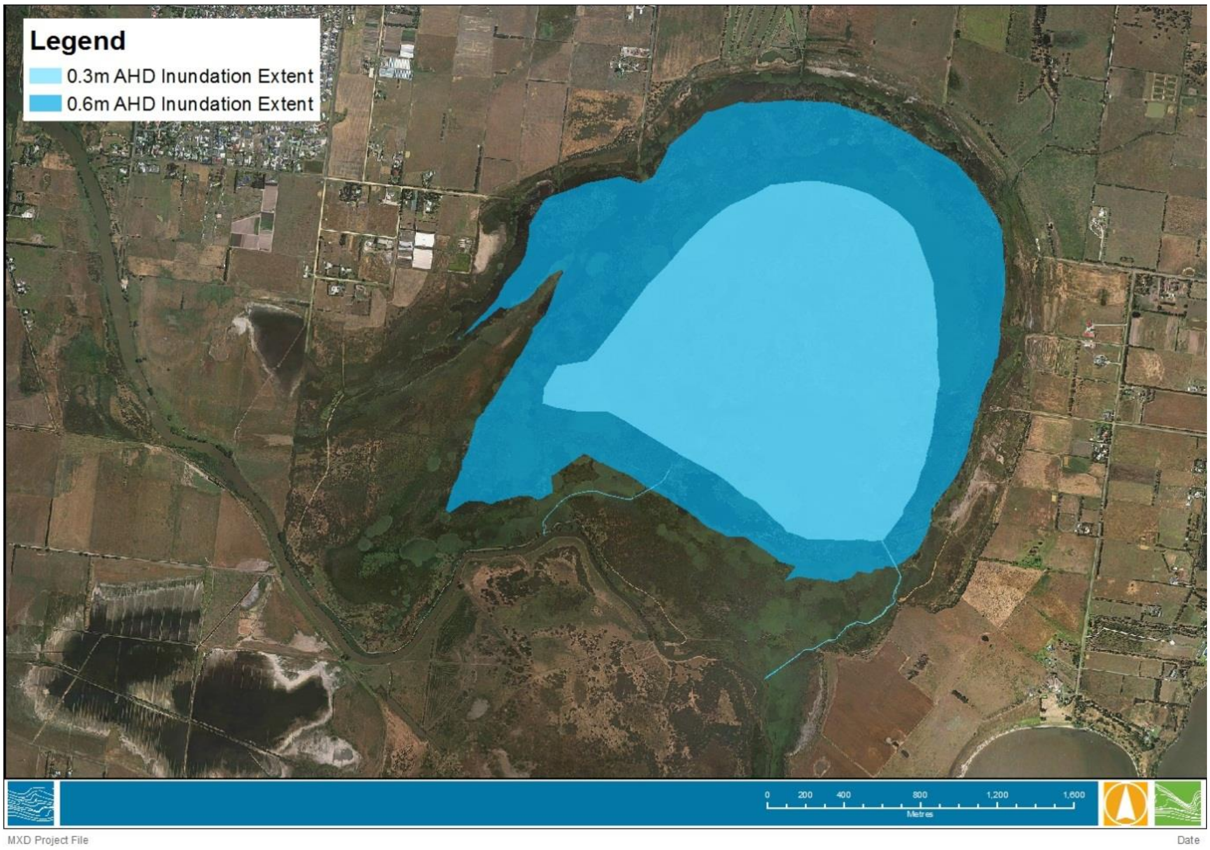

Figure 2-5 Predicted Extent of Estuarine Inundation

2.3 Lake Connewarre Salinity

The estuarine inundation assessment undertaken previously in Section 2.2 has identified the likely characteristics of the inundation of Reedy Lake that could be manipulated from Lake Connewarre. It has not however considered the likely salinity of that inundation.

Salinity in Lake Connewarre is highly variable and a function of a number of processes including:

- The rate of freshwater inflows, primarily from the Barwon River;
- Direct rainfall and rates of evaporation on Lake Connewarre;
- Extent of tidal exchange with marine water at Barwon Heads.

To provide an understanding of the long term salinity and variability of Lake Connewarre and the Lower Barwon, available salinity data has been accessed from the Estuary Watch community based estuarine monitoring program. Figure 2-6 displays the available salinity data for the Lower Breakwater and Tait Point at the western end of Lake Connewarre.

Figure 2-6 shows that salinity in Lake Connewarre is highly variable in response to seasonal and climatic variations. During particularly dry, hot summers such as the 2012/13 summer, hyper-saline conditions can occur in Lake Connewarre and this would potentially enable inundation of Reedy Lake with relatively high salinity water to be achieved during these periods. Conversely, during wet periods, including some wet summers, Lake Connewarre is unlikely to provide a particularly saline source of water to achieve the ecological objectives of this water management option in Reedy Lake.

It is however noted that the very lowest reaches of the Lower Barwon between the breakwater and Lake Connewarre are typically stratified such that a shallow layer of relatively fresh water often overlies a salty dense layer at depth. The surface salinity data collected by estuary watch program may therefore slightly underestimate the salinity of the water that could potentially flow through the outlet regulator and into Reedy Lake.

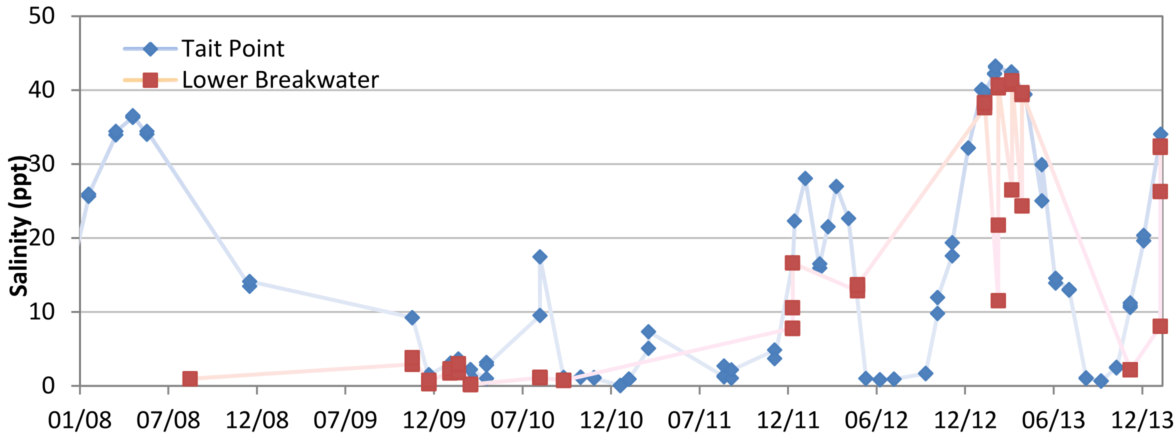

Figure 2-6 Estuary Watch Salinity Observations for Lake Connewarre and Lower Barwon below the Breakwater

2.4 Conclusions

Based on the hydrodynamic modelling analysis and review of available salinity data for Lake Connewarre, the following conclusions are provided on the ability to inundate Reedy Lake with saline water from Lake Connewarre, from a practical water management perspective:

- The modelling has confirmed that relatively shallow estuarine inundation to levels of approximately 0.3 m AHD is likely to be readily achieved in Reedy Lake from Lake Connewarre with the existing channel and regulator arrangement;
- Moderate increases to the outlet channel and regulator capacity are unlikely to significantly improve the ability to flood Reedy Lake via gravity flows from Lake Connewarre.
- Quite significant pumping rates and volumes are likely to be required to achieve moderate inundation levels of 0.5-0.6 m AHD in Reedy Lake. Based on the scenario considered in this assessment, the approximate costs to pump 1,500 ML into Reedy Lake via a diesel pump set over 6 months are detailed in the following table. The volume required to be pumped has been estimated based on a representative time period where natural inflows to the wetland also occurred. To fill the wetland without these supplementary flows would require a significant higher flow rate or pump period to achieve the required volumes.

Table 2-1 Overview of Pump Costings associated with Inundation of Reedy Lake

Duration of Pumping	Inundation Volume (ML)	Total Costs (including equipment hire & operation)
3 months	750	~$34,350
6 months	1500	~$68,700

- Inundation of Reedy Lake with saline water from Lake Connewarre could only be considered as an 'opportunistic' option. It is reliant on suitable seasonal conditions resulting in salinity in Lake Connewarre and the Lower Barwon River below the breakwater increasing to levels that would be detrimental to phragmites. These seasonal conditions are only likely to be generated in the summer and early autumn months. While the amount of available salinity data is limited, the following approximate guidance on the range of salinities and associated seasonal characteristics that could be expected are provided below:

- -Typical late summer type seasonal conditions could be expected to result in the salinities in the Lower Barwon below the breakwater of between 10-20 ppt.
- A relatively dry spring followed by an extended dry, hot summer may occasionally produce hyper saline conditions of between approximately 35 -45 ppt.
- Wet springs and summers may result in salinities below 5 ppt persisting in the Lower Barwon River below the breakwater.

3. HOSPITAL SWAMPS FLOODING OUTLET ASSESSMENT

3.1 Background

During the 2012 winter, high local rainfall and stormwater runoff from adjacent catchments resulted in flooding of private land around Hospital Swamps. Flooding occurred despite the Hospital Swamps outlet being opened as well as the inlet being closed for a large proportion of the winter (CCMA, 2014).

The original design of the Hospital Swamps outlet incorporated a 0.525 m diameter culvert with an invert at ~0.12 m AHD. To the immediate west of the culvert was a low earthen spillway approximately 10 m wide with a crest set at approximately 0.4 m AHD such that the typical supply level in the Hospital Swamps was approximately 0.45 – 0.5 m AHD. Extensive vegetation growth across the spillway since the last major maintenance works in 2003 has now most likely raised the crest of the spillway to approximately 0.6 m AHD. The extent of the phragmites growth across the spillway is also such that the spillway is not considered to provide a hydraulically efficient structure for regulating water levels in Hospital Swamps (pers. comm. Ian Mclaughlin, 12/02/2014).

It is considered likely that overflows from Hospital Swamps now occur via low points between the northern pools and Lake Connewarre. The hydraulic connectivity between these pools and the overland flow paths to Lake Connewarre is however also considered relatively inefficient.

The low hydraulic efficiency of the existing spillway and overland flow points are considered likely to be contributing to the persistence of high water levels in Hospital Swamps and flooding of adjacent private land.

3.2 Hospital Swamps Outlet Hydraulic Assessment

An assessment of the hydraulic capacity of the existing Hospital Swamps outlet channel and regulator has been undertaken in the hydrodynamic model. Options to increase the capacity of the Hospital Swamps outlet regulator have been tested in the hydrodynamic model.

To provide realistic, inflow scenarios to support the investigations of the Hospital Swamps outlet, an existing hydrologic model of catchment inflows has been utilised to provide design inflow hydrographs to the system. The hydrologic (RORB) model was developed from previous investigations associated with the Armstrong Creek urban growth area undertaken by Neil M Craigie Pty Ltd. The RORB model represents the predicted hydrological behaviour of the catchment flows under future anticipated land use and water sensitive urban design works in the catchment.

The RORB model has been used to generate 2 year ARI design catchment inflows for Hospital Swamps for a range of storm durations. The 2 year ARI design storm recurrence interval was chosen as it was determined that it represented a storm scenario and frequency that could reasonably be expected to be managed within the capacity of the existing Hospital Swamps outlet configuration. This approach also reflects the reality that Hospital Swamps is part of the Armstrong Creek and

Lower Barwon floodplain and will be susceptible to inundation during large events in either system, regardless of the works done to the Hospital Swamps outlet.

Figure 3-1 displays predicted inflow hydrographs for the 2 year ARI design event and range of storm durations. As can be seen from Figure 3-1, the magnitude of the catchment inflows to Hospital Swamps are predicted to be relatively large, even under relatively frequent design storm events.

The predicted inflow hydrographs for the 2 year ARI event were applied to the hydrodynamic model of Hospital Swamps to assess the existing hydraulic behaviour of the outlet. The hydrodynamic modelling scenarios were undertaken with the following assumptions:

- The Hospital Swamps inlet regulator was open;
- The existing 0.525 m diameter Hospital Swamps outlet culvert was open; and
- The existing low level spillway is overgrown such the crest height is now approximately 0.6 m AHD.

Figure 3-2 below displays the predicted results from the hydrodynamic model of Hospital Swamps for each of the catchment inflow events. From Figure 3-2, it can be seen that longer storm durations of between 24-72 hours are critical for Hospital Swamps and result in water levels exceeding 0.6 m AHD. The model also predicts a very slow decline in water levels in Hospital Swamps on the falling limb of the inflow events. The discharges through the Hospital Swamps outlet culvert are correspondingly relatively small compared to the inflows.

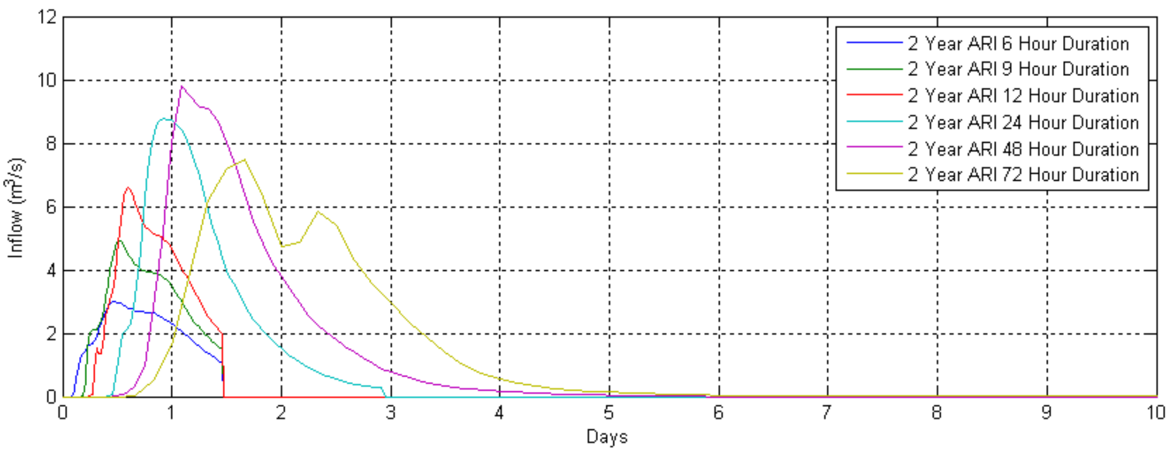

Figure 3-1 Predicted 2 year ARI Catchment Inflows to Hospital Swamps

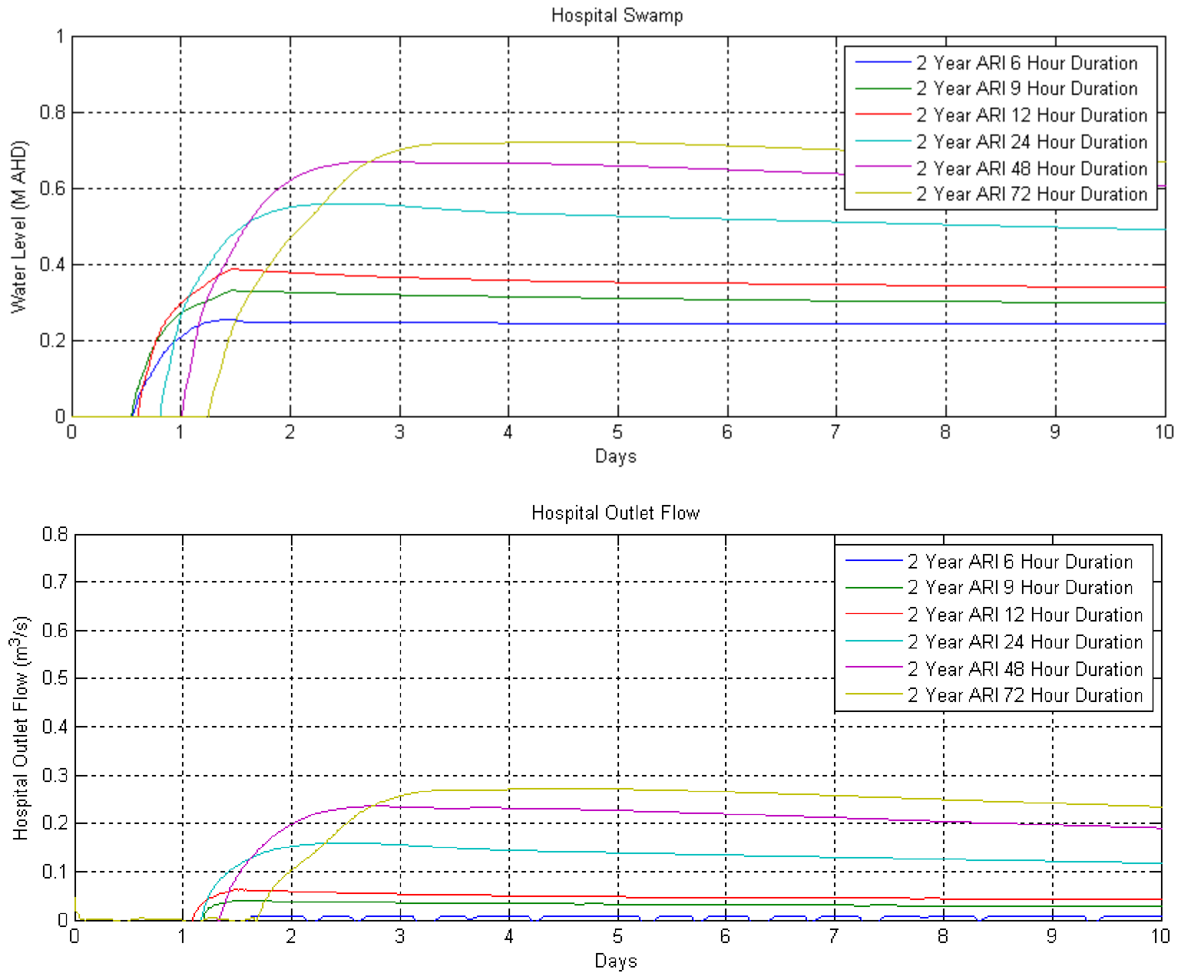

Figure 3-2 Predicted Hospital Swamps Water Levels and Outlet Discharges from the 2 Year ARI Catchment Inflow Storm Events

The relatively small capacity of the Hospital Swamps outlet culvert and the fact that the low level spillway is now overgrown with vegetation and not functioning as designed is considered to be contributing to the persistence of high water levels in Hospital Swamps following major inflows events from the catchment. The dimensions and condition of the outlet channel provide a significant control on how inflows to Hospital Swamps can be passed to Lake Connewarre.

Options to improve the capacity of the existing outlet structure have been tested in the hydrodynamic model. The options tested include the following:

- Replacement of the existing single 0.525 m diameter culvert with two 1.5 m x 0.9 m box culverts and penstock gates.
- Reinstatement of a 5 m wide, low level spillway adjacent to the outlet regulator with a crest elevation set at 0.4 m AHD.
- Replacement of the existing single 0.525 m diameter culvert with two 1.5 m x 0.9 m box culverts and penstock gates and reinstatement of a 5 m wide, low level spillway adjacent to the outlet regulator with a crest elevation set at 0.4 m AHD.
- Reinstatement of a 5 m wide, low level spillway adjacent to the outlet regulator with a crest elevation set at 0.5m AHD.

Figure 3-3 displays the predicted results for the different options for the 2 year ARI 72 hour critical duration storm. The results show that while upgrading the culverts alone would increase flows though the Hospital Swamps Outlet, it would have no influence on peak water levels in Hospital

Swamps, and only have a minimal influence on the drawdown rate of water levels. Upgrading the spillway only was shown to increase the flow through the Hospital Swamps outlet, and further increase the drawdown rate for water levels following an inflow event. Upgrading both the outlet and spillway would only slightly reduce peak water levels. However, it would significantly improve the drawdown rate of water levels below 0.6 m AHD following an inflow event.

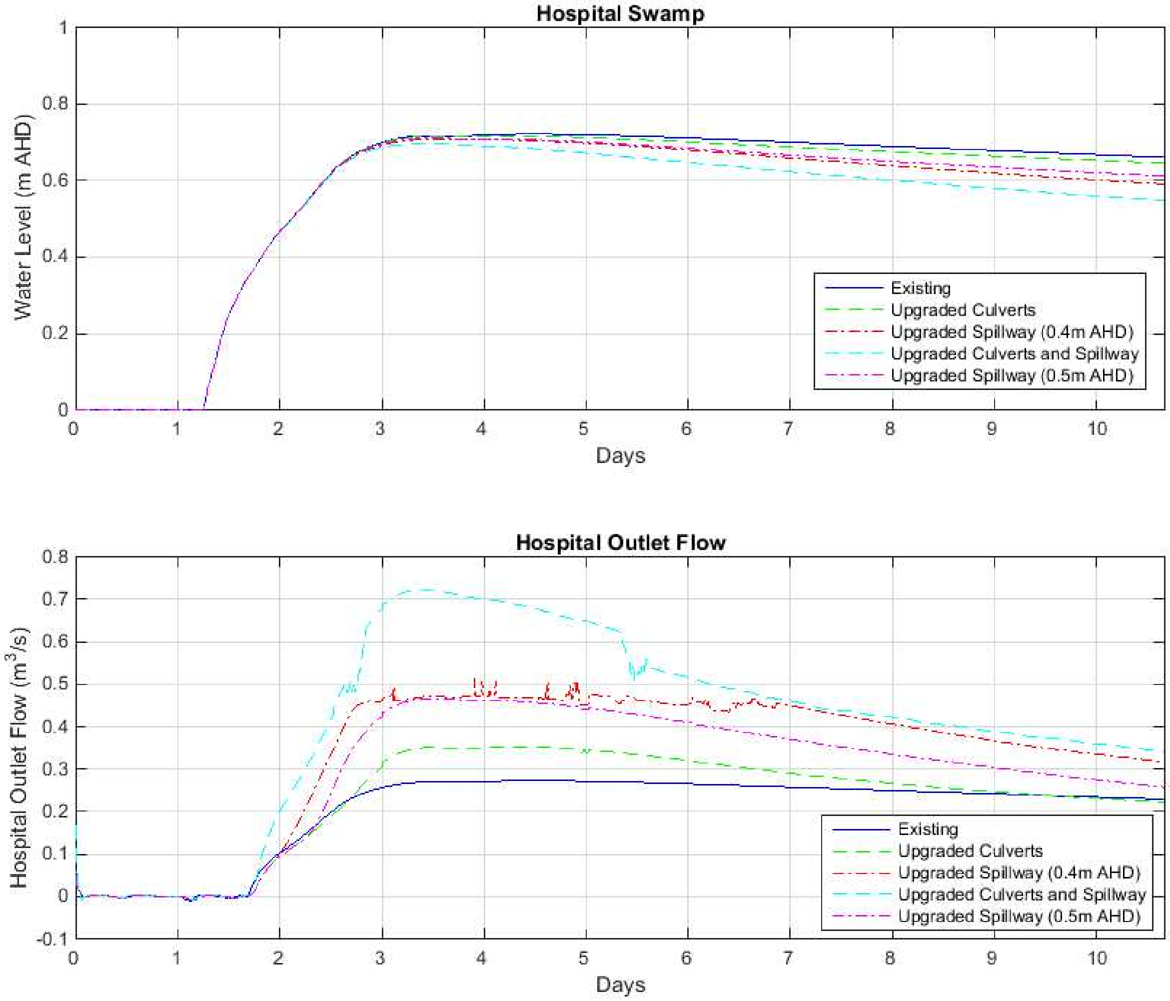

Figure 3-3 Comparison of Upgraded Outlet Compared to Existing for the 2 year AR, 72 Hour Critical Duration

3.3 Conclusions

The results of the hydrodynamic modelling have highlighted that the capacity of the outlet channel is relatively limited and provides a control on the rate at which large inflows to Hospital Swamps can be passed to Lake Connewarre. Short periods where water levels above 0.6m AHD occur could be expected regardless of the changes made to the outlet regulator due to the magnitude of the catchment generated inflows.

Upgrading the low level spillway and increasing the capacity of the outlet culverts could however be expected to improve the ability to manage water levels in Hospital Swamps and reduce the persistence of high water levels following major inflow events.

Long term options to reduce catchment inflows would assist to reduce the frequency and persistence of high water levels in Hospital Swamps.

4. FISH PASSAGE, MANAGEMENT, AND CONNECTIVITY

4.1 Overview

The lower Barwon River system has a relatively diverse native fish community, with some 44 species recorded in marine, estuarine and freshwater habitats (Lloyd et al. 2008; Hindell et al. 2008). Lake Connewarre is a major spawning and nursery area where fish breed annually followed by dispersal of large numbers of young fish (recruits) into the Barwon River system. Many fish species have obligatory parts of their life-cycle in both freshwater and estuarine habitats. This life-cycle style is termed 'diadromous' and movement between estuarine and freshwater habitats for breeding and feeding is a major ecological process in the lower Barwon system.

Reedy Lake and Hospitals Swamps provide extensive nursery habitats for juvenile fish which leave Lake Connewarre and from other areas in the Barwon system. However, passage is at present limited by regulating structures on the inlet and outlet of these systems. Fish accumulate below the regulators where they are unable to complete their migrations and key components of their life-cycle. The regulators which form tidal barriers are particularly detrimental because they restrict access to freshwater for diadromous species resulting in rapid reductions in the distribution and abundance of native fish (Stuart and Mallen-Cooper 1999). Regulators in estuarine waters, such as the Barwon breakwater, Reedy Lake outlet and Hospital Swamps outlet have historically restricted fish access to major freshwater habitats.

The Barwon breakwater vertical-slot fishway, completed in February 2013, provides a model for understanding fish migration and fish passage in the lower Barwon system. The breakwater fishway passes tens of thousands of fish per day, enabling these fish to complete their migrations between estuarine and freshwater reaches (J. O'Connor, Arthur Rylah Institute, pers. com.). These fish include many diadromous species such as galaxias, Australian grayling, congolli and yellow-eyed mullet.

4.2 Conceptual Model of Fish Migration in the Lower Barwon System

At Hospital Swamps and Reedy Lake, some 34 fish species and tens of thousands of fish per day are likely to require passage through the wetland inlet/outlet structures and overflow points, including small and medium sized fish (usually <300 mm long), and threatened species (e.g. Australian grayling).

The following fish migration model, from the literature and sampling at the Barwon breakwater fishway, provides a basis for prioritisation of fish passage and preferred fish passage options:

- Upstream migration by large numbers of small-bodied diadromous fish from the estuary into the freshwater Reedy and Hospital wetlands in spring and summer, many fish will move from the through the Reedy Lake and Hospital Swamps outlet regulators,
- Following a flow event there will also be freshwater fish (such as carp) moving from estuarine areas back upstream into freshwater habitats,
- Upstream and downstream migration of medium numbers of small-bodied fish through Reedy Lake and Hospital Swamps inlet regulators and Barge Hole regulators and Armstrong Creek in response to flow,
- Downstream migration of medium sized fish from the Reedy and Hospital wetlands into the Barwon River in autumn/winter,
- Bi-directional fish movement at wetland overflow points at high water,
- Upstream and downstream movements of large numbers of fish which exit the wetlands during a wetland drying phase.

4.3 Existing Constraints on Fish Passage

The following main constraints on fish passage and connectivity have been identified in the Lower Barwon system.

Outlet/Inlet Regulation

A fundamental constraint on fish passage and connectivity within the Lower Barwon system is the regulation of the inlet and outlets to Reedy Lake and Hospital Swamps. The blocking of the connectivity to these wetlands at times, as part of current water management practices, forms a physical barrier to natural fish movement and behaviour.

Regulator Hydraulics

Even when the inlet and outlet regulators to Reedy Lake and Hospital Swamps are open, the hydraulic environment through the culvert structures is unlikely to be optimal for fish passage under all conditions.

One of the problems of fish passage through culverts is the laminar flow of water. Laminar flow occurs when water is flowing parallel to the culvert surface and is uninterrupted through the culvert, so there is smooth undisturbed flow passing straight through with no eddies or turbulence. In this type of flow there is no space for fish to rest and they must swim constantly to complete the passage through the culvert.

In recent years, there has been a lot of work in North America and more recently in New Zealand examining the hydraulics of culverts and the swimming speed of the fish (Mitchell 1989; MacDonald and Davies 2007; Franklin and Bartels 2012). The characteristics of culverts that are important in determining the hydraulics and water velocities are the shape, cross-sectional area, slope, length, and roughness of the culvert material (e.g. rough concrete will slow the water velocity more than a smooth stainless steel pipe).

A head loss >100 mm in a culvert can produce a water velocity of >1.5 m/s and this can be considered impassable for most native fish (Table 4-1). Depending on the particular hydraulic environment at each inlet and outlet regulator, significant head difference/high velocities may occur at certain periods which limit fish passage into and out of these wetlands.

In culverts, the swimming speed of fish is very important because of the greater length of laminar, relatively high velocity flow than can exist compared to a natural stream environment. Hence, in culverts, fish must utilise their sustained swimming speed, a speed they can maintain for long periods (e.g. up to 200 minutes) rather than their burst speed. A general rule of thumb is that fish can swim at 3 times their body length (3BL) during sustained efforts.

For Common Galaxias (Galaxias maculatus), which will be a major species at the the Barwon wetlands, the fish biology suggests very conservative water velocities (e.g. <0.3 m/s) would be required to pass small-bodied fish through a long culvert.

Table 4-1 Typical Headloss, Velocity and Minimum Fish Sizes that Might Negotiate Passage within a Culvert

Headloss (mm)	Typical Max Water Velocity (m s^{-1})	Minimum Fish Length for Passage (mm)
2	0.15	<80
10	0.3	>100
20	0.45	>150
50	0.75	>250

Headloss (mm)	Typical Max Water Velocity (m s^{-1})	Minimum Fish Length for Passage (mm)
80	0.93	Impassable except to large fish (>400)
100	1.05	Impassable except to largest fish (>500)

Light

Many native fish have strong day-night movement patterns and several move almost exclusively when there is daylight (Jones 2011). Several species of fish, including Common Galaxias (*G. maculatus*) and Australian Smelt (*R. semoni)* move more during daylight than night. The Reedy Lake and Hospitals Swamps regulator culverts are submerged and there are likely to be low light issues for native fish. For any new culverts, extra light within the culvert will be useful such as high culverts with maximum freeboard or strategic light grids.

4.4 Ecological Prioritisation of Fish Passage

A key principle for prioritizing fish passage in coastal systems is that fish species diversity and fish abundance (or biomass) is greatest at the most downstream stream barrier, most often at tidal barriers (Figure 1). The reason why fish populations are relative abundant and biodiverse, compared to wholly freshwater, is that the life-cycle of these fish includes both an estuarine/marine and freshwater component. Hence, fish accumulate above and below tidal barriers because they have an obligatory need to move upstream and downstream to complete their life-cycle.

Across a region, stream barriers are usually scored against a number of criteria to determine fish passage priorities. For the Corangamite CMA, previous stream barrier prioritisations throughout the CMA jurisdiction have assessed stream barriers with the following criteria (Ryan et al. 2010):

(1) presence of threatened species;
(2) species diversity;
(3) drown out characteristics of the barrier;
(4) stream order;
(5) presence of nearby barriers;
(6) length of stream affected by barrier; and
(7) fish habitat quality.

However, these assessment criteria cannot be used to rationally prioritise the barriers on Hospitals Swamps and Reedy Lake because the barriers are all geographically close to one another, with very similar physical characteristics.

Instead it is proposed that in terms of ecological benefits, the barriers closest to the river estuary are more important to restore fish passage first. The occurrence of large numbers of estuarine and diadromous fish, such as Australian grayling and Australian mudfish and numerous other migratory fish species, makes remediation of the Reedy Lake and Hospital Swamps outlet regulators the top priority. Once fish passage is achieved on the tidal sites then the freshwater inlet regulators can be considered, the inlet regulators may become greater priorities as fish ascend into the wetlands.

The ecological justification for the prioritisation of the Lower Barwon regulators for fish passage is provided in Table 4-2. Based on the regulators identified for priority fish passage displayed in Table 4-2, evaluation of options to facilitate fish passage has primarily considered the Hospital Swamps outlet regulator and Reedy Lake outlet regulator.

Figure 4-1 Accumulation of Galaxids below the Barwon Breakwater Prior to the Vertical-Slot Fishway

Figure 4-2 Accumulation of Galaxids above the Closed Hospital Swamp Outlet Regulator (February 2014)

Table 4-2 Ecological Prioritisation of Regulators for Fish Passage Restoration

Regulator	Estuarine/Tidal Barrier	Ecological Justification	Priority
Reedy Lake outlet	Yes	• Estuarine/freshwater fish community require passage to complete life-history • High species diversity and abundance • Fish accumulations observed • High quality habitat upstream • Large catchment area upstream	**High**
Hospital Swamp outlet	Yes	• Estuarine/freshwater fish community require passage to complete life-history • High species diversity and abundance • Fish accumulations observed • High quality habitat upstream • Large catchment area upstream	**High**
Reedy Lake inlet	No	• Medium fish abundance and diversity • Fish accumulations observed • High quality habitat upstream • Large catchment area upstream	**Medium**
Hospital Swamp inlet	No	• Medium fish abundance and diversity • Large catchment area upstream • High quality habitat upstream • Large catchment area upstream	**Medium**
Barge Hole regulator	No	• Medium fish abundance and diversity • Large catchment area upstream	**Low**
Armstrong Creek inlet	No	• Small catchment area upstream • Only operable on rain/flow event • Relatively low fish species diversity/abundance expected • Low quality habitat	**Low**
Private regulator barge hole	No	• Relatively minor structure • Little freshwater outflow to irrigated land • Relatively low fish species diversity/abundance expected • Low quality habitat	**Low**

4.5 Review of Operational Options to Facilitate Fish Passage

While the existing wetland outlet structures are not ideal for facilitating fish passage and connectivity in terms of their hydraulic and light characteristics, it is considered likely that changes to the operation of these structures could enable some fish passage connectivity to be reinstated to the wetlands. The following sections review operational options and constraints associated with seasonal changes to the operation of the outlet structures.

4.5.1 Autumn Break Outlet Opening

To facilitate fish migration into the Hospital Swamps and Reedy Lake during the crucial spring period, it would be possible to temporarily open the outlets to these wetlands early in the wetland filling stage (Autumn break), when the head difference between the wetlands and Lake Connewarre are relatively small. This approach would minimise water use and have minimal impact on broader wetland inundation objectives, whilst also providing hydraulic conditions through the existing outlets in terms of headloss and velocities that would be most likely to facilitate fish passage through the existing structures.

4.5.2 Winter Outlet Opening

Opening of the wetland regulator outlets during winter months and high flow periods in the Barwon River is a potential option to facilitate fish passage during this period.

Hydraulic analysis of Reedy Lake and the inlet and outlet hydraulics has been undertaken to understand the likely impact of a sustained opening Reedy Lake outlet during typical winter conditions to provide fish passage connectivity.

The analysis has included consideration of a range of Barwon River inflow scenarios which demonstrated that the impact on Reedy Lake water levels due to opening of the outlet is somewhat sensitive to Barwon River inflows. The results of the analysis can be summarised as follows:

- For Barwon River flows of approximately 400 ML/d or greater, the full supply level of 0.7-0.9 m AHD in Reedy Lake can potentially be maintained with the Reedy Lake outlet opened,
- For Barwon River flows approximately less than 250 ML/d, the rate at which flows can exist Reedy Lake through the outlet exceeds that which can enter through the inlet and the water level in Reedy Lake could be expected to reduce to between 0.5-0.7 m AHD, depending on the Barwon River flow rates,
- All scenarios modelled resulted in relatively high velocities and headloss through the inlet and outlet regulators. Velocities exceeding 1 m/s are predicted through the outlet culverts. Velocities between 0.5 – 1.0 m/s are predicted through the inlet culverts.

The high headloss and velocities predicted through the outlet to Reedy Lake during the winter months are considered to limit the effectiveness of this option for facilitating fish passage.

4.5.3 Summer Drawdown Outlet Opening

To facilitate the movement of large numbers of fish out of the wetlands during drying phases in the wetland, it would be possible to temporarily open the outlets to these wetlands in late summer-early autumn with minimal water use and impacts on broader wetland inundation objectives.

4.5.4 Recommendations

Based on the review, the following trial of temporary operational changes to the existing outlet structures to facilitate fish passage is proposed:

- While the hydraulic and light characteristics of the existing structures are not ideal for facilitating fish passage, it is considered likely that temporary opening of the wetland outlet regulators during the late stages of the summer drying phase and early spring filling periods would provide an opportunity for some fish connectivity to be established with minimal water use or impact on broader hydrological and ecological objectives (Lloyd et al, 2012).

- Trialling of these operational changes would provide an opportunity to monitor the fish response in these wetlands to understand the species composition and fish numbers and sizes that may migrate between the wetlands and Lake Connewarre. This information would assist to evaluate the case for proceeding with specific fish passage structural solutions as well as confirming the preferred passage type and detailed design considerations.

4.6 Review of Structural Options to Facilitate Fish Passage

A variety of structural fish passage options are potentially available for the Hospital Swamps and Reedy Lake outlet structures, which would potentially facilitate improved passage of large numbers of small-bodied fish, whilst minimising water use and maximising wetland connectivity at all times of the year.

The following key design constraints and objectives have been considered for the evaluation of preferred structural fish passage options for the identified priority sites:

- Fishways that pass small-bodied fish (15-300 mm long) with low velocities (<1.0 m/s) and turbulence (average 18 W/m^3),
- Fishways require minimal freshwater use (e.g. <5 ML/d),
- An upper fishway operating range that ceases as the wetlands spill over the low banks,
- A fishway operating range that accounts for highly variable tidal tailwater fluctuations, and
- Minimal maintenance especially associated with aggressive vegetation encroachment.

The following sections review potential structural fish passage options with reference to the key design constraints and objectives for the priority sites listed above.

4.6.1 Retro-Fit Culvert Roughness

Over the last decade there has been increasing interest in adding roughness elements inside existing culvert barrels which breaks up the laminar flow, creating turbulence, hydraulic complexity and edge effects that facilitate fish passage (Doehring et al. 2011; 2012). A variety of materials and configurations have been trialled including: (i) rocks or timber blocks, (ii) side baffles, (3) chains or ropes, (4) pre-cast cones and (5) spoiler baffles e.g. (bio-baffles).

In the main, the addition of roughness elements is limited for sites with long periods of steady state headwater, or where the total head differential is relatively small. There are several options to retro-fit roughness units to culverts and these depend on the fish species and range of flows over which the culvert operates. The major options are:

- Retro-fit side culvert baffles or chain droppers which are advantageous where there is reasonable depth and variable headwater.
- Retro-fit rocks, baffles or hard wood blocks which break up laminar flow and provide resting areas for fish. Importantly the roughness units must break the water surface and are less effectiveness if headwater is variable and the units submerged.

A variety of baffles have been trialled to provide roughness for fish ascent. Baffles can be fixed to the culvert floor or to the side walls (Figure 4-3). In Queensland, one design that is passing large numbers of weak swimming small-bodied fish is side angle baffles. In addition, side baffles have fewer debris problems than floor fixed spoilers or rocks or pre-cast cones. The side baffles can also be fitted before the culverts are moved to site.

Figure 4-3 **(Left) Box Culverts with Retro-Fitted One-Side Baffles and (Right) Twin-Sided Baffles (photos courtesy Tim Marsden.)**

Advantages

- Can effectively pass fish where there is steady headwater and low head differential;
- For new culverts the baffles are easy and cheap to install; and
- Low water use and maintenance issues.

Disadvantages

- Roughening culverts does not work for submerged culverts due to limited natural light;
- There are construction access/safety issues with submerged pipes; and
- Submerged culverts do not usually adequately pass fish due to high discharge/water velocity.

Recommendation

Roughened culverts are not considered to provide an optimal fish passage solution for either the Hospital Swamps outlet or Reedy Lake outlet due to the following limitations:

- The existing culverts are typically submerged with very low natural light availability;
- At various times, the water management of the wetlands will result in relatively large head differences existing across the culverts which would likely generate very high velocities and result in significant water use;
- The high water use associated with using the existing culverts for primary fish passage would likely result in length of time that connectivity could be provided being reduced by the broader water management constraints for the wetlands.

4.6.2 Pre-Cast Cone Fishway

Pre-cast concrete or plastic cones have been developed in Queensland by Queensland Fisheries and James Cook University (Figure 4-4). These can be easily fixed within new or in some cases existing culverts to improve fish passage. There has been some biological assessment to demonstrate improvements to fish passage in relatively short culverts. At present, there are no cone fishways in Victoria.

Figure 4-4 (Left) Pre-Cast Plastic Cones and (Right) Concrete Cones which Break Up Laminar Flow and Provide Roughness for Fish to Ascend Culverts in Queensland (photos courtesy Queensland Fisheries).

Advantages

- Can effectively pass small-bodied fish where there is limited headwater variation and low head differential;
- For new culverts the baffles are relatively easy and cheap to install;
- Low water use and maintenance issues; and
- There is no de-watering gate or operation required if the upstream invert is set at an appropriate level (i.e. if the headwater falls below the fishway then the fishway ceases function automatically).

Disadvantages

- Cones do not work for submerged culverts due to limited natural light;
- Cone fishways have a limited headwater range but multiple culverts with different inverts (commence to flow) can be one solution;
- Replacement of at least one culvert at each site is required; and
- Cone fishways may not effectively pass glass eels.

Recommendation

Cone fishways potentially provide a solid solution for facilitating fish passage at the Lower Barwon wetland outlets.

4.6.3 Vertical Slot Fishway

Vertical-slot fishways have a proven track record in the Barwon River system and around Australia (Stuart and Mallen-Cooper 1999). They are relatively insensitive to headwater and tailwater variation, pass a variety of fish sizes and can be pre-cast.

Figure 4-5 Culvert Style, Vertical Slot Fishways (Cowwarr Weir & Barwon Breakwater)

Advantages

- Can effectively pass small-bodied fish;
- For new culverts the baffles are easy and cheap to install;
- Low water use and maintenance issues.

Disadvantages

- Cannot be fitted to the existing culverts;
- Usually require a de-watering gate and manual operation but the upstream invert can be set so that the fishway does not release water at low flows;
- Potentially cost more than the other solutions;
- Vertical-slot fishways do not effectively pass glass eels.

Recommendation

A vertical-slot fishway potentially provides a solid solution for facilitating fish passage at the Lower Barwon wetland outlets.

4.6.4 Rock Fishway

Rock fishways are excellent for passing small-bodied fish over a reasonably wide range of flows and have a proven track record for the Corangamite CMA.

Figure 4-6 Pollocksford Weir Rock Fishway on the Middle Reaches of the Barwon River

Advantages

- Excellent for passage of small-bodied fish and crustaceans;
- Insensitive to variable tailwater;
- Minimal cost.

Disadvantages

- Sensitive to variable headwater;
- Relatively high water use compared to vertical-slot or cone fishways;
- Can be quickly invaded by terrestrial invasive plants;
- Maintenance requirements are usually higher than other fishway types.

Recommendation

Due to high water use and maintenance requirements rock fishways are not considered to provide an optimal solution for the Lower Barwon wetland outlets.

4.6.5 Eel Passage

Short-finned eels are abundant in the lower Barwon River system but eels have a complex life-history with their early life-stages being particularly vulnerable to tidal barriers. Adult eels, most 10-30 years old, migrate from rivers downstream to estuaries and into the sea where they migrate to distant (possibly in the Coral Sea) marine spawning grounds for their one-off life-time spawning event after which they die. Larval eels change into unpigmented glass eels and mass migrations of small eels (40+ mm long) enter freshwater during spring and early summer.

Eels >150 mm long are strong swimmers but glass eels and the larger brown (e.g. <130 mm long) have a very poor swimming ability (burst swimming speed 0.6-0.9 m/s) but this is offset by a remarkably strong ability to climb waterfalls, weirs and even high dams by using the wetted perimeter, or splash zone, alongside the spillway area. Climbing is enhanced by rough surfaces or by moss and algae. The climbing ability of young eels has important implications for fishways. Young eels appear to prefer to climb and crawl over stream barriers and where they are required to swim through a fishway, even at low gradient and water velocity, there is relatively poor success.

As almost all fishways require fish to swim faster and for longer than most juvenile eels can accomplish, there has been greater success when the ecological function of the fishway considered. This means that the fish passage solution should include a specific *elver pass* designed to facilitate juvenile eel passage by climbing. Elver passes are common in North America, Europe and New Zealand but are only recently starting to gain momentum in Australia. The growth of the elver and eel industry in eastern Australia is increasing the importance of providing fishways for these fish and the most common elver passes are briefly discussed below.

Elver Ramps

A range of other elver fishways have been used, including locks and trap-and-transport but these have significant capital cost or human intervention requirements and are not considered further here. Elver ramps are the most common type of fishway and there is considerable data to support their success from North America, Europe and New Zealand. These consist of a steep (e.g. 1 vertical: 2 horizontal) pipe or ramp installed on the face of the stream barrier with a roughened surface, usually nylon brushes or gravel-lined channels which with the addition of water gives the elvers a rough surface to climb over. These types of fishways are usually inexpensive and an example is shown below in Figure 4-7 (Left).

Ropes

Mussel spat ropes, as shown in Figure 4-7 (Right), have recently been used in New Zealand for passing climbing galaxias and these also have potential for elvers.

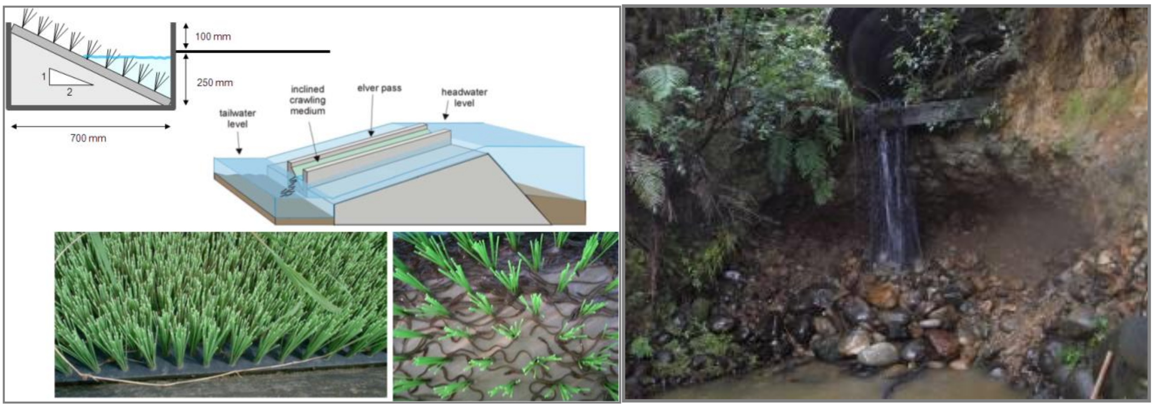

Figure 4-7 (Right) Mussel Spat Rope Used to Improve Passage of Galaxiids in New Zealand (photo courtesy Bruno David). (Left) A Roughened Ramp for Glass Eel Passage

4.6.6 Recommendations

Reedy Lake

To facilitate fish passage through the existing outlet structure, a vertical slot fishway to bypass the existing penstock and culverts is recommended.

Hospital Swamps

At the Hospital Swamps outlet a lower level, pre cast cone fishway is recommended to be incorporated into the spillway structure. With a lower crest level/cease to flow of approximately 0.3 m AHD this fishway would facilitate fish passage connectivity between Hospital Swamps and Lake Connewarre during drying phases in Hospital Swamps.

Eel Passage

Large eels (>200 mm long) will utilise traditional pool type fishways but juvenile eels require a separate inexpensive passage system. We propose a staged approach to assessing eel passage options, with an initial experimental stage at the Barwon Breakwater to test ropes and ramps and refine design and operational requirements for optimising passage of juvenile (<150 mm long) eels.

This would be followed by a second implementation stage for the Reedy Lake and Hospital Swamp systems.

4.7 Carp Management

Carp are a non-native pest fish which can reach high abundance in wetlands where they can detrimentally impact on local environmental assets such as water quality, vegetation and native fish. Reedy Lake has a considerable non-native carp population and there are a number of ways to manage these fish.

On its own, capture and removal of carp is unlikely to provide a long-term reduction in carp populations to an environmentally significant level (i.e. where damage is acceptable or recruitment reduced) unless undertaken in conjunction with wetland management strategies. The deficiency with all physical removal techniques for carp is that they are highly fecund (high number eggs of each per female) so that any remaining fish can quickly recover the population to original levels. Integrated control, using a number of methods, is the best strategy to adopt for controlling carp. Some of the main carp control techniques are outlined below and their application at the Barwon wetlands is briefly scoped.

4.7.1 Koi Hepes Virus

Koi Herpes Virus (KHV) was described in common carp in Israel in 1998 and has since spread throughout much of Europe, Asia, South Africa and the United States. The virus is spread by carp and is also water borne; young carp are highly susceptible and can die within hours of exposure. Although high mortalities have been reported (e.g. 70-100%) the virus has a preferred temperature range of 22-27°C. KHV has high specificity to carp (including Koi carp) and is currently the focus of a study to determine its potential as a biological control agent in Australia. The laboratory research has shown high potential for KHV in controlling carp in Australia, with no impacts on native fish reported. However, release of the virus is not likely before the year 2017, with strong public consultation and planning in the meantime. As for Myxamotisis and calicivirus, the KHV will be unlikely to kill all carp and will probably have declining impacts over time (e.g. 8-10 years). Hence, KHV is one component of a broader carp control program.

4.7.2 Wetland Water Management

Lloyd et al (2012) provides flow-ecology recommendations for meeting the ecological and hydrological objectives of both Reedy Lake and Hospital Swamps which consider all aspects of wetland health. The recommended watering regime to meet these objectives includes wetland drawdown and drying periods, which are natural wetland processes.

Drawdown and drying period for wetlands have the potential to reduce, control or eliminate carp populations.

Carp have been shown to be less adept at returning to the main river from wetlands flood waters than many native fish and often become trapped in floodplain lakes. At Reedy Lake, there is some potential for complete removal of carp when drying periods are implemented; recommended 2 years in 10 with the wetland dry from March to May (Lloyd et al, 2012).

4.7.3 Screens

Some progress has been made with screen technology, by basing their design on the biology of both carp and native fish, and screens are present on the Reedy Lake inlet regulator. Screens have some operational and maintenance requirements and only work for larger carp (e.g. > 250 mm long).

4.7.4 Cage Trapping

Cage trapping of carp is an effective technique for reducing the number of adult and sub-adult carp, and various design options are available. Carp cages have been applied successfully at a number of fishways on the mainstem of the Murray River to automatically separate adult carp from native fish. At Lock 1 (Blanchetown) over 550 tonnes have been removed since late 2007. A carp separation cage requires the intensive on-site management by a licensed fisherman. The carp cage will not be used during a natural flood event when access is limited. Bycatch of native fish (particularly medium-large bodied species) is limited but must be carefully managed. Impact on landscape carp populations is likely small as carp are only removed from one location. No carp cage is recommended for the Barwon wetlands at this stage.

4.7.5 Summary

There is a significant population of carp in the lower Barwon River system and these are likely to be impacting on ecosystem values. Carp are a highly resilient fish and can often recover rapidly from management actions. There are some unique opportunities for controlling carp in the lower Barwon wetlands with integration of the recommended watering regime (Lloyd et al, 2012), carp screens and the proposed release of the KHV virus.

4.8 Water Use

Consultation with project stakeholders has indicated that water use by the fish passage and the potential reduced ability to control inundation/ water levels in the wetlands due to the operation of fish passage is considered a significant constraint on the design of any potential fish passage structures.

Ideally, fish passage connectivity between the wetlands and Lake Connewarre should be provided the overwhelming majority of the time, particularly during drying periods when large numbers of fish could be expected to exit the wetlands. The water use associated with maintaining connectivity with the fish passage during these periods may however conflict with the broader water management objectives for the wetlands.

It is therefore considered that only low water use fish passage options are appropriate for these wetlands. In addition, it is considered that any fish passage options on the wetland outlets would need to incorporate careful consideration of cease to flow sill levels and/or automatic gates to enable the fish passage to be taken offline as required to manage water levels and inundation in the wetlands under certain conditions.

6. CONCEPT DESIGNS

Indicative concept designs for the Reedy Lake and Hospital Swamps outlets have been developed incorporating the preferred structural fish passage options and an upgraded outlet configuration in the case of the Hospital Swamps outlet. The concept designs have been developed to assist to communicate how it is envisaged the outlets could be modified and function to facilitate fish passage in the future, as well as to provide a basis for estimating likely implementation costs. The concept designs do not constitute detailed designs and various aspects of the concepts and elements within the concepts may be changed or modified during detailed design and as a result of ongoing stakeholder consultation.

6.1 Reedy Lake Outlet

The assessment has confirmed that modifications to the existing Reedy Lake outlet channel capacity and regulator are unlikely to significantly improve the ability to flood Reedy Lake via gravity flows from Lake Connewarre. Therefore no structural modifications to the outlet channel or regulator are proposed.

However, in order to facilitate fish passage through the existing structure, a concept design for a vertical slot fishway to bypass the existing penstock and culverts at the Reedy Lake outlet has been developed and is displayed indicatively in Figure 6-1. The rationale behind the design and key components of the concept is as follows:

- The fishway entrance needs to be adjacent to the outlet works to ensure the fish are attracted to fishway and do not move upstream past the entrance to the vertical slot fishway.
- A cattle grid type crossing for the access track would need to be incorporated to maintain appropriate light characteristics within the fish passage.
- To facilitate eel passage either ropes or ramps to for passage of juvenile (<150 mm long) eels. An indicative ramp type structure is shown on the figure.

Material quantity and unit cost/rate estimates have been developed for the concept to provide an indication of total cost for implementation.

Construction costs for each of the main elements of the concept have been prepared and are displayed in Table 6-1.

Table 6-1 Indicative Vertical Slot Fishway Implementation Costs – Reedy lake

Element	Amount
Detailed Design	$20,000
Contractors	$100,00
Materials	$75,000
Project Management	$30,000
Total	**$225,000**

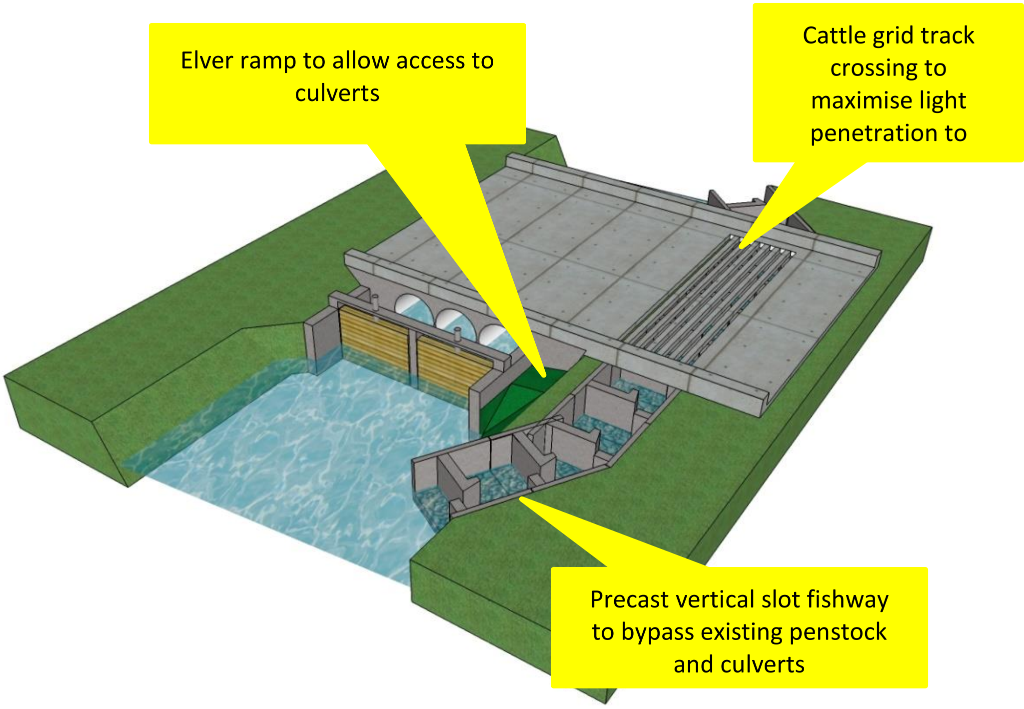

Figure 6-1 Reedy Lake Outlet Fish Passage Concept

6.2 Hospital Swamps Outlet

A proposed concept design for an upgraded Hospital Swamps outlet and dedicated fish passage has been developed and is displayed indicatively in Figure 6-2. The following summary provides the rationale behind the design and key components of the concept:

- Upgrading of the original low level spillway at the Hospital Swamps outlet regulator. The spillway will increase the capacity of the outlet to reduce the magnitude, frequency and persistence of high water level conditions in Hospital Swamps and adjacent private properties. The crest level of the spillway would be constructed to 0.4m AHD, i.e. the same crest level as the original spillway design for Hospital Swamps. It is proposed to construct the upgraded spillway from rock and concrete to prevent maintenance issues associated with vegetation encroachment, whilst providing a hydraulic environment that facilitates fish passage during spill events.
- A lower level, pre cast cone fishway is proposed to be incorporated into the spillway. The fishway would have a lower crest level/cease to flow of approximately 0.3m AHD. This would facilitate fish passage connectivity between Hospital Swamps and Lake Connewarre during drying phases in Hospital Swamps.
- It is proposed to upgrade the existing 0.525 m diameter culvert and penstock with two 1.5 x 0.9 m box culvert and penstocks. The increase culvert capacity would provide greater ability to manage water levels in Hospital Swamps during wet periods whilst enabling flows to be diverted through the fishway during dry periods to minimise water use, whilst still maintaining fish passage connectivity.
- The assessment results have shown that while upgrading the culverts alone would increase flows though the Hospital Swamps outlet, it would have no influence on peak water levels in Hospital Swamps, and only have a minimal influence on the rate of decrease in water levels in Hospital Swamps. Upgrading the spillway only was shown to increase the flow through

the Hospital Swamps outlet, and further increase the rate in lowering water levels in Hospital Swamps following an inflow event. Upgrading both the outlet and spillway would only slightly reduce peak water levels in Hospital Swamps. However, it would significantly improve the rate at which the water levels are reduced below 0.6 m AHD following an inflow event.

- To facilitate eel passage either ropes or ramps to for passage of juvenile (<150 mm long) eels. An indicative ramp type structure is shown on the figure.

Material quantity and unit cost/rate estimates have been developed for the concept to provide an indication of total cost for implementation.

Construction costs for each of the main elements of the concept have been prepared and are displayed in Table 6-2.

Table 6-2 Indicative Spillway, Culvert and Fishway Implementation Costs

Element	Amount
Detailed Design	$50,000
Contractors	$200,00
Materials	$75,000
Cone Fishway	$60,000
Project Management	$30,000
Total	**$415,000**

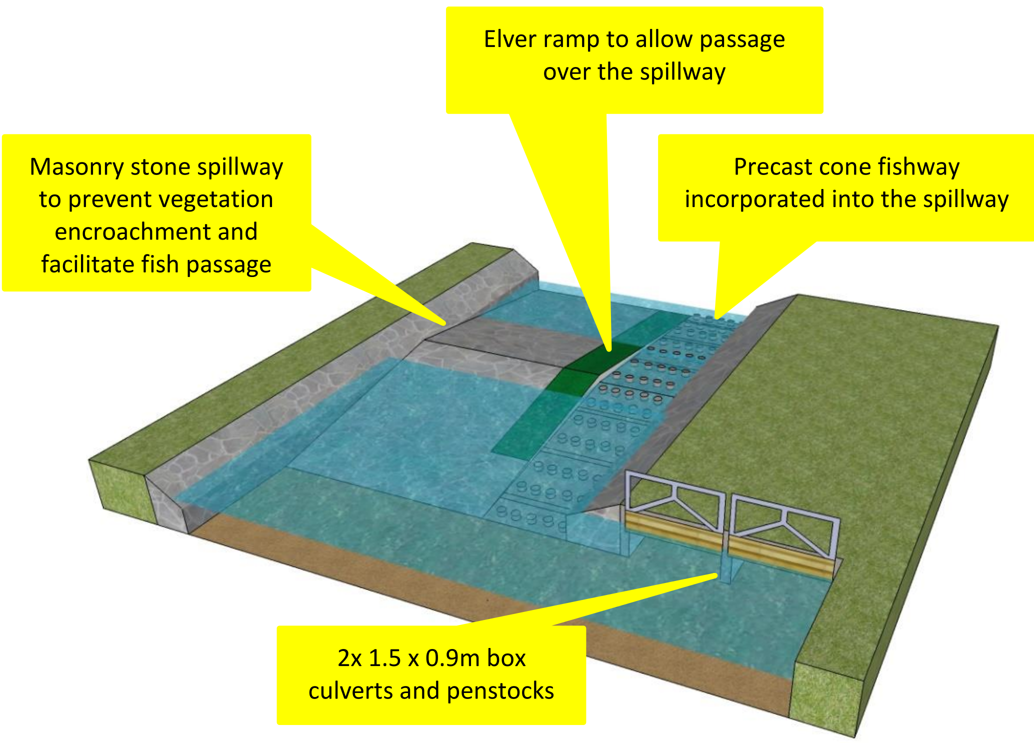

Figure 6-2 Hospital Swamp Outlet and Fish Passage Concept

7. CONCLUSIONS

7.1 Reedy Lake Inundation

The inundation analysis presented in this study for Reedy Lake has indicated the following:

- Relatively shallow estuarine inundation based on the existing channel and regulator arrangement is likely to be readily achieved in Reedy Lake.
- Moderate increases to the outlet channel capacity and regulator are unlikely to provide significantly improved ability to flood Reedy Lake via gravity flows from Lake Connewarre.
- Significant pumping rates and volumes are likely to be required to achieve moderate inundation levels of 0.5-0.6 m AHD in Reedy Lake.
- Inundation of Reedy Lake with high salinity flows could only be considered as an 'opportunistic' option. It is reliant on the salinity conditions in Lake Connewarre and the Lower Barwon River below the breakwater. Suitable salinity conditions occur seasonally and are generally only likely to occur in the summer and early autumn months.

7.2 Hospital Swamps Flooding Outlet

The assessment of the characteristics of the Hospital Swamps outlet has highlighted that the capacity of the outlet channel is relatively limited and provides a fundamental control on the rate at which large catchment generated inflows to Hospital Swamps can be passed to Lake Connewarre.

Due to the magnitude of catchment generated inflows, short periods where water levels increase above 0.6 m AHD could be expected to occur regardless of the changes made to the outlet regulator.

Upgrading the existing low level spillway and increasing the capacity of the outlet culverts could however be expected to improve the ability to manage water levels in Hospital Swamps and reduce the persistence of high water levels following major inflow events.

Long term options to reduce catchment inflows would assist to reduce the frequency and persistence of high water levels in Hospital Swamps.

7.3 Fish Passage, Management and Connectivity

This study has reviewed a range of structural options for facilitating fish passage which could be implemented in conjunction with existing or modified outlet structures for the wetlands, as well as testing of possible operational changes to the existing structures.

7.3.1 Structural Options to Facilitate Fish Passage

Reedy Lake

To facilitate fish passage through the existing outlet structure, a vertical slot fishway to bypass the existing penstock and culverts is proposed.

To facilitate eel passage we suggest a staged approach. Stage 1 -implemented at the Barwon Breakwater to test ropes and ramps to refine design and operational requirements for optimising passage of juvenile (<150 mm long) eels. Stage 2 – either refine designs or implement successful design at the Reedy Lake outlet structure.

Hospital Swamps

At the Hospital Swamps outlet a lower level, pre cast cone fishway is proposed to be incorporated into the spillway structure. With a lower crest level/cease to flow of approximately 0.3 m AHD this fishway would facilitate fish passage connectivity between Hospital Swamps and Lake Connewarre during drying phases in Hospital Swamps.

As for Reedy Lake, to facilitate eel passage the same staged approach is proposed.

7.3.2 Operational Changes as Fish Passage Options

Based on the fish passage options assessment and consideration of the water management constraints and functionality required of the outlet infrastructure to Hospital Swamps and Reedy Lake, the following trial of temporary operational changes to the existing outlet structures to facilitate fish passage are proposed:

- While the hydraulic and light characteristics of the existing structures are not ideal for facilitating fish passage, it is considered likely that temporary opening of the wetland outlet regulators during the late stages of the summer drying phase and early spring filling periods would provide an opportunity for some fish connectivity to be established with minimal water use or impact on broader hydrological and ecological objectives (Lloyd et al, 2012).
- Trialling of these operational changes would provide an opportunity to monitor the fish response in these wetlands to understand the species composition and fish numbers and sizes that may migrate between the wetlands and Lake Connewarre. This information would assist to evaluate the case for proceeding with specific fish passage structural solutions as well as confirming the preferred passage type and detailed design considerations.

7.4 Concept Designs

Indicative concept designs for the Reedy and Hospital Swamps outlets have been developed incorporating the preferred structural fish passage options and an upgraded outlet configuration in the case of the Hospital Swamps outlet. The concept designs have been developed to assist to communicate how it is envisaged the outlets could be modified and function to facilitate fish passage in the future, as well as to provide a basis for estimating likely implementation costs. The concept designs do not constitute detailed designs and various aspects of the concepts and elements within the concepts may be changed or modified during detailed design and as a result of ongoing stakeholder consultation.

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