Risk assessment of proposed management scenarios for Lake Alexandrina on the resident fish community

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Cover: Boundary Creek in the Lower Lakes (top photo) and an adult congolli (*Pseudaphritis urvillii,* bottom photo).

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Appendix

BMT WBM (2008). Results from simulations investigating potential salinity behaviour in the Lower Lakes and Murray River – August 2008 – December 2010. DJW: L.N1347.012.2yrPrognosticSimulations.FinalDraft.doc.

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Executive Summary

Introduction and background

The Coorong and Lower Lakes were designated as a wetland of international importance under the Ramsar convention in 1985 and have additionally been assigned as one of six 'icon sites' in the Murray-Darling Basin (MDB) under '*The Living Murray'* program. The primary objective of both programs is 'the maintenance and enhancement of the ecological character of the site'. Persistent drought conditions in the MDB combined with a history of over extraction, have led to historic low water levels in the Lower Lakes. This has resulted in the exposure of extensive areas of acid sulfate soils (ASS), which may have serious impacts on the quality of remaining water through acidification, mobilisation of metal ions, anoxia and the production of noxious gases. Thus, ASS represents a dire threat to the ecological and cultural character of the Lower Lakes as well as the agricultural and tourism sectors and there is great impetus for the management of this situation.

Predictions suggest that River Murray inflows are likely to remain below average in the foreseeable future and water levels in Lake Alexandrina are likely to continue receding. A critical low water level for 'runaway acidification' of -1.5 m AHD has been established for Lake Alexandrina. ASS are innocuous when inundated and therefore several management options have been proposed to maintain lake levels above -1.5 m AHD. With the prospect of significant freshwater inflows being very low, the managed intrusion of saltwater into the Lower Lakes from the Coorong via the Murray Barrages features prominently in the proposed management options. The intrusion of saltwater to maintain water levels in Lake Alexandrina may mitigate the immediate risk of acidification but it may have serious impacts on the freshwater adapted Lower Lakes ecosystem, including the resident fish community.

The present study assessed the risks of two management options (both involving a weir at Wellington) on selected fish species of the Lower Lakes and Coorong. The options assessed were,

1) Saltwater intrusion via Goolwa Barrage to maintain water levels in Lake Alexandrina above -1.5 m AHD.
2) Saltwater intrusion via Mundoo and/or Tauwitchere Barrage to maintain water levels in Lake Alexandrina above -1.5 m AHD, with the provision of a freshwater refuge. A regulator would be built between Hindmarsh Island and a point on the mainland near Clayton and a freshwater environment would be maintained between this regulator and Goolwa Barrage.

Methods

The process and methods used in this project were as follows,

- Collate background information and complete a literature review on the ecology of selected fishes of the Lower Lakes and Coorong, with emphasis on spawning requirements, habitat preferences and physico-chemical tolerances of different life stages
- Use this information to develop conceptual models on the life cycles of these species
- Using salinity modelling data for the proposed management options for the Lower Lakes, provided by BMT WBM, generate a draft risk assessment for given species based on each option
- Run a workshop with local and interstate experts
    - Refine conceptual models
    - Assess risks and consequences of both management options on individual species
    - Discussion on possible mitigating actions and the rationale of these actions given each management option
- Prepare final report and submit to DEH

The risk assessment method follows domestic and international standards (AS/NZS 4360/2004 and relevant ISO standards referred to in this document) for Environmental Risk Assessment. Relevant impacts were identified and each individual species received a risk assessment score comprised of likelihood, consequence and confidence (see Table 1). Likelihood relates to the probability of an impact occurring, while consequence is a measure of the estimated ecological affect on a given species in the event of the impact. Confidence relates to the amount of supporting information and agreement between experts on the consequence score given.

Table 1. Levels of Likelihood, Consequence and Confidence.

Likelihood	Consequence (impact)	Confidence
A – certain	1 – catastrophic	1 - local information available, documented process, experts agree
B – likely	2 – major (negative)	2 - regional information available, documented process, experts verify
C – moderate	3 – moderate (negative)	3 – limited information, documented process elsewhere in region or similar region, experts differ
D – unlikely	4 – minor (negative)	4 – Perception based on some information that is not local or regional
E – Rare	5 - insignificant	5 – Perception only, no supporting information

In order to classify impacts by a level of risk the following categorisation matrix was applied (Table 2). As such, all identified and analysed impacts may be evaluated as to the level of risk (low, medium or high) they pose to each individual species investigated based upon a combination of likelihood and consequence scores.

Table 2. Overall risk matrix, detailing the assignment of impacts to risk categories (low, medium or high) based upon combined scores for likelihood and consequence.

		Consequence				
		1	2	3	4	5
Likelihood	A	High				
	B			Medium		
	C				Low	
	D					
	E					

Risk Assessment

Both management options had a suite of negative impacts and very few positive impacts on the selected fish species. The impacts identified primarily relate to rising salinities in Lake Alexandrina (above species tolerance limits), continued lack of inflows into the Coorong and the obstruction of bi-directional fish movements between the Coorong and Lake Alexandrina, and between Lake Alexandrina and the River Murray.

The predicted response (change in abundance) of each fish species under both options is presented in Tables 3 and 4 below. Management option 1 is assessed at four points in time to show trajectories of changes in abundance (Table 3). All freshwater species, including Murray cod, golden perch and Yarra pygmy perch are likely to become extinct or exhibit significantly decreased abundances in Lake Alexandrina under option 1. The same will be true for Lake Alexandrina 'outside' of the refuge in option 2. Most species should persist within the refuge if water quality assumptions are met, which represents *c.* 10% of the total lake area. Declines are due to increased salinity, physical habitat loss and obstruction of dispersal migrations into the River Murray by the Wellington Weir upon the intrusion of saltwater into the lake.

Diadromous species will be negatively impacted under both options. The lack of freshwater inputs to the Coorong will result in an absence of navigational migratory cues for adults of both lamprey species and juvenile short-finned eels. Passage between the Coorong and Lake Alexandrina is largely obstructed with access to the lake only possible by 'over-topping' the barrages, which may result in high mortality rates. There is no access between the refuge and Coorong under option 2. Similarly the Wellington Weir will obstruct the upstream migration of lamprey species if they are able to enter the lake. The downstream spawning movement of catadromous adults (e.g. congolli) will be obstructed due to the delivery mechanism in option 1 and no access to the Coorong is currently provided in option 2. Therefore substantial decreases in abundance or local extinctions can be expected for diadromous species.

The continued absence of freshwater inflows to the Coorong will negatively impact estuarine and some marine species. Commercially important species like black bream and mulloway generally reside in areas of reduced salinity (i.e. below seawater) and may utilise salinity gradients for successful recruitment. Adults of these species are unlikely to move into the lake due to the delivery mechanism but larvae and juveniles may passively enter the lake but there are likely to be high mortality rates. These species may initially increase in abundance following the intrusion of saltwater into Lake Alexandrina but by December 2010, salinities will be well above the preferred ranges of these species. Attempts to return to the Coorong made by these species will be obstructed. Thus, for most estuarine and marine species, with the exception of yellow-eyed mullet and small-mouthed hardyhead, under both options, initial increases in abundance can be expected but in the longer term changes in abundance in Lake Alexandrina will be minor or negligible.

Table 3. Likely changes in fish abundance in Lake Alexandrina under management option 1. Key: ↓ - minor decrease, ⇩ - moderate decrease, ⇓ - major decrease, ↑ - minor increase, ⇧ - moderate increase, ⇑ - major increase, ≈ - no change, X – extinction or total emigration.

Species	Scientific name	August 2009	December 2009	February 2010	December 2010
Large-bodied native freshwater species					
Silver perch	*Bidyanus bidyanus*	↓	⇓	⇓	**X**
Golden perch	*Macquaria ambigua*	↓	⇓	⇓	**X**
Murray cod	*Macquaria peelii peelii*	↓	⇓	⇓	**X**
Bony herring	*Nematalosa erebi*	≈	⇩	⇩	⇓
Eel-tailed catfish	*Tandanus tandanus*	↓	⇓	⇓	**X**
River blackfish*	*Gadopsis marmoratus*	↓	⇓	**X**	**X**
Common small-bodied native freshwater species					
Carp gudgeon complex	*Hypseleotris* spp.	↓	⇓	⇓	**X**
Flat-headed gudgeon	*Philypnodon grandiceps*	↓	⇩	⇓	**X**
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	↓	⇓	⇓	**X**
Australian smelt	*Retropinna semoni*	≈	⇩	⇩	⇓
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	↓	⇩	⇓	**X**

* Species most common in the upper reaches of tributaries. Response reflects predictions for fish that may reside in the lake.

Table 3. continued

Species	Scientific name	August 2009	December 2009	February 2010	December 2010
Rare or endangered small-bodied native freshwater species					
Murray hardyhead	*Craterocephalus fluviatilis*	↓	↓	↓	↓ or **X**
Mountain galaxias*	*Galaxias olidus*	↓	↓	**X**	**X**
Murray rainbowfish	*Melanotaenia fluviatilis*	↓	↓	↓	**X**
Southern purple-spotted gudgeon	*Mogurnda aspersa*	↓	↓	↓	**X**
Southern pygmy perch	*Nannoperca australis*	↓	↓	**X**	**X**
Yarra pygmy perch	*Nannoperca obscura*	↓	↓	**X**	**X**
Exotic freshwater species					
Goldfish	*Carassius auratus*	↓	↓	↓	**X**
Common carp	*Cyprinus carpio*	↓	↓	↓	**X**
Tench	*Tinca tinca*	↓	↓	↓	**X**
Rainbow trout*	*Oncorhynchus mykiss*	↓	↓	↓	**X**
Brown trout*	*Salmo trutta*	↓	↓	↓	**X**
Eastern gambusia	*Gambusia holbrooki*	≈	↓	↓	↓
Redfin perch	*Perca fluviatilis*	↓	↓	↓	**X**
Diadromous species					
Pouched lamprey^	*Geotria australis*	↓	↓	↓	↓ or **X**
Short-headed lamprey^	*Mordacia mordax*	↓	↓	↓	↓ or **X**
Climbing galaxias@	*Galaxias brevipinnis*	↓	↓	↓	↓ or **X**
Common galaxias@	*Galaxias maculatus*	↓	↓	↓	↓
Short-finned eel@	*Anguilla australis*	↓	↓	↓	↓ or **X**
Estuary perch@	*Macquaria colonorum*	↓	↓	↓	↓ or **X**
Congolli@	*Pseudaphritis urvillii*	↓	↓	↓	↓ or **X**

^ - anadromous species, @ - catadromous species

Table 3 continued.

Species	Scientific name	August 2009	December 2009	February 2010	December 2010
Estuarine species					
Flat-tailed mullet	*Liza argentea*	≈	⇧	↑	≈
Yellow-eyed mullet	*Aldrichetta forsteri*	≈	⇧	⇧	⇧
River garfish	*Hyporhamphus regularis*	≈	⇧	↑	≈
Black bream	*Acanthopagrus butcheri*	≈	⇧	↑	≈
Bridled goby	*Arenogobius bifrenatus*	↑	⇧	⇧	≈
Tamar goby	*Afurcagobius tamarensis*	↑	⇧	⇧	≈
Bluespot goby	*Pseudogobius olorum*	↑	⇧	⇧	≈
Lagoon goby	*Tasmanobius lasti*	↑	⇧	⇧	≈
Greenback flounder	*Rhombosolea tapirina*	≈	⇧	↑	≈
Small-mouthed hardyhead	*Atherinosoma microstoma*	↑	⇧	⇧	⇧
Marine species					
Mulloway	*Argyrosomus japonicus*	≈	⇧	↑	≈
Sea mullet	*Mugil cephalus*	≈	⇧	↑	≈

Table 4. Likely changes in fish abundance in Lake Alexandrina under management option 2. Key: ↓ - minor decrease, ↓ - moderate decrease, ↓ - major decrease, ↑ - minor increase, ↑ - moderate increase, ↑ - major increase, ≈ - no change, X – extinction or total emigration.

Species	Scientific name	December 2010
Large-bodied native freshwater species		
Silver perch	*Bidyanus bidyanus*	↓
Golden perch	*Macquaria ambigua*	↓
Murray cod	*Macquaria peelii peelii*	↓
Bony herring	*Nematalosa erebi*	↓
Eel-tailed catfish	*Tandanus tandanus*	↓
River blackfish*	*Gadopsis marmoratus*	↓
Common small-bodied native freshwater species		
Carp gudgeon complex	*Hypseleotris* spp.	↓
Flat-headed gudgeon	*Philypnodon grandiceps*	↓
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	↓
Australian smelt	*Retropinna semoni*	↓
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	↓
Rare or endangered small-bodied native freshwater species		
Murray hardyhead	*Craterocephalus fluviatilis*	↓
Mountain galaxias*	*Galaxias olidus*	↓
Murray rainbowfish	*Melanotaenia fluviatilis*	↓
Southern purple-spotted gudgeon	*Mogurnda aspersa*	↓
Southern pygmy perch	*Nannoperca australis*	↓
Yarra pygmy perch	*Nannoperca obscura*	↓
Exotic freshwater species		
Goldfish	*Carassius auratus*	↓
Common carp	*Cyprinus carpio*	↓
Tench	*Tinca tinca*	↓
Rainbow trout*	*Oncorhynchus mykiss*	↓
Brown trout*	*Salmo trutta*	↓
Eastern gambusia	*Gambusia holbrooki*	↓
Redfin perch	*Perca fluviatilis*	↓

* Species most common in the upper reaches of tributaries. Response reflects predictions for fish that may reside in the lake.

Table 4 continued.

Species	Scientific name	December 2010
Diadromous species		
Pouched lamprey^	*Geotria australis*	↓ or **X**
Short-headed lamprey^	*Mordacia mordax*	↓ or **X**
Climbing galaxias@	*Galaxias brevipinnis*	↓ or **X**
Common galaxias@	*Galaxias maculatus*	↓
Short-finned eel@	*Anguilla australis*	↓ or **X**
Estuary perch@	*Macquaria colonorum*	↓ or **X**
Congolli@	*Pseudaphritis urvillii*	↓ or **X**
Estuarine species		
Flat-tailed mullet	*Liza argentea*	≈
Yellow-eyed mullet	*Aldrichetta forsteri*	↑
River garfish	*Hyporhamphus regularis*	≈
Black bream	*Acanthopagrus butcheri*	≈
Bridled goby	*Arenogobius bifrenatus*	≈
Tamar goby	*Afurcagobius tamarensis*	≈
Bluespot goby	*Pseudogobius olorum*	≈
Lagoon goby	*Tasmanobius lasti*	≈
Greenback flounder	*Rhombosolea tapirina*	≈
Small-mouthed hardyhead	*Atherinosoma microstoma*	↑
Marine species		
Mulloway	*Argyrosomus japonicus*	≈
Sea mullet	*Mugil cephalus*	≈

^ - anadromous species, @ - catadromous species

Mitigation

Neither of the two management options investigated is recommended. The preferred option to manage the impacts of ASS on the Lower Lakes, although not assessed, is the delivery of significant volumes of freshwater. This is highly unlikely and several mitigating strategies have been suggested to limit the risk to fish populations due to the proposed management options in question. The provision of a freshwater refuge in option could be viewed as a mitigation strategy for the loss of physical habitat and physico-chemical exclusion from habitat area due to raised salinities in option 1. Other significant mitigations strategies include,

- Provision of fish passage on the Wellington weir
- Delivery of saltwater 'through' the barrages rather than 'over'

- Release of excess water in the refuge (option 2) to the Coorong via the Goolwa vertical-slot fishway rather than delivering it to Lake Alexandrina over the Clayton regulator spillway
- Construct the Clayton regulator as far east as possible to incorporate high value habitats on Hindmarsh Island
- Regulate the Lakes and Coorong fishery to avoid over-exploitation of aggregated fish
- Control illegal pumping of freshwater from the freshwater refuge

1 Introduction

Persistent drought conditions in the Murray-Darling Basin (MDB) combined with a history of river regulation and over extraction of water resources have resulted in below average inflows to the Lower Lakes for at least the last three years. As a consequence, water levels in Lakes Alexandrina and Albert have continuously receded since mid 2006 to historic low levels. Predictions suggest inflows are likely to remain below average in the foreseeable future and lake levels are likely to continue receding.

Severely decreased water level poses many threats to the Lower Lakes ecosystem, perhaps none as pertinent as the exposure of acid sulfate soils (ASS). The exposure of ASS may have serious impacts on the quality of remaining water supplies including acidification, mobilisation of heavy metals, anoxia and the production of noxious gases. Thus, there exists a dire threat to the ecological and cultural character of the Lower Lakes as well as the agricultural and tourism sectors.

The Coorong and Lower Lakes were designated as a wetland of international importance under the Ramsar convention in 1985 and as such the Australian government is under obligation to retain the 'ecological character' of this site (see DEH 2000). Additionally, the Lower Lakes, Coorong and Murray Mouth have collectively been assigned as one of six 'icon sites' in the MDB under '*The Living Murray'* program, the primary objective of which is also, 'the maintenance and enhancement of the ecological character of the site' (see MDBC 2006). As such, there is great impetus for management of the current situation to mitigate the threats posed by reduced water levels and ASS.

Several short-term management options have been proposed for the Lower Lakes with the primary objective of maintaining water levels above critical levels for acidification. With the likelihood of significant freshwater inflows being very low, allowing some form of managed saltwater intrusion over the Murray Barrages appears the most likely scenario. Although this may mitigate the immediate threat posed by ASS, such management practises may have serious impacts on the freshwater adapted ecosystem of the Lower Lakes, including a diverse fish community unique within the MDB.

This report aims to assess the risk of the impacts of given management options for the Lower Lakes on the resident fish community. Specifically this report aims to assess the risk of the following two potential management options, both of which include the construction of the Wellington Weir to avoid the intrusion of saline water into the River Murray;

- Option 1. 'Saltwater intrusion via Goolwa Barrage' – Saltwater would be introduced to Lake Alexandrina from the Coorong over Goolwa Barrage, in order to maintain lake levels above a critical acidification level (-1.5 m AHD). The volume of saltwater required is dependent on the volume of freshwater inflows.

- Option 2. 'Saltwater intrusion at Mundoo and/or Tauwitchere with the provision of a freshwater refuge' – A regulator would be built between Hindmarsh Island and Clayton to provide a 'freshwater refuge' between this regulator and Goolwa Barrage. Saltwater would then be introduced to Lake Alexandrina from the Coorong over Mundoo and/or Tauwitchere Barrages. The volume of saltwater required is dependent on the volume of freshwater inflows from the River Murray.

2 Background

2.1 The Lower Lakes and Coorong

The Lower Lakes and Coorong Ramsar site comprises a vast area (>660 km^2) and a diverse range of habitat types (see Phillips and Muller 2006) at the terminus of the Murray-Darling River system in South Australia (Figure 1). Inflows to the lakes are primarily derived from the River Murray with some inflows from tributary streams draining the Eastern Mount Lofty Ranges (i.e. the Finniss River and Currency Creek), rainfall on the lake surface and groundwater inputs (Phillips and Muller 2006). Naturally inflows pass through Lake Alexandrina before entering the Coorong and finally the Southern Ocean via the Murray Mouth. The Coorong is a narrow (2-3 km wide) estuarine lagoon running southeast from the river mouth, parallel to the coast, for approximately 140 km.

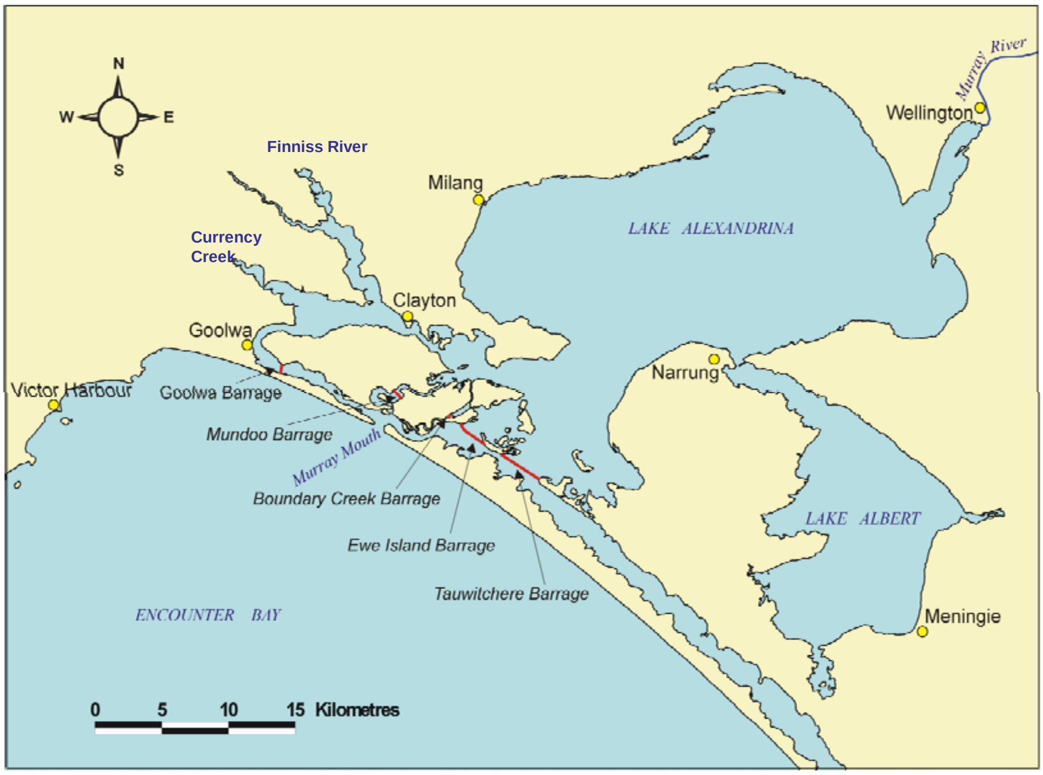

Figure 1. Map of the Lower Lakes and Coorong showing the position of the five tidal barrages.

Before large-scale water extraction in the MDB, freshwater inflows to the Lower Lakes were sufficient to maintain a freshwater environment in the lakes with minimal salt water intrusion (Sim and Muller 2004). After 1900, following significant water resource development upstream, decreased inflows resulted in an increased frequency of saltwater intrusion events (Sim and

Muller 2004). Between 1935 and 1945, five tidal barrages (at Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere) with a total length of 7.6 km, were constructed to prevent saltwater intrusion into the Lower Lakes and maintain stable freshwater storage for water extraction (Figure 1). The construction of the Murray Barrages dramatically reduced the extent of the Murray Estuary, creating an impounded freshwater environment upstream and an abrupt ecological barrier between marine and freshwater environments.

Pool level upstream of the barrages is typically regulated at *c.* 0.75 m AHD (Australian Height Datum). Freshwater is released to the Coorong via the barrages at water levels of 0.75-0.85 m AHD and water flows over wetland areas on islands (e.g. Hindmarsh and Mundoo) in the transition zone between Lake Alexandrina and the Coorong, around the barrages at water levels >0.85 m AHD. Water level in Lake Alexandrina is highly dynamic with wind seiche (short-term changes in water level due to wind stress) potentially influencing daily water level immediately upstream of the barrages by up to 0.5 m.

2.2 Current water levels and threats

With river regulation and increased extraction since barrage construction approximately 75% of mean flows in the MDB are abstracted for consumptive use (Jenson *et al.* 2000). As such, less than a third of average natural inflows now reach the Lower Lakes. When combined with the recent drought conditions experienced throughout the MDB, flows to South Australia and over Lock and Weir 1 (Blanchetown) have been below the post-regulation average for the last three years. Water levels in the Lower Lakes have receded and freshwater has not been released to the Coorong since March 2007.

Water levels in the Lower Lakes are currently the lowest on record (Figure 2) and predictions suggest inflows will remain below average and water levels are likely to continue receding (Figure 3). Decreased water level has already had a significant impact on the Lower Lakes ecosystem, particularly due to the loss of important wetland habitats on Hindmarsh and Mundoo Islands (at water levels < 0.3 m AHD) and extensive disconnection of the lake from edge habitats.

Perhaps the most alarming affect of lake level recession has been the exposure of ASS. ASS form naturally in waterlogged areas where large amounts of sulfate are present in surface and/or ground water together with large amounts of organic matter (Fitzpatrick *et al.* 2008). When such soils are exposed to oxygen, sulfuric acid is formed and mobilised together with various heavy metals. Thus, ASS may have serious impacts on water quality including acidification, mobilisation of heavy metals, anoxia and the production of noxious gases (Fitzpatrick *et al.* 2008). Such dramatic changes to water quality may have catastrophic impacts on the biota of the Lower Lakes and may also lead to the contamination of water supplies for stock, irrigation and human consumption. In other parts of Australia the drainage of ASS and resultant acidification of water have also been implicated in several large fish kills (Brown *et al.* 1983; Dawson 2002).

Due to the immediate risk posed by ASS, Lake Albert was disconnected from Lake Alexandrina in early 2008 and water was pumped into Lake Albert (*c.* 200 GL/year) to maintain water levels above critical trigger levels (-0.4 m AHD) to avoid acidification. With further receding water levels in Lake Alexandrina, pumping to Lake Albert ceased in June 2009. It has been suggested that a water level of -1.5 m AHD in Lake Alexandrina represents a critical trigger level for acidification. Given predictions of further receding water levels in Lake Alexandrina, active management of this system to maintain water levels above -1.5 m AHD appears necessary.

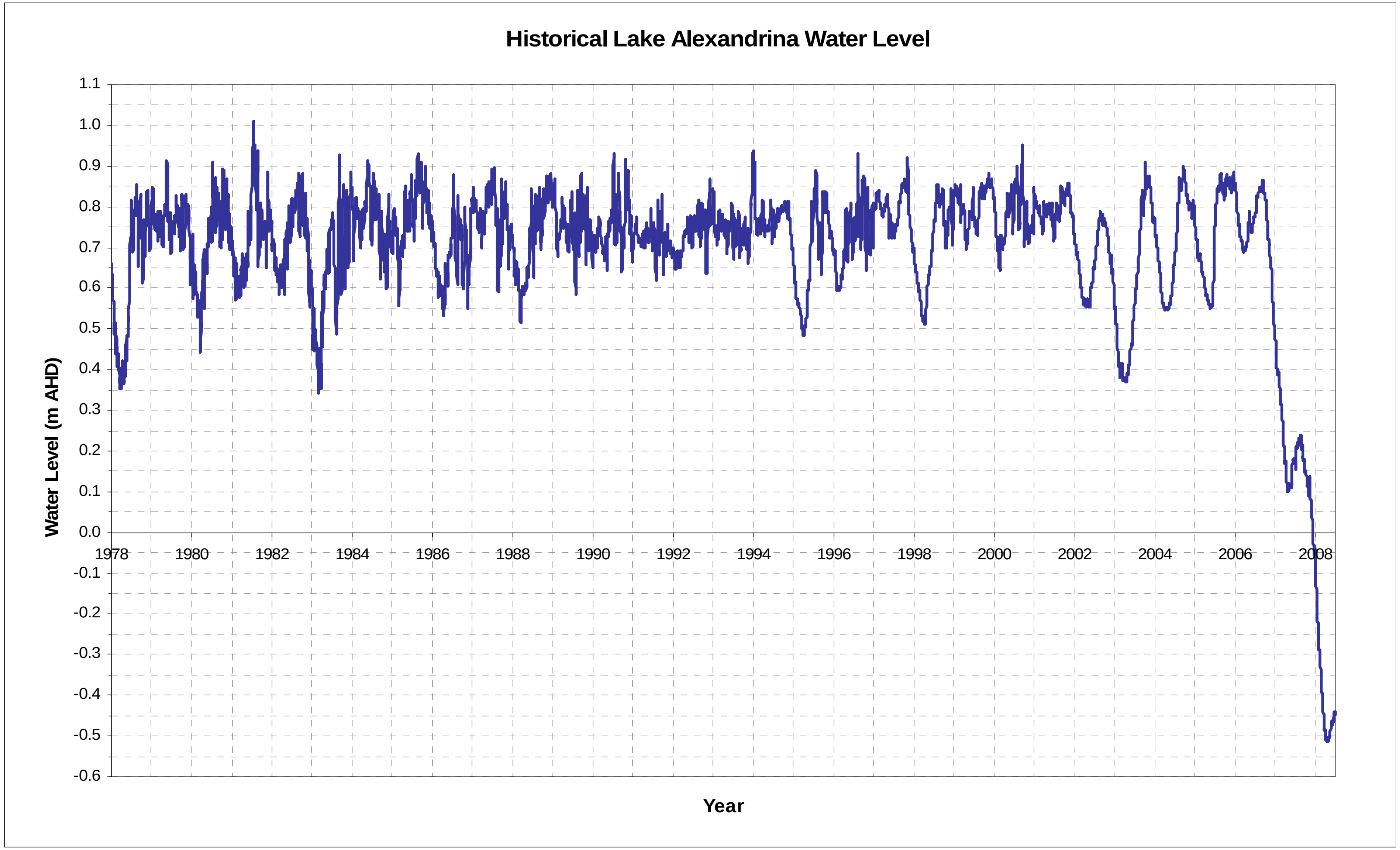

Figure 2. Water level in Lake Alexandrina between 1978 and June 2008. Graph provided by the Department of Water Land and Biodiversity Conservation (DWLBC).

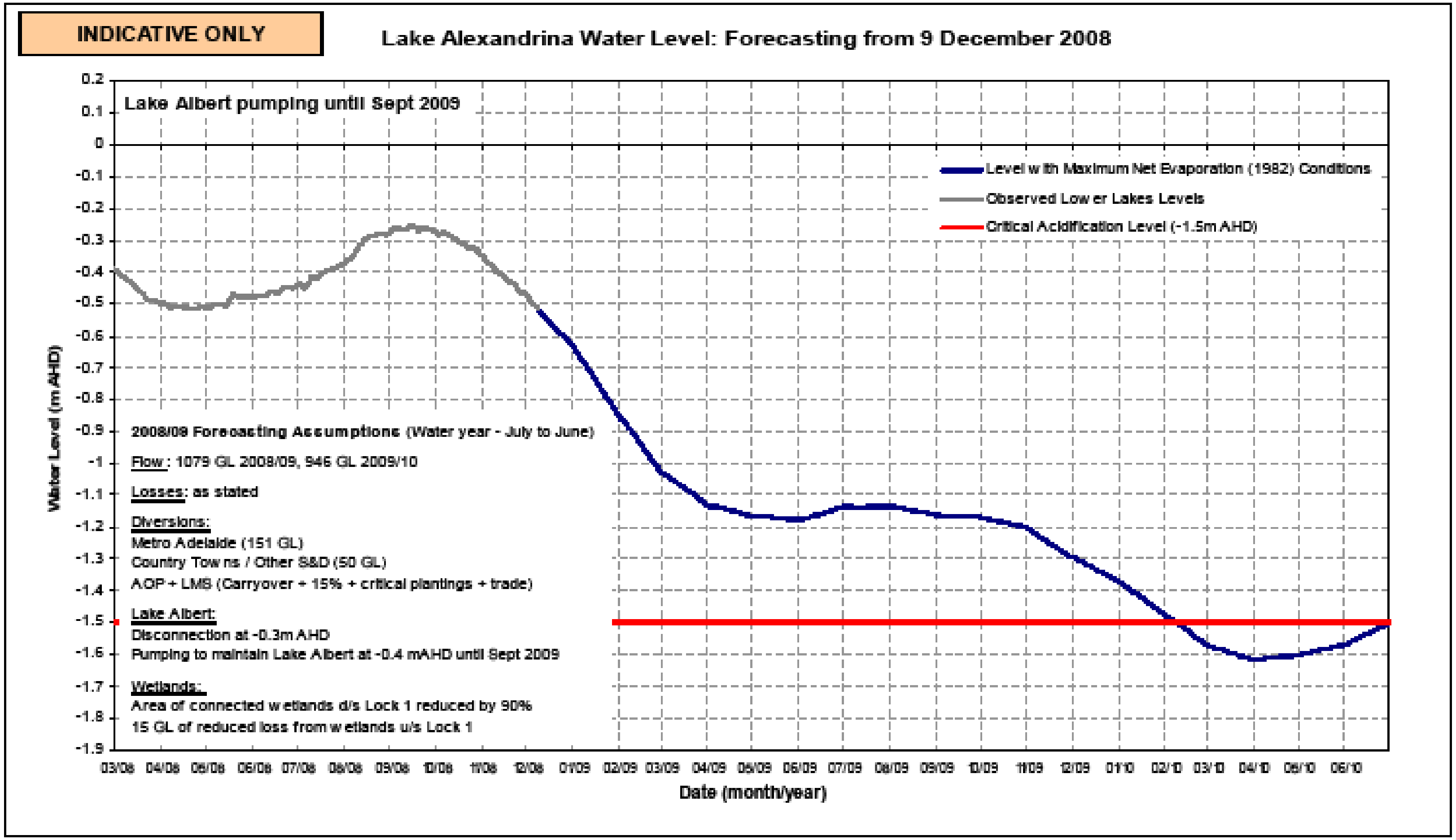

Figure 3. Predicted water levels in Lake Alexandrina through 2009 and the beginning of 2010. Assumptions of flow, salinity of inflowing water, water losses, diversions and critical acidification level are indicated. Graph provided by DWLBC.

2.3 Management Options

Several management options have been proposed to mitigate the risk of ASS exposure on the Lower Lakes ecosystem. Most scenarios involve the maintenance of water levels in Lake Alexandrina above -1.5 m AHD and for the purpose of this risk assessment we will be considering two options.

2.3.1 Option 1: Saltwater intrusion via Goolwa barrage

Based on current water level predictions, trigger levels for acidification (-1.5 m AHD) will be reached and hence saltwater intrusion commenced in October 2009. For this option saltwater from the Coorong would be allowed to 'over-top' a number of barrage gates at Goolwa Barrage (Figure 4) during high tides. Goolwa barrage consists of 123 bays with 'stop-log' configurations and the height of these bays may be manipulated by adding or removing stop logs and thus managed saltwater intrusion would be achieved by lowering the effective height (removal of stop logs) of the barrage.

The volume of saltwater released into the Lake Alexandrina is dependent upon the volume of freshwater inflows from the River Murray and Eastern Mount Lofty Ranges (EMLR) tributaries and direct rainfall and likely losses of water (WBM). Thus the volume of seawater required is equal to the total volume of water required to keep Lake Alexandrina above -1.5 m AHD minus the volume of freshwater inflows and water losses (e.g. evaporative loss, pumping to Lake Albert).

Three different regimes of freshwater inflow have been considered within this option. The Murray-Darling Basin Commission (MDBC, now the Murray-Darling Basin Authority, MDBA) has provided predictions for possible inflows over the South Australian border, which, after taking into account diversions from the river in South Australia, evaporative and seepage losses, equate to inflows into Lake Alexandrina of 350 (896 GL/year over the SA border), 250 (796) and 150 (696) GL/year (for the period June 2009 - May 2010). In the lower inflow scenarios the amount of saltwater required to maintain lake levels above critical triggers is increased. Given the annual pumping volume to Lake Albert is approximately 200 GL, freshwater inflows to Lake Alexandrina under the 150 GL scenario would be insufficient to continue pumping to Lake Albert without seawater intrusion. The most likely scenario appears to be that of 150 GL/year flow into the Lower Lakes and given the precautionary principle, this scenario will be the only one investigated as it represents the 'worst case' scenario.

If saltwater is introduced at Goolwa, it must travel some 40 km before reaching the lake proper and areas of bed elevation < 2.5 m AHD (Figure 4). An area of shallow bathymetry exists to the east of Clayton, around 20 km from Goolwa Barrage. Minimum bed level in the area is approximately -1.15 m AHD, 0.35 m above the proposed managed level (WBM). As such, it is necessary to build up water levels between Goolwa Barrage and Clayton before water may bypass this obstruction and move into the lake proper.

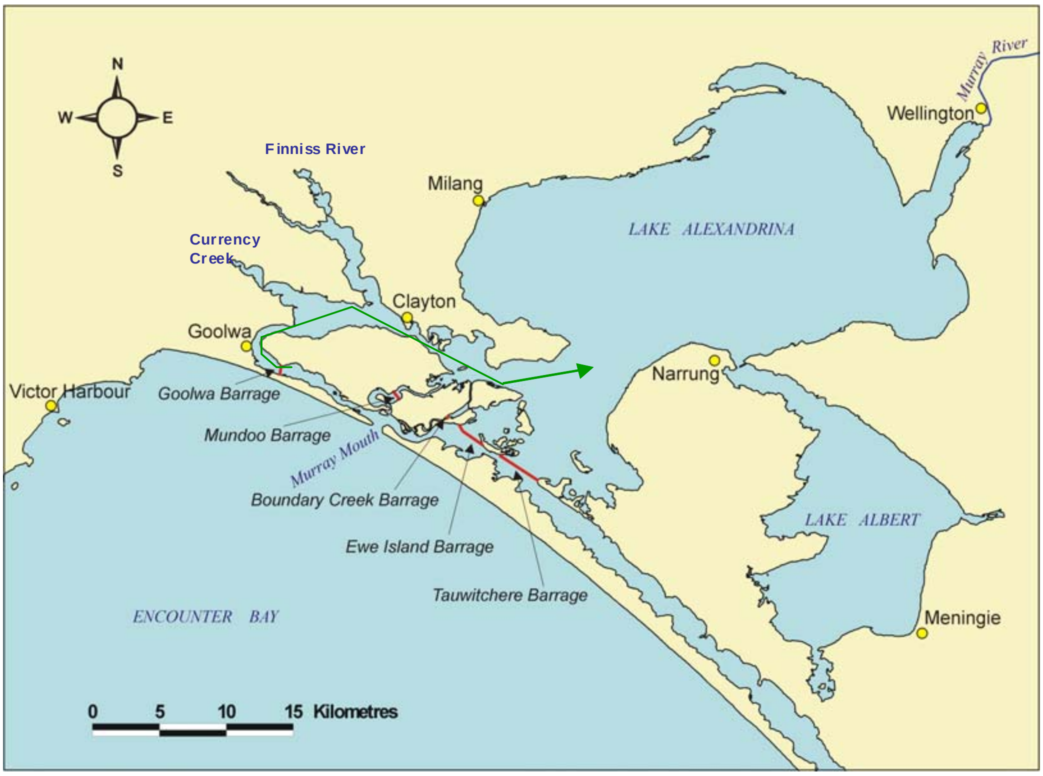

Figure 4. Map of Lower Lakes and Coorong, showing the position of the five tidal barrages and delivery pathway of saltwater to Lake Alexandrina (green arrow).

2.3.2 Option 2: Saltwater intrusion at Mundoo and/or Tauwitchere with the provision of a freshwater refuge

This option is similar to the previous one but involves the provision of a freshwater refuge area between Goolwa Barrage and a regulator near Clayton. A regulator would be built between a point on the mainland near Clayton and Hindmarsh Island (Figure 5). Freshwater would be pumped into the refuge from Lake Alexandrina or from Wellington through the new Lower Lakes pipeline, depending on the current salinity of water in Lake Alexandrina. This option aims for salinities < 1500 $\mu S.cm^{-1}$ within the refuge and therefore lake water may be too saline. With pumping, water levels within the refuge will rise to *c.* 0.3 m AHD. Freshwater inflows from the

Finniss River and Currency Creek during winter/spring should then be sufficient to raise water levels within the refuge to *c.* 0.7 m AHD. Any excess water, in the advent of high tributary inflows, would be released into Lake Alexandrina via a spillway on the Clayton regulator. Currently, there is no plan to provide fish passage on this structure or to operate the Goolwa Barrage fishway.

Following construction of the new regulator, saltwater intrusion would be managed at Mundoo and/or Tauwitchere Barrage (Figure 5). Tauwitchere Barrage has 130 bays with stop-log configurations and hence, intrusion at Tauwitchere could be managed as per Goolwa. The same is true for Mundoo but there are fewer bays. Tauwitchere Barrage is also comprised of 192 automated/remotely controlled hydraulic radial gates. Managing intrusion via these gates would allow greater control over the volume of water moving through the barrages and greater response to variations in downstream tide levels, however, there is some doubt over the operational capability of these structures.

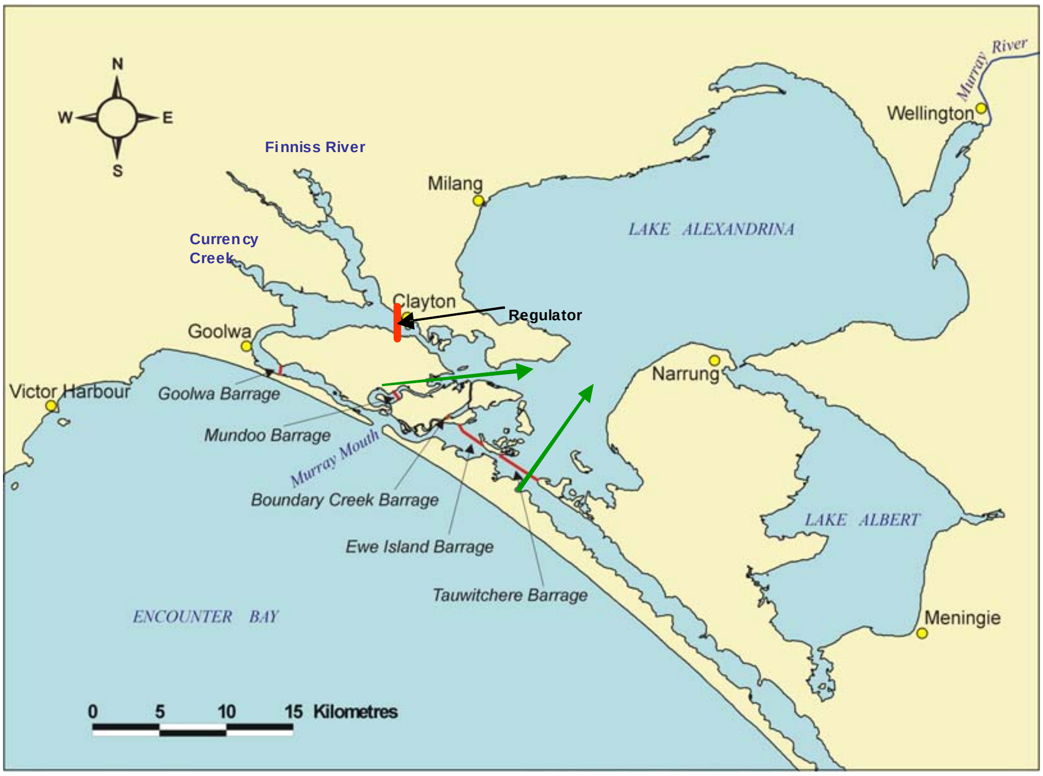

Figure 5. Map of Lower Lakes and Coorong, showing the position of the five tidal barrages, the proposed position of the new Clayton regulator and delivery pathway for saltwater (green arrows).

Similar to Goolwa, there is an area of shallow bathymetry immediately upstream of the Tauwitchere Barrage (-0.5 m AHD). The area immediately upstream of Tauwitchere Barrage will be dry before intrusion and water will spill straight onto dry sand flats. Water must 'build up' in this area before it can flow into the lake proper.

3 Fish species of the Lower Lakes and Coorong

A diverse range of fish species (43 species) have been selected for risk assessment (Table 5). These include species with varying life histories (i.e. freshwater, diadromous, estuarine and marine), size (i.e. 40mm->1000mm), origin (i.e. native verse exotic), conservation and commercial value (Table 5). The majority of freshwater and some diadromous species are common and widespread while others are known from a small number of specimens or have not been recorded in the region for many years but were included due to their rare or endangered status on a state or national scale. Estuarine and marine species were selected based on either their current residence in the Lower Lakes or potential residence in the Lake Alexandrina given the likely management options and/or commercial importance. As such, for the purpose of this project fish species are further grouped as follows;

- Freshwater species – this represents a diverse group likely to be seriously impacted by the proposed management options and therefore these species are grouped further,
  - Large-bodied native freshwater species
    - Native species with average adult length >150mm that complete their lifecycle wholly within freshwater environments.
  - Common small-bodied native freshwater species
    - Native species with average adult length <150mm that complete their lifecycle wholly within freshwater environments and are considered common in the South Australian MDB and specifically the Lower Lakes region.
  - Rare and endangered small-bodied native freshwater species
    - Native species with average adult length <150mm that complete their lifecycle wholly within freshwater environments and are considered rare in the South Australian MDB and specifically the Lower Lakes region or possess a state or national conservation status.
  - Exotic freshwater species
    - Introduced species that complete their lifecycle within freshwater environments.
- Diadromous species
  - Species that require movement between freshwater and estuarine/marine environments in order to complete their life cycle. This includes both catadromous (adult freshwater residence, downstream spawning migration of adults, estuarine/marine spawning, upstream migration of juvenile fish) and

anadromous species (adult marine residence, upstream spawning migration of adults, freshwater spawning, downstream migration of juveniles).

- Estuarine species
    - Estuarine resident species that generally complete their lifecycle within estuaries. This includes several commercially important species.
- Marine species
    - Species often present in estuaries but may complete their lifecycle in coastal marine waters. This includes commercially important species.

Table 5. Selected species of the Lower Lakes and Coorong. Fish are 'grouped' as follows: L-Large-bodied native freshwater species, SC-Common small-bodied native freshwater species, SR-Rare or endangered small-bodied native freshwater species, EX-Exotic freshwater species, D-Diadromous species, ES-Estuarine species and M-Marine species. The status of each species is indicated, as is their distribution in the Lower Lakes and Coorong.

Species	Scientific name	Grouping	Status*	Lower Lakes and Coorong distribution	Source
Silver perch	*Bidyanus bidyanus*	L	PROT [VU]	Rare in the Lower Lakes. Once widespread. Little recent data	1
Golden perch	*Macquaria ambigua*	L		Widespread in Lower Lakes	1
Murray cod	*Macquaria peelii peelii*	L	[R] VU	Rare in Lower Lakes. Once widespread. Little recent data	1
Bony herring	*Nematalosa erebi*	L		Very common and widespread	1, 4, 6, 12, 15
Eel-tailed catfish	*Tandanus tandanus*	L	PROT [VU]	Rare in the Lower Lakes. Last collected near Pomanda Point	11
River blackfish	*Gadopsis marmoratus*	L	PROT [EN]	Recorded in the upper reaches of tributaries that enter Lake Alexandrina	5
Carp gudgeon complex	*Hypseleotris* spp.	SC		Uncommon but widespread	4, 10
Flat-headed gudgeon	*Philypnodon grandiceps*	SC	[R]	Very common and widespread	4, 8, 10
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	SC	[R]	Moderately common and widespread	2, 4, 6, 8
Australian smelt	*Retropinna semoni*	SC		Very common and widespread	4, 6, 8, 12
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	SC	[R]	Moderately common and widespread	4, 6, 8, 12
Murray hardyhead	*Craterocephalus fluviatilis*	SR	[EN] VU	Declining, primarily distributed around Hindmarsh Island, Goolwa channel, Clayton and Milang Bay. Formerly locally abundant	4, 8, 12, 15
Mountain galaxias	*Galaxias olidus*	SR	[VU]	One record from the Lower Lakes (1928). Present in the upper reaches of tributaries.	4
Murray rainbowfish	*Melanotaenia fluviatilis*	SR	[R]	Rare. Last record in Lower Lakes proper from 1986. Still found in main channel at Wellington	2, 15
Southern purple-spotted gudgeon	*Mogurnda aspersa*	SR	PROT [EN]	No records for many years	
Southern pygmy perch	*Nannoperca australis*	SR	PROT [EN]	Formerly abundant in Hindmarsh Island area. Declining, likely restricted to remaining irrigation drains on Mundoo Island and near Milang. Populations remain in upper reaches of tributaries	4, 7, 8, 12
Yarra pygmy perch	*Nannoperca obscura*	SR	PROT [EN] VU	Declining with possible local extinctions already witnessed. Formerly common in Hindmarsh Island area, has not been collected since 2007. Possibly some fish persisting in remaining irrigation drains on Mundoo Island, if present at all. Represents the only population of this species in the MDB (captive population being held for later re-introduction).	4, 7, 8, 12, 14
Goldfish	*Carassius auratus*	E		Common, widespread but patchy	4, 15
Common carp	*Cyprinus carpio*	E		Very common and widespread	1, 4, 15
Tench	*Tinca tinca*	E		Not recorded in lakes proper, but recorded at the Bremer River mouth and found in upper reaches of some tributary streams	9, 10, 15
Rainbow trout	*Oncorhynchus mykiss*	E		Not typically found in the Lakes but found in upper reaches of some tributary streams where it is stocked	9, 10
Brown trout	*Salmo trutta*	E		Not typically found in the Lakes but found in upper reaches of some tributary streams where it is stocked	9, 10
Eastern gambusia	*Gambusia holbrooki*	E		Very common and widespread	4, 6, 8, 12
Redfin perch	*Perca fluviatilis*	E		Very common and widespread	4, 6, 8, 12

Table 5 continued.

Species	Scientific name	Grouping	Status*	Lower Lakes and Coorong distribution	Source
Pouched lamprey	*Geotria australis*	D	[EN]	Rare. Record from 2006 entering the Lakes	13
Short-headed lamprey	*Mordacia mordax*	D	[EN]	Rare. Records from 2006/07 entering the Lakes. Downstream migrant recorded in 2008 (Goolwa)	13, 15
Climbing galaxias	*Galaxias brevipinnis*	D	[R]	Single record from the upper reaches of a tributary	9
Common galaxias	*Galaxias maculatus*	D		Very common and widespread	4, 6, 7, 8, 12
Short-finned eel	*Anguilla australis*	D	[R]	Recent (2008) record in Goolwa channel. SA museum specimens from Lake Alexandrina fringes	9, 15
Estuary perch	*Macquaria colonorum*	D	[EN]	Very few records. Formerly common before construction of barrages	3, 4, 10
Congolli	*Pseudaphritis urvillii*	D	[R]	Moderately common and widespread. Thousands of juveniles were witnessed migrating into lakes in 2006/07. Abundance and distribution have declined since construction of barrages	4, 6, 7, 8, 12, 13
Flat-tailed mullet	*Liza argentea*	ES		Rare in Lower Lakes, common in Coorong. Recent records from around Tauwitchere and Goolwa	13
Yellow-eyed mullet	*Aldrichetta forsteri*	ES		Rare in Lower Lakes, common in Coorong. Supports a commercial fishery. Recent records in Lower Lakes from around Tauwitchere, Goolwa and Hunters creek	8, 13
River garfish	*Hyporhamphus regularis*	ES		Rare in Lower Lakes, common in Coorong. Record from Hunters creek	8
Black bream	*Acanthopagrus butcheri*	ES		Very rare in Lower Lakes, moderately common in Coorong. Supports commercial fishery. Some commercial catches of this species in the Lower Lakes. Also been recorded moving into the barrage fishways	1, 13
Bridled goby	*Arenogobius bifrenatus*	ES		Moderately common, restricted distribution in Lower Lakes, common in Coorong. Generally found close to the barrages in the Lower Lakes	8, 12, 13
Tamar goby	*Afurcagobius tamarensis*	ES		Common in the Coorong. Moderately common and patchily distributed in the Lower Lakes	4, 8, 12, 13
Bluespot goby	*Pseudogobius olorum*	ES		Common in Coorong and Lower Lakes, widely distributed	4, 8, 12, 13
Lagoon goby	*Tasmanobius lasti*	ES		Common in Coorong and Lower Lakes, widely distributed	4, 8, 12, 13
Greenback flounder	*Rhombosolea tapirina*	ES		Common in Coorong. Supports a commercial fishery. Rare in Lower Lakes, records from Hunters creek and upstream of Tauwitchere barrage	7, 13
Small-mouthed hardyhead	*Atherinosoma microstoma*	ES		Very common in Coorong and Lower Lakes. Widely distributed	4, 8, 13
Mulloway	*Argyrosomus japonicus*	M		Very rare in Lower Lakes, moderately common in Coorong. Supports commercial fishery. Some commercial catches of this species in the Lower Lakes. Also been recorded moving into the barrage fishways	1, 13
Sea mullet	*Mugil cephalus*	M		Rare in Coorong	1

Literature sources coded as: 1-SARDI Unpublished CPUE Lakes and Coorong data, 2-(Lloyd and Walker 1986), 3-(Eckert and Robinson 1990), 4-(Wedderburn and Hammer 2003), 5-(Hammer 2004), 6-(Higham *et al.* 2005b), 7-(Bice and Ye 2006), 8-(Bice and Ye 2007), 9-(McNeil and Hammer 2007), 10-(Lintermans 2007), 11-(Rowntree and Hammer 2007), 12-(Bice *et al.* 2008), 13-(Jennings *et al.* 2008), 14-(Hammer 2008), 15-Other SARDI Unpublished data.

Key
PROT = protected in South Australia
R = rare, VU = vulnerable, EN = endangered
*Symbols in brackets represent state status as proposed under the *Department for Environment and Heritage 2003 Discussion Paper*, whilst symbols without brackets represent national listings.

3.1 Biology and life history of fishes of the Lower Lakes and Coorong

This section provides a summary of information on the biology, ecology and life history strategies of the selected fishes of the Lower Lakes and Coorong. Specifically knowledge of spawning (i.e. mode, egg type, sites, and timing), habitat associations of different life stages (i.e. larval, juvenile, adult) and physico-chemical tolerances (i.e. salinity at different life stages, temperature, dissolved oxygen and pH) are summarized in tabulated form for the selected species. The information presented provides the basis for constructing conceptual models on the lifecycles of selected fishes (see section 3.2). Where possible examples and sources of information directly from the Lower Lakes and Coorong region were used, but in its absence, information was summarised from other regions of South Australia and in a broader context, Australia or internationally.

It is important to consider that geographically separate populations of the same species may possess differing biological and life history characteristics and as such knowledge inferred from catchments outside of the Lower Lakes and Coorong must be considered 'hypothesized' (McNeil and Hammer 2007). However, the information presented represents the best possible summary of available information for these species.

3.1.1 Life history strategies and spawning

The selected species are primarily characterised by four general life history strategies:

- Obligate freshwater species – those that complete their lifecycle within freshwaters and were further grouped by combinations of: size (large or small, < or > 150 mm TL), status (common or rare/endangered) and origin (native/exotic),

- Diadromous species – those requiring movement between freshwater and saltwater environments. This includes anadromous, catadromous and amphidromous species (see Figure 6),

- Estuarine species – those species that are dependent upon estuarine environments and complete their lifecycles entirely within estuaries, and

- Marine species – species that may complete their lifecycles in the marine environment but commonly enter estuarine environments at some stage of their lifecycle.

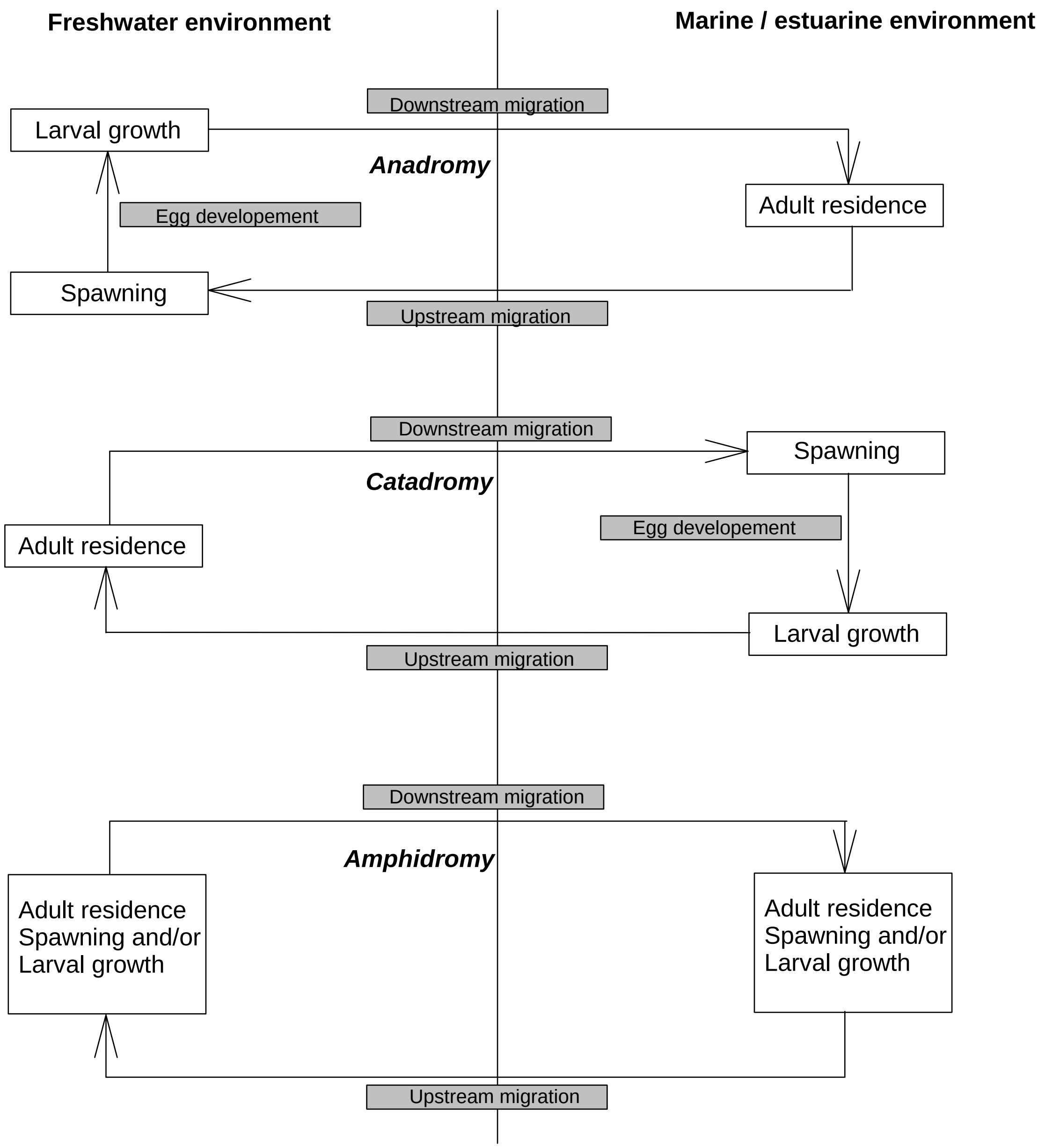

Figure 6. Schematic representation of different forms of diadromy. Amphidromous species exhibit movements between freshwater and marine/estuarine environments that are not for the purposes of reproduction.

Spawning characteristics of these species are summarized in Table 6. Specifically these include spawning mode, egg type, spawning sites/notes and spawning period:

Spawning mode - Spawning mode categories are based on spawning style, duration, development of larvae at first feeding (e.g. well developed and mobile) and the occurrence of parental care.

The development of larvae at first feeding relates to the ability of larvae to capture and ingest prey of various sizes (Humphries *et al.* 1999). These categories were primarily developed for obligate freshwater species of the MDB by Humphries *et al.* (1999) but diadromous, estuarine and marine species have tentatively been categorised as members of the mode they best represent;

- Mode 1 – Spawn once in a relatively short season; between a thousand and tens of thousands of demersal eggs, often laid into a nest; exhibit parental care; larvae well developed upon first feeding; spawning independent of flow; (e.g. Murray cod).
- Mode 2 - Spawn once when appropriate conditions occur and can delay spawning until this time; hundreds of thousands of semi-buoyant or planktonic eggs; no parental care; larvae moderately developed at time of first feeding; spawning linked to increased flow and floods; (e.g. golden perch).
- Mode 3a – Exhibit either protracted, serial or repeat spawning over an extended period; eggs usually demersal and adhesive but may be semi-buoyant or pelagic; there may be parental care; larvae typically show poor development at time of first feeding and must feed on microcrustaceans and algae; spawning independent of flow; (e.g. flat-headed gudgeon).
- Mode 3b – Similar to fishes in mode 3 but spawn only once over a shorter spawning period; (e.g. Murray rainbowfish).

Egg type – these categories are adapted from terminology used by McNeil and Hammer (2007);

- N - eggs are guarded and/or laid in nest.
- A - adhesive eggs are attached to structure or vegetation with no following parental care,
- R - demersal eggs are distributed randomly.
- P - surface drifting pelagic eggs.
- L - bear live young.

Spawning sites/notes – species specific information on fine-scale spawning habitats, spawning migrations and conditions needed for spawning and any other information relevant to spawning.

Spawning period – time of year these species are known to spawn. The information presented represents a combination of different types of data from various sources that in some way infer spawning in these species. These include actual investigations of spawning periods but also observations of 'ripe' fish and the presence of larvae as an indication of spawning.

Table 6. Lifecycle and spawning information (mode, egg type, spawning sites/notes and period) for selected fishes of the Lower Lakes and Coorong. Spawning modes as described by Humphries *et al.* (1999). Egg type: N – eggs guarded or laid in nest, A – adhesive eggs attached to structure/vegetation with no parental care, R – demersal eggs distributed randomly, P – surface drifting pelagic eggs, L – bear live young, Adapted from McNeil and Hammer (2007).

Species	Scientific name	Spawning mode	Egg type	Spawning sites/notes	Spawning period	Source
Large-bodied native freshwater species						
Silver perch	*Bidyanus bidyanus*	2	p	In riverine reaches typically migrates upstream prior to spawning. Unknown in the Lakes. Spawning activity appears to increase during floods. Semi-bouyant eggs. Spawns at water temps >23°C	Spring and summer	5, 11, 26
Golden perch	*Macquaria ambigua*	2	p	In rivers spawning is normally flow related. Spawning at water temps >20°C. Potential spawning migrations (upstream and possibly downstream). Unknown in the Lakes. Eggs are non-adhesive and semi-bouyant	Spring and summer	5, 11, 26
Murray cod	*Macquaria peelii peelii*	1	n	May undergo short spawning migrations. Spawning occurs at water temps >15°C. Eggs deposited on hard surfaces i.e. rocks, logs, etc. and are guarded by the male. Unknown in the Lakes. Flow may be important for recruitment	Spring and early summer	5, 11, 16, 24, 26
Bony herring	*Nematalosa erebi*	4	p	Spawning takes place in shallow bays in Lake Alexandrina in late spring and summer. Spawning takes place at water temps >20°C	Spring and summer	6
Eel-tailed catfish	*Tandanus tandanus*	1	n	Eggs are spawned into a nest of pebbles, gravel and other course material. Eggs are non-adhesive and settle in nest. Spawning at water temps 20-24°C. Male guards nest. Unknown in Lakes. Movements thought to only be local	Spring and summer	5, 11, 26
River blackfish	*Gadopsis marmoratus*	1	n	Eggs spawned in wood hollows, undercut banks and root masses. Spawning at water temps >16°C. Eggs are adhesive and guarded by male	Spring and early summer	5, 11, 26
Common small-bodied native freshwater species						
Carp gudgeon complex	*Hypseleotris* spp.	4	n	Adhesive eggs deposited on structure. Male guards eggs. Spawning at water temps >22°C	Spring and summer	5, 11, 26
Flat-headed gudgeon	*Philypnodon grandiceps*	3	n	Adhesive eggs deposited on structure. Male guards eggs. Spawning at water temps >18°C	Spring and summer	5, 11, 26
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	3?	n	Adhesive eggs deposited on structure. Male guards eggs. Spawning at water temps >19°C (in aquaria). Unknown in Lakes	Spring and summer	5, 11, 26
Australian smelt	*Retropinna semoni*	3	r	Adhesive eggs are distributed over structure. Water temps >11°C	Late winter - summer	5, 11, 26
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	3?	a	Adhesive eggs are attached to aquatic vegetation. Peak spawning may occur in spring at water temps >24°C. Unknown in the Lakes	Spring and summer	5, 11, 26

Table 6 continued.

Species	Scientific name	Spawning mode	Egg type	Spawning sites/notes	Spawning period	Source
Rare or endangered small-bodied native freshwater species						
Murray hardyhead	*Craterocephalus fluviatilis*	3	a	Adhesive eggs are attached to aquatic vegetation. Unknown in the Lakes	Spring and summer	5, 11, 20, 23, 26
Mountain galaxias	*Galaxias olidus*	4	a	Adhesive eggs are laid on the underside of stones and other debris	Spring and early summer	26
Murray rainbowfish	*Melanotaenia fluviatilis*	4	a	Adhesive eggs are laid onto aquatic vegetation. Spawning occurs when water temps are >20°C. Unknown in Lakes	Spring and summer	5, 11, 26
Southern purple-spotted gudgeon	*Mogurnda aspersa*	3	n	Adhesive eggs are deposited on structure. Spawning occurs at water temps 20-30°C. Male guards eggs	Summer	5, 11, 24, 26
Southern pygmy perch	*Nannoperca australis*	4	a	Eggs are scattered near/on structure, e.g. submerged vegetation. Spawning occurs at water temps >16°C	Spring and early summer	5, 11, 26
Yarra pygmy perch	*Nannoperca obscura*	4	a	Eggs are scattered near/on structure, e.g. submerged vegetation. Spawning occurs at water temps >16°C	Spring	25, 27
Exotic freshwater species						
Goldfish	*Carassius auratus*	3?	a	Adhesive eggs deposited on structure. Spawning occurs at water temps >17°C	Summer	26
Common carp	*Cyprinus carpio*	3	a	Adhesive eggs deposited on structure. Spawning occurs at water temps >17°C	Spring and summer	18, 26
Tench	*Tinca tinca*	3	a	Adhesive eggs deposited on structure. Unknown in Lakes	Spring and summer	26
Rainbow trout	*Oncorhynchus mykiss*	4	n	Slightly adhesive eggs are deposited in a gravel nest in flowing water. Prefers cool water temps	Winter and spring	26
Brown trout	*Salmo trutta*	4	n	Slightly adhesive eggs are deposited in a gravel nest in flowing water. Prefers cool water temps	Autumn and winter	26
Eastern gambusia	*Gambusia holbrooki*	?	l	Bear live young in slow-flowing areas	Spring and summer	26
Redfin perch	*Perca fluviatilis*	3	a	Eggs deposited in ribbons amongst vegetation. Spawning occurs at temperature >12°C	Spring	26, 28
Diadromous species (anadromous*, catadromous^)						
Pouched lamprey*	*Geotria australis*	4?	r	Migrate upstream in winter/spring to spawn. Spawning likely occurs in headwater streams. Unknown in the Lakes, spawning potentially further upstream	Winter and spring	5, 11, 26
Short-headed lamprey*	*Mordacia mordax*	4?	r	Migrate upstream in winter to spawn. Spawning occurs in depressions or shallow flowing habitats. Unknown in the Lakes, potentially further upstream	Winter and spring	5, 11, 26
Climbing galaxias^	*Galaxias brevipinnis*	4	a	Eggs are spawned on riparian vegetation in lower riverine reaches and develop out of the water. Self-sustaining landlocked populations also exist	Autumn and winter	5, 11, 26
Common galaxias^	*Galaxias maculatus*	4	a	Downstream migration to spawn in the lower reaches of rivers and estuaries. Eggs are deposited on riparian vegetation and develop out of the water. Juveniles then migrate upstream. Self-sustaining landlocked populations exist	Autumn	5, 11, 26
Short-finned eel^	*Anguilla australis*	?	p (?)	Migrates to the Coral Sea near New Caledonia to spawn.	-	5, 11, 26
Estuary perch^	*Macquaria colonorum*	2?	p	Migrates to estuarine reaches spawning when water temps are 14-19°C. Eggs are non-adhesive and semi-buoyant. Unknown in Lakes and Coorong	Winter	5, 11, 26
Congolli^	*Pseudaphritis urvillii*		r?	Downstream migration to spawn in estuarine/marine reaches although, specific spawning information is unknown. Possible spatial segregation of sexes (females upstream, males downstream). Juveniles then migrate upstream	Autumn and winter	2, 26, 29

Table 6 continued.

Species	Scientific name	Spawning mode	Egg type	Spawning sites/notes	Spawning period	Source
Estuarine species						
Flat-tailed mullet	*Liza argentea*	4?	p (?)	Likely the same as other mullets	??	
Yellow-eyed mullet	*Aldrichetta forsteri*	4	p	Spawning occurs in the Coorong, specific sites unknown	Summer and early autumn	21
River garfish	*Hyporhamphus regularis*	3	r	In NSW, lay eggs with filaments to allow attachment to vegetation	Winter and spring/summer	10, 22
Black bream	*Acanthopagrus butcheri*	3	p	Spawning occurs in the Coorong, more specifically suggested near the Murray Mouth. Literature on water temps vary but all are >15°C. Eggs are pelagic but buoyancy depends on salinity at spawning site and as such may settle out of suspension. Considerable variation in literature about salinities during spawning and importance of freshwater inflows. 20-25,000 mg/L in Hopkins estuary, Vic.	Spring/summer/autumn	4, 12, 13, 15, 17
Bridled goby	*Arenogobius bifrenatus*	3	n	Adhesive eggs attached to substrate or in burrows. Guarded by male	Spring and summer	3, 11, 12
Tamar goby	*Afurcagobius tamarensis*	3	n (?)	Spawning information limited. Possible guarding of eggs by male, common in gobies	Spring	12, 26
Bluespot goby	*Pseudogobius olorum*	3	n	Spawns in upper reaches of estuaries and possibly freshwater. Eggs deposited in vegetation and male guards eggs. Unknown in Lakes and Coorong	Spring	9, 26
Lagoon goby	*Tasmanobius lasti*	?	n (?)	Very little known, however likely guarding of eggs by male as in other goby species	Spring(?)	26
Greenback flounder	*Rhombosolea tapirina*	3	p	Spawns in the Coorong. Some authors suggest at water temps <13°C. Eggs buoyant and pelagic	Autumn and winter	1, 14
Small-mouthed hardyhead	*Atherinosoma microstoma*	3	a	Spawns in Lower Lakes and Coorong. Adhesive eggs attached to submerged surfaces	Spring and early summer	8
Marine species						
Mulloway	*Argyrosomus japonicus*	?	p (?)	Likely spawns outside of Coorong, although actual locations are not known, possibly on ocean beaches (aggregations of adults in spring/summer suggest perhaps at the Murray mouth?). Coorong represents a nursery area for juvenile fish. Highly mobile	Spring and summer (?)	18
Sea mullet	*Mugil cephalus*	3	p	Likely spawn in the ocean outside of the Coorong	winter	7, 11

Literature sources are coded as follows: 1-(Kurth 1957), 2-(Hortle 1978), 3-(Cadwallader and Backhouse 1983), 4-(Hall 1984), 5-(Koehn and O'Connor 1990), 6-(Puckridge and Walker 1990), 7-(Whitfield 1990), 8-(Molsher *et al.* 1994), 9-(Neira and Potter 1994), 10-(Potter and Hyndes 1994), 11-(McDowall 1996), 12-(Newton 1996), 13-(Haddy and Pankhurst 1998), 14-(Barnett and Pankhurst 1999), 15-(Sarre and Potter 1999), 16-(Ye *et al.* 2000), 17-(Norriss *et al.* 2002), 18-(Ferguson and Ward 2003), 19-(Smith and Walker 2004), 20-(Ellis 2005), 21-(Higham *et al.* 2005a), 22-(Stewart *et al.* 2005), 23-(Bice and Ye 2006), 24-(Koehn and Harrington 2006), 25-(Llewellyn 2006), 26-(Lintermans 2007), 27-(McNeil and Hammer 2007), 28-(Nunn *et al.* 2007), 29-(Jennings *et al.* 2008)

3.1.2 Habitat associations

A summary of habitat associations of the selected species are presented in Table 7. Many species may be associated with different habitats at different stages of their lifecycle and therefore habitat associations for larvae, juveniles and adults are presented where possible. This is of particular importance for diadromous species for which different life stages reside in environments with differing physical and physico-chemical characteristics (e.g. congolli) but may also be important for obligate freshwater and estuarine species.

Scale is important when investigating habitat associations of fish (see Boys and Thoms 2006) and therefore where possible both broad and fine scale associations are presented. Targeted research on fine-scale habitat associations has not been conducted for many of the selected species although qualitative and observational information is available from a range of sources.

Table 7. Habitat associations of selected species of fish from the Lower Lakes and Coorong. Broad and fine scale habitat associations are described for larval, juvenile and adult life stages where possible.

Species	Scientific name	Habitat association			Source
		Larval	Juvenile	Adult	
Large-bodied native freshwater species					
Silver perch	*Bidyanus bidyanus*	Larvae are rarely collected. Unknown in Lakes	Likely the same as adults	Lowland, turbid and slow-flowing riverine reaches. Specific habitat pref unknown for Lakes. Most literature from interstate	29
Golden perch	*Macquaria ambigua*	Larvae are rarely collected. Drift downstream with current. Collected in main channel, anabranches, and weir pools	Similar to adults, associated with structure and river edges	Typically lowland, turbid and slow-flowing riverine reaches. Often associated with structure, possibly deeper holes and rocky areas in lakes	1, 6, 13, 25, 27, 29, 33,
Murray cod	*Macquaria peelii peelii*	Usually found in fast-flowing habitats. Unknown in Lakes	Likely reflects adult habitat	Prefer habitat with instream cover such as rocks, snags and undercut banks. Deep holes. Unknown in Lakes, possibly deeper holes and rocky areas	17, 25, 29
Bony herring	*Nematalosa erebi*	Found in a variety of environments	Same as adults	Found in a variety of habitats. Open water	7, 25, 30, 33
Eel-tailed catfish	*Tandanus tandanus*	Rarely collected. The main channel in the Murray. Unknown in Lakes	Likely same as adults	Slow-flowing turbid streams and lake habitats, often with fringing vegetation. Benthic species	6, 29
River blackfish	*Gadopsis marmoratus*	Burrowed into leaf litter substrate, silt/detrital substrate	Deep permanent pools, cool flowing water, fringing macrophytes	Stream habitats with good instream cover, vegetation, etc.	6, 29, 30
Common small-bodied native freshwater species					
Carp gudgeon complex	*Hypseleotris* spp.	Main channel, shallow ponds, weir pools, anabranches	Same as adults	Slow-flowing and still water habitats, wetlands. Normally associated with macrophytes beds and other aquatic vegetation	18, 25, 29, 33
Flat-headed gudgeon	*Philypnodon grandiceps*	Main channel, weir pools, anabranches	Same as adults	Variable. Benthic species normally in slow-flowing areas of streams, lakes and dams. Often found on muddy substrates with abundant cover, i.e. rocks, logs, vegetation	25, 28, 29, 33
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Unknown	Likely same as adults	Typically in calm waters on muddy and weedy substrates with abundant cover, i.e. rocks, logs, vegetation	28, 29
Australian smelt	*Retropinna semoni*	Main channel, shallow ponds, weir pools, anabranches	Same as adults	Various slow-flowing or still-water habitats including main channel, lakes, weir pools and wetlands. pelagic	18, 25, 28, 29, 33
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Main channel, weir pools, anabranches	Same as adults	Littoral habitats of slow-flowing rivers, lakes, wetlands, etc. Often associated with aquatic vegetation	25, 29, 33

Table 7 continued.

Species	Scientific name	Habitat association			Source
		Larval	Juvenile	Adult	
Rare or endangered small-bodied native freshwater species					
Murray hardyhead	*Craterocephalus fluviatilis*	Unknown	Likely same as adults	Margins of lakes, wetlands and billabongs. Slow-flowing. Typically associated with aquatic vegetation, often irrigation drains in the Lower Lakes although now more common at more open sites	26, 28, 29, 31
Mountain galaxias	*Galaxias olidus*	Unknown	Likely same as adults	Generally shallow flowing areas with structural heterogeneity	30
Murray rainbowfish	*Melanotaenia fluviatilis*	Various, weir pools, ponds and fast creeks	Likely same as adults	Slow-flowing rivers, streams and wetlands. Often aquatic vegetation	18, 29
Southern purple-spotted gudgeon	*Mogurnda aspersa*	Unknown	Likely same as adults	Benthic species normally in slow-flowing areas of streams, wetlands and billabongs. Often found in areas with abundant cover, i.e. rocks, logs, vegetation	29
Southern pygmy perch	*Nannoperca australis*	Open water and submerged veg in Tasmania. Likely submerged vegetation in the Lakes	Similar to adults. Shallows amongst vegetation	Typically off-channel habitats i.e. wetlands, small creeks and irrigation drains in the Lower Lakes. Highly asoociated with in-stream structure most importantly vegetation but also fine woody debris and rocks	14, 19, 21, 22, 26, 28, 30
Yarra pygmy perch	*Nannoperca obscura*	Unknown. Likely submerged vegetation in the Lakes	Similar to adults. Shallows amongst vegetation	Typically off-channel habitats i.e. wetlands, small creeks and irrigation drains in the Lower Lakes. Highly associated with in-stream structure most importantly vegetation	19, 21, 26, 28, 30, 34

Table 7 continued.

Species	Scientific name	Habitat association			Source
		Larval	Juvenile	Adult	
Exotic freshwater species					
Goldfish	*Carassius auratus*	Unknown	Likely same as adults	Slow-flowing rivers, streams and wetlands. Normally in association with aquatic vegetation	29
Common carp	*Cyprinus carpio*	Wetlands and floodplain habitats	Wetlands and floodplain habitats	Variable. Slow-flowing turbid rivers, streams, wetlands and Lakes. In open water and in association with aquatic vegetation in the Lower Lakes	29, 30, 36
Tench	*Tinca tinca*	Unknown	Likely same as adults	Slow-flowing or still waters often on muddy substrate in association with aquatic vegetation. Deep holes in tributaries of Lower Lakes	5, 15, 29, 30
Rainbow trout	*Oncorhynchus mykiss*	Unknown	Deep, permanently flowing pools with cool oxygenated water	Deep, permanently flowing pools with cool oxygenated water	15, 29, 30
Brown trout	*Salmo trutta*	Unknown	Deep, permanently flowing pools with cool oxygenated water	Deep, permanently flowing pools with cool oxygenated water	15, 29, 30
Eastern gambusia	*Gambusia holbrooki*	Likely same as adults	Same as adults	Still and slow-flowing habitats, often in littoral zone. Often associated with vegetation commonly in off-channel habitats, i.e. irrigation drains	15, 28, 29, 30
Redfin perch	*Perca fluviatilis*	Likely in association with vegetation	Likely same as adults	Slow-flowing habitats i.e. Lake, billiabongs etc. In Lakes often found in higher abundances in 'outside' i.e. lake habitat. Often with structure e.g. vegetation	15, 28, 29, 30

Table 7 continued.

Species	Scientific name	Habitat association			Source
		Larval	Juvenile	Adult	
Diadromous species					
Pouched lamprey	*Geotria australis*		Ammocoete: soft substrates i.e. mud and silt. Potentially in slow-flowing waters? Prefers shady areas	Most of adult life spent in marine environment. Little known in freshwater apart from upstream spawning migration	6, 15, 29, 30
Short-headed lamprey	*Mordacia mordax*		Ammocoete: soft substrates i.e. mud, sand and silt. Slow-flowing waters near stream edge	Most of adult life spent in marine environment. Little known in freshwater apart from upstream spawning migration	6, 15, 29, 30
Climbing galaxias	*Galaxias brevipinnis*	Has pelagic marine larvae or lentic larvae depending on life-history of given population (i.e. land-locked?)	Likely similar to adults	Generally inhabits clear flowing streams in forested areas, around aquatic vegetation	15, 30
Common galaxias	*Galaxias maculatus*	Has pelagic marine larvae or lentic larvae depending on life-history of given population (i.e. land-locked?). Typically catadromous in Lakes but possible recruitment in the Lakes in 07/08	Juveniles migrate upstream from estuary. In freshwater likely similar to adults	Generalist, found in a variety of habitats in the Lower Lakes. Typically slow flowing or still waters, streams and lake margins	28, 29, 35
Short-finned eel	*Anguilla australis*	Ocean	Lower reaches of rivers/estuaries. Found in sediments	Rivers lakes and swamps in slow flow or still waters. Last recorded in open water /lake habitat in the Lower Lakes	6, 29, 36
Estuary perch	*Macquaria colonorum*	Ocean and estuaries?	Likely similar to adults	Typically in tidal influenced estuarine waters but will penetrate into freshwaters. Associated with structure	6, 29
Congolli	*Pseudaphritis urvillii*	Estuary, specific habitats unknown	Typically found in estuaries before migrating into freshwater	Terminal wetlands and lowland streams. Off-channel and main channel habitats in the Lower Lakes. Often with structure but also on sandy and mud substrates	2, 28, 29, 30

Table 7 continued.

Species	Scientific name	Habitat association			Source
		Larval	Juvenile	Adult	
Estuarine species					
Flat-tailed mullet	*Liza argentea*	Unknown. Estuary and ocean?	Same as adult although likely more common around structure, i.e. shallow reef, and shallow sandy beaches	Pelagic, estuary. Show a preference for deeper channels and gutters than juveniles	15, 35
Yellow-eyed mullet	*Aldrichetta forsteri*	Estuary and ocean?	Same as adult although likely more common around structure, i.e. shallow reef, and shallow beaches	Pelagic, estuary. Show a preference for deeper channels and gutters than juveniles	23, 35
River garfish	*Hyporhamphus regularis*	Unknown	Likely same as adults	Estuaries. Typically associated with sea grass beds	24
Black bream	*Acanthopagrus butcheri*	Planktonic in estuary prior to settlement in littoral zones	Likely similar to adults. Although probably more common in shallow habitats with complex structure, i.e. reef	Estuaries, lower reaches of rivers and tidal lakes. Deep pools/holes/channels containing hard substrates and complex structure	4, 9, 16, 36
Bridled goby	*Arenogobius bifrenatus*	Estuary, specific habitat unknown	Likely similar to adults	Mud and sandy substrates in estuaries and freshwater where it seeks shelter in burrows. Also structurally complex habitat	15, 36
Tamar goby	*Afurcagobius tamarensis*	Estuary and possibly freshwater, specific habitat unknown	Likely similar to adults	Still or slow-flowing waters on silt or mud substrate with structure i.e. rocks, and vegetation, in both estuary and adjacent freshwaters	3, 15, 26, 32, 35, 36
Bluespot goby	*Pseudogobius olorum*	Estuary and possibly freshwater, specific habitat unknown	Likely similar to adults	Shallow areas, Muddy and rocky substrates, often with aquatic vegetation in freshwater and estuary. Has been associated with sheltered off-channel habitats in the Lakes and Coorong	3, 15, 21, 28, 30, 36
Lagoon goby	*Tasmanobius lasti*	Estuary and freshwater, specific habitat unknown	Likely similar to adults	Still or slow-flowing waters on silt or mud substrate with structure i.e. rocks, and vegetation, in both estuary and adjacent freshwaters	21, 28, 30
Greenback flounder	*Rhombosolea tapirina*	Larvae are pelagic in ocean and estuary	Inhabit more shallow areas than adults, e.g. beaches, intertidal zones	Estuary, preferring unvegetated sandy and muddy substrates	4, 8, 10, 12, 36
Small-mouthed hardyhead	*Atherinosoma microstoma*	Estuarine and freshwater, specific habitat unknown	Likley similar to adults	Typically estuarine but being euryhaline also found in abundance in the Lower Lakes. Associated with eel-grass in estuaries. Generalist, typically abundant in all habitats in the Lower Lakes	11, 15, 21, 26, 28, 32

Table 7 continued.

Species	Scientific name	Habitat association			Source
		Larval	Juvenile	Adult	
Marine species					
Mulloway	*Argyrosomus japonicus*	Likely larval development in ocean	Estuaries, hyposaline water. Typically in deep holes and gutters	Adults are typically found in nearshore surf zones in the region and occasionally enter estuaries	4, 20
Sea mullet	*Mugil cephalus*	Larval development in ocean	Likely same as adults	Pelagic in inshore areas, coastal embayments, estuaries and sometimes freshwater	15

Literature sources are coded as follows: 1-(Lake 1967), 2-(Hortle 1978), 3-(Cadwallader and Backhouse 1983), 4-(Hall 1984), 5-(Clements 1988), 6-(Koehn and O'Connor 1990), 7-(Puckridge and Walker 1990), 8-(May and Jenkins 1992), 9-(Kailola *et al.* 1993), 10-(Connolly 1994), 11-(Molsher *et al.* 1994), 12-(Edgar and Shaw 1995), 13-(Gehrke *et al.* 1995), 14-(Humphries 1995), 15-(McDowall 1996), 16-(Willis *et al.* 1999), 17-(Humphries *et al.* 2002), 18-(Meredith *et al.* 2002), 19-(Woodward and Malone 2002), 20-(Ferguson and Ward 2003), 21-(Wedderburn and Hammer 2003), 22-(Hammer 2005), 23-(Higham *et al.* 2005a), 24-(Stewart *et al.* 2005), 25-(Zampatti *et al.* 2005), 26-(Bice and Ye 2006), 27-(Boys and Thoms 2006), 28-(Bice and Ye 2007), 29-(Lintermans 2007), 30-(McNeil and Hammer 2007), 31-(Wedderburn *et al.* 2007), 32-(Bice *et al.* 2008), 33-(Cheshire and Ye 2008), 34-(Hammer 2008), 35-(Jennings *et al.* 2008), 36-SARDI Unpublished data.

3.1.3 Water quality tolerance

Water quality can greatly influence the structure and composition of fish assemblages. Influences on populations are primarily driven by the physiological response different species exhibit to different water quality variables and the tolerance of these species to extremes (SKM 2003). Simply, fish must tolerate the general physical and chemical conditions of a given water body in order to persist.

Interannual flow variability in the MDB is extremely high (Walker 1986; Puckridge *et al.* 1998) and many native species have evolved within a highly variable environment in terms of water quality conditions. As such, many native freshwater species appear to be moderately-highly tolerant of a range of water quality conditions (Lintermans 2007; McNeil and Closs 2007). Also, the majority of fish species in the MDB are derived from relatively recent marine ancestors and consequently have retained moderate-high salinity tolerance (Hart *et al.* 1991; Clunie *et al.* 2002).

Information on the tolerance of given species to particular variables (i.e. salinity, temperature, dissolved oxygen, pH) provides insight on factors potentially affecting fish assemblage structure and may assist in predicting fish response and assessing the impacts of drought or management interventions (i.e. salt water intrusion). Laboratory based trials to elucidate species tolerances to certain variables are invaluable and generally provide information of the tolerance of given species up to lethal limits. However, prior to lethal levels being reached different water quality variables may have a range of sub-lethal impacts on fish, such as increased risk of infection, reduction in available habitat (e.g. due to vegetation loss) and decreased growth rates or reproductive success, but this has received little attention in Australia.

The influence of water quality on a certain species may also vary throughout its lifecycle. Different life stages of fish (i.e. egg, larval, juvenile, adult) often possess varying physiological tolerances and abilities to avoid unfavourable conditions through movement, and as such, some life stages are more vulnerable to poor conditions. The water quality tolerances of selected fishes from the Lower Lakes and Coorong (where available) are summarised in Table 8. Great focus is placed upon species' tolerances to salinity at different life stages (i.e. egg, larvae, juvenile and adult), whilst also considering tolerances to temperature and dissolved oxygen.

Spatial differences in salinity have been shown to greatly influence fish assemblages (Echelle *et al.* 1972; Gill and Potter 1993; Wedderburn *et al.* 2008). Differing salinity may directly affect metabolism by impacting osmoregulation and indirectly affect fish through impacts on habitat (e.g. macrophytes; Nielsen *et al.* 2003). For the purpose of this study we have primarily focused on the direct physiological impacts of salinity on fish. Species-specific salinity tolerances were mostly gleaned from reports of laboratory trials and LC50 values are presented (the salinity concentration that results in 50% mortality of test subjects over a given time) in Table 8. This is not a conservative estimate, as a 50% mortality rate represents a highly significant impact on a fish population (Clunie *et al.* 2002) and the salinity at which individuals become stressed is likely to be much lower. However, information of this type represents the best tolerance data available. Field observations of these species in the MDB at high salinities are also included. Non-lethal effects of salinity (e.g. limits to sperm motility) are presented where available but information is scant.

Temperature may also greatly influence fish assemblages (Matthews 1998). Fish, particularly small-bodied species, have internal body temperatures relative to external water temperatures and as such, drastic changes in water temperature are accompanied by severe changes in internal physiology (Crawshaw 1979). At water temperatures above tolerances proteins denature causing death. Low temperatures may impact fishes by reducing spawning cues (Preece and Jones 2002), development rates (Clarkson and Childs 2000) and the ability to capture prey and escape predation due to limited swimming ability (Walker *et al.* 2005). The tolerance information presented is a combination of laboratory trials and field observations.

Many water quality variables are not mutually exclusive but rather exhibit synergistic relationships (SKM 2003). This is true for dissolved oxygen and water temperature whereby the solubility of oxygen decreases with increasing temperature and metabolic demands also increase (Matthews 1998). Most fish avoid hypoxic waters but may tolerate periods of depleted aquatic oxygen either through physiological adaptation or behavioural mechanisms. Several native MDB species are able to survive periods of hypoxia via air surface ventilation (McNeil and Closs 2007). The information presented in Table 8 is primarily based upon laboratory trials.

The general effects of acidity (low pH) and alkalinity (high pH) on fish are well understood (Fromm 1980), yet species specific information for Australian species is scant and is not presented in Table 8. Although tolerance to decreased or elevated pH may vary between species, adults of most fish species are intolerant of pH below 5 or above 10. At low pH a fish's ability to regulate internal pH deteriorates, resulting in the inability of blood to be saturated with oxygen (Matthews 1998). However, subtle variation in pH (between pH 5-10) may lead to sub-lethal impacts such as decreased fertilisation rates (Craig and Baksi 1977), reduced egg and larval development (Von Westernhagen 1988) and may potentially represent a chemical barrier to fish movement (Kroon 2005). Nonetheless, for the purpose of this report pH below 5 or above 10 will be considered beyond the tolerance of all selected fish species.

Table 8. Physico-chemical tolerances of selected fishes from the Lower Lakes and Coorong region. Salinity tolerances of eggs, larvae and adults are presented where possible. LC50 values, the salinity concentration that results in 50% mortality of test subjects over a given time, are used where available. Observations in the MDB do not imply high tolerance but notes records of these species at given salinities. Temperature tolerance and tolerance of hypoxia are also presented where possible.

Species	Scientific name	Salinity tolerance (mg.L^{-1})			Temperature tolerance	DO/Hypoxia	Source
		egg/larval/juvenile	Adult	Observations MDB			
Large-bodied native freshwater species							
Silver perch	*Bidyanus bidyanus*	9000 LC50 (eggs) 7600 LC50 (larvae, direct) 21,000 LC50 (juvenile, slow)	13, 700 LC50 (direct) 16,000 LC50 (slow)		2-37°C	>2 mg.L^{-1}	1, 21, 32, 36, 39, 41
Golden perch	*Macquaria ambigua*	12,000 LC50 (larvae, direct) 22,400 (juvenile, slow)	14,400 LC50 (direct) 33, 000 LC50 (slow)	8030	4-37°C	2.7 mg.L^{-1} (larvae)	16, 25, 40, 42
Murray cod	*Macquaria peelii peelii*	9410 LC50	13,200 LC50 (direct) 15,700 LC50 (slow)		10-37°C		7, 16, 29, 33
Bony herring	*Nematalosa erebi*		35,000	>25,000 Estuary; Coorong	9-38°C		7, 13, 43
Eel-tailed catfish	*Tandanus tandanus*	11,400 LC50 (larvae, direct) 19,000 (juvenile, slow)	13,600 LC50 (direct) 17,800 LC50 (slow)	4660	4-38°C		1, 7, 16, 40, 42
River blackfish	*Gadopsis marmoratus*	6000 LC50	10,000	8890	5-28°C	Low	11, 13, 15, 40

Table 8 continued.

Species	Scientific name	Salinity tolerance (mg/L)			Temperature tolerance	DO/Hypoxia	Source
		egg/larval/juvenile	Adult	Observations MDB			
Common small-bodied native freshwater species							
Carp gudgeon complex	*Hypseleotris* spp.	7,600 (eggs) 6,300 LC50 (larvae, direct) 30,200 (juvenile, slow)	38,000 LC50 (direct) 50,000 LC50 (slow)	1980		Tolerant below 1 $mg.L^{-1}$ (short periods) ASR, eggs vulnerable	9, 14, 38, 42
Flat-headed gudgeon	*Philypnodon grandiceps*	21,000 (eggs) 12,300 (larvae, direct) 40,300 (juvenile, slow)	23,700 LC50 (direct) 40,000 LC50 (slow)	>25,000 estuary		Tolerant below 1 $mg.L^{-1}$ (short periods) ASR	16, 38, 42, 44
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	21,000 (eggs) 6900 LC50 (larvae, direct) 35,000 LC50 (juvenile, slow)		33,000			40, 42
Australian smelt	*Retropinna semoni*	28,000 (juvenile)	59,000 LC50 (direct)	>25,000 estuary	28°C	Moderate tolerance <2 $mg.L^{-1}$, ASR-poor	11, 14, 38, 40, 44
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*		43,700 LC50 (slow)	8800	9-36°C		3, 7, 14, 40
Rare or endangered small-bodied native freshwater species							
Murray hardyhead	*Craterocephalus fluviatilis*	≥30,000	45,900, 110,000	>35,000, Highly tolerant	10-28°C		29, 31, 37
Mountain galaxias	*Galaxias olidus*			9020	32°C		6, 37, 40
Murray rainbowfish	*Melanotaenia fluviatilis*	12,000 LC50 (fry) 33,500 LC50 (juvenile, slow)	21,100 LC50 (direct) 30,000 LC50 (slow)	2050	28°C		9, 11, 14, 40, 42
Southern purple-spotted gudgeon	*Mogurnda aspersa*	12,200 LC50 (larvae, direct) 21,000 LC50 (juvenile, slow)	17,100 LC50 (direct)		19-34°C		29, 37, 42
Southern pygmy perch	*Nannoperca australis*			<10,000	3-38°C	Tolerant below 1 $mg.L^{-1}$ (short periods) ASR	1, 3, 38
Yarra pygmy perch	*Nannoperca obscura*	6300 LC50 (larvae, direct)		3010	10-30°C		37, 40

Table 8 continued.

Species	Scientific name	Salinity tolerance (mg/L)			Temperature tolerance	DO/Hypoxia	Source
		egg/larval/juvenile	Adult	Observations MDB			
Exotic freshwater species							
Goldfish	*Carassius auratus*		13,056 LC50 (direct) 19,176 (slow)	7500		Tolerant below 1 mg.L^{-1} (short periods) ASR	10, 33, 40
Common carp	*Cyprinus carpio*	8330 (limit to sperm motility) 11,715 LC50 (juvenile, direct) 13,070 LC50 (juvenile, slow)	12,800 LC50 (direct)	7500		Tolerant below 1 mg.L^{-1} (short periods) ASR	6, 27, 33, 39, 40
Tench	*Tinca tinca*		11,600 LC50 (direct)	5000			40
Rainbow trout	*Oncorhynchus mykiss*	3000 LC50	35,000 LC50 (slow)	4500		Poor tolerance. Not found in hypoxic habitats	13, 33, 40
Brown trout	*Salmo trutta*	3000 LC50	35,000 LC50 (slow)	4000		Poor tolerance Not found in hypoxic habitats	13, 33, 40
Eastern gambusia	*Gambusia holbrooki*		17,100 LC50 (direct) 59,000 (for 30d)	19,500	44°C	Highly tolerant <1 mg.L^{-1}, efficient ASR	13, 38, 40
Redfin perch	*Perca fluviatilis*		8000 LC50 (direct)	7,500		Moderate tolerance <2 mg.L^{-1}, ASR-poor	13, 38, 40, 44
Diadromous species							
Pouched lamprey	*Geotria australis*	Ammocoetes in freshwater	marine	>25,000 Coorong			11, 41
Short-headed lamprey	*Mordacia mordax*	Ammocoetes in freshwater	marine	>25,000 Coorong			11, 41
Climbing galaxias	*Galaxias brevipinnis*		35,000	8000	<23°C		11, 13, 40
Common galaxias	*Galaxias maculatus*	49,000	45,000 LC50 (direct) 62,000 LC50 (slow)	*c.* 25,000 (adults) >25,000 (juveniles)			3, 40, 44
Short-finned eel	*Anguilla australis*		Likely highly tolerant	13,400 (vic)	Wide range	Likely tolerates low oxygen	3, 6
Estuary perch	*Macquaria colonorum*			>2000			37
Congolli	*Pseudaphritis urvillii*	98,000 LC50 (juvenile, slow 14°C) 92,000 LC50 (juvenile, slow 23°C)	Probable free movement between salt and fresh	>35,000 catches in Coorong	20°C		4, 37, 40, 42, 43

Table 8 continued.

Species	Scientific name	Salinity tolerance (mg/L)			Temperature tolerance	DO/Hypoxia	Source
		egg/larval/juvenile	Adult	Observations MDB			
Estuarine species							
Flat-tailed mullet	*Liza argentea*			>35,000 Coorong			43
Yellow-eyed mullet	*Aldrichetta forsteri*	88,000 LC50 (juvenile, slow 14°C) 86,000 LC50 (juvenile, slow 23°C)		>35,000 Coorong	14-24°C?		5, 42
River garfish	*Hyporhamphus regularis*						
Black bream	*Acanthopagrus butcheri*	10,000-35,000 (egg) 82,000 LC50 (juvenile, slow 14°C) 88,000 LC50 (juvenile, slow 23°C)		300 - >40,000 Preferred range likely 10,000 – 35,000	26°C		30, 32, 34, 42
Bridled goby	*Arenogobius bifrenatus*			34,000 (larvae) 1800 - >35,000 Coorong (juv/adult)	26°C	Highly tolerant <1 $mg.L^{-1}$ efficient ASR	12, 24, 44
Tamar goby	*Afurcagobius tamarensis*	72,000 LC50 (juvenile, slow 14°C) 70,000 LC50 (juvenile, slow 23°C)		1800 - >35,000 Coorong	23°C	Highly tolerant $mg.L^{-1}$ efficient ASR	12, 24, 42, 44
Bluespot goby	*Pseudogobius olorum*	>35,000		1800 - >35,000 Coorong	28°C	Highly tolerant $mg.L^{-1}$ efficient ASR	12, 17, 44
Lagoon goby	*Tasmanobius lasti*			1000 - >35,000 Coorong	26°C		17, 44
Greenback flounder	*Rhombosolea tapirina*	35,000-45,000 (fertilisation) 15,000-45,000 (eggs) 15,000-35,000 (juvenile)	Likely wide range	15,000- >35,000	Likely wide range		19, 22, 23
Small-mouthed hardyhead	*Atherinosoma microstoma*		Upper 108,000 LC50 (direct) Lower 3300 LC50 (direct) 2000-120,000 (slow)	Extremely wide range 100-130,000			2, 8, 20

Table 8 continued.

Species	Scientific name	Salinity tolerance (mg/L)			Temperature tolerance	DO/Hypoxia	Source
		egg/larval/juvenile	Adult	Observations MDB			
Marine species							
Mulloway	*Argyrosomus japonicus*	5000-35,000 (larvae) 63,000 LC50 (juvenile, slow, 14°C) 58,000 LC50 (juvenile, slow 23°C)		15,000-25,000 (preferred for juveniles) >35,000 Coorong	30°C		18, 28, 35, 36, 43
Sea mullet	*Mugil cephalus*	50,400 LC50 (fry, direct)		Juveniles sometimes found in freshwater			26

Literature sources are coded as follows: 1-(Lake 1967), 2-(Lui 1969), 3-(Chessman and Williams 1974), 4-(Hortle 1978), 5-(Chubb *et al.* 1981), 6-(Cadwallader and Backhouse 1983), 7-(Merrick and Schmida 1984), 8-(Potter *et al.* 1986), 9-(Williams 1987), 10-(Jasim 1988), 11-(Koehn and O'Connor 1990), 12-(Gee and Gee 1991), 13-(Hart *et al.* 1991), 14-(Williams and Williams 1991), 15-(Bacher and Garnham 1992), 16-(Jackson and Pierce 1992), 17-(Gill and Potter 1993), 18-(Gray and McDonall 1993), 19-(Kailola *et al.* 1993), 20-(Molsher *et al.* 1994), 21-(Guo *et al.* 1995), 22-(Hart and Purser 1995), 23-(Hart *et al.* 1996), 24-(Newton 1996), 25-(Rowland 1996), 26-(Hotos and Vlahos 1998), 27-(Karimov and Keyser 1998), 28-(Fielder and Bardsley 1999), 29-(O'Brien and Ryan 1999), 30-(Haddy and Pankhurst 2000), 31-(Hardie 2000), 32-(Sarre *et al.* 2000), 33-(Clunie *et al.* 2002), 34-(Partridge and Jenkins 2002), 35-(Aquaculture SA 2003), 36-(Ferguson and Ward 2003), 37-(SKM 2003), 38-(McNeil 2004), 39-(Whiterod and Walker 2006), 40-(McNeil and Hammer 2007), 41-(Jennings *et al.* 2008), 42-(McNeil and Westergaard In Prep), 43-(SARDI Unpublished CPUE Lakes and Coorong data), 44-(SARDI Unpublished data).

3.2 Conceptual models

Conceptual models have been developed to illustrate the lifecycles of the selected fishes (Figures 7-19). The models essentially depict the different life stages of fish, key processes/events (e.g. spawning, recruitment) and different environmental factors (e.g. water quality, habitat availability) that facilitate or hinder progression between life stages. Specific habitat and salinity tolerance of different life-stages have been included where known. Given predicted salinities and likely impacts on habitat due to proposed management options, these models will facilitate elucidating potential impacts (negative or positive) on fishes at different life stages.

For the development of conceptual models fish were further categorised by similarities in life-history and spawning modes described by Humphries *et al.* (1999). For example the 'large-bodied native freshwater fish' grouping was split into 3 groupings, A – Golden perch and silver perch (flow-dependent spawners; Figure 7), B – Murray cod (flow independent spawner but flow dependent recruiter?; Figure 8) and C – river black fish and catfish (flow independent spawners, nesters; Figure 10). Similarly, eastern gambusia formed a group separate to other exotic species (Figures 13 and 14) as it is a live bearer and estuarine species were further grouped based on body size (i.e. large-bodied, Figures 17 and small-bodied, Figure 18).

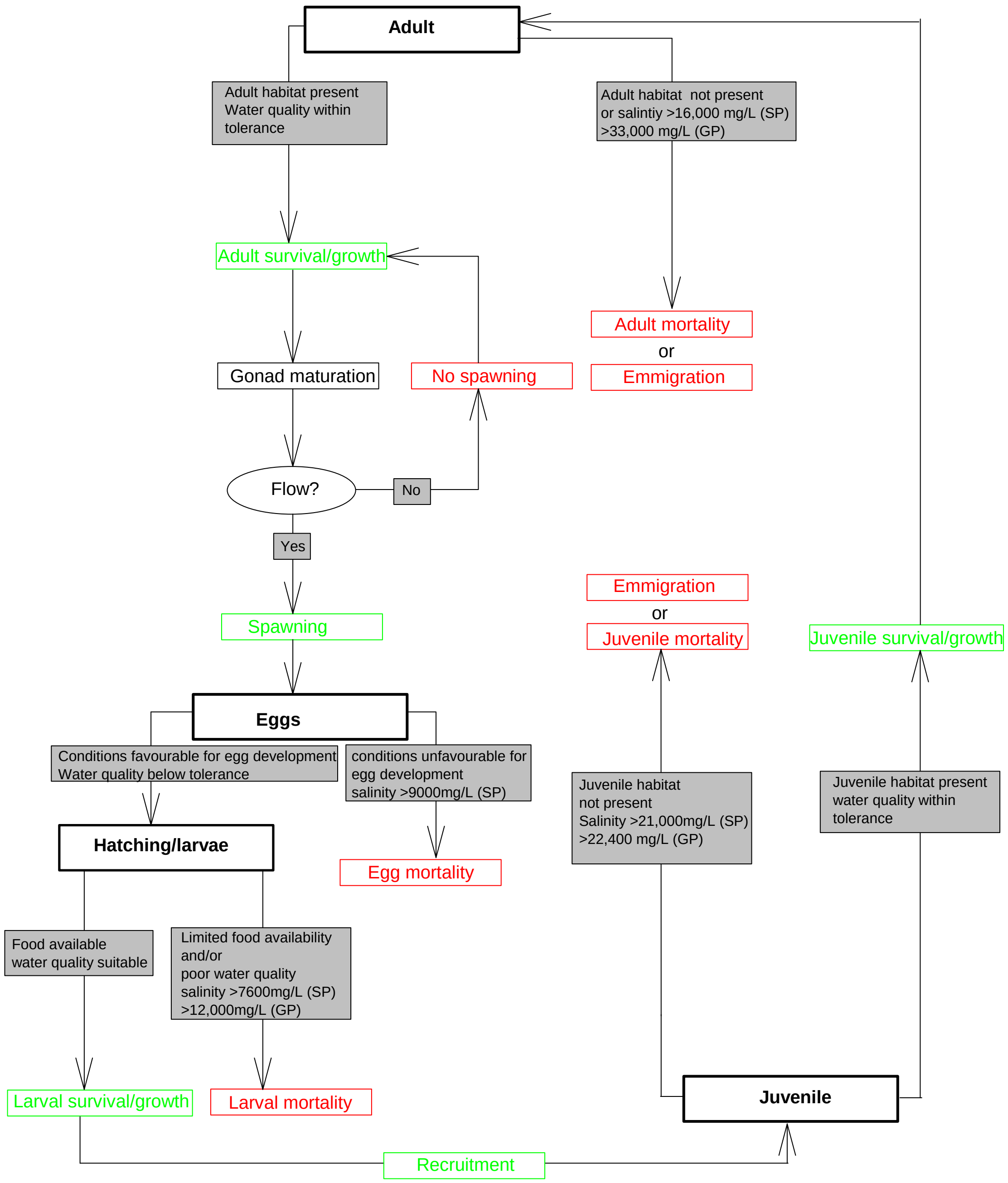

Figure 7. Lifecycle of silver perch and golden perch. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

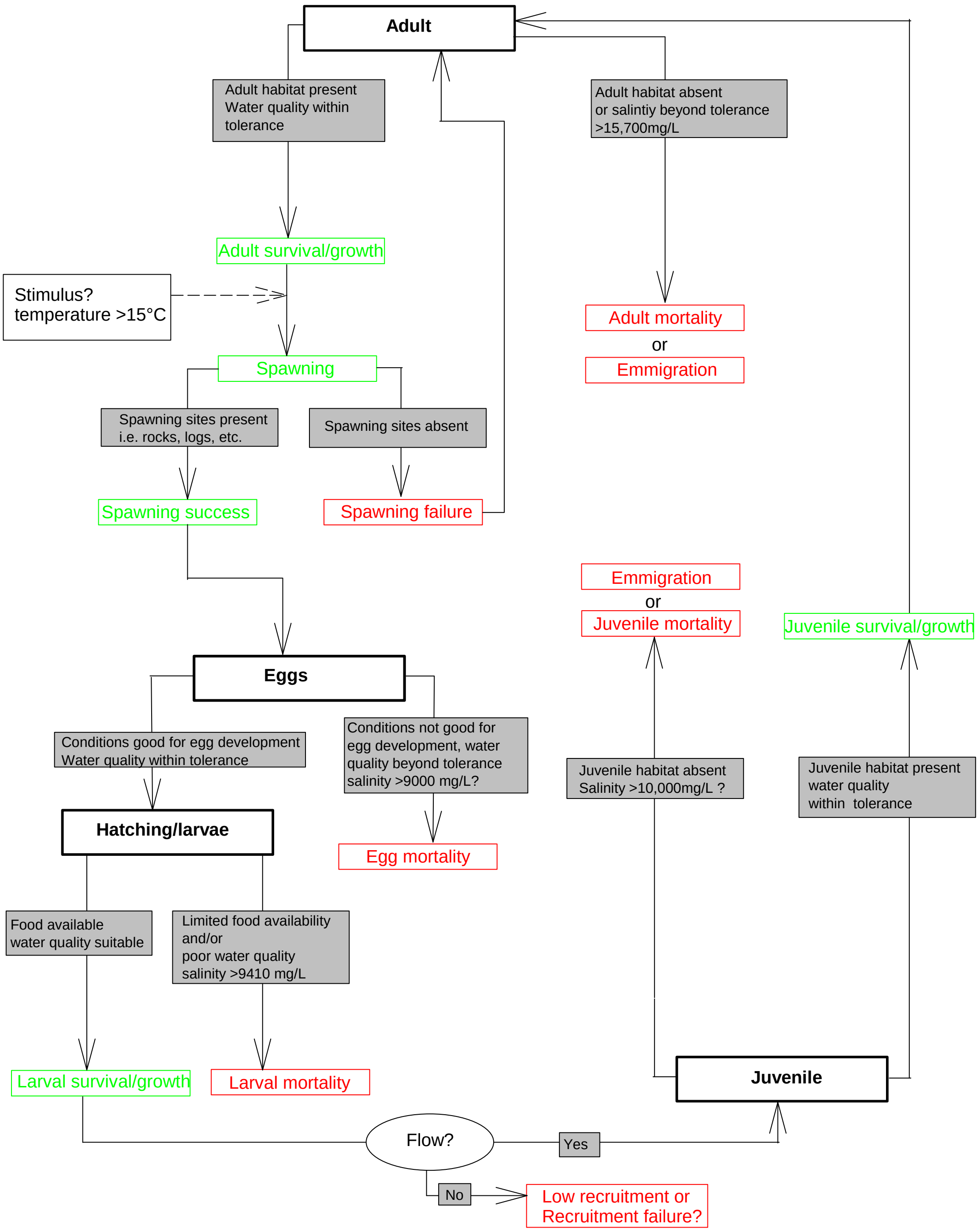

Figure 8. Lifecycle of Murray cod. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

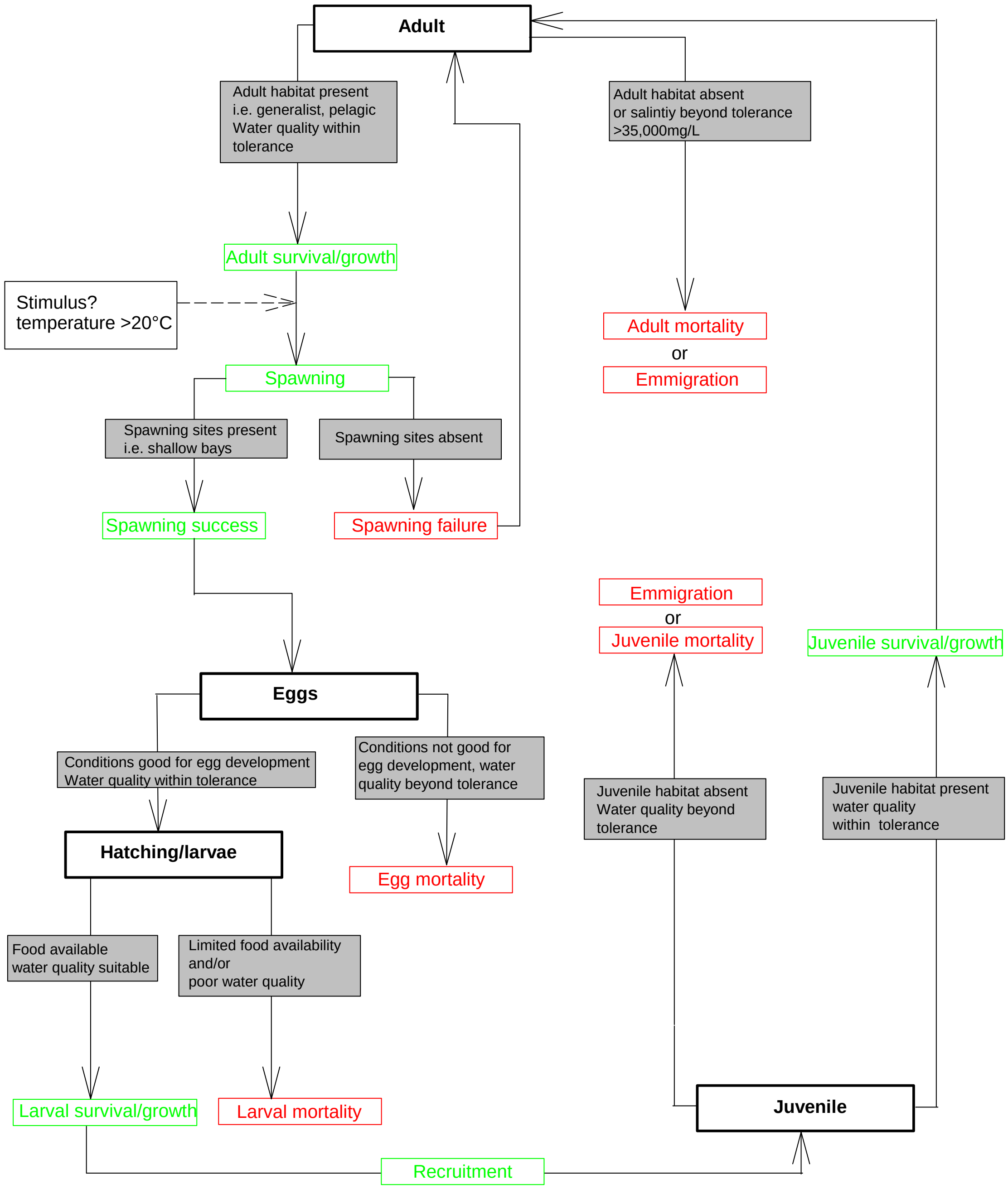

Figure 9. Lifecycle of bony herring. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

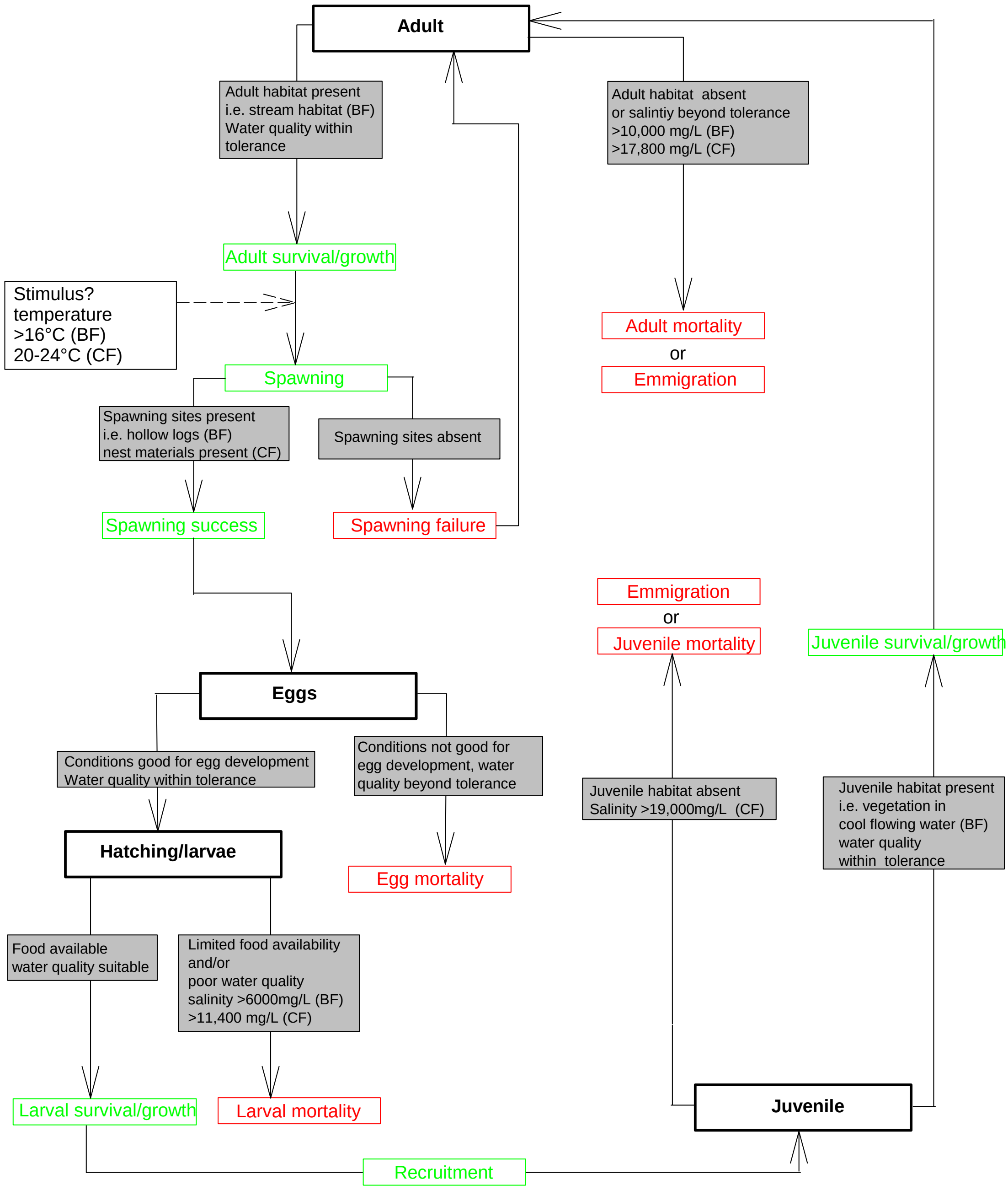

Figure 10. Lifecycle of river blackfish (BF) and eel-tailed catfish (CF). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

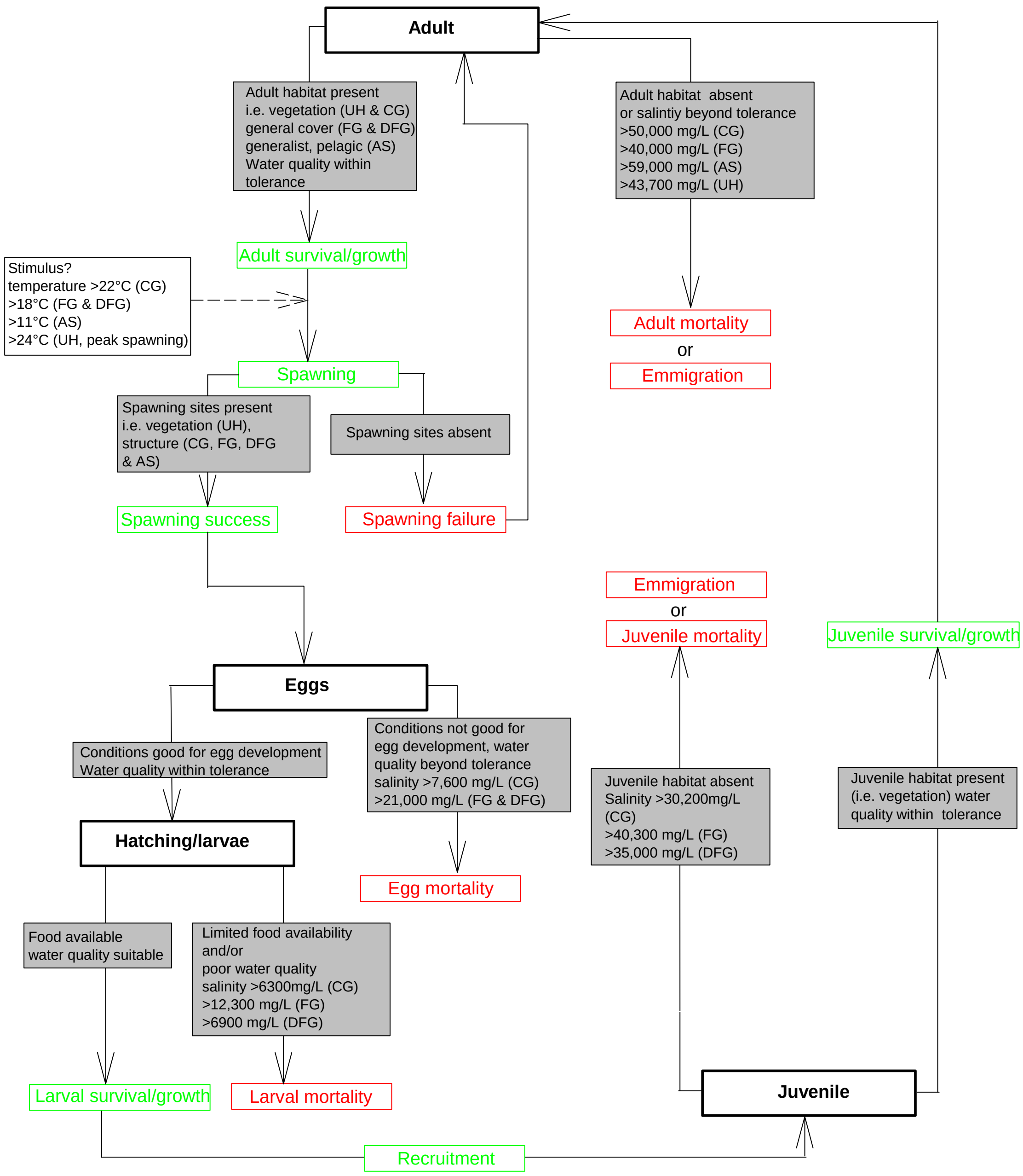

Figure 11. Lifecycle of common small-bodied native freshwater species, carp gudgeon complex (CG), flat-headed gudgeon (FG), dwarf flat-headed gudgeon (DFG), Australian smelt (AS) and unspecked hardyhead (UH). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

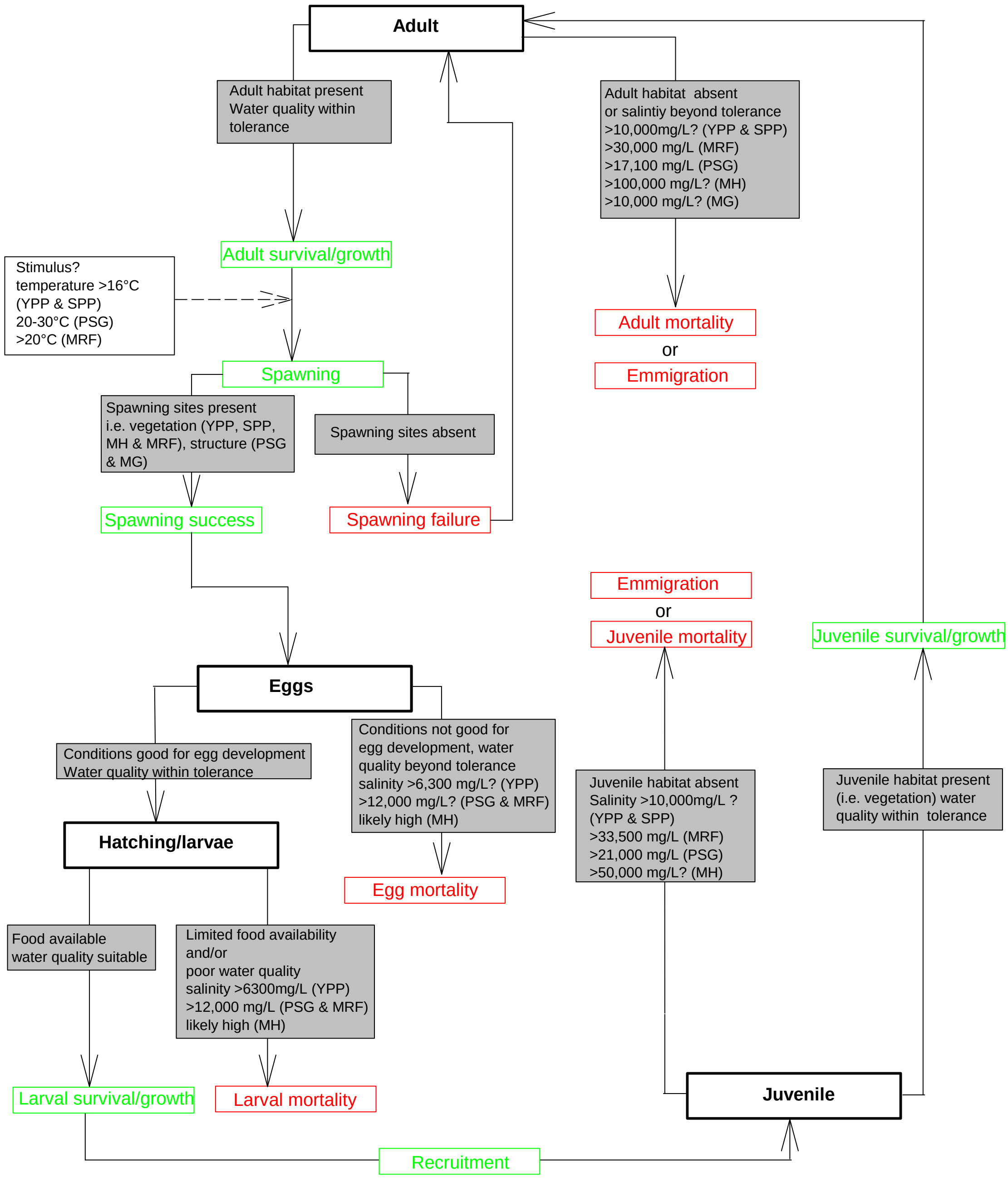

Figure 12. Lifecycle of rare or endangered small-bodied native freshwater species, Yarra pygmy perch (YPP), southern pygmy perch (SPP), southern purple-spotted gudgeon (PSG), Murray rainbow fish (MRF), Murray hardyhead (MH) and Mountain Galaxias (MG). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

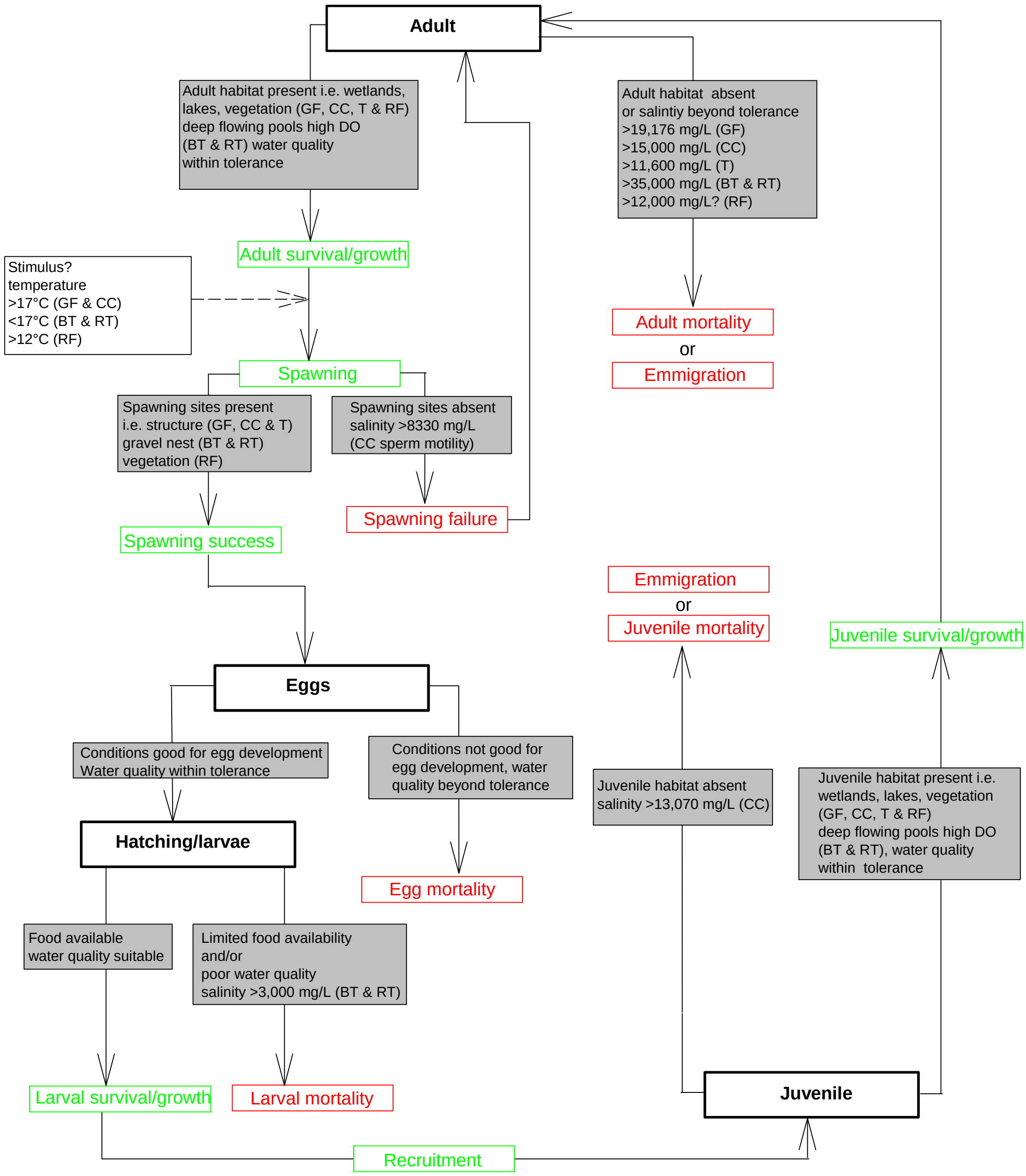

Figure 13. Lifecycle of exotic freshwater species, goldfish (GF), common carp (CC), tench (T), brown trout (BT), rainbow trout (RT) and redfin perch (RF). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

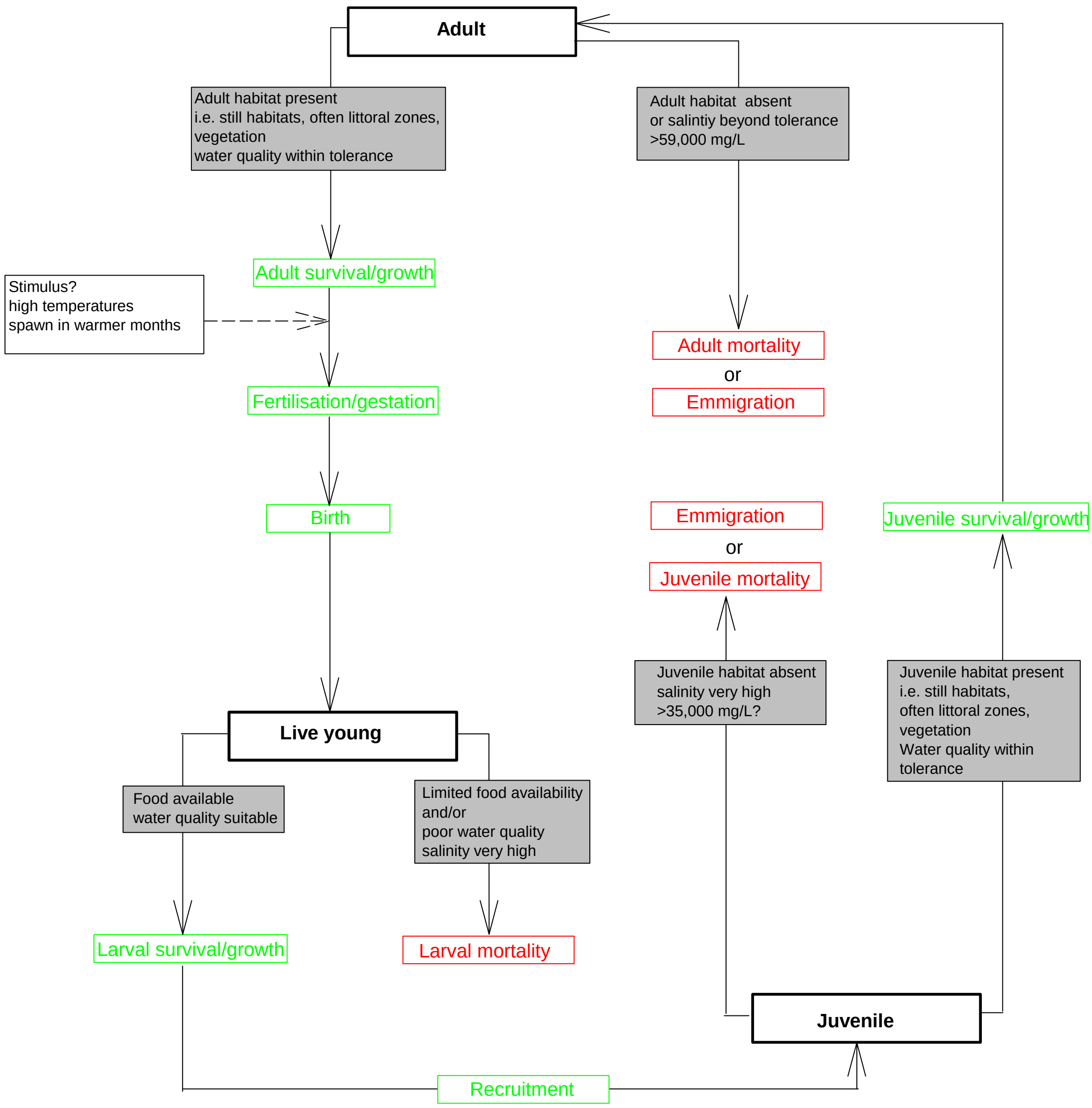

Figure 14. Lifecycle of the exotic freshwater species, eastern gambusia. Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

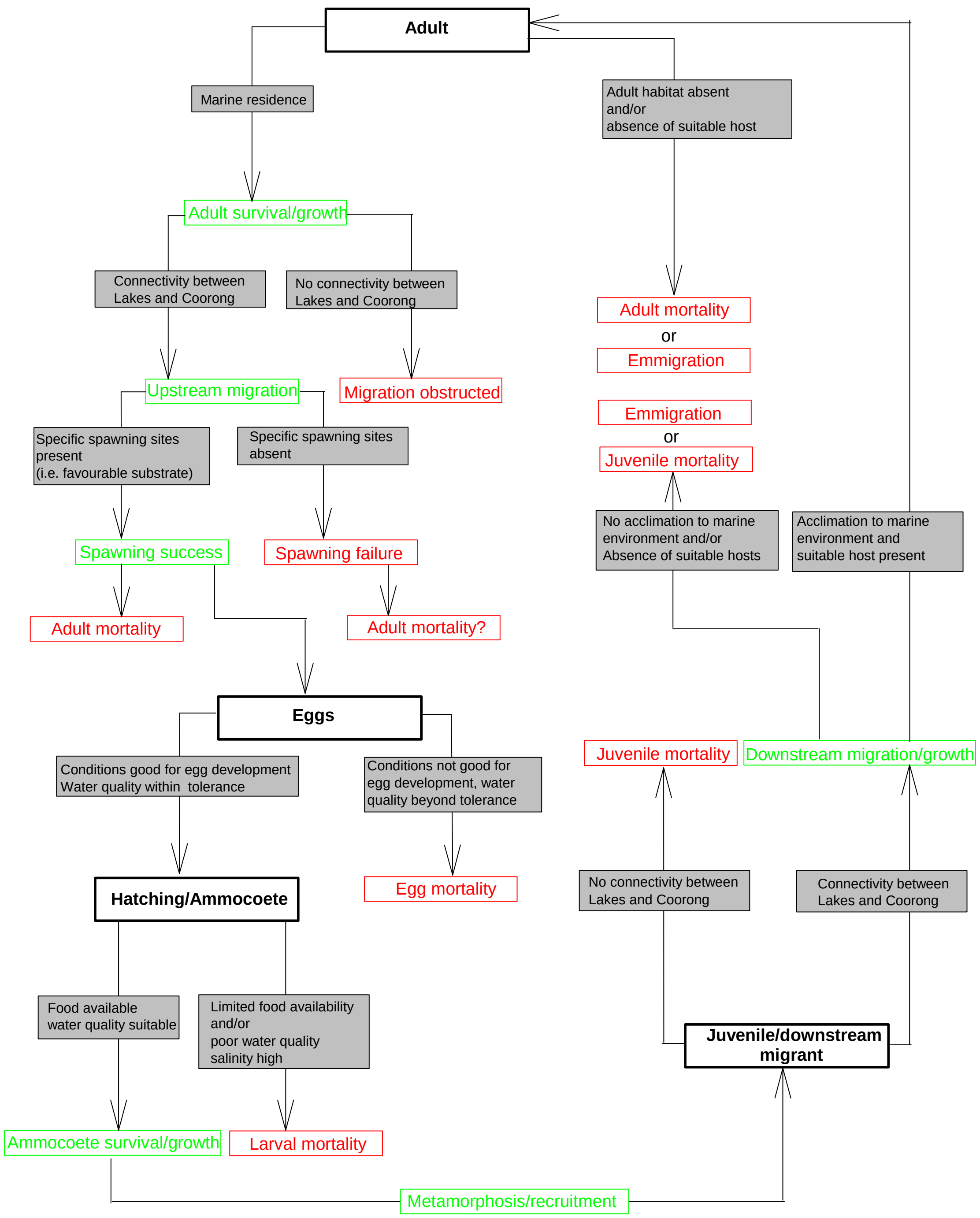

Figure 15. Lifecycle of pouched lamprey and short-headed lamprey, Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

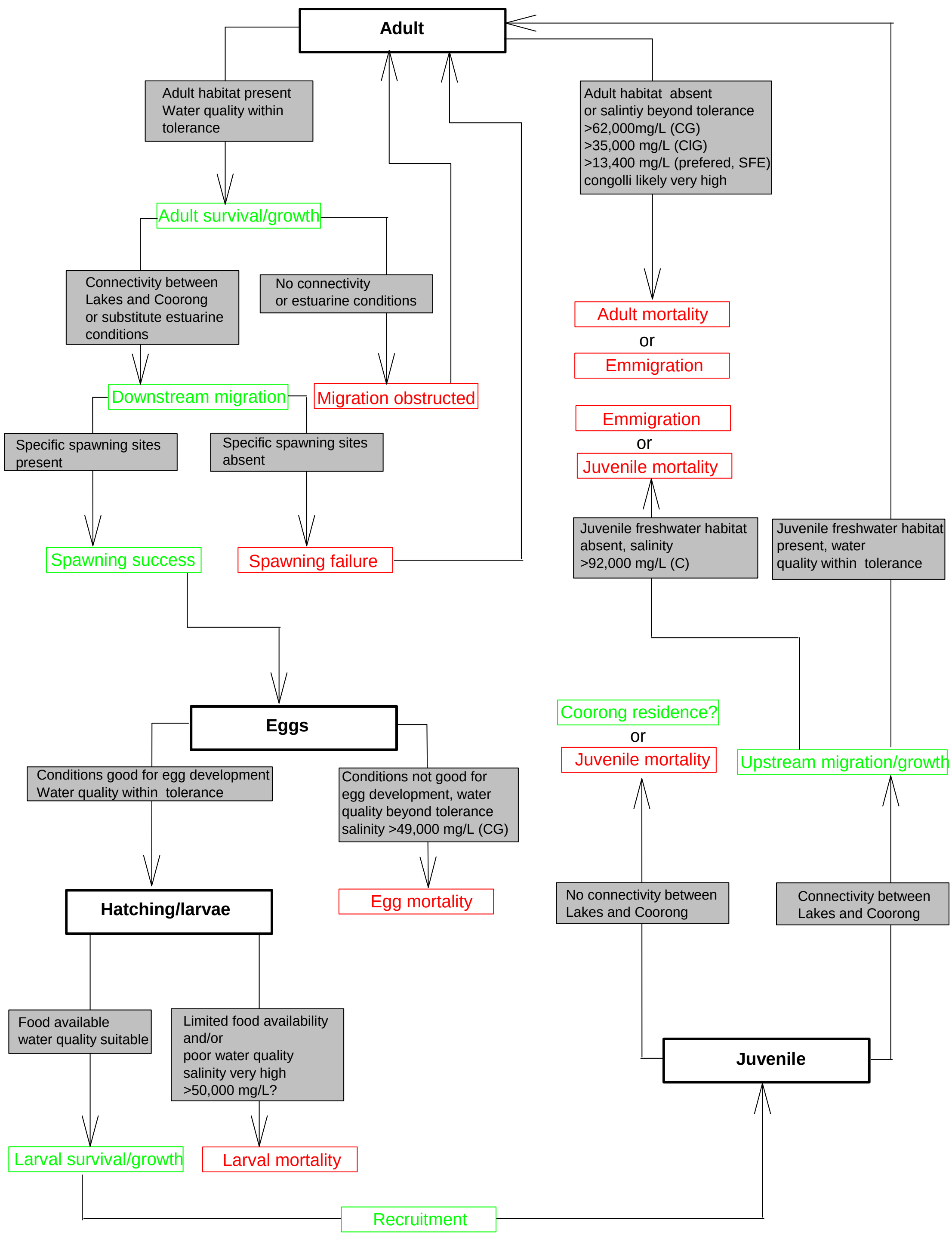

Figure 16. Lifecycle of Catadromous species, common galaxias (CG), climbing galaxias (ClG), short-finned eel (SFE) and congolli (C). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

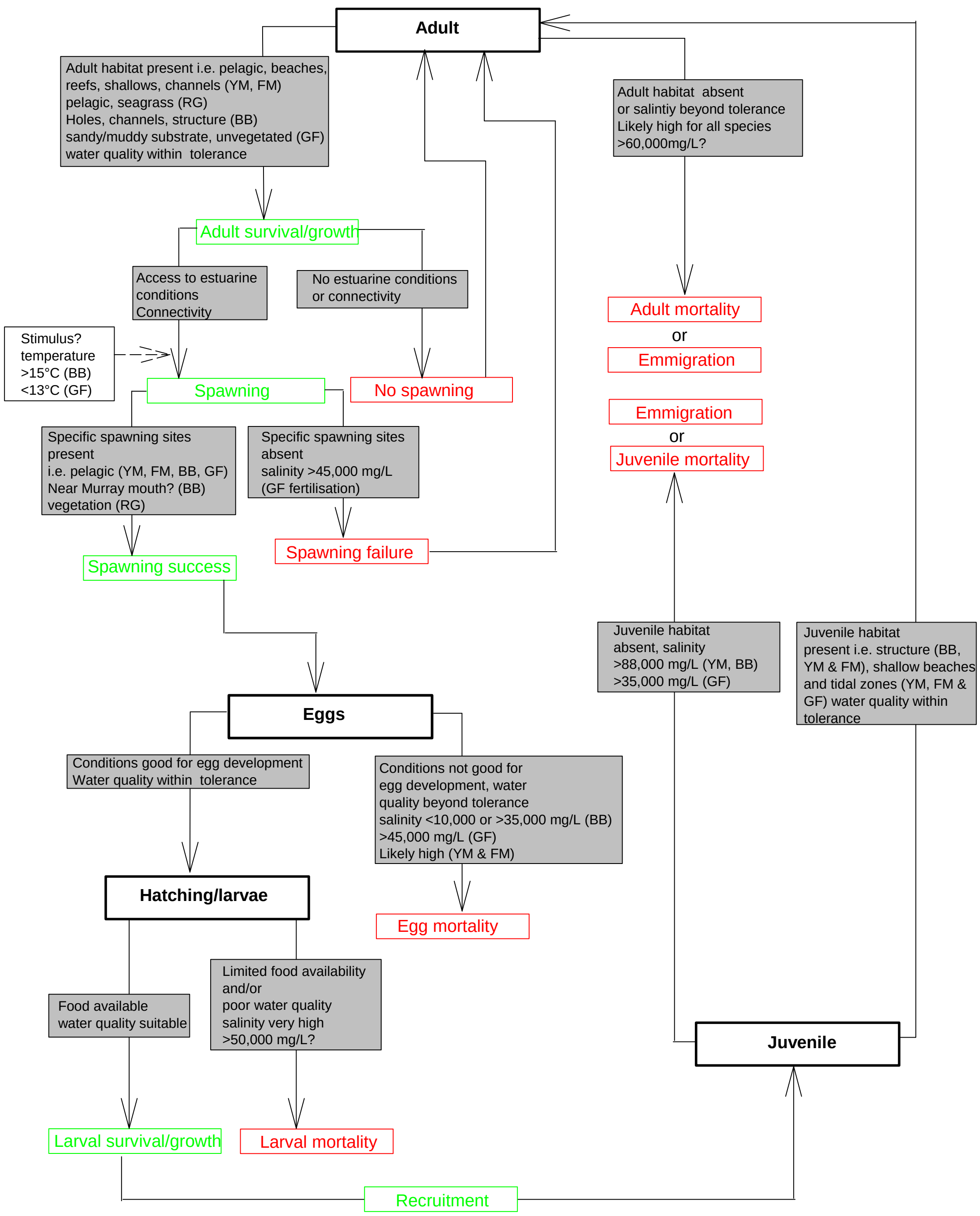

Figure 17. Lifecycle of large-bodied estuarine species, yellow-eyed mullet (YM), flat-tailed mullet (FM), black bream (BB), river garfish and greenback flounder (GF). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

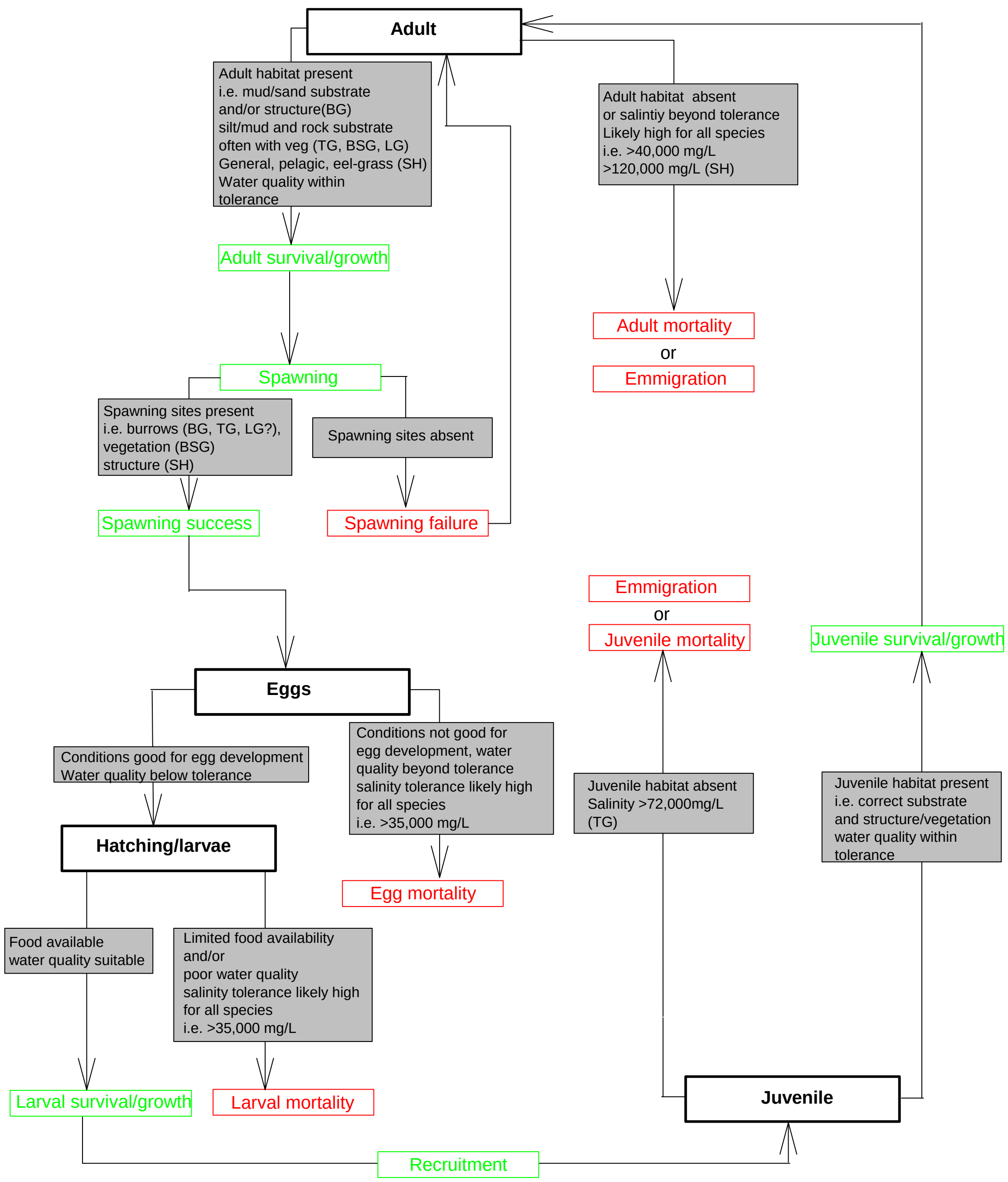

Figure 18. Lifecycle of small-bodied estuarine species, bridled goby (BG), Tamar river goby (TG), blue-spot goby (BG), lagoon goby (LG) and small-mouthed hardyhead (SH). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

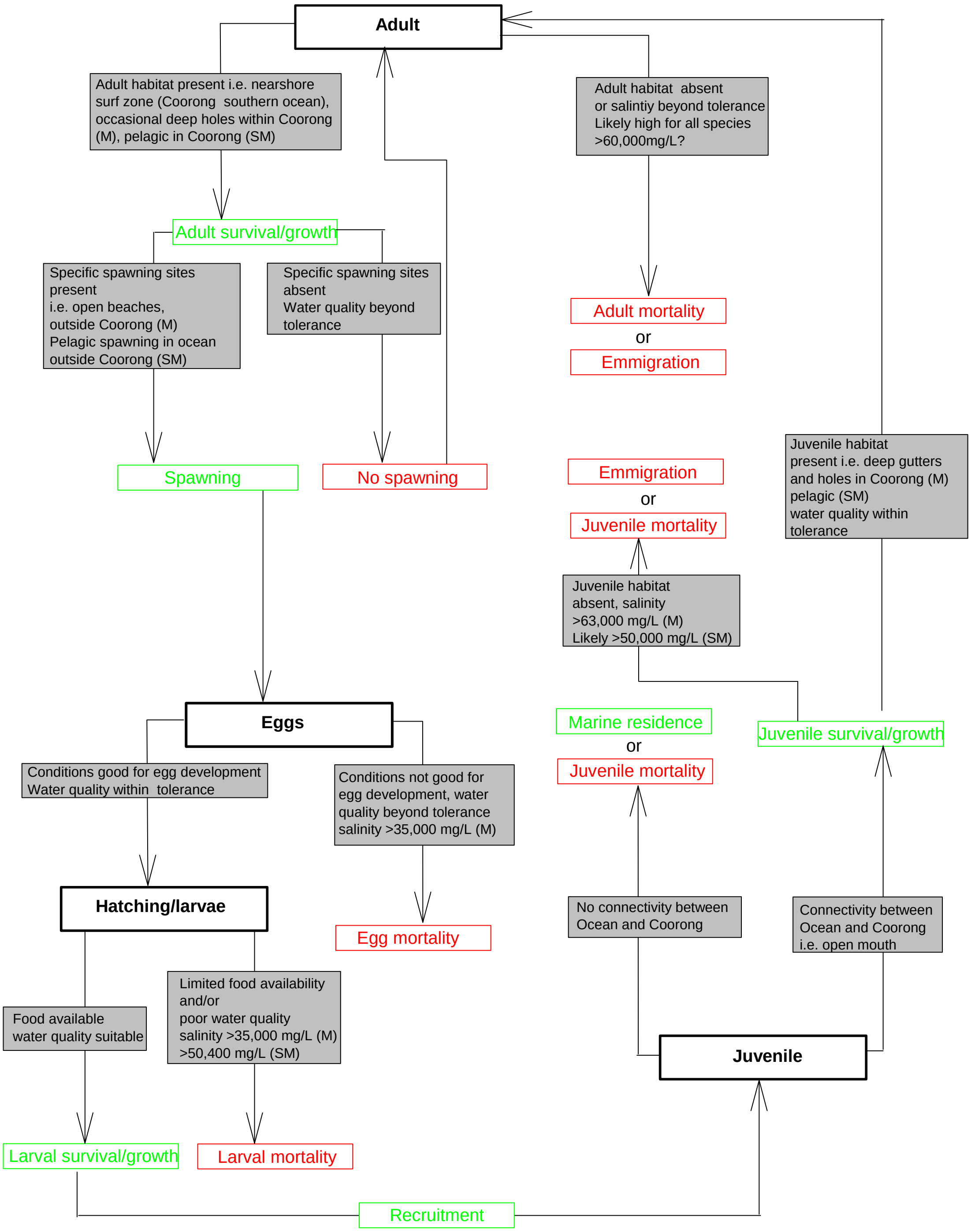

Figure 19. Lifecycle of marine species, mulloway (M) and sea mullet (SM). Different life stages indicated by bold text. Positive events are shown in green and negative events in red. Habitat requirements and salinity tolerances are presented where possible.

4 Methodology

4.1 General approach

We aimed to compare the predicted distribution, abundance and viability of fish populations under given management options to 'normal operating conditions' in the Lower Lakes (*c.* 0.75 m AHD, sustained low freshwater inflows). The distribution and abundance of most species in the Lower Lakes, pre-drought, was well known and predicted changes to fish populations are judged against this knowledge.

The process for completing this study was:

- Collate background information on the ecology of selected fishes of the Lower Lakes and Coorong, with emphasis on spawning requirements, habitat preferences and physico-chemical tolerances of different life stages. This information was used to develop conceptual models on the life-cycles of these species
- Using the modelling data on proposed management options for the Lower Lakes, provided by BMT WBM, we generated a draft risk assessment for selected species based on each option
- A workshop was undertaken with local and interstate experts to,
    - Refine conceptual models
    - Assess risks of both management options on individual species
    - Discuss possible mitigating actions and the rationale of these actions given each management option
- Prepare draft report and submit to DEH, external experts and SARDI Aquatic Sciences internal review
- Prepare final report and submit to DEH

4.2 Risk assessment method

The risk assessment framework used follows the principles and practises within domestic and international Standards for Environmental Risk Assessment (AS/NZS 4360/2004 and relevant ISO standards referred to in this document). The main components of this framework are as follows:

- Identify risks

Identify and define all potential positive and negative 'aspects' and 'impacts' that may influence the distribution and abundances of fish species as a result of the two management scenarios under investigation. Impacts represent the direct pressure or threat to species (e.g. disconnection of the Lower Lakes from EMLR tributaries), whilst aspects represent the causal link between a management option and a direct impact (e.g. extreme low water level).

- Analyse risks

  Determine both the likelihood of an impact occurring under a given management option and the consequences of such an event occurring. Together these scores form a measure of risk. Additionally, we propose a score be given for confidence in the assigning of consequence values. Confidence in the assessment relates to the amount of information available to support the consequence scores given and facilitates the identification of significant knowledge gaps.

- Evaluate risks

  Estimated risk levels for each potential impact can then be evaluated against pre-established criteria and impacts may be categorised from low to high risk for individual fish species or groups of species. By applying a significance threshold relevant to the project, a list of significant impacts can be generated that require further discussion, treatment and/or mitigation.

4.2.1 Determining likelihood, consequence and confidence levels

The likelihood of a particular impact occurring under a given management option is derived from information on the nature of the intervention and subsequent modelling data. This involves explicitly defining the management options under investigation and any assumptions being made on the part of researchers or in modelling runs.

Impacts were assigned a likelihood value (A-E) related to the probability of an impact occurring under a management option (Table 9). Assigning likelihood values to most impacts is uncomplicated as they are explicitly defined within management option descriptions (e.g. the loss of connectivity between the River Murray and Lake Alexandrina is certain (i.e. likelihood = A) as the construction of the Wellington Weir is assumed under both options, see section 4.1) but for other impacts the likelihood values are, to some extent, arbitrary and were assigned with agreement from experts at the workshop.

Table 9. Levels of likelihood, consequence and confidence.

Likelihood	Consequence (impact)	Confidence
A – certain	1 – catastrophic	1 - local information available, documented process, experts agree
B – likely	2 – major (negative)	2 - regional information available, documented process, experts verify
C – moderate	3 – moderate (negative)	3 – limited information, documented process elsewhere in region or similar region, experts differ
D – unlikely	4 – minor (negative)	4 – Perception based on some information that is not local or regional
E – Rare	5 - insignificant	5 – Perception only, no supporting information

Correctly assigning the predicted ecological affects of a given impact on a species to a numerical consequence value is critical in providing thorough risk assessment. Each relevant impact was assigned a consequence value for each species, ranging from catastrophic (1) to insignificant (5; Table 9). For the purpose of this study, the level of consequence of a given impact on each species was assessed based upon losses/gains in habitat within the Lower Lakes and Coorong Ramsar site, recruitment failure and/or obstruction of migratory pathways (Table 10).

- Habitat loss/gain

  Habitat loss is a broad consequence that may incorporate both physical habitat loss and physico-chemical exclusion from habitat area due to diminished water quality. Physical habitat loss relates to the absence of favoured 'habitat types' or characteristics (e.g. dense aquatic vegetation) and reductions in lake surface area expected with extremely reduced water levels. Habitat loss via physico-chemical exclusion may occur if salinity in areas of Lake Alexandrina increases above a species upper tolerance limit. Physico-chemical habitat loss is interpreted spatially using modelling data.

- Recruitment failure

  For the purpose of this study we propose that recruitment is defined as the development of an individual to at least 1 year of age. At this stage of development physico-chemical tolerances are often similar to adults and individuals are highly mobile and therefore possess a far greater chance of survival compared to earlier life stages. Recruitment in most species under investigation is likely to be threatened by the absence of spawning habitats, changes in flow regime, connectivity and perhaps most importantly changes in salinity. When investigating the consequences of changes in salinity on recruitment the lake is viewed as a homogenous habitat whereby, given favourable water quality conditions, fish could complete their lifecycle in 100% of the lake area. This is an obvious overestimate but provides a reference against which the impact of salinity on recruitment can be assessed. As such, failed recruitment is viewed as >90% of Lake area being above the salinity tolerance of early life stages (i.e. egg or larvae). This differs from adult habitat loss via physico-chemical exclusion as eggs and larvae are typically less tolerant and mobile than their adult con-specifics (Hart *et al.* 1991) and thus adults may persist without recruitment occurring.

- Obstruction of migratory pathways

  Diadromous fish species require longitudinal connectivity between freshwater and marine/estuarine environments in order to complete their life-cycle (McDowall 1988). Similarly, many obligate freshwater species undergo large-scale longitudinal movements within freshwater reaches, whilst other non-migratory species may undertake opportunistic or avoidance movements when faced with unfavourable conditions (Lucas and Baras 2001). Thus, the obstruction of migratory pathways has significant consequences for many fish species.

As the life histories of the selected species differ, so do criteria for assessing the ecological consequences of a given impact. This primarily relates to differences in movement patterns and life span. Specifically, diadromous species are likely to be greatly affected by in stream barriers to movement whilst recruitment failure in a given year does not represent a dire threat to populations of long-lived species but represents an immediate and critical threat to short-lived species. Thus, ecological criteria for assigning the consequence level of an impact differ between species and groupings and are presented in Table 10.

A confidence score was also determined for each consequence value assigned to each species for every impact. Confidence represents a measure of support for a consequence value assignation in the form of publications, regional information and agreement amoung experts at the workshop. Whilst confidence measures are not used directly when assigning the overall risk of an impact or management option (see next section) they do allow researchers to highlight knowledge gaps that may require further research.

Table 10. Ecological consequence of impacts on fish species of the Lower Lakes associated with given levels of 'consequence'.

Consequence level	Large-bodied native freshwater species	Common small-bodied native freshwater species	Uncommon or endangered small-bodied freshwater species	Exotic freshwater species	Diadromous species	Estuarine species	Marine species
1 – catastrophic / monumental	Imminent risk of local extinction or total emigration. Near total loss/gain (>90%) of adult and/or juvenile habitat	Imminent risk of local extinction or total emigration. Recruitment failure (>90% loss of habitat area for early life stages (most species are short-lived)). Near total loss /gain (>90%) of adult and/or juvenile habitat	Imminent risk of local extinction or total emigration. Recruitment failure (>90% loss of habitat area for early life stages (most species are short-lived)). Near total loss/gain (>90%) of adult and/or juvenile habitat	Imminent risk of local extinction or total emigration. Near total loss/gain (>90%) of adult and/or juvenile habitat	Imminent risk of local extinction or total emigration. Total obstruction of migratory pathways. Near total loss/gain (>90%) of adult and/or juvenile habitat.	Imminent risk of local extinction or total emigration. Near total loss/gain (>90%) of adult and/or juvenile habitat. Total obstruction of migratory pathways	Imminent risk of local extinction or total emigration. Near total loss/gain (>90%) of adult and/or juvenile habitat
2 – major	Significant loss/gain of adult and/or juvenile habitat (>40%). Recruitment failure >90% loss of habitat area for early life stages	Significant loss/gain of adult and/or juvenile habitat. (>40%) Major impact on recruitment, >70% loss of habitat area for early life stages	Significant loss/gain of adult and/or juvenile habitat. (>40%) Major impact on recruitment, >70% loss of habitat area for early life stages	Significant loss/gain of adult and/or juvenile habitat. (>40%) Recruitment failure >90% loss of habitat area for early life stages	Significant obstruction of migratory pathways. Significant loss/gain of adult and/or juvenile habitat (>40%) Recruitment failure, >90% loss of habitat area for early life stages.	Significant obstruction of migratory pathways. Significant loss/gain of adult and/or juvenile habitat. (>40%) Recruitment failure >90% loss of habitat area for early life stages	Significant loss/gain of adult and/or juvenile habitat. (>40%) Recruitment failure >90% loss of habitat area for early life stages
3 – moderate	Some loss/gain of adult and/or juvenile habitat (20-40%) with some areas remaining where recruitment may occur, >40% loss of habitat area for early life stages	Some loss/gain of adult and/or juvenile habitat (20-40%) with some areas remaining where recruitment may occur, >40% loss of habitat area for early life stages	Some loss/gain of adult and/or juvenile habitat (20-40%) with some areas remaining where recruitment may occur, >40% loss of habitat area for early life stages	Some loss/gain of adult and/or juvenile habitat (20-40%) with some areas remaining where recruitment may occur, >40% loss of habitat area for early life stages	Partial obstruction of migratory pathways. Some loss/gain of adult and/or juvenile habitat (20-40%) with some areas remaining where recruitment may occur, >40% loss of habitat area for early life stages	Partial obstruction of migratory pathways. Some loss/gain of adult and/or juvenile habitat (20-40%) with some areas remaining where recruitment may occur, >40% loss of habitat area for early life stages	Some loss/gain of adult and/or juvenile habitat (20-40%) with some areas remaining where recruitment may occur, >40% loss of habitat area for early life stages
4 – minor	Minor loss/gain of adult and/or juvenile habitat (<20%), significant recruitment likely to still occur, <40% loss of habitat area for early life stages	Minor loss/gain of adult and/or juvenile habitat (<20%), significant recruitment likely to still occur, <40% loss of habitat area for early life stages	Minor loss/gain of adult and/or juvenile habitat (<20%), significant recruitment likely to still occur, <40% loss of habitat area for early life stages	Minor loss/gain of adult and/or juvenile habitat (<20%), significant recruitment likely to still occur, <40% loss of habitat area for early life stages	Minor loss/gain of adult and/or juvenile habitat (<20%), significant recruitment likely to still occur, <40% loss of habitat area for early life stages	Minor loss/gain of adult and/or juvenile habitat (<20%), significant recruitment likely to still occur, <40% loss of habitat area for early life stages	Minor loss/gain of adult and/or juvenile habitat (<20%), significant recruitment likely to still occur, <40% loss of habitat area for early life stages
5 – insignificant	No change to habitat area or recruitment dynamics	No change to habitat area or recruitment dynamics	No change to habitat area or recruitment dynamics	No change to habitat area or recruitment dynamics	No change to habitat area or recruitment dynamics	No change to habitat area or recruitment dynamics	No change to habitat area or recruitment dynamics

4.2.2 Assigning overall risk for individual impacts

In order to classify impacts by a level of risk the following categorisation matrix was applied (Table 11). As such, all identified and analysed impacts may be evaluated as to the level of risk (low, medium or high) they pose to each species investigated based upon a combination of likelihood and consequence scores.

Table 11. Overall risk matrix, detailing the assignment of impacts to risk categories (low, medium or high) based upon combined scores for likelihood and consequence.

		Consequence				
		1	2	3	4	5
Likelihood	A	High				
	B			Medium		
	C				Low	
	D					
	E					

Overall risk is likely to differ between species for some impacts. For example, an impact that is certain to occur (likelihood = A), may have a moderate negative affect on a long-lived freshwater species (consequence = 3, therefore medium risk) but may have a catastrophic affect on a short-lived freshwater species (consequence = 1, therefore high risk). Due to the large number of species investigated, when the overall risk of a given impact is reported (see results), the greatest (i.e. worst) risk score determined across all species is presented. Each impact that was determined to be of 'high risk' (Table 11) is discussed in detail with reference to the species affected.

4.2.3 Assigning overall risk of management on individual species

No cumulative measure was applied to determine the overall risk posed by a management option on each species, but rather the greatest risk score from all impacts was assumed. Although some impacts are additive, that is the overall risk of a management option may be increased due to the cumulative consequences of several impacts, the consequence of many impacts analysed is independent of others. For example, the total obstruction of movement between freshwater and marine environments will have catastrophic consequences on a diadromous fish species and thus the risk of this impact would be high. Regardless of other potential impacts as a result of management this impact alone renders the particular option high risk for this species. However, it is still important that other impacts that are viewed as a lesser risk (i.e. medium or low) are taken into account, particularly when discussing mitigation.

The overall risk of management options on individual species is then presented as predicted fish response (i.e. increases/decreases in distribution and/or abundance) due to this option. Species were investigated individually for each option and predicted changes in distribution and abundance were primarily derived from consequence scores and the underlying criteria by which this score was assigned.

4.2.4. Temporal scale of risk assessment

Given saltwater intrusion to maintain water levels may occur over several years (given evaporative losses) until freshwater inflows are restored, it is imperative that temporal variation in risk is captured within the scope of the project. Nevertheless, the predictive power of modelling data (based on given management options) is greatly reduced with increasing temporal projection and therefore we are limited in the temporal scope of this assessment. In order to capture the 'best possible' temporal scope of the proposed management options (given the salinity profile modelling data provided) assessments will be undertaken at four different points in time as follows;

1) Prior to commencement of management option (i.e. August 2009 for saltwater intrusion via Goolwa barrage (commencement some time in October))
2) Shortly after commencement of management option (i.e. December 2009)
3) Approximately five months after commencement of management option (i.e. February 2009)
4) Approximately 14 months after commencement of management option (i.e. December 2010)

This approach was taken for option 1 (i.e. saltwater intrusion via Goolwa Barrage) but not for option 2 (i.e. saltwater intrusion via Mundoo and/or Tauwitchere Barrage with the provision of a freshwater refuge) as no salinity profile modelling had been prepared. It is believed that the spread of increased salinity through Lake Alexandrina with intrusion via Tauwitchere or Mundoo Barrages would occur at a faster rate than via Goolwa Barrage. Therefore, we can assume that the salinity profile in the lake in December 2010 would likely mirror that of modelling from December 2010 for the Goolwa intrusion option. As such, option 2 was assessed at one point in time, namely December 2010.

5 Modelling data and predictions

The impacts of option 1 were assessed with the use of modelling and predictive tools. A two dimensional finite element, hydrodynamic and salinity model was developed for the Lower Lakes by BMT WBM Engineering and Environmental Consultants. WBM have provided modelling on the spatial salinity profile of Lake Alexandrina under three different freshwater flow scenarios (150, 250 and 350 GL/yr inflow to the lake), but we have only assessed the 150 GL/yr flow scenario (696 GL/yr across the SA border) as this represents the 'worst case' scenario. Intrusion would begin in October 2009 and saline water intrudes further into Lake Alexandrina with time. Figures 20-23 depict the modelled spatial salinity profile of Lake Alexandrina in August 2009 (prior to saltwater intrusion, Figure 20), December 2009 (2 months after saltwater intrusion, Figure 21), February 2010 (5 months after saltwater intrusion, Figure 22) and December 2010 (14 months after saltwater intrusion, Figure 23). By December 2010 the vast majority of lake area is hyper-saline (>65,000 $\mu S.cm^{-1}$) with a small area of lower salinity around the River Murray confluence. There is no need for depth profiling as modelling suggests mixing within Lake Alexandrina will be sufficient to break down any stratification. For further information on the modelling procedure used see the attached document (Appendix 1)

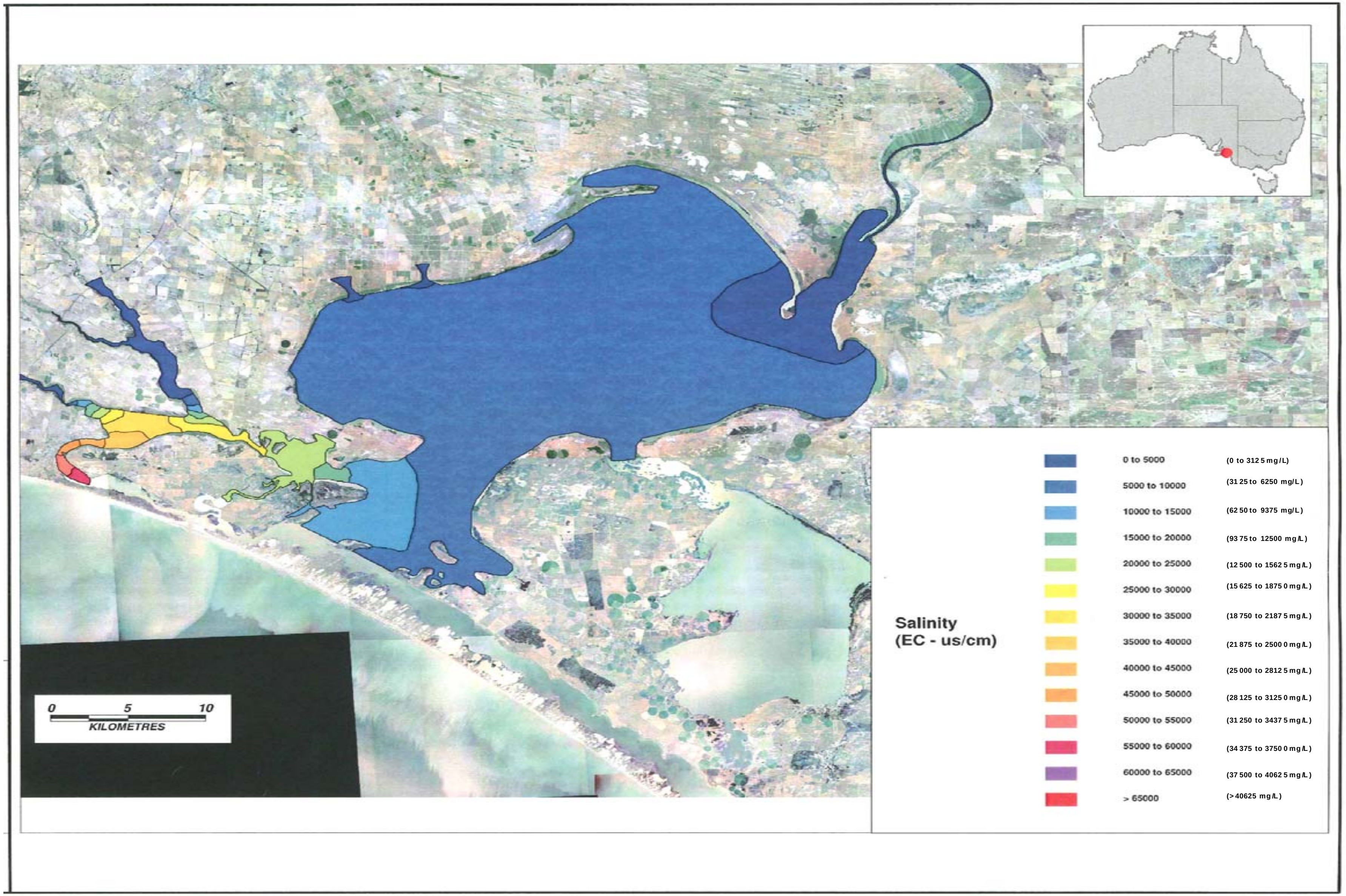

Figure 20. Modelled spatial salinity profile in Lake Alexandrina in August 2009, prior to saltwater intrusion via Goolwa barrage.

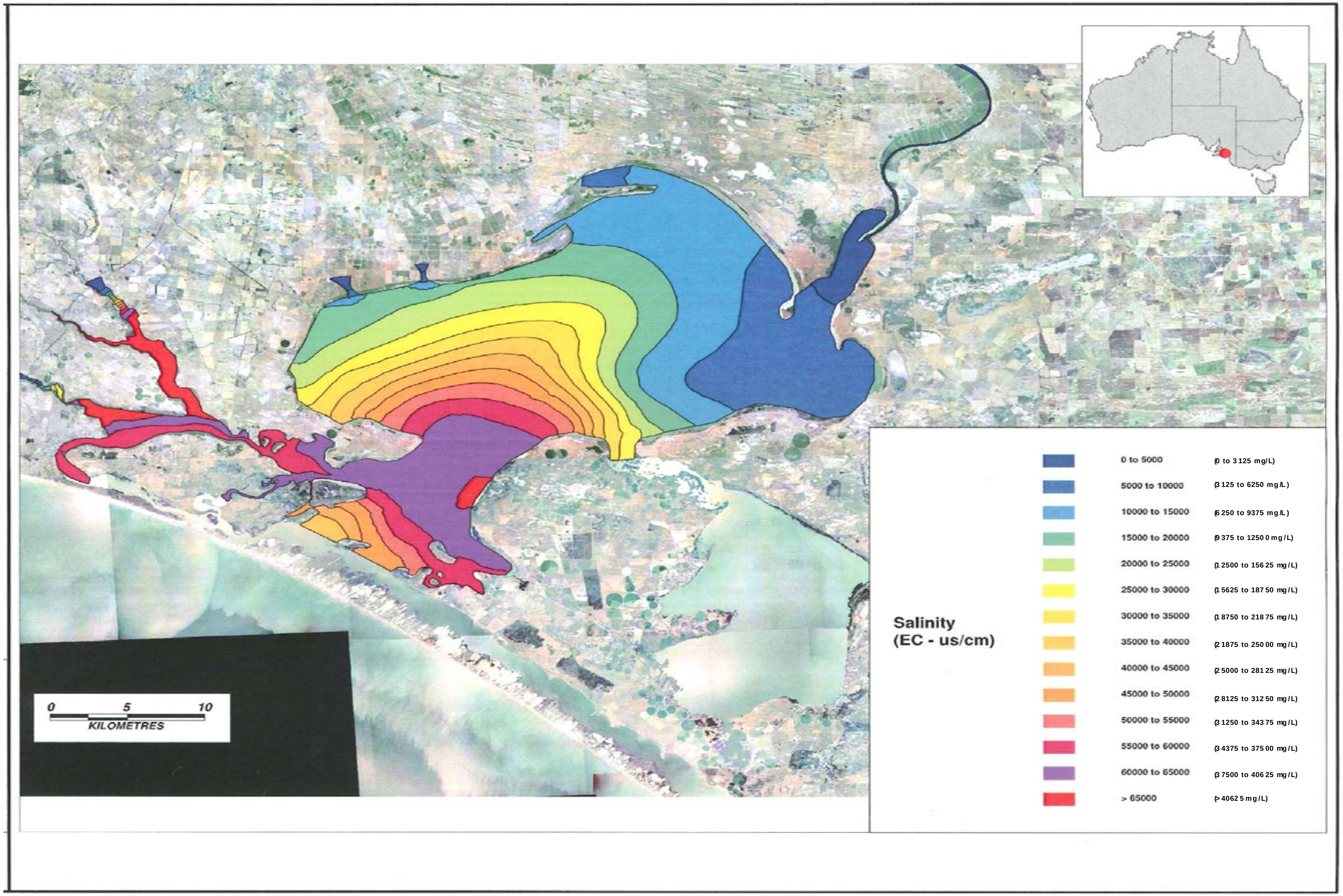

Figure 21. Modelled spatial salinity profile of Lake Alexandrina in December 2009, following saltwater intrusion.

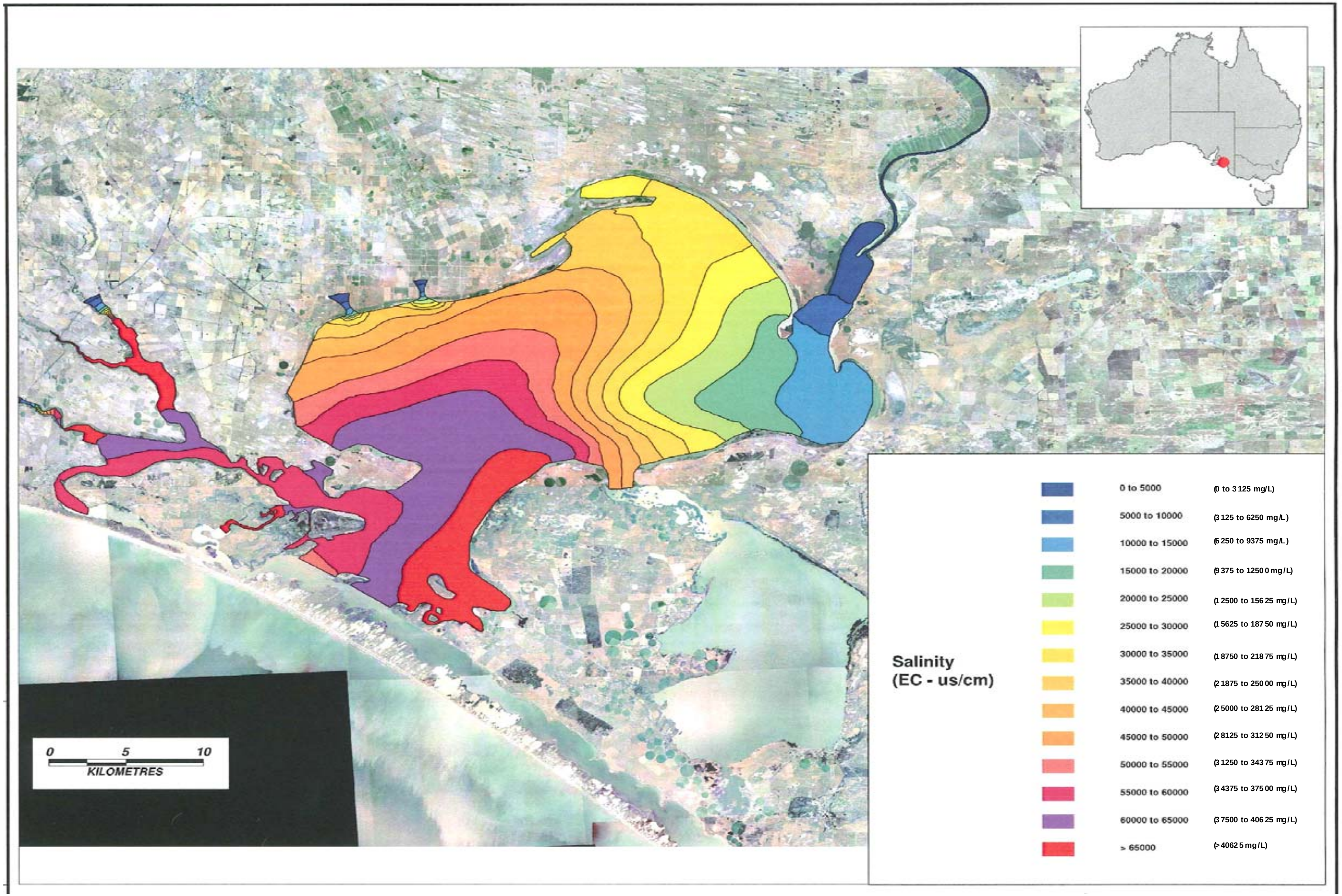

Figure 22. Modelled spatial salinity profile of Lake Alexandrina in February 2010, following saltwater intrusion.

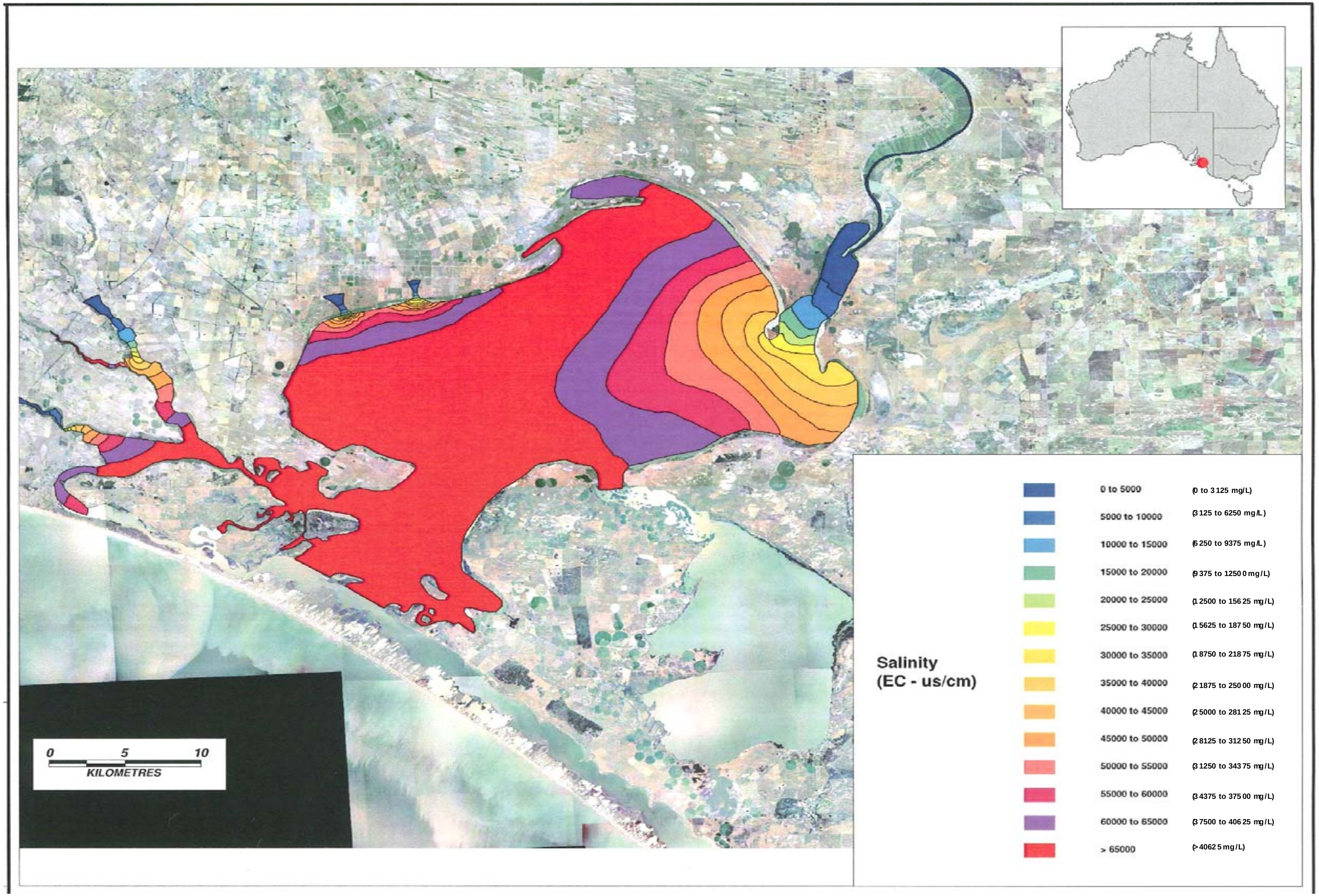

Figure 23. Modelled spatial salinity profile of Lake Alexandrina in December 2010, following saltwater intrusion.

There is no modelling data for option 2. Seawater intrusion via Tauwitchere or Mundoo Barrage would result in the centre of the lake reaching high salinities at a faster rate than option 1 due to the shorter travel distance for saltwater (WBM). As no modelling has been carried out this option will not be assessed at four points in time but will be assessed once assuming salinities in Lake Alexandrina would be similar to those for December 2010 in the option 1 modelling (Figure 23). Several other assumptions have been made for both options.

5.1 Assumptions of management options

Unfortunately, predicting the ecological impacts and outcomes of management options requires a large amount of assumption. This is necessary in the absence of substantial modelling information. Many assumptions have been made for option 2 but this is the 'best possible' approach given the current situation.

5.1.2 Option 1

- River Murray inflows of 150 GL/yr into Lake Alexandrina (696 GL/yr over the South Australian border)
- Lake level to be maintained at -1.5 m AHD
- Wellington Weir in place, with no provision for fish passage
- Saltwater to be delivered from the Coorong by 'over-topping' Goolwa Barrage
- Goolwa Barrage fishway not operating
- Pumping to Lake Albert will have ceased
- Approximately 40 GL/yr inflows from the EMLR tributaries. These are disconnected unless flowing
- Fisheries still operating
- 1982 local environmental conditions (high evaporation, low rainfall)

5.1.3 Option 2

- River Murray inflows of 150 GL/yr into Lake Alexandrina (696 GL/yr over the South Australian border)
- Lake level 'outside' refuge to be maintained at -1.5 m AHD

- Assume salinities of Lake Alexandrina 'outside' of the refuge in December 2010 will be similar to those seen in the December 2010 modelling output in option 1
- Wellington Weir in place, with no provision for fish passage
- Temporary regulator constructed near Clayton
- Construction of the regulator will have minimal impact on water quality within the refuge
- Refuge represents *c.* 10% of the total lake area
- Refuge water level will be raised to *c.* 0.3 m AHD with pumping from Lake Alexandrina or delivery from Lower Lakes pipeline
- Tributaries will surcharge refuge to *c.* 0.7 m AHD in winter 2009
- Post winter 2009, tributary inlows will be sufficient to maintain water level in refuge around 0.7 m AHD
- Any excess water will be released to the lake via a spillway on the Clayton regulator
- No plans for providing fish passage on the Clayton regulator spillway
- Goolwa Barrage fishway not operating
- Salinity in refuge post construction of ≤ 1500 $\mu S.cm^{-1}$ (950 $mg.L^{-1}$) after freshening from Lower Lakes pipeline and EMLR tributary flows
- All selected freshwater and diadromous fishes are present in some number within the refuge
- Saltwater to be delivered from the Coorong by 'over-topping' Mundoo and/or Tauwitchere Barrage
- Pumping to Lake Albert will have ceased
- Fisheries still operating
- 1982 local environmental conditions (high evaporation, low rainfall)

6 Results

6.1 General results of risk assessment

Of the potential impacts identified, 16 were deemed to be relevant for option 1 (i.e. saltwater intrusion via Goolwa) and 19 for option 2 (i.e. saltwater intrusion via Tauwitchere and/or Mundoo with the provision of a freshwater refuge). These were scored across risk categories for each species and the breakdown of risk scores is presented in Table 12. Some impacts were more significant for some species than others; therefore, the 'greatest' score (greatest consequence) of an impact across all species is presented in Table 12.

Table 12. Breakdown of risk scores by category for 16 and 19 impacts of the two management options in question. Impacts are colour coded by level of risk; red – high, beige – medium.

Option 1 'Saltwater intrusion via Goolwa'			Option 2 'Saltwater intrusion with provision of a freshwater refuge'		
Category	**# negative impacts**	**# positive impacts**	**Category**	**# negative impacts**	**# positive impacts**
A1	6		A1	5	
A2	1		A2	3	
A3	2	1	A3	1	1
A4	1		A4	1	4
B3	1		B3	1	
B4	1		C3	2	
C3	2		D1	1	
D1	1				
Total	**15**	**1**	**Total**	**14**	**5**

There are likely to be many other 'aspects' and 'impacts' of the proposed management options but knowledge on such impacts is scant or modelling has not been carried out. As such, impacts were restricted to those for which we could obtain reliable modelling data or the process of impact is well understood. Relevant impacts that were assessed for both options and the most significant risk score and the species that received this score are presented in Tables 13 and 14.

For option 1, the consequence of most impacts is constant through time (e.g. with the Wellington Weir in place, loss of connectivity between the River Murray and Lake Alexandrina is constant from August 2009 to December 2010). However, some impacts, most importantly 'changes in the spatial salinity profile of Lake Alexandrina', will change through time. The results of assessment at December 2010 are presented in Table 13 and 14 but the temporal change in these impacts will be discussed in detail when specific significant impacts are discussed with reference to the species affected.

Table 13. Management option 1, 'saltwater intrusion via Goolwa Barrage': Aspects and impacts (with comments on impacts) and the 'most' significant risk score (species are included) in December 2010. Positive impacts are coloured in green.

Saltwater intrusion via Goolwa barrage			
Aspect	**Impact**	**Comments**	**Significant score and species**
Low water level (-1.5 m AHD)	Unvegetated, open habitat only	With Lake Alexandrina at this extremely low level there will be no vegetated habitats which provide shelter and foraging opportunities as well as spawning sites for some fish. Instead the lake will be dominated by open water habitat not suitable for all species. This could also lead to increased aggregation and consequently increased predation, competition, disease transmission and potentially exploitation.	A 1 2 Yarra pygmy perch, southern pygmy perch
	Disconnection of Lakes and EMLR tributaries	At -1.5 m AHD, the confluences of all EMLR tributaries will be disconnected from Lake Alexandrina except during seasonal flows and connection would be minimal. These tributaries represent important habitat for some species and are viewed as biodiversity hotspots within the Ramsar site.	B 4 3 Yarra pygmy perch, congolli, etc
	High level of interaction with unconsolidated, fine sediments	Fine unconsolidated sediments are more common at greater depths and at lake levels of -1.5 m AHD, harder substrates such as sand are largely exposed. Such unconsolidated substrates may effect respiration and foraging (due to increased turbidity).	A 3 3 Congolli, goby spp
Acidification	pH of water <5 or >10	For the purpose of this assessment we are viewing pH below 5 or above 10 as fatal to all fish species being considered. The greatest risk of changes to pH is posed by exposed ASS. The objective of the management options being considered is to maintain pH within favourable levels and thus low pH should not be an issue. However significant exposure of ASS has already occurred and localised areas of low pH are likely.	D 1 1 All species
	pH of sediment <5 or >10	Same as above; however, high pH in sediments may directly effect the development of fish eggs and/or impact benthic species.	C 3 3 Eel-tailed catfish
	Release of metal ions (heavy metals and others) from ASS processes	Many metals are directly toxic to fish. Once ASS are exposed sulfuric acid may be formed and released and metal ions are mobilised. Upon re-wetting these metals are mobilised in the water column.	B 3 3 All species
	Localised deoxygenation of the water column from disturbance of ASS	The release of metal ions from ASS and increasing acidity can cause anoxia. Localised areas of low dissolved oxygen concentrations are likely to occur around the littoral areas of Lake Alexandrina. Due to the prevalent wind seiching (wind driven water movement) seen in the system, exposed ASS may be regularly dried and inundated and in this zone increased sulfuric acid and metal transport may result in lowered dissolved oxygen.	C 3 3 Yarra pygmy perch, southern pygmy perch

Table 13 continued.

Saltwater intrusion via Goolwa barrage			
Aspect	**Impact**	**Comments**	**Significant score and species**
Changes in salinity	Changes in the spatial salinity profile of the Lower Lakes in relation to species tolerance	As saltwater is introduced into Lake Alexandrina salinity will increase. With evapo-concentration the salinity of Lake Alexandrina would gradually increase to a state where the vast majority of the lake would be hyper-saline. Most fish, particularly freshwater species, can only survive within a range of salinities and as such the salinities predicted to be experienced under this option may be beyond the tolerance of given species'.	A 1 2 Golden perch, Murray cod, Yarra pygmy perch, etc
	Establishment of calcareous 'tube worm' reefs	The dominant physical structure within the Coorong is calcareous reef created by reef building tube worms. These structures are beginning to increase in number in the immediate area upstream of the barrages as evapo-concentration causes salinity to rise and become more favourable for these 'reef building species'. As saltwater is allowed into Lake Alexandrina from the Coorong salinity will rise and 'reef builders' will be passively transported in. Consequently there may be an increase in the number and size of these calcareous reefs. These reefs likely provide significant habitat for estuarine fishes in the Coorong and may perform the same function in Lake Alexandrina.	A 3 2 Black bream
	Entrapment by hyper-saline conditions	Salinity gradients will form in areas of the lake at certain times, which do not lead upstream to 'fresher' environments. Therefore it is possible fish may be attracted to these gradients but become entrapped by surrounding areas of hyper-saline water	A 3 3 Black bream, mulloway
Changes to freshwater inflows	Loss of wind induced water movement or mixing between Lake Alexandrina and the River Murray	With the Wellington Weir in place transfer of water between Lake Alexandrina and the River Murray via seiching would be inhibited. It has been suggested that in the absence of substantial inflows this process may be ecologically important.	A 4 3 All species
	Static small-volume flows of River Murray water provided to Lake Alexandrina (no flow variability)	Under the current option, freshwater inflows from the River Murray will remain consistent but will be of a very low volume. Some fish species rely on variability in flow as cues for spawning or such variability may increase recruitment success.	A 2 2 Golden perch, silver perch
	Loss of freshwater flow to the Coorong (loss of a salinity gradient)	Estuarine fish species typically inhabit areas of reduced salinity (relative to seawater). Many species require these areas of lowered salinity (relative to marine levels) to spawn, recruit and survive. Catadromous species also utilise salinity gradients for spawning and recruitment, whilst adult lampreys and juvenile eels use salinity gradients as a navigational cue for upstream migration.	A 1 2 Lamprey spp, congolli, black bream, mulloway

Table 13 continued.

Saltwater intrusion via Goolwa barrage			
Aspect	**Impact**	**Comments**	**Significant score and species**
Infrastructure and barriers to passage	Loss of connectivity between the River Murray and Lake Alexandrina	Diadromous species (catadromous but more importantly anadromous species (lampreys)) require free movement between Lake Alexandrina and the River Murray. Migratory freshwater species (i.e. potamodromous) also undertake longitudinal movements. With greatly increased salinities within Lake Alexandrina, non-migratory freshwater fish species may also attempt to move upstream to avoid these unfavourable conditions. With the Wellington Weir in place, passage will be totally obstructed for all species/	A 1 1 Lamprey spp
	Loss of connectivity between marine (Coorong and Southern Ocean) and freshwater (Lake Alexandrina) environments	As above, diadromous species require movement between marine and freshwater environments in order to complete their lifecycles. The Murray Barrages have been closed since March 2007 and will remain 'closed' (delivery mechanism below) as part of this management option. Therefore the movement of diadromous species will be obstructed. The return movement of estuarine fish species back into the Coorong after movement into Lake Alexandrina will also be obstructed.	A 1 1 Lampreys, congolli, black bream and mulloway, yellow-eyed mullet
	Saltwater delivery mechanism: 'over-topping'	The current delivery mechanism for saltwater intrusion is to lower the effective height of the barrage by removing stop logs and allowing water from the Coorong to 'over-top' the barrage and fall into Lake Alexandrina. As saltwater is flowing in the reverse direction to the natural order, migration cues for fish to enter Lake Alexandrina from the Coorong will be limited. Adult estuarine fish are unlikely to enter the lake in this manner but early life stages (eggs, larvae and juveniles) are likely to be passively transported into the Lake. With water levels in Lake Alexandrina at *c.* -1.5 m AHD and tide height in the Coorong high enough to allow significant water exchange, a head loss of ≥ 2 m can be expected. Thus water and any entrained biota must fall > 2 m onto water and possibly dry sand flats. This may result in significant mortalities of entrained biota, particularly early life stages. This delivery mechanism also provides no scope allowing the return movements of fish (particularly estuarine fish) back to the Coorong.	A 1 2 Lampreys, congolli, black bream, mulloway, yellow-eyed mullet

Table 14. Management option 2, 'saltwater intrusion via Mundoo and/or Tauwitchere Barrage with the provision of a freshwater refuge': Relevant aspects and impacts (with comments) and the 'most' significant risk score (species are included) in December 2010. Positive impacts are coloured in green.

Saltwater intrusion via Mundoo and/or Tauwitchere barrage with the provision of a freshwater refuge			
Aspect	**Impact**	**Comments**	**Significant scores and species**
Varying water levels: Refuge (0.3-0.7 m AHD) Lake Alexandrina proper (-1.5 m AHD)	Vast majority of habitat unvegetated, open habitat	Within the refuge (approximately 10% of total lake area) vegetated freshwater habitats may exist (assuming salinities are within limits for growth of vegetation). However, within Lake Alexandrina 'outside' of the refuge there will be no vegetated habitats which provide shelter and foraging opportunities to fish. Instead the lake will be dominated by open water habitat not suitable for all species. This could also lead to increased aggregation and consequently increased predation, competition, disease transmission and potentially exploitation.	A 2 2 Yarra pygmy perch, southern pygmy perch
	Reconnection or maintenance of connectivity between EMLR tributaries and Lake within refuge	With a regulator built near Clayton and water levels in the refuge maintained above 0.3 m AHD, the Finniss River and Currency Creek will remain connected or be reconnected with the Goolwa channel within the Refuge. These tributaries represent important habitat for some species and are viewed as biodiversity hotspots within the Ramsar site. However, the Angas and Bremer Rivers, which enter the Lake outside of the refuge, will remain disconnected at -1.5 m AHD.	A 4 3 Yarra pygmy perch, southern pygmy perch
	Re-establishment of submerged vegetation within refuge	Water levels within the refuge are to be maintained at 0.3 m AHD via the pumping of Lake water from outside of the refuge before being filled to *c.* 0.7 m AHD from EMLR tributary flows (Finniss River and Currency Creek). This should (assuming salinities are maintained at low levels) allow the re-establishment of submerged vegetation within the refuge. Submerged vegetation is a very important component of habitat for many fish species, providing shelter, foraging opportunities and spawning sites.	A 4 3 Yarra pygmy perch, Murray hardyhead, carp gudgeon
	Reconnection of vegetated fringing habitats within refuge	As above, increased water levels within the refuge will result in reconnection with fringing vegetation which was disconnected to varying degrees once water levels went below 0 m AHD. Fringing vegetation provides a similar habitat function to submerged vegetation.	A 4 3 Yarra pygmy perch, Murray hardyhead, carp gudgeon
	High level of interaction with unconsolidated, fine sediments	As per option 1, refer to Table 13.	A 3 4 Congolli, goby spp

Table 14 continued.

Saltwater intrusion via Mundoo and/or Tauwitchere barrage with the provision of a freshwater refuge			
Aspect	**Impact**	**Comments**	**Significant score and species**
Acidification	pH of water <5 or >10	As per option 1, refer to Table 13.	D 1 1 All species
	pH of sediment <5 or >10	As per option 1, refer to Table 13.	C 3 3 congolli
	Release of metal ions (heavy metals and others) from ASS processes	As per option 1, refer to Table 13.	B 3 3 All species
	Localised deoxygenation of the water column from disturbance of ASS and peat soils	As per option 1, refer to Table 13.	C 3 3 Yarra pygmy perch, southern pygmy perch
Changes in salinity	Changes in the spatial salinity profile of the Lower Lakes in relation to species tolerance	As saltwater is introduced into Lake Alexandrina salinity will increase. With evapo-concentration the salinity of Lake Alexandrina would gradually increase to a state where the majority of the Lake would be hyper-saline. Most fish, particular freshwater species, can only survive within a range of salinities and as such the salinities predicted to be experienced under this option may be beyond the tolerance of a given species. Salinities within the refuge however (assuming a salinity of <1500 EC, approximately 10% of total lake area), will be within freshwater species tolerances.	A 2 2 Golden perch, Murray cod, Yarra pygmy perch, etc
	Establishment of calcareous 'tube worm' reefs	The dominant physical structure within the Coorong is calcareous reef created by marine algae and tube worms. These structures are beginning to increase in number in the immediate area upstream of the barrages as evapo-concentration causes salinity to rise and become more favourable for these 'reef building species'. As saltwater is allowed into Lake Alexandrina from the Coorong salinity will rise and 'reef builders' will be passively transported in. Consequently there may be an increase in the number and size of these calcareous reefs. These reefs provide significant habitat for estuarine fishes in the Coorong and may perform the same function in Lake Alexandrina. Such reefs will not establish within the refuge.	A 3 2 Black bream

Table 14 continued.

Saltwater intrusion via Mundoo and/or Tauwitchere barrage with the provision of a freshwater refuge			
Aspect	**Impact**	**Comments**	**Significant score and species**
Freshwater flow	Loss of wind induced water movement or mixing between Lake Alexandrina and the River Murray	As per option 1, refer to Table 13.	A 4 3 All species
	Static small-volume flows of River Murray water provided to Lake Alexandrina (no flow variability)	As per option 1, refer to Table 13.	A 2 2 Golden perch
	Loss of freshwater flow to the Coorong (loss of a salinity gradient)	As per option 1, refer to Table 13.	A 1 1 Lampreys, congolli, black bream, mulloway
	Seasonal small-volume flows from tributaries in refuge (flow variability)	The Finniss River and Currency Creek were once perennial streams but are now seasonal with the bulk of flows in winter and spring. With water level in the refuge maintained above 0.3 m AHD, connection with these tributaries will be constant and winter/spring flows will provide some flow variability within the refuge. This may provide some species with spawning cues or provide conditions for increased recruitment.	A 4 3 Golden perch
Infrastructure and barriers to passage	Loss of connectivity between the River Murray and Lake Alexandrina	As per option 1, refer to Table 13.	A 1 1 Lampreys
	Loss of connectivity between marine (Coorong and Southern Ocean) and freshwater (Lake Alexandrina) environments	As per option 1, refer to Table 13.	A 1 1 Lampreys, congolli, black bream, mulloway, yellow-eyed mullet
	Creation of incorrect migration cues below the Clayton regulator AND no connectivity between the refuge and Lake Alexandrina	Under the current option, excess freshwater within the refuge and brackish water to be expelled from the refuge, will be released via a spillway at Clayton. Any freshwater or diadromous species surviving in the lake would then be attracted to the spillway where they would be entrapped by a large surrounding area of hyper-saline water and passage into the refuge would not be facilitated.	A 1 1 Lampreys, congolli
	Saltwater delivery mechanism: 'over-topping'	As per option 1, refer to Table 13.	A 1 2 Lampreys, congolli, black bream, mulloway

6.2 Significant impacts of management options on specified species groups and predicted responses

Any impact determined to be a 'high risk' (see Table 12) for at least one species is discussed further with reference to the species' affected. Impacts of this magnitude severely threaten the persistence of a given species in the region.

6.2.1 High risk impacts of Option 1

There are seven significant negative impacts and no significant positive impacts on the selected species as a result of management option 1. There are some minor positive affects on some species and these are also discussed below.

'Unvegetated, open habitat only'

At lake levels of -1.5 m AHD, the remaining water is disconnected from all fringing vegetation. Propagules of submerged vegetation do not occur at these depths (< -1.5 m AHD), whilst the predicted salinities in Lake Alexandrina are not favourable for the growth of most aquatic macrophytes (Jason Nicol pers. comm.). Habitat in the form of vegetation will be sparse or absent under this option.

Many fish species are associated with vegetation to some degree, either as habitat for different life stages or as a spawning substrate. The lack of vegetated habitats represents a significant risk to three species groupings, namely rare and endangered small-bodied native freshwater species, common small-bodied native freshwater species and exotic freshwater species.

Many threatened small-bodied freshwater fish in the MDB are thought to be habitat specialists (Mallen-Cooper 2001). Mountain galaxias are primarily found in forested stream habitats, whilst southern pygmy perch, Yarra pygmy perch, Murray hardyhead and southern purple-spotted gudgeon are specialists of off-channel habitats. Mountain galaxias, southern purple-spotted gudgeon and Murray rainbowfish are known from only a small number of specimens in the Lower Lakes and have not been collected for over a decade (Wedderburn and Hammer 2003). Conversely, Yarra pygmy perch, southern pygmy perch and Murray hardyhead have traditionally been locally abundant in the Lower Lakes (Wedderburn and Hammer 2003; Higham *et al.* 2005a; Bice and Ye 2006; Bice and Ye 2007) until recently (Bice *et al.* 2008; Hammer 2008).

Yarra pygmy perch and southern pygmy perch are known to be associated with aquatic vegetation (Cadwallader 1979; Woodward and Malone 2002) and in the Lower Lakes were traditionally most abundant in vegetated, off-channel irrigation drains and wetlands around Hindmarsh Island (Wedderburn and Hammer 2003; Bice and Ye 2006; Bice and Ye 2007; Hammer 2007). These habitats were disconnected, dried and desiccated as lake levels fell below 0.3 m AHD. Yarra pygmy perch have not been collected since 2007 and only two known locations remain within the Ramsar site where southern pygmy perch persist. The absence of vegetated habitat in Lake Alexandrina will have catastrophic consequences for any remaining pygmy perch (both species).

Murray hardyhead have also shown a preference for specific habitats in the Lower Lakes at normal operating levels (Wedderburn and Hammer 2003; Bice and Ye 2006). This species was found in similar habitats to the pygmy perch species but as water levels began to recede in 2006/2007 Murray hardyhead displayed a shift in habitat use toward more open habitat (Bice and Ye 2007). This may represent a mechanism to avoid unfavourable conditions and disperse in order to find other favourable habitat areas. Nonetheless, Murray hardyhead prefer off-channel habitats (Wedderburn *et al.* 2007) and a continued absence of preferred adult habitat and spawning habitat (i.e. vegetation) will likely have a major impact on this species.

The common small-bodied native species are typically viewed as generalists, inhabiting a range of off-channel, lake and riverine habitats (Mallen-Cooper 2001). Although abundant in a variety of different habitats, most of these species exhibit some degree of micro-habitat preference within their broader habitat area. Such micro-habitats are important for small-bodied species as they provide protection from predators, shelter and abundant food (Keast 1984; Copp 1997), whilst many species also spawn directly on vegetation. Carp gudgeon and unspecked hardyhead, and to a lesser degree, flat-headed gudgeon and dwarf flat-headed gudgeon, are found in areas with aquatic vegetation and may use vegetation as a spawning substrate (Lintermans 2007). Extremely low water levels and the corresponding loss of such habitat forces fish into open water where there may be increased aggregation and consequently predation, competition and disease transmission.

For introduced species (apart from salmonids, which are more common in the EMLR tributaries), the predominance of unvegetated open water habitat will also represent a negative impact. Common carp, goldfish, tench, eastern gambusia and redfin perch are all to some degree associated with aquatic vegetation (Lintermans 2007). Carp are often abundant in areas of aquatic vegetation and may spawn on vegetation but are also found in open water. Both goldfish and tench appear to be highly associated with aquatic vegetation and are uncommon in open water habitats (Clements 1988; SARDI Unpublished data). Gambusia are often found in high abundances in well vegetated wetland and drain habitats in the Lower Lakes (Bice and Ye 2007), whilst redfin are more commonly caught in lake habitat rather than wetlands in the Lower Lakes (Bice *et al.* 2007) but still exhibit a propensity for vegetation, on which they spawn (Nunn *et al.* 2007).

'Changes in the spatial salinity profile of the Lower Lakes in relation to species tolerance'

The change in the salinity profile of Lake Alexandrina represents a significant negative impact for all obligate freshwater species groups. The impact however, differs between species due to differences in salinity tolerances. Prior to the managed intrusion of saltwater (August 2009), increased salinity in the lake due to evapo-concentration, will have already had a minor negative impact on most large-bodied native species (physico-chemical loss of <20% of adult habitat), with the exception of bony herring. By December 2009, adult habitat loss of >40% can be expected for all species except bony herring, whilst total recruitment failure, as a result of salinities beyond the tolerance of early life stages, can be expected for silver perch, Murray cod and river blackfish. Results for February 2010 are similar with significant adult habitat loss (>40%) and recruitment failure for all species, apart from bony herring, which may still recruit. By December 2010 adult habitat loss of 90-100%, due to physico-chemical exclusion can be expected for golden perch, silver perch, Murray cod, eel-tailed catfish and river blackfish, and all species will exhibit recruitment failure with 100% of lake area above the salinity tolerance of early life stages. Bony herring are more tolerant of saline conditions than the former species and will likely experience major loss of adult habitat (40-90%) and probable recruitment failure.

Adults of common small-bodied native species are quite tolerant of elevated salinities and as such, increased salinity in the lake due to evapo-concentration in August 2009 will not significantly impact these species. In December 2009, following the intrusion of saltwater, approximately 20-40% of the lake area would be beyond the tolerance of adults of all species, perhaps with the exception of Australian smelt. Recruitment in carp gudgeon, flat-headed gudgeon and dwarf flat-headed gudgeon would be severely diminished with salinities in ≥70% of the lake area above the tolerance of early life stages. The tolerance of early life stages of unspecked hardyhead and Australian smelt are unknown; however, considering the typical preference for freshwater and absence of unspecked hardyhead from saline waters (Wedderburn *et al.* 2007), tolerance is probably similar to other native freshwater species. In February 2010, adult habitat loss in the order of 50-80% could be expected for all species except Australian smelt, with a corresponding lake area of 70-90% with salinities above early life stage tolerances. By December 2010, adult habitat loss via physico-chemical exclusion will be 90-100% for all species except Australian smelt, which may persist in significantly reduced numbers. It is unlikely that Australian smelt would recruit in these salinities and as a short-lived species (see Leigh 2002) would probably not persist for long.

In general, the salinity tolerances of threatened small-bodied freshwater species appear narrow when compared to the common small-bodied species, with the exception of Murray hardyhead, which are highly tolerant of saline conditions (Wedderburn *et al.* 2008). Based upon field observations for both pygmy perch species, salinity concentrations in 10-20% of the lake area will likely be beyond their upper tolerance limits in August 2009, prior to saltwater intrusion. By December 2009, after saltwater intrusion, adult habitat loss for both species will be in the order of 50-70%, whilst 80-90% of the lake area will be beyond the tolerance of early life stages and recruitment failure will occur. By February 2010, changes in the salinity profile of Lake Alexandrina would result in adult habitat loss of approximately 90% and 95-100% by December 2010. Southern purple-spotted gudgeon, mountain galaxias and Murray rainbowfish would exhibit a similar declining trajectory to that of both pygmy perch species.

Murray hardyhead possess a far greater tolerance of saline conditions, having been found at salinities of at least 40,000 $mg.L^{-1}$ (McGuckin 1999) and are therefore may to persist for longer. The actual tolerance of this species has not been studied in the laboratory but Wedderburn *et al.* (2008) determined that Murray hardyhead were capable of osmoregulation at salinities of 85,000 $mg.L^{-1}$ and suggested upper tolerance limits for adults may be similar to that of small-mouthed hardyhead (LC50 108,000 $mg.L^{-1}$) (Lui 1969). Although found in several saline water bodies in the MDB this species is not normally found in hyper-saline water bodies and is not present in the Coorong, where small-mouthed hardyhead dominate, despite salinities potentially being within tolerance limits. Thus, this species may be limited by the tolerance of its early life stages or competition (Wedderburn *et al.* 2008). Data suggest that early life stages may be tolerant of salinities up to 25,000 $mg.L^{-1}$, with recruitment observed in some water bodies of this salinity (Lyon and Ryan 2005; SARDI Unpublished data). Therefore, adult habitat loss via physico-chemical exclusion may be minimal until December 2010 when approximately 50% of the lake area may be above adult preference. However, in December 2010 approximately 90-100% of the lake area will likely be above the tolerance of early life stages and therefore recruitment failure is likely.

When compared to native species, introduced fish with the exception of eastern gambusia, are not highly tolerant of raised salinities. Redfin perch in particular are intolerant of salinities of just 8000 $mg.L^{-1}$ (Hart *et al.* 1991). Thus, changes in salinity will have drastic negative impacts on these populations. Prior to saltwater intrusion (August 2009), changes in salinity would have had a minor impact (habitat loss <20%) on all species within this group apart from gambusia. After saltwater intrusion in December 2009 redfin can expect habitat loss in the order of 80% and likely recruitment failure. The lake area within the tolerance of tench will be reduced by approximately 70% and the area inhabitable by carp and goldfish reduced by approximately 60%. Carp recruitment will also be severely impacted as sperm motility is limited above 8330 $mg.L^{-1}$ (Karimov and Keyser 1998). By

August 2010 habitat loss for each species will be similar to December 2009; however recruitment failure is likely for all species. By December 2010 90-100% of the lake area will be above the tolerance of adults of the aforementioned species.

Adult eastern gambusia are highly tolerant of a range of water quality parameters, including salinity (Alcaraz and Garcia-Berthou 2007). As livebearers, progeny are spawned highly developed compared to the larvae of egg laying species. Larvae are typically much less tolerant of raised salinities than juveniles and adults (Hart *et al.* 1991) and thus the accelerated development of gambusia at time of spawning may also infer relatively high tolerance for this life stage. As such, gambusia is unlikely to be significantly affected by changes in salinity until December 2010. Prolonged exposure to hyper-saline conditions will eventually lead to mortality and recruitment failure in this species, however, adult habitat loss will likely be less than for other species (<90%).

The diadromous, estuarine and marine species investigated are generally tolerant of raised salinities. Nevertheless, the majority of these species exhibit preferences for habitats with salinities lower than those predicted for December 2010. Freshwater stages of diadromous species will be negatively affected by increased salinities, whilst estuarine and marine species will show variable responses.

Many of the selected estuarine species are dependent on freshwater inflows but preferentially do not reside in 'completely' freshwater and are uncommon in Lake Alexandrina (with the exception of small-mouthed hardyhead and all four goby species). For these species, increasing salinity in Lake Alexandrina, assuming movement into the lake is somehow facilitated, would initially represent an opportunity for an increase in range. Salinity gradients will be present for several months after intrusion with large areas suitable for the residence of estuarine species. Therefore between October 2009 and February 2010 there may be an increase in abundance of estuarine species in Lake Alexandrina. By December 2010, after extensive saltwater intrusion and evapo-concentration, salinities in the vast majority of the lake will be hyper-saline. These salinities are likely beyond preferred ranges. Conditions in the lake will also not be favourable for spawning and recruitment in many species (e.g. black bream). Therefore by December 2010, the impact of changes in the spatial salinity profile on most estuarine species will be minor or insignificant, with a minor increase or no increase in range and abundance. This impact may be negative as fish that could have resided in the Coorong would now be trapped within the hyper-saline lake.

Change in the salinity profile of Lake Alexandrina will represent a greater positive impact for some species. Yellow-eyed mullet are tolerant of raised salinities and therefore will likely increase in abundance, whilst small-mouthed hardyhead may have a major increase in abundance. Small-mouthed hardyhead are one of the most salt-tolerant fish in the world, able to tolerate salinities

>100,000 mg/L (Lui 1969) and is the only fish able to tolerate salinities in the southern lagoon of the Coorong where it thrives (Molsher *et al.* 1994). Small-mouthed hardyhead also tolerate relatively low salinities and are commonly caught in Lake Alexandrina (Bice and Ye 2007; Jennings *et al.* 2008) and therefore upon increases in salinity this species is likely to become the dominant fish within the lake.

'Static small-volume flows of River Murray water provided to Lake Alexandrina'

The delivery of static low-volume flows of River Murray water to Lake Alexandrina will represent a major impact to golden perch and silver perch. A small volume (150 GL) of freshwater from the River Murray will flow into the lake in the year following the commencement of saltwater intrusion under option 1 and it is likely that this water will be provided as consistent low-volume inputs. Ecological processes in large rivers, to a large extent are controlled by flow variability (Puckridge *et al.* 1998) and fish spawning is one such process. It is widely believed that golden perch and silver perch are stimulated to spawn by floods (Harris and Gehrke 1994; Schiller and Harris 2001) and increases in within-channel flows (Mallen-Cooper and Stuart 2003). A lack in variability of flow from the River Murray would likely result in an absence of spawning cues for golden perch and silver perch and thus recruitment failure is likely. Murray cod are not flow-cued spawners but it has been suggested that increased flow may enhance recruitment in this species (Humphries *et al.* 1999). Therefore the delivery of static low-volume freshwater inflows to Lake Alexandrina may also majorly impact this species.

'Loss of freshwater flow to the Coorong (loss of salinity gradient)'

Freshwater flows to estuaries transport nutrients and sediment that drive estuarine productivity (Goecker *et al.* 2009) and maintain a mixing zone between marine and freshwater environments. These inflows create salinity gradients which provide navigational cues for diadromous fish and zones of brackish salinities preferred by many estuarine and marine species.

Freshwater flows into estuaries are equally important for anadromous and catadromous species but for different reasons. Anadromous species, like short-headed lamprey and pouched lamprey, which migrate upstream as adults to spawn in freshwater habitats, likely use salinity gradients and olfactory cues as a navigational guide. In 2006/07, low-volume freshwater inflows were delivered to the Coorong via the Murray Barrages, and short-headed lamprey were regularly sampled migrating upstream, into the lake in spring (Bice *et al.* 2007). In 2007/08 following the cessation of freshwater flows to the Coorong, no short-headed were collected migrating upstream during the migration season (Jennings *et al.* 2008).

Catadromous species like congolli and common galaxias exhibit adult freshwater residence, estuarine spawning and upstream migration into freshwater habitats as juveniles. Such species may utilise brackish zones as spawning and nursery areas and salinity gradients likely act as a navigational guide for juveniles migrating upstream. Similar to lampreys, following the cessation of freshwater flows in 2007/08, Jennings *et al.* (2008) recorded a decrease in the abundance of juvenile congolli attempting to migrate upstream of approximately 99%.

Short-finned eel are also catadromous but this species spawns in the Coral Sea (Lintermans 2007). Larvae are carried down the east coast of Australia and migration into freshwater rivers occurs after metamorphosis into a 'glass eel' stage. Movement upstream into rivers is stimulated by the presence of salinity and olfactory cues (McCleave and Jellyman 2002), which will not exist in the absence of freshwater inputs to the Coorong.

The abundance of many estuarine fish species has been shown to be associated with freshwater inflows (see Gillanders and Kingsford 2002) and several authors have suggested the importance of freshwater inputs to the Coorong for estuarine fish (Hall 1984; Geddes and Hall 1990). Most estuarine resident species show a preference for areas with salinities below sea water but adults are typically tolerant of salinities equal to seawater and above. However, it is widely believed that areas of reduced salinity have a positive affect on spawning and recruitment in estuarine fish species. For example, the preferred salinity range for spawning in black bream is thought to be 15,000-25,000 $mg.L^{-1}$ (Newton 1996; Haddy and Pankhurst 1998) and it has been suggested that this species may require freshwater inputs to the Coorong in order to recruit (Ferguson and Ye 2008).

Freshwater inflows may be important for recruitment in estuarine fishes for reasons other than decreased salinity. Freshwater inflows typically increase turbidity in estuaries through the transport of suspended sediment and increased algal production from freshwater nutrient inputs. Piscivorous fish are typically visual predators and as such increased turbidity may reduce piscivorous predation of juvenile and larval estuarine fish (Gregory and Levings 1998; De Robertis *et al.* 2003). Secondly, increased algal production may lead to high abundances of larval food resources and consequently recruitment (Fiksen *et al.* 2002).

Mulloway, particularly juveniles, also show a preference for turbid estuaries with relatively high freshwater inputs and lowered salinities (Gray and McDonall 1993; Griffiths 1996). It has been hypothesised that estuarine residence of juvenile fish may reduce predation, particularly by con-specific adults and increase growth rates (Gray and McDonall 1993). It is likely that the Coorong represents an important juvenile nursery for mulloway and Ferguson *et al.* (2008) have recently demonstrated the importance of freshwater inflows to the Coorong for this species. Ageing analysis of commercial catches has shown strong year classes from previous years of high freshwater input and low recruitment or recruitment failure in years of low or no inflows (Hall 1986). The continued lack of freshwater inputs into the Coorong will likely result in diminished recruitment for mulloway.

'Loss of connectivity between River Murray and Lake Alexandrina'

Longitudinal movements in riverine systems are undertaken by many fish including obligate freshwater and diadromous species. Long-distance upstream migrations are undertaken by two potamodromous species in the MDB, golden perch and silver perch, and it is likely that these movements are for the purpose of spawning and dispersal (Reynolds 1983; Mallen-Cooper *et al.* 1995; Baumgartner *et al.* 2008). With the Wellington Weir in place and no provision for fish passage, connectivity between Lake Alexandrina and the River Murray will be lost and the movement of these species' would be completely obstructed, denying dispersal and access to potential spawning grounds.

Other freshwater species (large-bodied, small-bodied and exotic), although perhaps not truly potamodromous, may attempt to escape Lake Alexandrina and move into the River Murray as salinity in the lake increases. Dispersal migration in freshwater fishes is an important mechanism in avoiding unfavourable conditions (Northcote 1978) and has been recorded elsewhere in Australia (see Bishop *et al.* 1995). This movement to avoid unfavourable conditions would allow the persistence of these individuals in the River Murray and potentially represent a source for re-colonisation of the lake upon the re-establishment of favourable conditions.

Lamprey species' migrate between marine and freshwater environments to spawn. It is widely believed that these species spawn in soft, silty sediments (Koehn and O'Connor 1990) in riverine reaches and have been collected as far upstream in the MDB as Yarrawonga (Lintermans 2007). Access to the River Murray, therefore, is paramount to the persistence of these species'. If individuals are able to gain access to the lake (unlikely) they must then move into the river, which will be obstructed upon the construction of the Wellington Weir.

Obstruction of passage between the lake and river is of less importance to the catadromous species present as they typically reside preferentially within the lake. However, with increasing salinities in the lake, adults of these species may migrate towards the river in search of freshwater habitats but these dispersal migrations will be obstructed.

'Loss of connectivity between marine (the Coorong) and freshwater environments (Lake Alexandrina)'

Movement between freshwater and marine environments is of extreme importance to diadromous species. Man-made physical barriers and the resulting loss of connectivity between freshwater and marine/estuarine environments have been implicated in the reductions of diadromous fish populations in Australia (Harris 1984; Gehrke *et al.* 2002) and overseas (Fraser 1972). As such the continued lack of connectivity between the Coorong and the rest of the MDB may catastrophic consequences for native diadromous species.

Both short-headed lamprey and pouched lamprey likely spawn upstream of the Lower Lakes in the River Murray. Therefore obstruction of passage for this species, denies access to upstream spawning habitats and the species' may be lost from the MDB.

Climbing galaxias, common galaxias, short-finned eel, estuary perch and congolli are all catadromous, with adult freshwater residence, downstream spawning migrations of adults, estuarine/marine spawning and upstream migrations of juvenile fish. Therefore, in order to complete their life cycles, these species require bi-directional passage. Passage in both directions will be obstructed for these species and consequently all may be lost from the lake.

In 2007/08 common galaxias were able to utilise salinity gradients within Lake Alexandrina to spawn and recruit, showing a flexible reproductive strategy (Jennings *et al.* 2008). This was not true for congolli for whom habitat segregation by sex may exacerbate the issue of poor connectivity. Preliminary data suggests that adult females typically reside in Lake Alexandrina, whilst males predominantly reside in the Coorong below the barrages (Jennings *et al.* 2008). As a result, under conditions of limited connectivity sexes are isolated from one another and recruitment is diminished.

The lack of connectivity between estuarine and freshwater environments also represents a negative impact for estuarine species. The pelagic larvae and juveniles of some estuarine fish may passively move over the barrage but there is no provision of passage for the return of these fish into the Coorong. Although in the short-term salinities within Lake Alexandrina may be favourable for the survival and recruitment of estuarine fish species, by December 2010, approximately 90% of the lake area will be outside the preferred salinity ranges of most species, with the exception of yellow-eyed mullet and small-mouthed hardyhead. Individuals may attempt to move back into the Coorong but this movement will not be facilitated.

'Saltwater delivery mechanism'

Saltwater will be delivered by lowering the effective height of Goolwa Barrage and allowing water from the Coorong to 'over-top' the barrage and spill into the lake. This involves a fall of ≥2 m and may place severe physical stress on entrained biota that move over the barrage. The vast majority of fish that will move into the lake are likely to be in egg or larval stages, which are highly fragile when compared to adults and consequently, high mortality rates of early life stages of estuarine and potentially diadromous species can be expected due to the saltwater delivery mechanism.

6.2.2 High risk impacts of Option 2

There are eight significant negative impacts and no significant positive impacts on the selected species as a result of management option 2. These are several minor positive impacts and these are also discussed.

'Vast majority of habitat unvegetated, open habitat'

The potential re-establishment of vegetation within the refuge was viewed as a minor positive impact for several species. More so, the re-establishment of vegetation represents a natural mitigating measure that reduces the severity of impact as a result of unfavourable conditions in the rest of the lake.

Similar to option 1, at a lake level of -1.5 m AHD the only remaining aquatic habitat will be unvegetated, open water habitat; however, within the freshwater refuge vegetation may be re-established. Nevertheless, the vast majority of the lake area (*c.* 90%) will be comprised of unvegetated, open water habitat, which, as mentioned above, is unfavourable to all rare and endangered small-bodied freshwater species, most common small-bodied native freshwater species and most exotic freshwater species.

The area to be included within the refuge primarily includes open channel habitats and very few wetlands. Previously high value habitats for rare and endangered species including Yarra pygmy perch, southern pygmy perch and Murray hardyhead on Hindmarsh Island will not be inundated under this option. The capacity of the refuge to provide suitable habitat for these species is therefore limited.

'Changes in the spatial salinity profile of the Lower Lakes in relation to species tolerance'

Similar to the impact in option 1; however, the area of Lake Alexandrina where favourable salinities (<1500 $\mu S.cm^{-1}$) will be maintained is greater due to the provision of a freshwater refuge. By December 2010, the total lake area 'outside' of the refuge would likely be uninhabitable for most freshwater species. Within the refuge (*c.* 10% of the lake area) salinities may be favourable for the persistence of all of these species. As such, under this option, most freshwater species (large, small, common, rare, native and exotic) can expect a habitat loss of 80-90% due to physico-chemical exclusion. Recruitment in most species (perhaps with the exception of Australian smelt and bony herring) would not occur outside of the refuge but may occur within the refuge.

As per option 1, initial conditions in Lake Alexandrina proper will be favourable for range extensions of most estuarine and marine species. In December 2010, however, the majority of the lake will be hyper-saline and above the preferred ranges for most of these species. Conditions will be favourable for yellow-eyed mullet and small-mouthed hardyhead, which will exhibit marked increases in abundance.

'Static small-volume flows of River Murray water provided to Lake Alexandrina'

As per option 1, the delivery of only static small-volume flows of River Murray water to Lake Alexandrina will have a negative impact on the spawning and recruitment of golden perch and silver perch. Within the refuge however, variable seasonal flows from EMLR tributaries may provide changes in hydrology and water level that cue spawning in these species. These flows will not be sufficient to cause 'over bank' flows but golden perch have been shown to spawn and recruit with increased 'within-channel' flows and water level rises in the middle reaches of the Murray (Mallen-Cooper and Stuart 2003). Golden perch typically spawn in spring and summer at water temperatures over 20°C (Lintermans 2007) and if inflows are received during this period there may be the potential for spawning and recruitment success.

'Loss of freshwater flow to the Coorong (loss of salinity gradient)'

As per option 1, see above.

'Loss of connectivity between the River Murray and Lake Alexandrina'

As per option 1, see above.

"Loss of connectivity between marine (the Coorong) and freshwater environments (Lake Alexandrina and/or refuge)'

Movement between freshwater and marine environments is of extreme importance to diadromous species. Man-made physical barriers and the resulting loss of connectivity between freshwater and marine/estuarine environments have been implicated in the reductions of diadromous fish populations in Australia (Harris 1984; Gehrke *et al.* 2002) and overseas (Fraser 1972).

Conditions in Lake Alexandrina proper are not likely to offer favourable habitat for freshwater dependent life stages of diadromous species. Conditions within the refuge, however, would be favourable for the residence of adult life stages of catadromous species and potentially ammocoetes of lamprey species. Connectivity between the refuge and the Coorong will not be facilitated foregoing an opportunity to conserve diadromous species under this option.

'Creation of incorrect migratory cues below the Clayton regulator'* AND *'no connectivity the refuge and Lake Alexandrina'

Any excess freshwater that may accumulate within the refuge from EMLR tributary inflows will be released into Lake Alexandrina via a spillway on the Clayton regulator. Any diadromous and estuarine species present 'outside' of the refuge are likely to be attracted to these inflows. Currently there is to be no provision of fish passage on this structure and therefore diadromous fish are likely to accumulate below this barrier, which may lead to increased predation, amoung other impacts. When these inflows cease, fish will become entrapped by an area of hyper-saline water and may exhibit high mortality rates.

'Saltwater delivery mechanism: "over-topping"'

As per option 1, see above.

6.3 Summary of fish responses

A summary of predicted fish abundances under the two management options is presented in Tables 15 and 16. The abundance of the selected species within Lake Alexandrina for option 1 is summarised for each species at the four points in time when assessment was undertaken. The predictions represent an interpretation of all impacts on a given species to give an accurate estimation of abundance. Fish species are grouped by life-history (freshwater, diadromous, estuarine and marine). Freshwater species are further grouped by size (large-bodied or small-bodied), conservation status (rare and/or endangered or common) and origin (native or exotic).

Nearly all native freshwater species (14 of 17 species) will likely become extinct in Lake Alexandrina by December 2010 as a result of management option 1 (saltwater intrusion via Goolwa barrage). Recruitment failure may be exhibited by the three remaining species, namely bony herring, Australian smelt and Murray hardyhead, and therefore persistence in the long-term post December 2010 is unlikely. Changes in the spatial salinity profile of Lake Alexandrina will influence all species, whilst some species will also be threatened by habitat changes from lowered water levels prior to saltwater intrusion (e.g. southern pygmy perch). As salinity in Lake Alexandrina increases, mobile species, including golden perch, Murray cod and some small-bodied fish, are likely to attempt avoidance movements into the River Murray but passage will be obstructed by the Wellington Weir. Fish will accumulate below this barrier and be exposed to increased predation and potentially exploitation before likely mortality with rising salinities. Under option 2, all native freshwater species would likely exhibit major decreases in abundance due to changes in the spatial salinity profile of Lake Alexandrina 'outside' of the refuge (*c.* 90% of total lake area) but will persist within the refuge, assuming salinity goals are met and vegetation re-establishes.

The response of all exotic freshwater species, with the exception of eastern gambusia, would be similar to that of large bodied native species. By December 2010 under option 1 carp, goldfish, tench, rainbow trout, brown trout and redfin are likely to be extinct in Lake Alexandrina due to changes in the spatial salinity profile. Gambusia may remain in restricted areas in low abundances. The mobile species, particularly carp and redfin, are likely to accumulate below the Wellington Weir as they seek to move upstream and avoid the unfavourable conditions in the lake following saltwater intrusion. All of these species, with the exception of the salmonids, which are more common in the upper reaches of the tributaries, will persist and potentially undergo rapid increases in abundance within the refuge under option 2.

Diadromous species are significantly threatened under both options, primarily due to the construction of further instream barriers to migration, absence of migration cues and absence of favourable conditions for spawning and recruitment. The anadromous upstream spawning migration of adult lamprey (both species) will be hindered by a number of factors. The lack of freshwater inflow to the Coorong will result in an absence of migratory cues (i.e. salinity gradient and olfactory cues) and if migration is stimulated, the only access to Lake Alexandrina, under both options, is 'over' the Murray Barrages. These species potentially spawn upstream in the River Murray and therefore their migration will be again obstructed by the Wellington Weir. It is unlikely that lampreys will spawn in Lake Alexandrina particularly after saltwater intrusion. There will also be significant obstruction of downstream migrations of juveniles (new recruits). These individuals do not feed until they reach the estuarine/marine environment (Bird and Potter 1981) and their movements into the estuary will be totally obstructed due to the mechanism for saltwater delivery. Therefore, as a result of both option 1 and 2, major decreases in abundance or extinction of both of these already rare species can be expected in the MDB.

All catadromous species will also be significantly threatened under both options. Short-finned eel spawn in the Coral Sea and glass eels carried by currents down the east coast of Australia, rely upon salinity and olfactory cues to locate estuaries and stimulate upstream migration (McCleave and Jellyman 2002). Such cues are absent under both options and connectivity is not facilitated. Congolli and common galaxias also require movement into the estuary but spawn in the local region and potentially recruit within the Coorong. A lack of freshwater inflows to the Coorong may result in the absence of conditions favourable to recruitment. Common galaxias, however, possess a flexible life history, forming land-locked populations in other regions of Australia (Chapman *et al.* 2006) and may potentially complete their lifecycle within Lake Alexandrina. This may not be possible for congolli, a species which exhibits a degree of habitat segregation by sex, with adult females residing in the lake and adult males residing in the Coorong (see Hortle 1978; Jennings *et al.* 2008). The downstream migration of females to spawning grounds will be totally obstructed under both options. If spawning did occur in the Coorong, upstream migrating juveniles would be put under considerable physical stress by 'over-topping' the Murray Barrages.

Conditions in the lake will eventually become unfavourable for catadromous species. Whilst all catadromous species are highly tolerant of raised salinities, the predicted salinities are well outside their preferred ranges. The freshwater refuge in option 2 would provide suitable habitat for adults of catadromous species; however, there is no provision for catadromous fish movement between the refuge and their estuarine spawning habitats. With the exception of common galaxias, major decreases in abundance and perhaps the eventual local extinction of the remaining catadromous species can be expected as a result of both management options.

Most estuarine species can expect only minor increases or no increase in distribution and abundance in Lake Alexandrina. The response of estuarine fish species to both management options varies between species. Under both options, increased salinity in Lake Alexandrina immediately following saltwater intrusion would lead to the creation of habitat area suitable for most estuarine species but with saltwater delivery via 'over-topping', adults of most species, particularly the larger species (e.g. black bream), are unlikely to move into the lake. Larvae and juveniles may passively move into the lake but mortality rates for these individuals are likely to be high. Individuals that survive moving into the lake will find conditions suitable for growth and recruitment and therefore there may be initial increases in abundance. By December 2010, salinities in Lake Alexandrina will be above the preferred salinities of adults of most species and beyond the salinities required for spawning and recruitment in many species. Fish may attempt to return to the Coorong but such movements will not be facilitated.

Consequently, by December 2010, most species would experience only minor increases or no increase in distribution and abundance. The exceptions to his rule are yellow-eyed mullet and particularly small-mouthed hardyhead. Yellow-eyed mullet are more tolerant of raised salinities than the other commercial species and therefore can expect a moderate increase in abundance. Small-mouthed hardyhead are one of the most salt-tolerant species in the world and dominate fish assemblages in the hyper-saline regions of the Coorong. This species is already present in significant abundance in Lake Alexandrina and would likely become the predominating species in the lake under both options.

Mulloway and sea mullet are likely to respond in a similar fashion to the majority of estuarine species. Mulloway will be severely impacted by the continued lack of freshwater inputs to the Coorong and will likely exhibit diminished recruitment. The saltwater delivery mechanism is not conducive to movement but small juveniles may passively move into Lake Alexandrina. Initial conditions will be favourable for growth and recruitment; however by December 2010 salinities in Lake Alexandrina, under both options, will be well above the preferred range for juvenile mulloway. Therefore individuals may attempt to return to Coorong but this movement will not be facilitated. Consequently, mulloway and sea mullet can expect only small increases or no increase in abundance.

Table 15. Likely changes in fish abundance in Lake Alexandrina under management option 1. Key: ↓ - minor decrease, ⇓ - moderate decrease, ⇩ - major decrease, ↑ - minor increase, ⇑ - moderate increase, ⇧ - major increase, ≈ - no change, X – extinction or total emigration.

Species	Scientific name	August 2009	December 2009	February 2010	December 2010
Large-bodied native freshwater species					
Silver perch	*Bidyanus bidyanus*	↓	⇩	⇩	**X**
Golden perch	*Macquaria ambigua*	↓	⇩	⇩	**X**
Murray cod	*Macquaria peelii peelii*	↓	⇩	⇩	**X**
Bony herring	*Nematalosa erebi*	≈	⇓	⇓	⇩
Eel-tailed catfish	*Tandanus tandanus*	↓	⇩	⇩	**X**
River blackfish*	*Gadopsis marmoratus*	↓	⇩	**X**	**X**
Common small-bodied native freshwater species					
Carp gudgeon complex	*Hypseleotris* spp.	↓	⇩	⇩	**X**
Flat-headed gudgeon	*Philypnodon grandiceps*	↓	⇓	⇩	**X**
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	↓	⇩	⇩	**X**
Australian smelt	*Retropinna semoni*	≈	⇓	⇓	⇩
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	↓	⇓	⇩	**X**

* Species most common in the upper reaches of tributaries. Response reflects predictions for fish that may reside in the lake.

Table 15 continued.

Species	Scientific name	August 2009	December 2009	February 2010	December 2010
Rare or endangered small-bodied native freshwater species					
Murray hardyhead	*Craterocephalus fluviatilis*	↓	↓	↓	⇩ or **X**
Mountain galaxias*	*Galaxias olidus*	↓	⇩	**X**	**X**
Murray rainbowfish	*Melanotaenia fluviatilis*	↓	⇩	⇩	**X**
Southern purple-spotted gudgeon	*Mogurnda aspersa*	↓	⇩	⇩	**X**
Southern pygmy perch	*Nannoperca australis*	⇩	⇩	**X**	**X**
Yarra pygmy perch	*Nannoperca obscura*	⇩	⇩	**X**	**X**
Exotic freshwater species					
Goldfish	*Carassius auratus*	↓	⇩	⇩	**X**
Common carp	*Cyprinus carpio*	↓	⇩	⇩	**X**
Tench	*Tinca tinca*	↓	⇩	⇩	**X**
Rainbow trout*	*Oncorhynchus mykiss*	↓	⇩	⇩	**X**
Brown trout*	*Salmo trutta*	↓	⇩	⇩	**X**
Eastern gambusia	*Gambusia holbrooki*	≈	↓	↓	⇩
Redfin perch	*Perca fluviatilis*	↓	⇩	⇩	**X**
Diadromous species					
Pouched lamprey^	*Geotria australis*	⇩	⇩	⇩	⇩ or **X**
Short-headed lamprey^	*Mordacia mordax*	⇩	⇩	⇩	⇩ or **X**
Climbing galaxias@	*Galaxias brevipinnis*	↓	⇩	⇩	⇩ or **X**
Common galaxias@	*Galaxias maculatus*	↓	⇩	⇩	⇩
Short-finned eel@	*Anguilla australis*	⇩	⇩	⇩	⇩ or **X**
Estuary perch@	*Macquaria colonorum*	⇩	⇩	⇩	⇩ or **X**
Congolli@	*Pseudaphritis urvillii*	⇩	⇩	⇩	⇩ or **X**

^ - anadromous species, @ - catadromous species

Table 15 continued.

Species	Scientific name	August 2009	December 2009	February 2010	December 2010
Estuarine species					
Flat-tailed mullet	*Liza argentea*	≈	⇑	↑	≈
Yellow-eyed mullet	*Aldrichetta forsteri*	≈	⇑	⇑	⇑
River garfish	*Hyporhamphus regularis*	≈	⇑	↑	≈
Black bream	*Acanthopagrus butcheri*	≈	⇑	↑	≈
Bridled goby	*Arenogobius bifrenatus*	↑	⇑	⇑	≈
Tamar goby	*Afurcagobius tamarensis*	↑	⇑	⇑	≈
Bluespot goby	*Pseudogobius olorum*	↑	⇑	⇑	≈
Lagoon goby	*Tasmanobius lasti*	↑	⇑	⇑	≈
Greenback flounder	*Rhombosolea tapirina*	≈	⇑	↑	≈
Small-mouthed hardyhead	*Atherinosoma microstoma*	↑	⇑	⇑	⇑
Marine species					
Mulloway	*Argyrosomus japonicus*	≈	⇑	↑	≈
Sea mullet	*Mugil cephalus*	≈	⇑	↑	≈

Table 16. Likely changes in fish abundance in Lake Alexandrina under management option 2. Key: ↓ - minor decrease, ↓ - moderate decrease, ↓ - major decrease, ↑ - minor increase, ↑ - moderate increase, ↑ - major increase, ≈ - no change, X – extinction or total emigration.

Species	Scientific name	December 2010
Large-bodied native freshwater species		
Silver perch	*Bidyanus bidyanus*	↓
Golden perch	*Macquaria ambigua*	↓
Murray cod	*Macquaria peelii peelii*	↓
Bony herring	*Nematalosa erebi*	↓
Eel-tailed catfish	*Tandanus tandanus*	↓
River blackfish*	*Gadopsis marmoratus*	↓
Common small-bodied native freshwater species		
Carp gudgeon complex	*Hypseleotris* spp.	↓
Flat-headed gudgeon	*Philypnodon grandiceps*	↓
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	↓
Australian smelt	*Retropinna semoni*	↓
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	↓
Rare or endangered small-bodied native freshwater species		
Murray hardyhead	*Craterocephalus fluviatilis*	↓
Mountain galaxias*	*Galaxias olidus*	↓
Murray rainbowfish	*Melanotaenia fluviatilis*	↓
Southern purple-spotted gudgeon	*Mogurnda aspersa*	↓
Southern pygmy perch	*Nannoperca australis*	↓
Yarra pygmy perch	*Nannoperca obscura*	↓
Exotic freshwater species		
Goldfish	*Carassius auratus*	↓
Common carp	*Cyprinus carpio*	↓
Tench	*Tinca tinca*	↓
Rainbow trout*	*Oncorhynchus mykiss*	↓
Brown trout*	*Salmo trutta*	↓
Eastern gambusia	*Gambusia holbrooki*	↓
Redfin perch	*Perca fluviatilis*	↓

* Species more common in the upper reaches of tributaries. Response reflects predictions for fish that may reside in the lake.

Table 16 continued.

Species	Scientific name	December 2010
Diadromous species		
Pouched lamprey^	*Geotria australis*	↓ or **X**
Short-headed lamprey^	*Mordacia mordax*	↓ or **X**
Climbing galaxias@	*Galaxias brevipinnis*	↓ or **X**
Common galaxias@	*Galaxias maculatus*	↓
Short-finned eel@	*Anguilla australis*	↓ or **X**
Estuary perch@	*Macquaria colonorum*	↓ or **X**
Congolli@	*Pseudaphritis urvillii*	↓ or **X**
Estuarine species		
Flat-tailed mullet	*Liza argentea*	≈
Yellow-eyed mullet	*Aldrichetta forsteri*	↑
River garfish	*Hyporhamphus regularis*	≈
Black bream	*Acanthopagrus butcheri*	≈
Bridled goby	*Arenogobius bifrenatus*	≈
Tamar goby	*Afurcagobius tamarensis*	≈
Bluespot goby	*Pseudogobius olorum*	≈
Lagoon goby	*Tasmanobius lasti*	≈
Greenback flounder	*Rhombosolea tapirina*	≈
Small-mouthed hardyhead	*Atherinosoma microstoma*	↑
Marine species		
Mulloway	*Argyrosomus japonicus*	≈
Sea mullet	*Mugil cephalus*	≈

^ - anadromous species, @ - catadromous species

7 Mitigation strategies

With the risk of each management option assessed against each of the selected species, the following discussion considers mitigation strategies that may limit the detrimental impacts on the fishes of Lake Alexandrina. Significant impacts will be discussed individually.

7.1 Impact 1: *'Unvegetated, open freshwater habitat only'* (option 1) and *'Vast majority of habitat unvegetated, open freshwater habitat'* (option 2)

- Under option 1 there is no habitat for species highly associated with aquatic vegetation. These are Yarra pygmy perch and southern pygmy perch and to a lesser degree Murray hardyhead and several common small-bodied species.
- Under option 2 the area of suitable habitat for rare and endangered species associated with aquatic vegetation is limited and does not include high value habitats on Hindmarsh Island.

7.1.1 Mitigation

- *Construct the regulator further to the east*

The provision of a freshwater refuge in management option 2 could be viewed as a mitigating strategy for the loss of vegetated habitat in management option 1. The ecological benefit of this refuge, however, could be dramatically increased if the regulator was constructed further to the east. Under the current proposal the regulator will be built near Clayton and would not incorporate Holmes Creek/Mundoo channel or Boundary Creek. The highest value habitat for both pygmy perch species and Murray hardyhead in the region is the wetland and irrigation drain habitats on the eastern side of Hindmarsh Island (Hammer *et al.* 2002; Wedderburn and Hammer 2003; Higham *et al.* 2005b; Bice and Ye 2006; Bice and Ye 2007; Bice *et al.* 2008). Inundation of these habitats would likely ensure the persistence of these *EPBC* and state protected species (if still present), as well as many other small-bodied species. By placing the regulator further to the east, there are greater options for the delivery of low-volume freshwater flows to the Coorong, to enhance estuarine productivity and facilitate diadromous fish passage. Water could be delivered through Mundoo barrage whilst the Hunters Creek fishway could be operated to facilitate diadromous fish passage.

There may be significant cost and construction time issues with building a regulator further to the east. This would nevertheless result in far greater ecological benefits than the current proposed location.

- *Greater regulation of Lakes and Coorong Fishery*

With severely reduced water levels, golden perch are likely to be aggregated in the remaining deep areas of Lake Alexandrina and may be exposed to over-exploitation. Following saltwater intrusion the majority of fish will attempt to enter the Murray River and may become aggregated below the Wellington Weir. Observation and regulation of the golden perch fishery should be undertaken to ensure harvesting is sustainable.

7.2 Impact 2: *'Changes in the spatial salinity profile of the Lower Lakes in relation to species tolerance'*

- Under option 1, by December 2010, salinities in Lake Alexandrina will be above the tolerances of two *EPBC* (*Environmental Protection and Biodiversity Conservation Act 1999*) listed species, Murray cod and Yarra pygmy perch, and several species protected under the *Fisheries Management Act* (2007), including silver perch, eel-tailed catfish, river blackfish, southern pygmy perch and southern purple-spotted gudgeon.
- Under option 2, by December 2010, salinities in approximately 90% of Lake Alexandrina will be above the tolerances of the aforementioned species.

7.2.1 Mitigation

- *Deliver greater volumes of freshwater to the system*

The provision of a freshwater refuge in management option 2, to some degree, is a mitigating strategy for the impact of changes in the salinity profile of Lake Alexandrina in option 1. The refuge represents *c.* 10% of the total lake area. The impact of salinity on the distribution and abundance of freshwater species in Lake Alexandrina is therefore still considerable. This impact could be mitigated by increasing the size of the refuge or with the purchase and delivery of further freshwater to the system. The greater the volume of freshwater inflows to Lake Alexandrina, the less saltwater needed to maintain water levels of -1.5 m AHD. Salinities, although raised, would be far less than those predicted under the current modelling and may facilitate greater persistence of freshwater species in some areas.

The delivery of greater volumes of freshwater would also produce conditions more favourable to estuarine and diadromous fish than under the current proposal. If enough freshwater was delivered, the risk of the lake becoming hyper-saline would be significantly reduced. Salinity gradients would be established over a greater area and allow for the residence and possible spawning and recruitment of estuarine and potentially commercially important species.

7.3 Impact 3: 'Loss of freshwater flow to the Coorong (loss of salinity gradient)'

- Absence of migratory cues for diadromous species.
- Absence of conditions suitable for catadromous spawning and recruitment
- Absence of conditions suitable for spawning and recruitment of estuarine and marine fish, including commercially important species, i.e. black bream, greenback flounder, yellow-eyed mullet and mulloway.

7.3.1 Mitigation

- *Deliver excess freshwater from refuge to the Coorong via the Goolwa vertical-slot fishway*

Under option 1, there are no possible mitigating strategies for this impact. However, under option 2, there is more flexibility in the maintenance of water levels and operation of the Murray Barrages. Currently excess freshwater in the refuge from EMLR tributary inflows is to be released into Lake Alexandrina via a spillway on the Clayton regulator. A far more ecologically beneficial practise would be to release this water into the Coorong via the Goolwa vertical-slot fishway. This would create an estuarine environment downstream of the Goolwa Barrage and dramatically increase production within the immediate area downstream. Estuarine and catadromous fish spawning and recruitment may be facilitated whilst the dual benefit of providing fish passage for diadromous species in and out of the refuge would also be achieved.

7.4 Impact 4: *'Static small-volume flows of River Murray water provided to Lake Alexandrina'*

- Absence of spawning cues and conditions suitable for recruitment of golden perch and silver perch

7.4.1 Mitigation

- *Deliver greater volumes of freshwater to the system*

Under both options there will be no spawning of golden perch and silver perch within Lake Alexandrina. Given that changes in salinity will likely result in the extirpation of these species from the lake mitigating strategies to enhance spawning and recruitment are somewhat irrelevant. However, with greater volumes of freshwater inputs these species may persist in the northern region of lake and variability in these inflows may stimulate spawning. This is unlikely and providing passage for these species into the River Murray is probably more beneficial.

7.5 Impact 5: 'Loss of connectivity between the River Murray and Lake Alexandrina'

- Upstream migrations of both lamprey species obstructed.
- Dispersal migrations (escaping unfavourable conditions in Lake Alexandrina) of freshwater species obstructed.

7.5.1 Mitigation

- *Provide fish passage on the Wellington weir (fishway construction)*

The provision of fish passage on the Wellington Weir will mitigate this impact, allowing obligate migrations of lamprey species and dispersal movements of freshwater species. There will be a diverse range of species from a large size range (40->1000 mm total length) attempting to migrate and the biomass of potential migrants may be enormous. As part of the Murray-Darling Basin Commission's 'Sea to Hume Dam' fish passage restoration program, several fishways have been constructed on main channel weirs of the River Murray and on the Murray Barrages and now successfully pass a range of fish species (Barrett and Mallen-Cooper 2006).

7.6 Impact 6: 'Loss of connectivity between marine and freshwater environments'

- Upstream migrations of adult lampreys and downstream migration of juveniles (new recruits) obstructed.
- Downstream spawning migrations of adult catadromous fish and upstream migration of juvenile (new recruits) fish obstructed.
- Upstream and return downstream movement of estuarine species obstructed.

7.6.1 Mitigation

- *Potential changes in the saltwater delivery mechanism and operation of Goolwa vertical-slot fishway*

Under option 1, the scope for mitigating lost connectivity between the Coorong and Lake Alexandrina is limited. With saltwater delivered via over-topping, the volitional movement of fish into Lake Alexandrina is unlikely and downstream spawning movements of catadromous species and return movements of estuarine fish to the Coorong will be obstructed. Re-establishing connectivity through the construction of fishways would be very difficult under this option. If water was delivered in a different manner, connectivity may be partially restored. If rather than 'lowered', barrage gates were 'opened' during times of low tide in the Coorong (lower head differential and water velocities) some connectivity between the Coorong and Lake Alexandrina may be restored.

Under option 2, connectivity between the Coorong and the freshwater refuge could be facilitated by the operation of the Goolwa vertical slot fishway. This would be of great benefit to catadromous species, allowing bi-directional passage between freshwater and marine/estuarine environments thus enabling these species to complete their life cycles. Nevertheless, the problem of obstructing return movements of estuarine and marine species from Lake Alexandrina 'outside' of the refuge still remains. There is the potential to provide passage for these species by delivering water via Mundoo barrage 'through' barrage gates rather than 'over' the barrage.

7.7 Impact 7: 'Saltwater delivery mechanism'

- High rates of mortality of entrained estuarine and catadromous fish larvae and juveniles
- Does not allow passage into the Coorong for diadromous and estuarine species

7.7.1 Mitigation

- *Potential changes in the saltwater delivery mechanism*

As mentioned previously, allowing saltwater into Lake Alexandrina by removing 'whole' gates or using radial gates to allow water 'through' the barrages rather than 'over' the barrages would greatly benefit a range of fish species. Mortality rates associated with movement into the lake would be significantly reduced, whilst return passage into the Coorong may be facilitated.

8 The preferred management option

The re-establishment of favourable water levels with the delivery of freshwater inflows is preferred to the two options being assessed. Even the maintenance of water levels above the acidification threshold of -1.5 m AHD via the delivery of freshwater inflows from the River Murray is preferred to the two assessed options. However, there are considerable economic and political limitations to providing such an outcome.

Of the two options assessed, option 2, 'the delivery of saltwater via Mundoo and/or Tauwitchere Barrage, with the provision of a freshwater refuge', is more beneficial to the maintenance of the ecological character of the site. Several negative impacts on the fish communities of Lake Alexandrina and the Coorong as a result of management option 2 have been identified in this study and mitigating strategies for some of these impacts have been suggested.

Therefore, assuming the two options in question are the only likely management options available, the following method for management should be undertaken,

- A freshwater refuge to be provided between Goolwa Barrage and a new regulator to maintain some freshwater habitat for freshwater and diadromous species and maintain connectivity with EMLR tributaries. The new regulator should be constructed as far east as possible to incorporate high value habitats on Hindmarsh Island.
- Deliver any excess freshwater in the refuge to the Coorong (rather than Lake Alexandrina) via the Goolwa vertical-slot fishway. This will provide an estuarine environment below the barrage for estuarine fish spawning and recruitment and facilitate the passage of diadromous species in and out of the refuge.
- Provide passage for the 'whole' fish community on the Wellington Weir. This will allow the upstream migration of lampreys (if they are able to get into Lake Alexandrina) and dispersal migrations of various freshwater species (avoidance of unfavourable conditions in Lake Alexandrina).
- Deliver saltwater to Lake Alexandrina 'outside' of the refuge 'through' Mundoo and/or Tauwitchere Barrage rather than 'over' the barrages. This will provide greater connectivity for diadromous and estuarine species and also reduce mortality rates associated with passage past the barrages.
- Control commercial fishing within the freshwater refuge and immediately below the Wellington weir to avoid the over-exploitation of aggregations of golden perch. Observe and regulate the Lakes and Coorong fishery prior to saltwater intrusion to avoid the over-exploitation of already aggregated stocks.

- Control illegal pumping of freshwater from the refuge and secure sufficient water from the EMLR tributaries to maintain water levels within the refuge and allow some release of freshwater to the Coorong.

9 Further investigations and monitoring

The predictions and suggestions made in this report are based on several assumptions associated with the management options investigated and represents the 'best possible' assessment given the current situation. To better inform management agencies on the likely impacts on native fish populations the following investigation and research should be carried out.

- Impacts on fish assemblages as a result of the proposed management options are likely not limited to those identified by this project. Several other major impacts from saltwater intrusion, such as the effect on trophic dynamics, may significantly influence fish assemblages. Information of this nature is lacking and would provide greater insight and predictive power.

- Modelling of changes in the salinity profile 'within' the proposed refuge is probably of most importance. For the purpose of this project we assumed 'within refuge' salinities of <1500 $\mu S.cm^{-1}$. This represents a best case scenario and in reality salinity may be much higher. Prior to pumping, salinity within the refuge will be high, as may the salinity of pumped water if it is to come from the lake. Refuge salinities will also vary based on EMLR inflows. This modelling must be carried out to determine, with greater confidence, the capacity of the refuge to conserve freshwater fish species.

- Modelling of the changes in the salinity profile of Lake Alexandrina 'outside' of the refuge under option 2 would also be valuable. Predictions of salinities used in this project are likely to be conservative and dedicated modelling information would also provide greater predictive power.

- The dynamics of changes in pH and metal ion release from exposed ASS needs to be investigated in greater detail. pH will increase and metal ions may be released into remaining water as wind seiching causes exposed areas of ASS to be re-wetted. Similarly, vast areas of ASS within the refuge will be re-wetted after the construction of the Clayton regulator and the resulting effect on water quality has not been investigated. High concentrations of metal ions (particularly aluminium which is common in ASS in the Lower Lakes) in water can be fatal for fish.

- The feasibility of using alternative options for saltwater delivery must be investigated. The current proposed mechanism is ecologically absurd and will likely produce no ecological benefit. Removing 'whole' barrage gates or utilising automated radial gates at Tauwitchere and Mundoo must be investigated as saltwater delivery via these pathways provides greater ecological connectivity.

- Maintaining lake levels higher than -1.5 m AHD should also be investigated. Options for allowing the volitional passage of estuarine species in and out of Lake Alexandrina are far greater if lake levels are to be maintained at a greater height. However, this may have a greater impact on the ability of the Lower Lakes to recover from saltwater intrusion.

- A rigorous quantitative monitoring program must be implemented to determine the 'real' impact of the management option undertaken. Extensive and targeted sampling of fish assemblages must be conducted prior to the commencement of saltwater intrusion and after saltwater intrusion. Changes in fish assemblages within the refuge area should also be investigated. Such monitoring may identify population declines or increases and may provide a tool for adaptive management of the system. This will also provide ground-truthing for predictions made in this and other projects.

10 Conclusion

The Lower Lakes and Coorong Ramsar site is under extreme threat of ecological collapse on a scale never witnessed in the MDB and perhaps Australia in general. Whilst the proposed management options for the site may mitigate the risk posed by ASS, drastic changes in the fish community can be expected with the potential for the local extinction of some species. Therefore both investigated options are high risk and neither is viewed as favourable. The most ecologically beneficial solution to the current threat posed by low water levels and ASS is the purchase and delivery of large volumes of freshwater from the River Murray but this is highly unlikely due to economic and political limitations. Of the two options considered, option 2, 'saltwater intrusion via Mundoo and/or Tauwitchere Barrage with the provision of a freshwater refuge' appears the best option. Nevertheless, this option would still result in significant impacts on the resident fish community.

All groups of species (freshwater, diadromous, estuarine and marine) are impacted under this option. Most freshwater species can expect decreases in distribution and abundance of ≥ 90%. The passage of all diadromous species will be obstructed and consequently recruitment failure can be expected, whilst return movements of estuarine and marine species, upon rising salinities in Lake Alexandrina, will not be facilitated. These species can expect initial increases in abundance but this impact will become minor or insignificant in the longer term. The lake will eventually come to be dominated by the estuarine small-mouthed hardyhead, a highly salt-tolerant species, with a situation somewhat resembling that of the Coorong southern lagoon in the recent past.

It must be stressed that the predictions made in this report are based on many assumptions. Data on many factors that may influence fish populations as part of these management options are scarce. However, the predictions presented represent the 'best case' assessment given the information available and are likely quite accurate.

Several mitigating options have been identified that would limit the negative impact on the resident fish community under option 2. These are:

- Construct the Clayton regulator as far east as possible
- Control the exploitation of aggregated fish by the commercial and recreational sectors
- Control illegal pumping of freshwater from the refuge
- Release excess water in the refuge through Goolwa Barrage and operate the Goolwa vertical-slot fishway
- Provide fish passage on the Wellington weir

- Investigate and consider changes to the method for saltwater delivery

Regardless of mitigating strategies, the fish community of the Lower Lakes and Coorong will be detrimentally affected. The current situation in the region and the MDB in general is a result of mismanagement of the river system and decades of over allocation of water resources. This has lead to reduced resilience in the system and made the MDB more vulnerable to drought and the combination of these two factors has resulted in the present day situation. This highlights the need to re-instate large-volume freshwater flows to the Lower Lakes and Coorong and without these inflows any management solutions are reactionary and extremely limited in maintaining the ecological character of the Ramsar site.

11 References

Alcaraz C and Garcia-Berthou E (2007) Life-history variation of invasive mosquitofish *(Gambusia holbrooki*) along a salinity gradient. *Biological Conservation* **139**, 83-92.

Aquaculture SA (2003) 'Mulloway aquaculture in South Australia.' PIRSA, FS No. 35/03, Adelaide.

Bacher G and Garnham J (1992) 'The effect of salinity to several to several freshwater aquatic species of southern Victoria.' Freshwater Ecology Section, Flora and Fauna Division, Department of Conservation and Environment. EPA Report SRS 92/003.

Barnett C and Pankhurst N (1999) Reproductive biology and endocrinology of greenback flounder *Rhombosolea tapirina* (Gunther 1862). *Marine and Freshwater Research* **50**, 35-42.

Barrett J and Mallen-Cooper M (2006) The Murray River's 'Sea to Hume Dam' fish passage program: Progress to date and lessons learned. *Ecological Management and Restoration* **7**, 173.

Baumgartner LJ, Stuart IG and Zampatti BP (2008) Synthesis: what have we learnt about fish passage in the Murray-Darling Basin. In 'The Sea to Hume Dam: Restoring Fish Passage in the Murray River'. (Ed. J Barrett) pp. 76-85. (Murray-Darling Basin Commission, Canberra)

Bice C, Jennings P and Zampatti B (2007) 'Fish movement and recruitment in the Coorong and Lower Lakes: 2006/07 progress report.' South Australian Research and Developement Institute (Aquatic Sciences), Adelaide, 48pp. SARDI Publication No. 2007/000555-1. SARDI Research Report Series No. 232.

Bice C, Wilson P and Ye Q (2008) 'Threatened fish populations in the Lower Lakes of the River Murray in spring 2007 and summer 2008.' South Australian Research and Developement Institute (Aquatic Sciences), Adelaide. 32pp. SARDI Publication number F2008/000801-1.

Bice C and Ye Q (2006) 'Monitoring threatened fish communities on Hindmarsh Island, in the Lower Lakes of the River Murray, South Australia in 2005.' South Australian Research and Developement Institute (Aquatic Sciences), Adelaide, SARDI Publication Number RD06/0004-1.

Bice CM and Ye Q (2007) 'Monitoring threatened fish communities on Hindmarsh Island, in the Lower Lakes of the River Murray, South Australia, in the summers of 2006 and 2007 with reference to baseline data from 2005.' South Australian Research and Developement Institute (Aquatic Sciences), Adelaide, 47pp. SARDI Publication Number F2007/000551-2.

Bird DJ and Potter IC (1981) Proximate body composition of the larval, metamorphosing and downstream migrant stages in the life cycle of the Southern Hemisphere lamprey, *Geotria australis*. *Environmental Biology of Fishes* **6**, 285-297.

Bishop KA, Pidgeon RWJ and Walden DJ (1995) Studies on fish movement dynamics in a tropical floodplain river: Prerequisites for a procedure to monitor the impacts of mining. *Australian Journal of Ecology* **20**, 81-107.

Boys C and Thoms M (2006) A large-scale, hierarchical approach for assessing habitat associations of fish assemblages in large dryland rivers. *Hydrobiologia* **572**, 11-31.

Brown T, Morley A, Sanderson N and RD T (1983) Report of a large fish kill resulting from natural acid water conditions in Australia. *Journal of Fish Biology* **22**, 335-350.

Cadwallader PL (1979) Distribution of native and introduced fish in the Seven Creeks river system, Victoria. *Australian Journal of Ecology* **4**, 361-385.

Cadwallader PL and Backhouse G (Eds) (1983) 'A guide to freshwater fishes of victoria.' (Victorian Government printing house: Melbourne)

Chapman A, Morgan DL, Beatty SJ and Gill HS (2006) Variation in life history of land-locked lacustrine and riverine populations of *Galaxias maculatus* (Jenyns 1842) in Western Australia. *Environmental Biology of Fishes* **77**, 21-37.

Cheshire K and Ye Q (2008) 'Larval fish assemblages below Locks 5 and 6, in the River Murray, South Australia from 2005 to 2007: with reference to water manipulation trials ' South Australian Research and Developement Institute, Aquatic Sciences, Adelaide, pp 42. SARDI Publication Number F2007/000705-1

Chessman B and Williams W (1974) Distribution of fish in inland saline waters in Australia. *Australian Journal of Marine and Freshwater Research* **25**, 167-172.

Chubb C, Potter I, Grant C, Lenanton R and Wallace J (1981) Age structure, growth rates and movements of sea mullet, *Mugil cephalus* L. and yellow-eye mullet, *Aldrichetta forsteri* (Valenciennes), in the Swan-Avon River system, Western Australia. *Australian Journal of Marine and Freshwater Research* **32**, 605-628.

Clarkson R and Childs M (2000) Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin Big-River fishes. *Copeia* **2000**, 402-412.

Clements J (1988) 'Salmon at the Antipodes. A History and Review of the Trout, Salmon and Char, and Introduced Coarse Fish in Australia.' (John Clements, Ballarat, Australia)

Clunie P, Ryan T, James K and Cant B (2002) 'Implications for rivers from salinity hazards: Scoping study. Report for the MDBC-project R2003.' Arthur Rylah Institute, Heidleberg, Victoria, Australia.

Connolly R (1994) A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary. *Australian Journal of Marine and Freshwater Research* **45**, 1033-1044.

Copp GH (1997) Importance of marinas and off-channel water bodies as refuges for young fishes in a regulated lowland rivers. *Regulated Rivers: Research & Management* **13**, 303-307.

Craig G and Baksi W (1977) The effects of depressed pH on flagfish reproduction, growth and survival *Water Research* **11**, 621-626.

Crawshaw L (1979) Responses to rapid temperature change in vertabrate ectotherms. *American Zoologist* **19**, 225-237.

Dawson K (2002) Fish kill events and habitat losses of the Richmond river, NSW Australia: An overview *The Journal of Coastal Research* **36**, 216-221.

De Robertis A, Ryer CH, Veloza A and Brodeur RD (2003) Differential effects of turbidity on prey consumption of piscivorous and planktivorous fish. *Canadian Journal of Fisheries and Aquatic Sciences* **60**, 1517-1526.

DEH (2000) 'Coorong and Lakes Alexandrina and Albert Ramsar Management Plan.' Department of Environment and Heritage, Adelaide.

Echelle A, Echelle A and Hill L (1972) Interspecific interactions and limiting factors of abundance and distribution in the Red River pupfish, *Cyprinodon rubrofluviatilis*. *American Midland Naturalist* **88**, 109-130.

Eckert J and Robinson R (1990) The fishes of the Coorong. *South Australian Naturalist* **65**, 5-30.

Edgar G and Shaw C (1995) The production and trophic ecology of shallow-water fish assemblages in southern Australia. I. Species richness, size-structure and production of fishes in Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* **194**, 53-81.

Ellis I (2005) 'Ecology and breeding seasonality of the Murray hardyhead *Craterocephalus fluviatilis* (McCulloch), Family Atherinidae, in two lakes near Mildura, Victoria.' Murray-Darling Freshwater Research Centre, Lower Basin Laboratory, Mildura.

Ferguson G and Ward T (2003) 'Mulloway (*Argyrosomus japonicus*) Fishery.' South Australian Research and Developement Institute (Aquatic Sciences), Adelaide. 63pp.

Ferguson G and Ye Q (2008) 'Black Bream (*Acanthopagrus butcheri*). Stock Assessment Report for PIRSA Fisheries. SARDI Aquatic Sciences Publication No. F2008/000810-1.' South Australian Research and Developement Institute, Aquatic Sciences, Adelaide.

Ferguson GJ, Ward TM and Geddes MC (2008) Do recent age structures and historical catches of mulloway, *Argyrosomus japonicus* (Scianidae), reflect freshwater inflows in the remnant estuary of the Murray River, South Australia? *Aquatic Living Resources* **21**, 145-152.

Fielder D and Bardsley W (1999) A preliminary study on the effects of salinity on growth and survival of mulloway *Argyrosomus japonicus* larvae and juveniles. *Journal of the World Aquaculture Society* **30**, 380-387.

Fiksen O, Aksnes DL, Flyum MH and Giske J (2002) The influence of turbidity on growth and survival of fish larvae: a numerical analysis. *Hydrobiologia* **484**, 49-59.

Fitzpatrick R, Shand P, Marvanek S, Merry R, Thomas M, Raven M, Simpson S and McClure S (2008) 'Acid sulfate soils in subaqueous, waterlogged and drained soil environments in Lake Albert, Lake Alexandrina and River Murray below Blanchtown (Lock 1): properties, distribution, genesis, risks and management.' CSIRO Land and Water Science. Report 46/08.

Fraser JC (1972) Regulated discharge and the stream environment. In 'River Ecology and Man'. (Ed. RT Oglesby) pp. 263-285. (Academic Press: New York)

Fromm P (1980) A review of some physiological and toxicological responses of freshwater fish to acid stress. *Environmental Biology of Fishes* **5**, 79-93.

Geddes MC and Hall D (1990) The Murray Mouth and Coorong. In 'The Murray'. (Eds N MacKay and D Eastburn) pp. 201-214. (Murray-Darling Basin Commission, Canberra)

Gee J and Gee P (1991) Reactions of gobioid fishes to hypoxia: Bouyancy control and aquatic surface respiration *Copeia* **1**, 17-28.

Gehrke PC, Brown P, Schiller CB, Moffat DB and Bruce AM (1995) River regulation and fish communities in the Murray-Darling River system, Australia. *Regulated Rivers: Research & Management* **11**, 363-375.

Gehrke PC, Gilligan DM and Barwick M (2002) Changes in fish communities of the Shoalhaven River 20 years after construction of the Tallowa Dam, Australia. *River Research and Applications* **18**, 265-286.

Gill H and Potter IC (1993) Spatial segregation amongst goby species within an Australian estuary, with a comparison of the diets and salinity tolerance of the two most abundant species. *Marine Biology* **117**, 515-526.

Gillanders B and Kingsford M (2002) Impacts of changes in flow of freshwater on estuarine and open coastal habitats and the associated organism. *Oceanography and Marine Biology: an Annual Review* **2002**, 233-309.

Goecker ME, Valentine JF, Sklenar SA and Chaplin GI (2009) Influence from hydrological modification on energy and nutrient transference in a deltaic food web. *Estuaries and Coasts* **32**, 173-187.

Gray C and McDonall V (1993) Distribution and growth of juvenile mulloway, *Argyrosomus hololepidotus* (Pisces: Sciaenidae) in the Hawkesbury River, south-eastern Australia. *Australian Journal of Marine and Freshwater Research* **44**, 401-409.

Gregory RS and Levings CD (1998) Turbidity reduces predation on migrating juvenile Pacific salmon. *Transactions of the American Fisheries Society* **127**, 275-285.

Griffiths MH (1996) Life history of the dusky kob *Argyrosomus japonicus* (Scianidae) off the east coast of South Africa. *South African Journal of Marine Science* **17**, 135-154.

Guo P, Mather B and Capra M (1995) Salinity tolerance and osmoregulation in the silver perch, *Bidyanus bidyanus* Mitchell (Teraponidae), an endemic Australian freshwater teleost. *Marine and Freshwater Research* **46**, 947-952.

Haddy J and Pankhurst N (1998) Annual change in reproductive condition and plasma concentrations of sex steroids in black bream, *Acanthopagrus butcheri* (Munroe) (Teleostei: Sparidae). *Marine and Freshwater Research* **49**, 389-397.

Haddy J and Pankhurst N (2000) The effects of salinity on reproductive developement, plasma steroid levels, fertilisation and egg survival in black bream *Acanthopagrus butcheri*. *Aquaculture* **188**, 115-131.

Hall D (1984) The Coorong: biology of the major fish species and fluctuations in catch rates 1976-1984. *SAFIC* **8**, 3-17.

Hall DA (1986) 'An assessment of the mulloway (*Argyrosomus hololepidotus*) fishery in South Australia with particular reference to the Coorong Lagoon.' Department of Fisheries South Australia.

Hammer M (2004) 'The Eastern Mt Lofty's Fish Inventory: Distribution and Conservation of Freshwater Fishes of Tributaries to the Lower River Murray, South Australia.' Native Fish Australia (SA) Inc. and River Murray Catchment Water Management Board.

Hammer M (2005) 'Recovery monitoring for the Southern Pygmy Perch in the Mount Lofty Ranges, 2001-2005 review.' Native Fish Australia (SA) Inc, Adelaide.

Hammer M (2007) 'Distribution, status and urgent conservation measures for Yarra Pygmy Perch in the Murray-Darling Basin.' Aquasave consultants, Adelaide.

Hammer M (2008) 'Status review of wild and captive populations of Yarra pygmy perch in the Murray-Darling Basin.' Aquasave Consultants, Adelaide.

Hammer M, Wedderburn S and Westergaard S (2002) 'Freshwater fishes of Wyndgate: an island refuge.' Report to the Department of Environment and Heritage as part of the Biological Survey Program, Adelaide, South Australia.

Hardie S (2000) 'Examination of fish and invertebrate fauna in seven lakes in the Swan Hill-Kerang Region, Northern Victoria.' Department of Natural Resources and Environment, Victoria.

Harris J and Gehrke P (1994) Modelling the relationship between streamflow and population recruitment to manage freshwater fisheries. *Australian Fisheries* **6**, 28-30.

Harris JH (1984) Impoundment of coastal drainages of south-eastern Australia, and a review of its relevance to fish migrations. *Australian Journal of Zoology* **21**, 235-250.

Hart P, Bailey P, Edwards R, Hortle K, James K, McMahon A, Meredith C and Swadling K (1991) A review of the salt sensitivity of the Australian freshwater biota. *Hydrobiologia* **210**, 105-144.

Hart P, Hutchinson W and Purser G (1996) Effects of photoperiod, temperature and salinity on hatchery-reared larvae of the greenback flounder (*Rhombosolea tapirina* Gunther, 1862). *Aquaculture* **144**, 303-311.

Hart P and Purser G (1995) Effects of salinity and temperature on eggs and yolk sac larvae of the greenback flounder (*Rhombosolea tapirina* Gunther, 1862). *Aquaculture* **136**, 221-230.

Higham J, Ferguson G and Ye Q (2005a) 'Lakes and Coorong yellow-eye mullet (*Aldrichetta forsteri*) fishery.' South Australian Research and Developement Institute (Aquatic Sciences), Adelaide. SARDI Publication Number RD04/0162. 49pp.

Higham J, Ye Q and Smith B (2005b) 'Murray Darling Basin Drought Monitoring: 'Monitoring small-bodied fish in the Lower Murray during and after drought conditions in 2003-2004.' Project Final Report to the Department of Water, Land and Biodiversity Conservation.

Hortle M (1978) The ecology of the sandy, *Pseudaphritis urvillii,* in south-east Tasmania. Honours thesis, University of Tasmania.

Hotos G and Vlahos N (1998) Salinity tolerance of *Mugil cephalus* and *Chelon labrosus* (Pisces: Mugilidae) fry in experimental conditions. *Aquaculture* **167**, 329-338.

Humphries P (1995) Life history, food and habitat of Southern pygmy perch, *Nannoperca australis*, in the Macquarie River, Tasmania. *Marine and Freshwater Research* **46**, 1159-1169.

Humphries P, King A and Koehn J (1999) Fish, flows and floodplains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes* **56**, 129-151.

Humphries P, Serafini LG and King AJ (2002) River regulation and fish larvae: variation through space and time. *Freshwater Biology* **47**, 1307-1331.

Jackson G and Pierce B (1992) Salinity tolerance of selected adult Murray-Darling Basin fishes. *Newsletter of the Australian Society for Fish Biology* **22**, 35.

Jasim B (1988) Tolerance and adaptation of goldfish, *Carrasius auratus L.* to salinity. *Journal of Biological Sciences Research (1012-344X)* **19**.

Jennings P, Zampatti B and Bice C (2008) 'Fish movement and recruitment in the Coorong and Lower Lakes 2007/08 Progress Report.' South Australian Research and Developement Institute (Aquatic Sciences), Adelaide. 47pp

Jenson A, Good M, Harvey P, Tucker P and Long M (2000) 'River Murray barrages environmental flows: An evaluation of environmental flow needs in the Lower Lakes and Coorong.' A report for the Murray-Darling Basin Commission.

Kailola P, Williams M, Stewart P, Reichelt R, McNee A and Grieve C (Eds) (1993) 'Australian Fisheries Resources.' (Bureau of Resource Sciences, Department of Primary Industries and Energy and the Fisheries Research and Developement Corporation: Canberra)

Karimov B and Keyser D (1998) The effect of salt composition on the salinity tolerance of mirror carp (*Cyprinus carpio* L.) during early ontogeny. *Archive of Fishery and Marine Research* **46**, 225-239.

Keast A (1984) The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their invertebrate prey. *Canadian Journal of Zoology* **62**, 1289-1303.

Koehn J and Harrington D (2006) Environmental conditions and timing for the spawning of Murray cod (*Maccullochella peelii peelii*) and the endangered trout cod (*M. macquariensis*) in southeastern Australian rivers. *Rivers Research and Applications* **22**, 327-342.

Koehn JD and O'Connor WC (1990) 'Biological information for the management of native freshwater fish in Victoria.' Department of Conservation and Environment, Freshwater Fish Management Branch & Arthur Rylah Institute for Environmental Research, North Melbourne.

Kroon F (2005) Behavioural avoidance of acidified water by juveniles of four commercial fish and prawn species with migratory life stages. *Marine Ecological Progress Series* **285**, 193-204.

Kurth D (1957) An inverstigation of the greenback flounder, *Rhombosolea tapirina* Gunther. PhD Thesis, University of Tasmania

Lake JS (1967) Rearing experiments with five species of Australian freshwater fishes. 1. Inducement of spawning. *Australian Journal of Marine and Freshwater Research* **18**, 137-153.

Leigh SJ (2002) Aspects of the life-history and population biology of the Australian smelt, *Retropinna semoni* (Weber 1895) (Salmoniformes: Retropinnidae) for a lower Murray River population. B Sc (Hons) Thesis, University of Adelaide.

Lintermans M (2007) 'Fishes of the Murray-Darling Basin: An introductory guide.' (Murray-Darling Basin Commission, Canberra)

Llewellyn LC (2006) Breeding and development of the endangered purple-spotted gudgeon *Mogurnda aspersa* population from the Murray-Darling. *Australian Zoologist* **33**, 480-510.

Lloyd LN and Walker KF (1986) Distribution and conservation status of small freshwater fish in the River Murray, South Australia. *Transactions of the Royal Society of South Australia* **110**, 49-57.

Lucas M and Baras E (2001) 'Migration of Freshwater Fishes.' (Blackwell Sciences, Oxford)

Lui LC (1969) Salinity tolerance and osmoregulation in *Taenomembrus microstomus* (Gunther, 1861) (Pisces: Mugiliformes: Atherinidae) from Australian salt lakes. *Australian Journal of Marine and Freshwater Research* **20**, 157-162.

Lyon J and Ryan T (2005) Observations of the nationally threatened freshwater fish, Murray Hardyhead *Craterocephalus fluviatilis* McCulloch 1913, in three Victorian salt lakes. *The Victorian Naturalist* **122**, 78-84.

Mallen-Cooper M (2001) 'Fish passage in off-channel habitats of the Lower Murray River. Part 1. Overview of fish biology and fish passage.' Wetland Care Australia, NSW.

Mallen-Cooper M and Stuart IG (2003) Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications* **19**, 697-719.

Mallen-Cooper M, Stuart IG, Hides-Pearson F and Harris JH (1995) 'Fish migration in the Murray River and assessment of the Torrumbarry fishway. Final Report for Natural Resources Management Strategy Project N002.' NSW Fisheries Research Institute and the Cooperative Research Centre for Freshwater Ecology.

Matthews W (1998) 'Patterns in Freshwater Fish Ecology.' (Kluwer Academic Publishers, Massachusetts, USA)

May H and Jenkins G (1992) Patterns of settlement and growth of juvenile flounder *Rhombosolea tapirina* determined from otolith microstructure. *Marine Ecological Progress Series* **79**, 203-214.

McCleave JD and Jellyman DJ (2002) Discrimination of New Zealand stream waters by glass eels of *Anguilla australis* and *Anguilla dieffenbachii*. *Journal of Fish Biology* **61**, 785-800.

McDowall RM (1988) 'Diadromy in Fishes - Migrations between Freshwater and Marine Environments.' (Croom Helm, London, UK)

McDowall RM (Ed.) (1996) 'Freshwater fishes of south-eastern Australia.' (Reed: Sydney)

McGuckin J (1999) 'The fish fauna of Round, Golf Course, South and North Woorinen Lakes, April 1999.' Streamline Research, Melbourne.

McNeil D (2004) Ecophysiology and behaviour of Ovens River floodplain fish: hypoxia tolerance and the role of the physicochemical environment in structuring Australian billabong fish communities. PhD thesis, Latrobe University, Australia.

McNeil D and Hammer M (2007) 'Biological review of the freshwater fishes of the Mount Lofty Ranges.' South Australian Research and Developement Institute (Aquatic Sciences), Adelaide. 104pp. Publication number: F2006/000335.

McNeil D and Westergaard S (In Prep).

McNeil DG and Closs GP (2007) Behavioural responses of a south-east Australian floodplain fish community to gradual hypoxia. *Freshwater Biology* **52**, 412-420.

MDBC (2006) 'The Lower Lakes, Coorong and Murray Mouth Icon Site Environmental Management Plan 2006-2007.'

Meredith S, Gawne B, Sharpe C, Whiterod N, Conallin A and Zuwkowski S (2002) 'Dryland Floodplain Ecosystems: influence of flow patterns on fish production.' Murray-Darling Basin Research Centre, Mildura, report no. 1/2002.

Merrick JR and Schmida EG (1984) 'Australian freshwater fishes: Biology and Management.' (Griffen Press: Netley, South Australia)

Molsher RL, Geddes MC and Paton DC (1994) Population and reproductive ecology of small-mouthed hardyhead *Atherinosoma microstoma* (Gunther) (Pisces: Atherinidae) along a salinity gradient in the Coorong, South Australia. *Transactions of the Royal Society of South Australia* **118**, 207-216.

Neira F and Potter I (1994) The larval fish assemblage of the Nornalup-Walpole estuary, a permanantly open estuary on the south coast of Western Australia. *Australian Journal of Marine and Freshwater Research* **45**, 1193-1207.

Newton GM (1996) Estuarine icthyoplankton ecology in relation to hydrology and zooplankton dynamics in a salt-wedge estuary. *Marine and Freshwater Research* **47**, 99-111.

Nielsen D, Brock M, Rees G and Baldwin D (2003) Effects of increasing salinity on freshwater ecosystems in Australia. *Australian Journal of Botany* **51**, 655-665.

Norriss J, Tregonning J, Lenanton R and Sarre G (2002) 'Biological synopsis of the black bream, *Acanthopagrus butcheri* (Munroe) (Teleostei: Sparidae) in Western

Australia with reference to information from other southern states: Fisheries Research Report.' Department of Fisheries, Western Australia, Perth.

Northcote TG (1978) Migration strategies and production in freshwater fishes. In 'Ecology of Freshwater Fish Production'. (Ed. SD Gerking) pp. 326-359. (Blackwell Scientific Publications: Oxford)

Nunn A, Harvey J and Cowx I (2007) Variations in the spawning periodicity of eight fish species in three English lowland rivers over a 6 year period, inferred from 0+ year fish length distributions. *Journal of Fish Biology* **70**, 1254-1267.

O'Brien T and Ryan T (1999) Impact of saline drainage on key Murray-Darling Basin fish species: Final report to the Murray-Darling Basin Commission. NRMS Project R5004.

Partridge G and Jenkins G (2002) The effect of salinity on growth and survival of juvenile black bream (*Acanthopagrus butcheri*). *Aquaculture* **210**, 219-230.

Phillips B and Muller K (2006) 'Ecological Character Description of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance.' Department of Environment and Heritage.

Potter I and Hyndes G (1994) The composition of the fish fauna of a permanatly open estuary on the southern coast of Australia, and comparisons with a nearby seasonally closed estuary. *Marine Biology* **121**, 199-209.

Potter I, Ivantsoff W, Cameron R and Minnard J (1986) Life cycles and distribution of atherinids in the marine and estuarine waters of southern Australia. *Hydrobiologia* **139**, 23-40.

Preece R and Jones H (2002) The effect of Keepit Dam on the temperature regime of the Namoi River, Australia. *River Research and Applications* **18**, 397-414.

Puckridge J, Sheldon F and Walker K (1998) Flow variability and the ecology of large rivers. *Marine and Freshwater Research* **49**, 55-72.

Puckridge J and Walker KF (1990) Reproductive biology and larval developement of a gizzard shad, *Nematalosa erebi* (Gunther) (Dorosomatinae: Teleostei), in the River Murray, South Australia. *Australian Journal of Marine and Freshwater Research* **41**, 695-712.

Reynolds L (1983) Migration patterns of five fish species in the Murray-Darling River system. *Australian Journal of Marine and Freshwater Research* **34**, 857-871.

Rowland S (1996) Developement of techniques for the large-scale rearing of the larvae of the Australian freshwater fish golden perch, *Macquaria ambigua* (Richardson, 1845). *Marine and Freshwater Research* **47**, 233-242.

Rowntree J and Hammer M (2007) 'Assessment of fishes, aquatic habitat and potential threats at the proposed location of the Wellington Weir, South Australia '

Report to the Department of Environment and Heritage, South Australia. Aquasave Consultants.

SARDI (Unpublished CPUE Lakes and Coorong data).

SARDI (Unpublished data).

Sarre G, Platell M and Potter I (2000) Do the dietary compositions of *Acanthopagrus butcheri* in four estuaries and a coastal lake vary with body size and season and within and amongst these water bodies? *Journal of Fish Biology* **56**, 103-122.

Sarre G and Potter I (1999) Comparisons between the reproductive biology of black bream *Acanthopagrus butcheri* (Teleostei: Sparidae) in four estuaries with widely differing characteristics. *International Journal of Salt Lake Research* **8**, 179-210.

Schiller C and Harris J (2001) Native and alien fish. In 'Rivers as Ecological Systems: The Murray-Darling Basin'. (Ed. W Young) pp. 229-258. (The Murray-Darling Basin Commission, Canberra)

Sim T and Muller K (2004) 'A Fresh History of the Lakes: Wellington to the Murray Mouth, 1800's to 1935.' River Murray Catchment and Water Management Board, South Australia.

SKM (2003) 'Review of the habitat associations of native fish in the Murray-Darling Basin. Final report for Murray-Darling Basin Commission project R2105.' Sinclair Knight Merz PTY LTD, Armadale, Victoria.

Smith B and Walker KF (2004) Reproduction of the common carp in South Australia, shown by young-of-the-year samples, gonadosomatic index and the histological staging of ovaries. *Transactions of the Royal Society of South Australia* **128**, 249-257.

Standards Australia (2004) Australian / New Zealand Standard: Risk Management. AS/NZS 4360: 2004. Standards Australia, Sydney, 32 pp.

Stewart J, Hughes J, Gray C and Walsh C (2005) 'Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (*Hyporhamphus australis*) and river garfish (*H. regularis ardelio*) in NSW waters ' Primary Industries Science and Research, Cronulla, Final Report Series No. 73 FRDC Project 2001/027.

Von Westernhagen H (1988) Sublethal effects of pollutants on fish eggs and larvae. In 'Fish Physiology. Part A. Eggs and Larvae'. (Eds W Hoar and D Randall) pp. 253-346)

Walker J, Ghalambor C, Griset O, McKenney D and Reznick D (2005) Do faster starts increase the probability of evading predators? *Functional Ecology* **19**, 808-815.

Walker K (1986) The Murray-Darling river system. In 'The Ecology of River Systems '. (Eds B Davies and K Walker) pp. 631-659. (Dr W. Junk Publishers, Dordrecht)

Wedderburn S and Hammer M (2003) 'The Lower Lakes Fish Inventory: Distribution and Conservation of Freshwater Fishes of the Ramsar Convention Wetland at the Terminus of the Murray-Darling Basin, South Australia.' Native Fish Australia (SA) Inc., Adelaide.

Wedderburn S, Walker K and Zampatti B (2008) Salinity may cause fragmentation of hardyhead (Teleostei: Atherinidae) populations in the River Murray, Australia. *Marine and Freshwater Research* **59**, 254-258.

Wedderburn S, Walker KF and Zampatti BP (2007) Habitat separation of *Craterocephalus* (Atherinidae) species and populations in off-channel areas of the lower River Murray, Australia. *Ecology of Freshwater Fish* **16**, 442-449.

Whiterod N and Walker K (2006) Will rising salinity in the Murray-Darling Basin affect common carp (*Cyprinus carpio* L.)? *Marine and Freshwater Research* **57**, 817-823.

Whitfield A (1990) Life-history of fishes in South African estuaries. *Environmental Biology of Fishes* **28**, 295-308.

Williams MD and Williams WD (1991) Salinity tolerances of four species of fish from the Murray-Darling River system. *Hydrobiologia* **210**, 145-160.

Williams W (1987) Salinization of rivers and streams: An important environmental hazard. *Ambio* **16**, 180-185.

Willis S, Laurenson L, Mitchell B and Harrington D (1999) Diet of larval and juvenile black bream, *Acanthopagrus butcheri*, in the Hopkins River estuary, Victoria, Australia. *Proceedings of the Rpyal Society of Victoria* **111**, 283-295.

Woodward G and Malone B (2002) Patterns of abundance and habitat use by *Nannoperca obscura* (Yarra pygmy perch) and *Nannoperca australis* (Southern pygmy perch). *Proceedings of the Rpyal Society of Victoria* **114**, 61-72.

Ye Q, Jones K and Pierce B (2000) 'Murray cod (*Maccullochella peelii peelii*), Fishery Assessment Report to PIRSA for Inland Waters Fishery Management Committee.' South Australian Fisheries Assessment Series 2000/17.

Zampatti B, Nicol J, Leigh S and Bice C (2005) '2005 progress report for the Chowilla fish and aquatic macrophyte project.' South Australian Research and Developement Institute, Aquatic Sciences, Adelaide. SARDI Publication Number RD04/0167.

Appendix 1

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20 October 2008

Wetlands Manager
Department of Environment and Heritage
GPO Box 1047
Adelaide SA 5001

Attention: Russell Seaman

Dear Russell

RE: RESULTS FROM SIMULATIONS INVESTIGATING POTENTIAL SALINITY BEHAVIOUR IN THE LOWER LAKES AND MURRAY RIVER – AUGUST, 2008 - DECEMBER, 2010.

Further to requests following our presentation of previous model simulations to representatives of the South Australian Government on 15 August, 2008, we have undertaken additional simulations investigating the potential extents of saline intrusion into the lower reaches of the Murray River, should salt water be introduced to the Lower Lakes via Goolwa Barrage.

A previous report (L.N1347.011.PartialWeirClosure.Final, dated 11 August, 2008) describes the modelling methodology, along with outstanding sources of uncertainty and the results of model simulations examining the potential effects of constructing a structure that partially closes the connection between Lake Alexandrina and the Murray River at Pomanda Island.

The present report does not repeat any of this previous information, instead building on previous findings and presenting the improvements that have been made to the model validation since that time, and the subsequent modelling that has been undertaken to examine potential salt dynamics in the next two years.

Reference should be made to the previous letter for additional background information.

Boundary Conditions for the Present Simulations

Flow over Lock 1

The Murray Darling Basin Commission has provided us with a significant amount of data relating to expected flows at Lock 1 for 2008/2009, and a number of possible scenarios for the 2009/2010 period.

These flow rates are shown on Figure 1.

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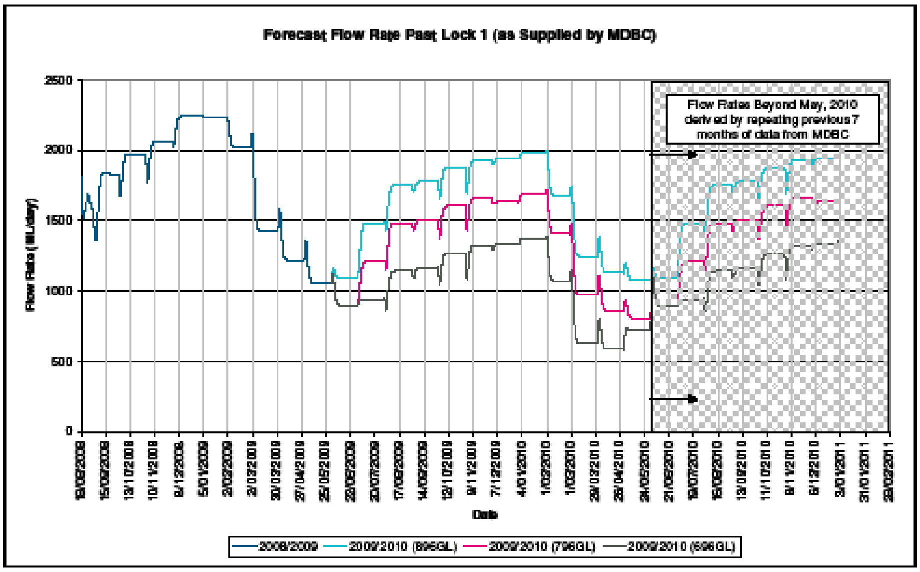

Figure 1 Lock 1 Flow Scenarios
(as supplied by the Murray Darling Basin Commission)

A few points need to be noted:

- The time series are the same until May, 2009. During June 2009, the flow rates for the 896 GL scenario differ from those for the 696 and 796 GL scenario. The MDBC have been queried regarding this and have noted that the same flow volume and pattern were adopted for the 696 and 796 GL scenarios within BIGMOD. We are unsure why this is the case, but feel that, for the purposes of the present round of simulations, this is not a significant issue.
- The time series provided by the MDBC only extended to the end of May, 2010. Beyond this date, we have replicated the flows from June, 2009. Feedback gained from the MDBC indicates that it is difficult to make reasonable predictions beyond the middle of 2010 at this point in time. This should be taken into account when interpreting the model results.

Losses and Gains of Water along the River between Lock 1 and Wellington

Four main off takes are operated by SA Water along the river between Lock 1 and Wellington. In addition, an allowance needs to be made for the extraction of irrigation water from this reach of the River. The predicted monthly totals for each diversion, as supplied by the MDBC are provided in Figure 2.

Evaporation also occurs from the surface of the River, resulting in a loss of water from the system. For the 1982 conditions being used in these simulations, the net balance of rainfall and evaporation represents a total loss of 1.171 metres in a calendar year. To determine a volumetric loss, this needs to be multiplied by the surface area of the River. From a digital elevation model (DEM) of the River between Wellington and Lock 1, based on points collected by SA Water in February, 2008, we have calculated that the surface area of the River varies by less than 1.5% when it falls from -0.25 to -1.4 m AHD. Accordingly, a single value of surface area is appropriate for estimating evaporative loss from this stretch of River. From the same DEM we have estimated a surface area of around 31.4×10^6 m^2. With a linear loss of 1.171 metres over the calendar year, this results in volumetric net evaporative loss of around 36.8×10^6 m^3 (36.8 GL). This loss will be calculated internally by the RMA model.

The three differing flow scenarios (from June 2009 onwards) being considered by this modelling exercise (896 GL/yr, 796 GL/yr and 696 GL/yr SA Border allocations), correspond to flows into Lake Alexandrina of 350 GL/yr, 250 GL/yr and 150 GL/yr respectively. Considering the total flow over Lock 1, diversions and net evaporative losses, it is clear that there is another loss from the River that has to be accounted for. Correspondence with the MDBC has confirmed that this is normally considered to be a 'seepage' loss. The total quantity of seepage loss needed to deliver the flow rates specified to Lake Alexandrina is summarised in Table 1.

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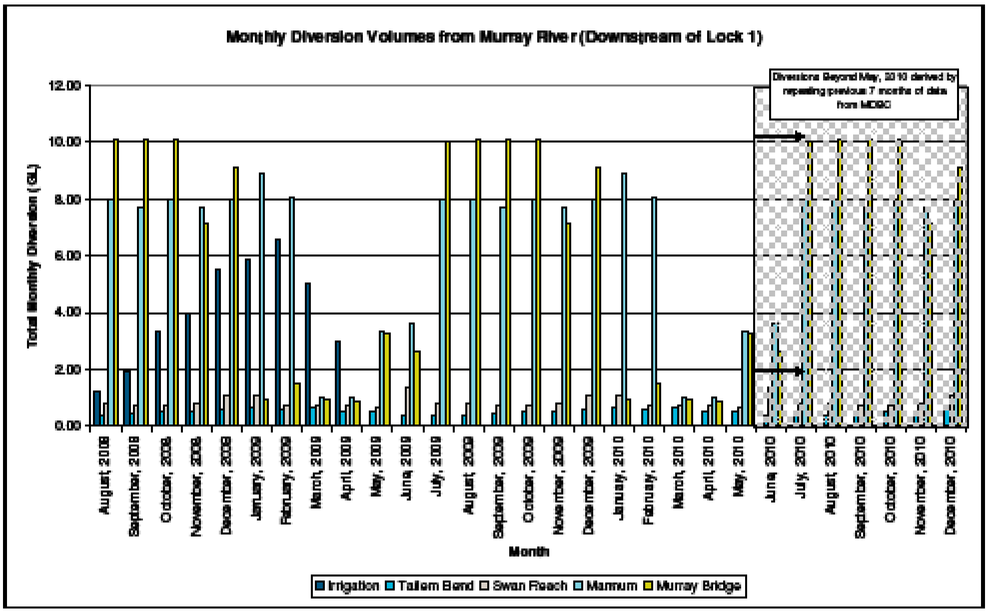

Figure 2 Diversions between Lock 1 and Wellington

(as supplied by the Murray Darling Basin Commission)

Table 1 Volumetric Balance of Water along Murray River between Lock 1 and Wellington (3 flow scenarios, June 2009 – May 2010)

Scenario (SA Border Allocation)	Flow Over Lock 1 from MDBC (GL/yr)	Diversions between Lock 1 and Wellington (Total GL/yr)	Estimated Evaporative Loss between Lock 1 and Wellington (GL/yr)	Required Flow to Alexandrina (GL/yr)	Seepage Loss Required to Balance (GL/yr)
896 GL/yr	576.9	156.5	36.80	350	33.58
796 GL/yr	478.8	156.5	36.80	250	35.57
696 GL/yr	379.6	156.5	36.80	150	36.33

As there are uncertainties regarding the actual location of this seepage loss, we have subtracted this amount loss from the flow passing Lock 1. The seepage loss has been applied uniformly throughout the year.

Inflows and Extractions from the Lakes

The main inflows and extractions from Lake Alexandrina are:

- Tributary inflows
- Pumping to maintain water level in Lake Albert.

Tributary Inflows have been derived for Currency Creek, and the Finniss, Angas and Bremer Rivers using the South Australian EPA's E2 catchment model for the area. The catchment model used 1982 conditions for input.

The present strategy for managing Lake Albert is to maintain water levels in Lake Albert at -0.4 m AHD, which is 0.1 m above the presently adopted critical acidification threshold of -0.5 m AHD.

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Data from the Waltowa recorder in Lake Albert was obtained for the period around August 18, 2008. It was determined that an appropriate starting water level in Lake Albert was -0.17 m AHD. During the initial stages of our simulations, we have assumed this water level would be allowed to fall back to its proposed managed level of around -0.4 m AHD, meaning that for the first two months of simulation, it is assumed that *no* water is pumped into Lake Albert. The estimated pumping rates to Albert over the period of simulation are shown on Figure 3.

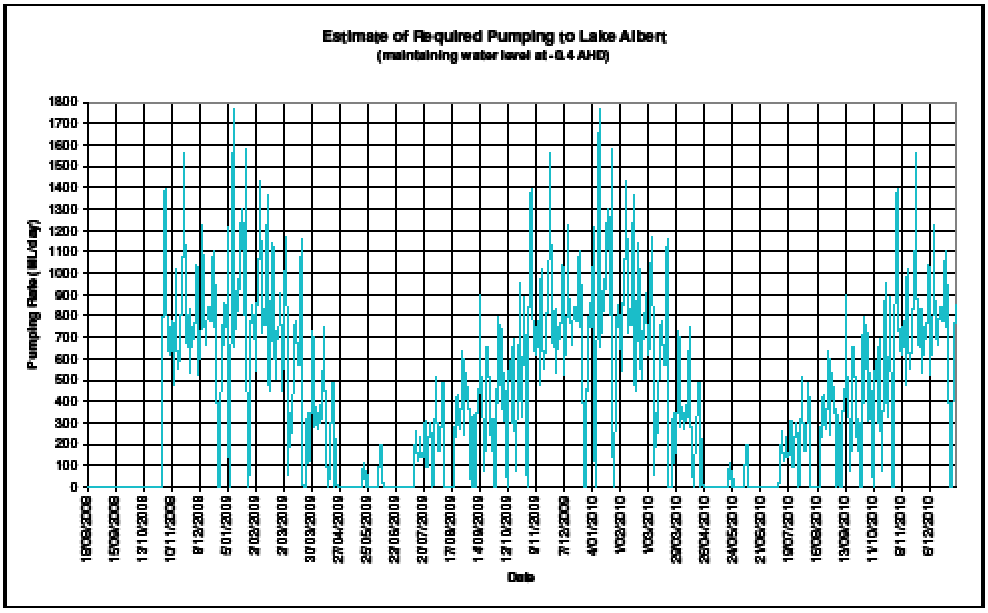

Figure 3 **Estimated Pumping Rates to Lake Albert**
(based on 1982 evaporation conditions)

It is worth noting that the annual pumping volume to Lake Albert is around 200 GL. In other words, for the scenario where 150 GL passes Wellington annually, the pumping to Albert is well in excess of inflows to Lake Alexandrina (in the absence of seawater introduction).

Overall Water Balance and Determination of Rate of Seawater Introduction

The initial water level adopted in the model simulations was -0.30 m AHD, which has been derived considering the water levels measured at various locations around the Lake on August 18, 2009.

Starting at this water level, and considering the various inflows (adjusted flow over Lock 1, inflows from tributaries to Alexandrina and direct rainfall) and losses (water diversions along the river, flows to Lake Albert and evaporation) it has been possible to iteratively estimate water levels and volumes with time, prior to the model simulations being executed. This has been achieved using a spreadsheet model that calculates the overall water balance, and then adjusts the stored volume of water and resulting water level within the system on a daily basis. The result of these calculations is illustrated in Figure 4 and Figure 5. Results are shown until May 31, 2009. Beyond this point in time, the flows over Lock 1 differ for the three scenarios being considered. However, a check against these time series has been undertaken to ensure the RMA model is providing a reasonable water balance for the required scenarios.

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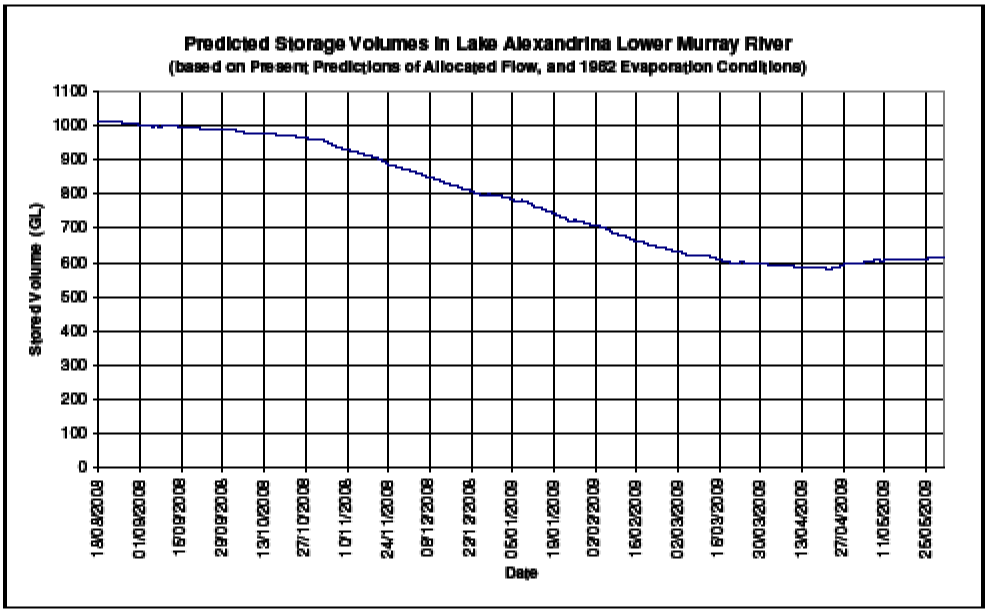

Figure 4 Estimated Volume of Water Stored between Lock 1 and Tidal Barrages (August 18, 2008 – May 31, 2009)

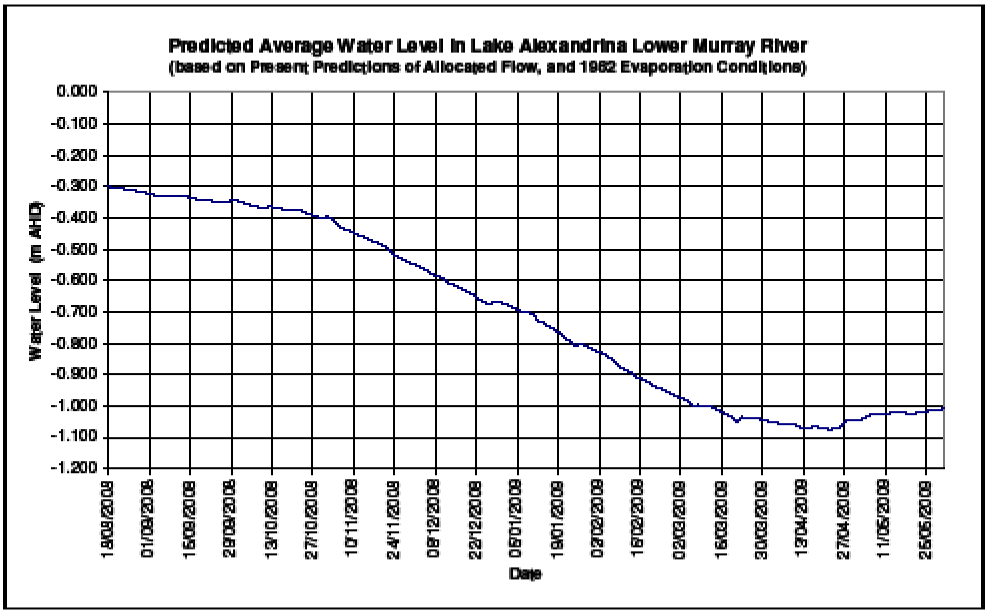

Figure 5 Estimated Average Water Level between Lock 1 and Tidal Barrages (August 18, 2008 – May 31, 2009)

Salt Load over Lock 1

The salinity of the flows passing Lock 1 is based on figures provided by the MDBC, covering the period between August, 2008 and May, 2010. As for the flows, the time series begin to diverge from May, 2009. From May, 2010, for which data was not provided by the MDBC, the salinities have been based on a repeat of the previous year's values. As can be seen from Figure 6, this results in a discontinuity in the salt values being applied to the upstream end of the RMA model. Analyses of model predictions which extend beyond the end of May, 2010 need to keep this in mind.

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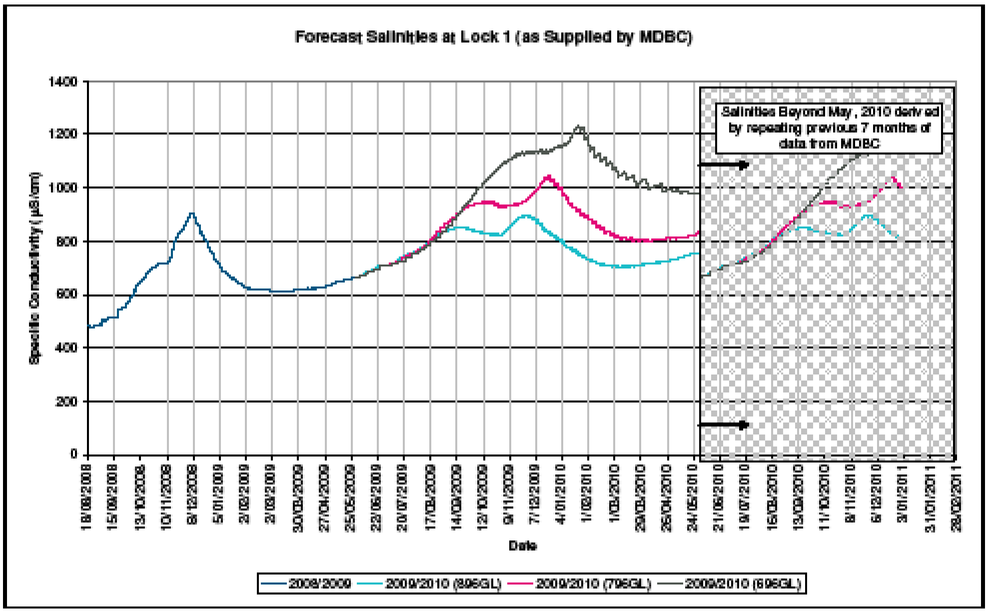

Figure 6 **Forecast Salinities at Lock 1 (provided by MDBC)**

Salt Load along the River

In addition to the above, there is a known salt load entering the River via groundwater and other sources such as wetland drainage. Given the present low water levels in the River, the main source of this salt load over the next couple of years has been assumed to be groundwater.

A relationship between water level and salt load has been provided to us by the MDBC and is reproduced as Table 2. We note that minimum and maximum values for salt load were provided between Lock 1 and Murray Bridge. For the prognostic simulations, we have adopted the maximum loads provided.

Table 2 **Relationship of Salt Load to the River and Water Level below Lock 1.**
(As provided by the Murray Darling Basin Commission)

Elevation (m AHD)	Lock 1 to Murray Bridge		Murray Bridge to Wellington (t/d)
	Maximum (t/d)	Minimum (t/d)	
-1.5	220	70	60
-0.2	80	25	22
0	0	0	0

Given the water balance outlined above, and the water level/salt load relationship provided in Table 2, it is possible to estimate, before executing the model simulations, what the total load of salt will be along the length of the River. In RMA, the salt is introduced to the model via a flow of water. Based on previous advice on groundwater rates provided by DWLBC, a concentration of 4.5625 tonnes/ML has been adopted for this flow. The resulting salt load, in tonnes/day, and the corresponding flow rate are shown in Figure 7 and Figure 8 respectively.

At the managed water level of -1.3 m AHD, salt load is estimated to be around 250 tonnes/day, carried by a flow of 55 ML/day.

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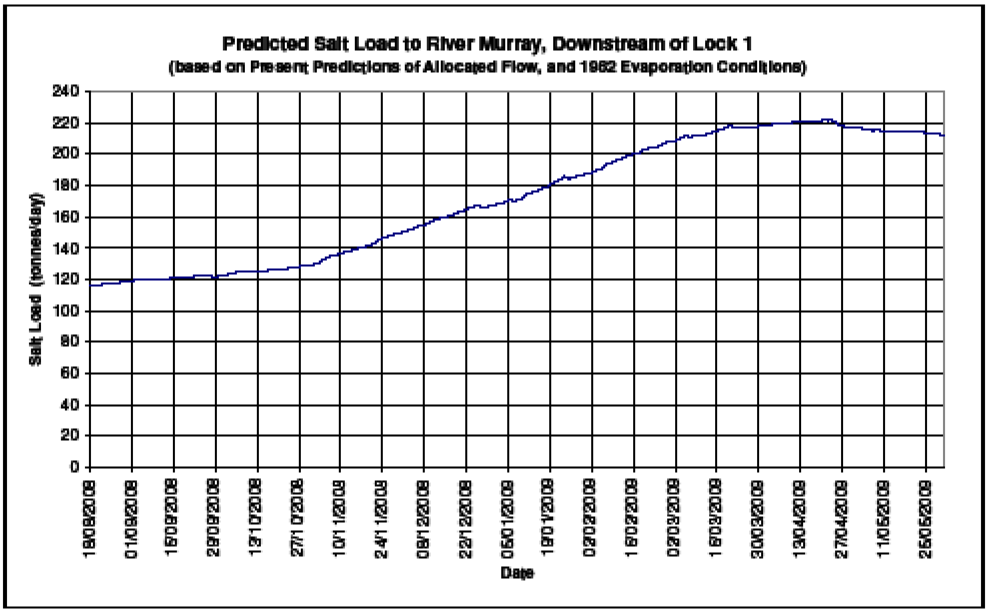

Figure 7 Salt Load from Groundwater and Other Sources to the Murray River (between Lock 1 and Wellington)

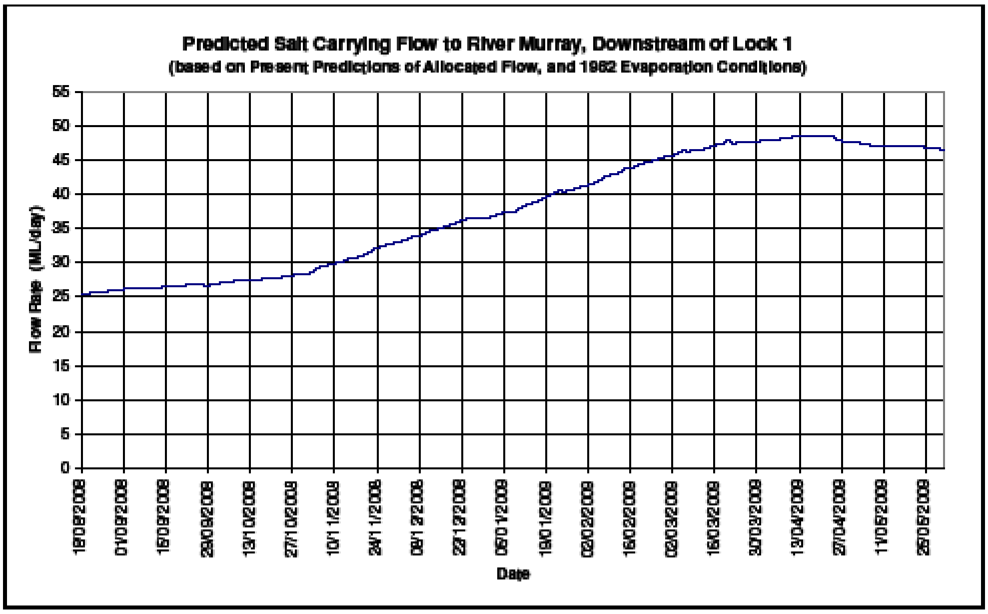

Figure 8 Flow Rate Conveying Salt from Groundwater and Other Sources to the Murray River (between Lock 1 and Wellington)

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Results from Present Simulations

Water Level in Lake Alexandrina

The points used for reporting simulated results of water level and salinity, as predicted by the RMA model are shown in Figure 9. As background to the discussion of salinities, the simulated water level changes in the centre of Lake Alexandrina (Point 20) have been presented for all three scenarios in Figure 10.

Figure 10 shows that the simulations do not differ until the end of May 2009. At this point in time, the time series of flow over Lock 1 changes between the scenarios as shown in Figure 1. The divergence in water levels between May and October, 2009 illustrates the impact of a lessening flow entering the lower reaches of the Murray River. For all three simulations, we have begun introducing flows into the lower lakes via Goolwa Barrage. This occurs one month earlier than we originally calculated using a volumetric balance of the system and is necessary to build up water levels between Goolwa Barrage and Clayton. To the east of Clayton, at the northern end of Mundoo Channel, a pronounced area of shallow bathymetry exists. The minimum bed level in this area is around -1.15 m AHD, some 0.15 m above the proposed managed water level of -1.3 m AHD. Accordingly, it is necessary to introduce some water early, to ensure that water levels build up to a high enough level to overcome this obstacle and introduce water into Lake Alexandrina when it is needed (i.e. when its water level falls towards -1.3 m AHD).

Following this initial injection of water, we have calculated the number of gate openings and the crest level at Goolwa Barrage, necessary to maintain average daily water levels above -1.3 m AHD throughout subsequent two monthly periods. In other words, we have assumed that gates will be adjusted once every two months, to ensure that water levels in the subsequent two month period do not fall below a daily average water level of -1.3 m AHD. Of course, with the presence of a wind generated seiche on Lake Alexandrina, the actual instantaneous water level would tend to oscillate above and below this level on a sub-daily time scale.

This effort at balancing flows results in the simulated water levels shown in Figure 10. Due to the variations in adopted patterns of barrage openings no clear pattern in water levels emerges when comparing the three simulations. The main difference is evident in comparing the Salinity values as, for the lower river flow scenarios, more seawater is being introduced to balance the water level in the Lake Alexandrina.

During December and November of 2010, the water levels in Lake Alexandrina fall below the target level. However, as there are inconsistencies relating to the values adopted for salinity flowing over Lock 1 during the latter half of 2010 (and our original commission which was to progress models through to the middle of 2010). In the interest of expedient delivery of model results, we have not undertaken an additional model iteration to ensure that water levels are maintained at this stage of the simulation.

Salinities in Lake Alexandrina

As per our previous simulations looking at partial construction of the Weir at Pomanda Island, we have reported salinity values at six points (Points 1 through 6 on Figure 9). The predicted time series of salinity at these six points are provided on Figure 11 through Figure 16 respectively. These time series have been smoothed by averaging over a 24 hour period. The time series begin to diverge around the middle of 2009 (when a difference between flows over Lock 1 has been input to the model simulations), but becomes most obvious during the summer of 2009/2010, when seawater is released into the Lake.

The model simulations illustrate the strong moderating effect that flows from the Murray River have on salinities in Lake Alexandrina during the extremely dry conditions expected over the next couple of years. This effect is notable at all points, but the influence is most obvious in the areas close to the location where the Murray River flows into the Lake (e.g. Points 5 and 6).

Points 1 and 2, which are closest to the source of seawater (Goolwa Channel) show a strong tendency towards hypersaline conditions (i.e. > 60,000 EC) for very low inflow conditions. Point 2 is very close to the offtake location for pumping into Lake Albert. That hypersaline water could end up being pumped into Lake Albert becomes a possibility.

Point 5 represents the point which is closest to the location where we have extract information to drive the downstream boundary of the ELCOM model. ELCOM subsequently simulates the movement of salt in the lower river channel, including any salt wedge dynamics. There is a strong influence of river inflow at this particular location, and the dynamics of the lake seiche cause salinity values to fluctuate, as water sloshes backwards and forwards and salinity is periodically affected to a greater or lesser degree by water exiting the Murray River in the vicinity of Pomanda Island. During 2010, these 'spikes' in salinity are commonly above 20000 µs/cm for the 696 GL/yr scenario, occasionally above 15000 EC for the 796 GL/yr scenario, and always below 10000 EC for the 896 GL/yr scenario.

The simulated development of salinity across the Lakes with time is provided in Attachments B through D.

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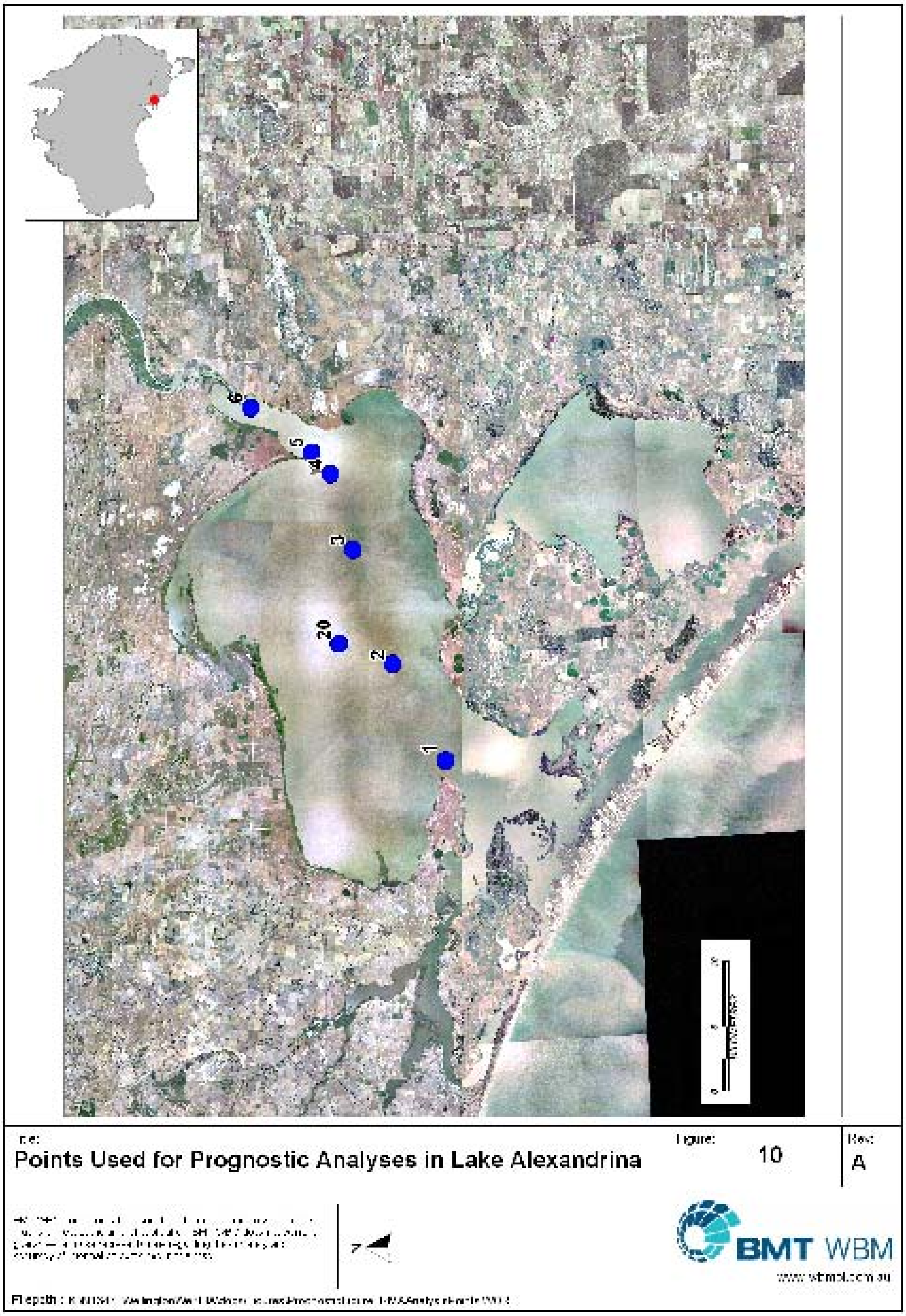

Figure 9 **Reporting Points in Lake Alexandrina**

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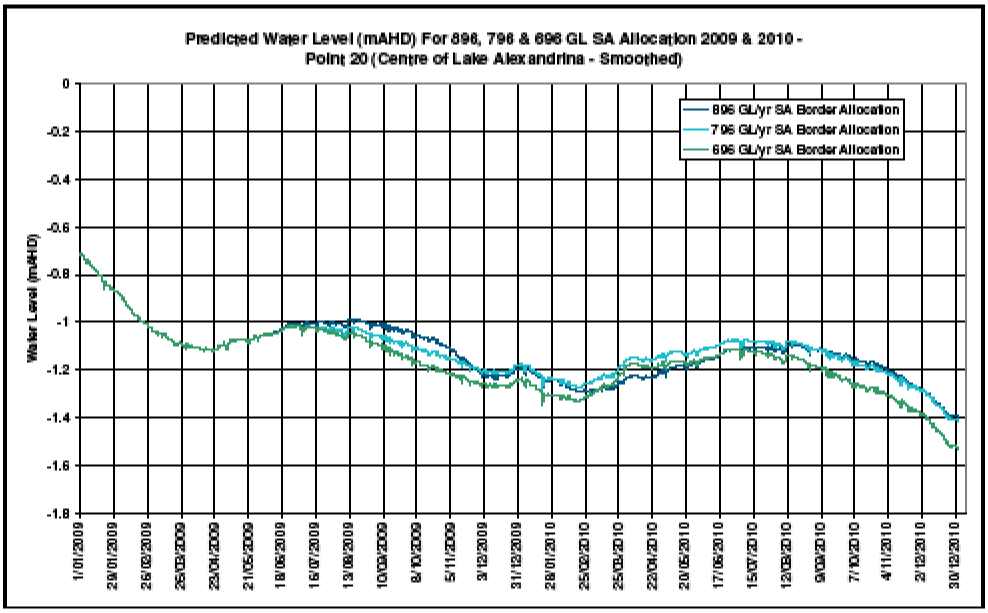

Figure 10 Simulated Water Levels in the Centre of Lake Alexandrina (Point 20)

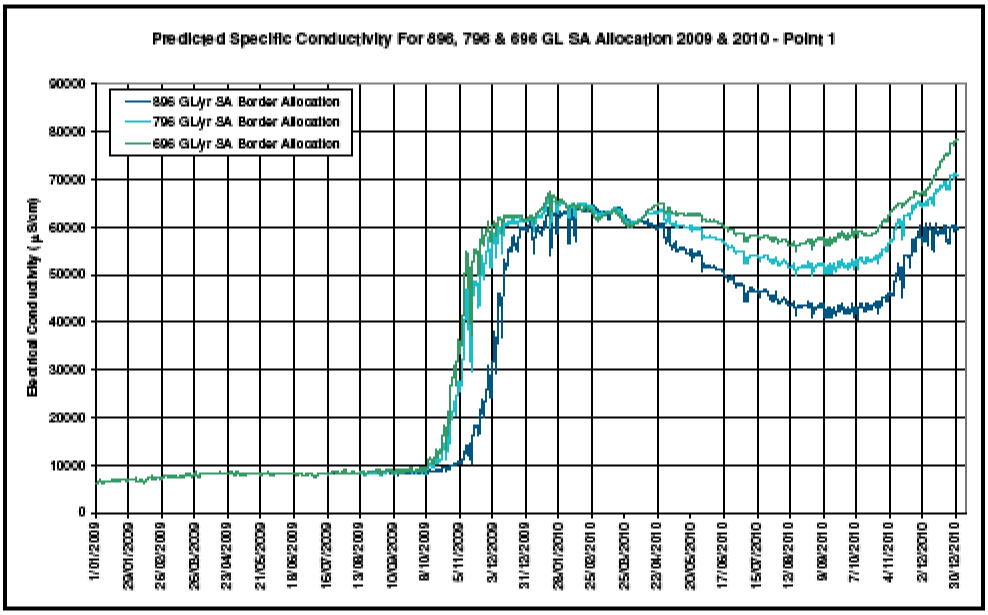

Figure 11 Predicted Salinities in Lake Alexandrina – Point 1

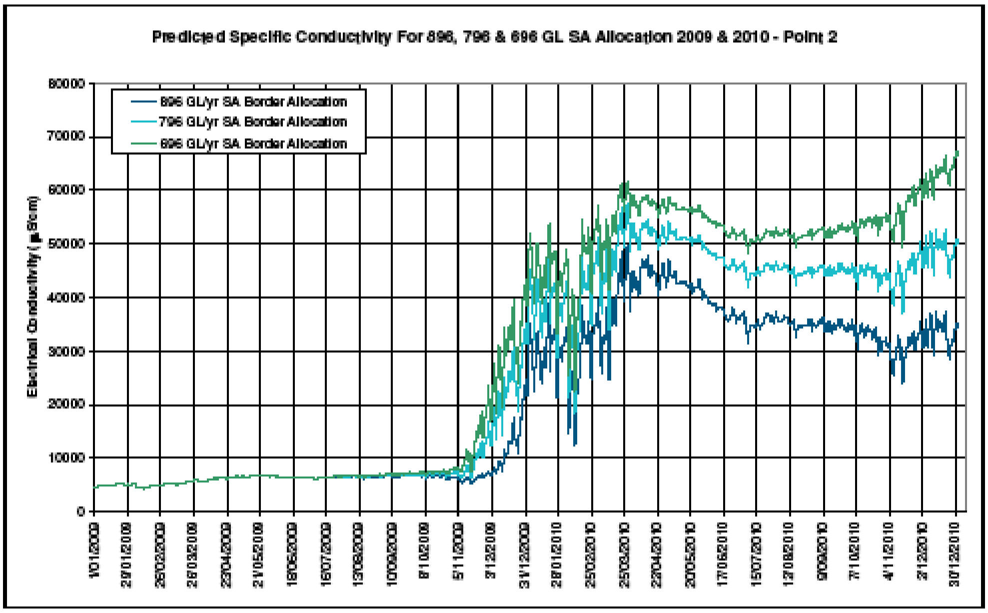

Figure 12 Predicted Salinities in Lake Alexandrina – Point 2

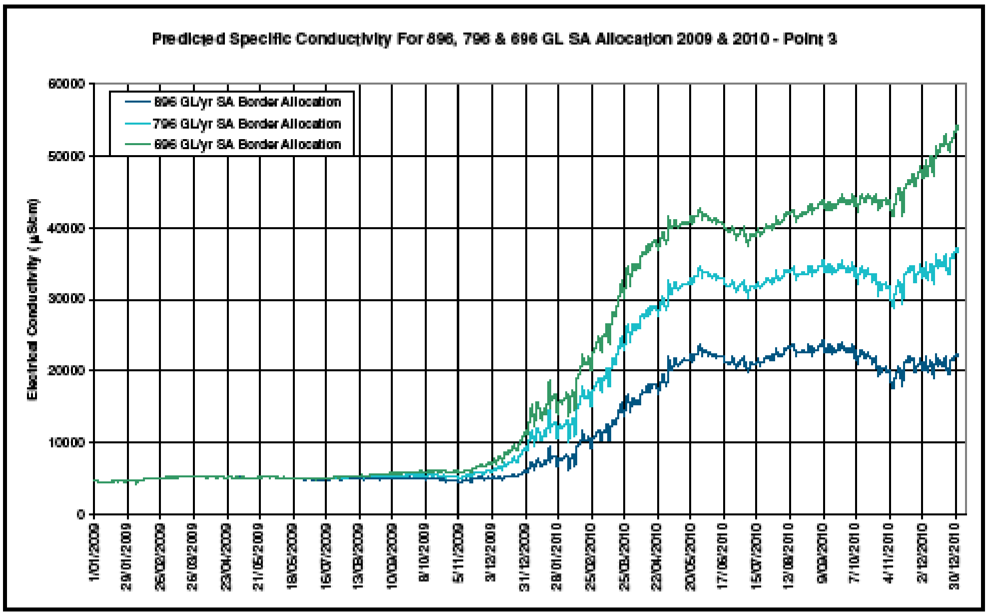

Figure 13 Predicted Salinities in Lake Alexandrina – Point 3

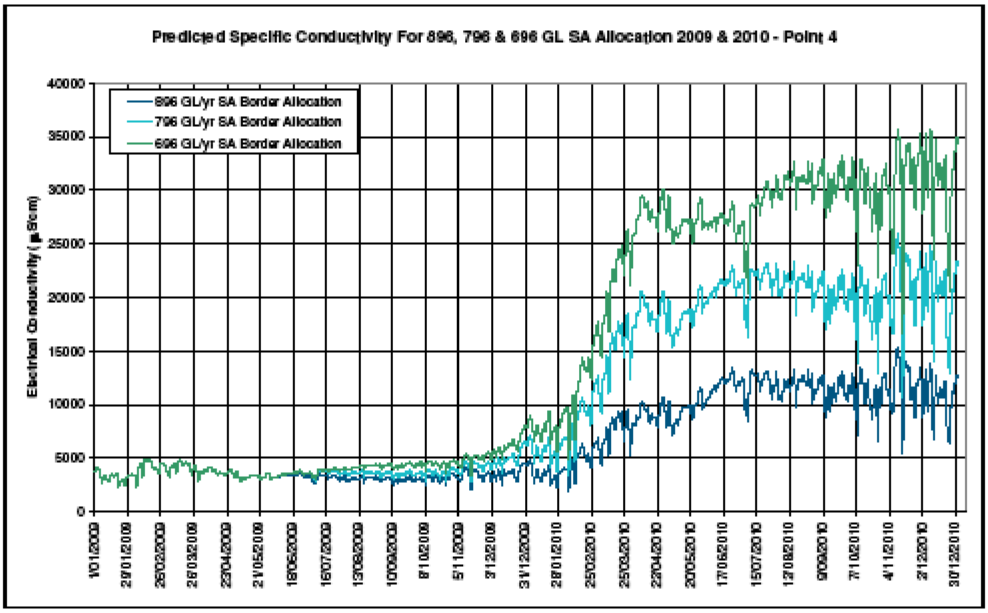

Figure 14 **Predicted Salinities in Lake Alexandrina – Point 4**

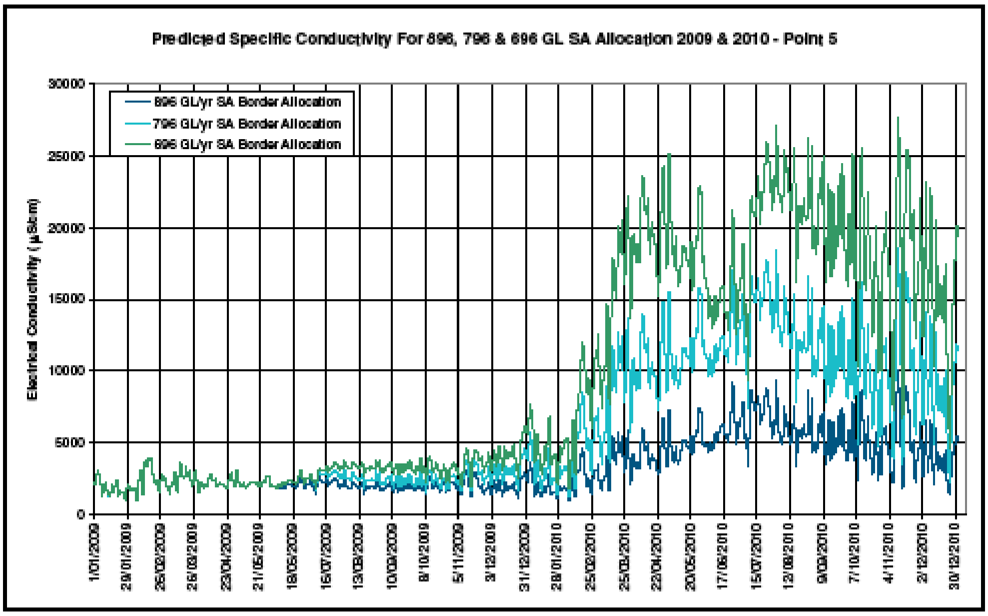

Figure 15 **Predicted Salinities in Lake Alexandrina – Point 5**

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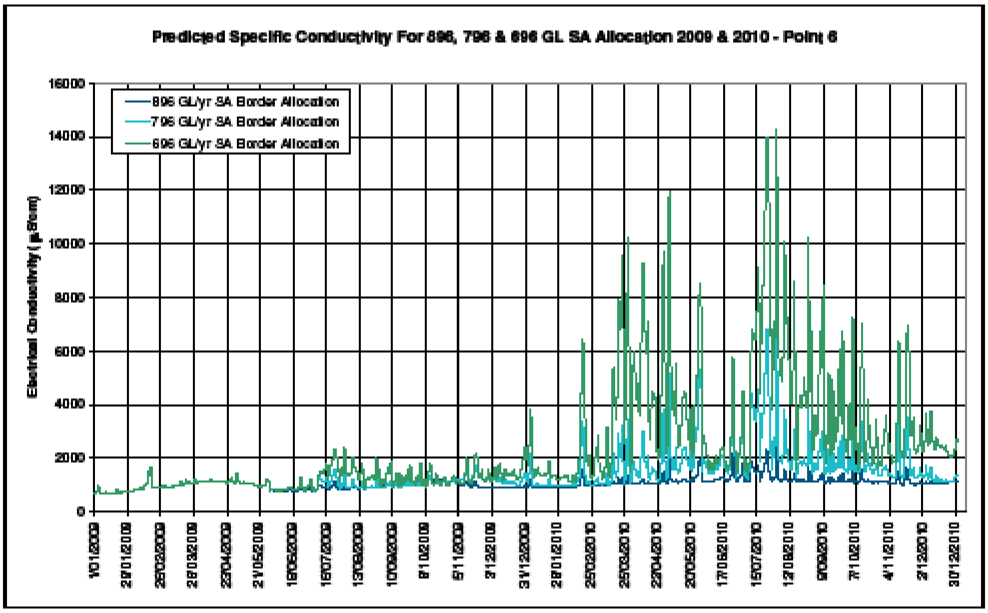

Figure 16 Predicted Salinities in Lake Alexandrina – Point 6

<u>Salinities in the Lower Murray River</u>

Boundary conditions at Pomanda Island and Murray Bridge were extracted from the RMA simulations and used to drive a 3 dimensional (depth varying) ELCOM model of the lower reaches of the Murray River for the given scenarios. To retain compatibility with the water balance represented by the conditions provided by the RMA model, an extraction was made from the Tailem Bend offtake within the ELCOM model domain.

Results have been extracted from the ELCOM model simulations at four locations as shown on Figure 17.

The simulated value of EC at the top and bottom of the water column for all three simulations at Wellington, Tailem Bend, Woods Point and Swanport are shown on Figure 18 through Figure 21 respectively.

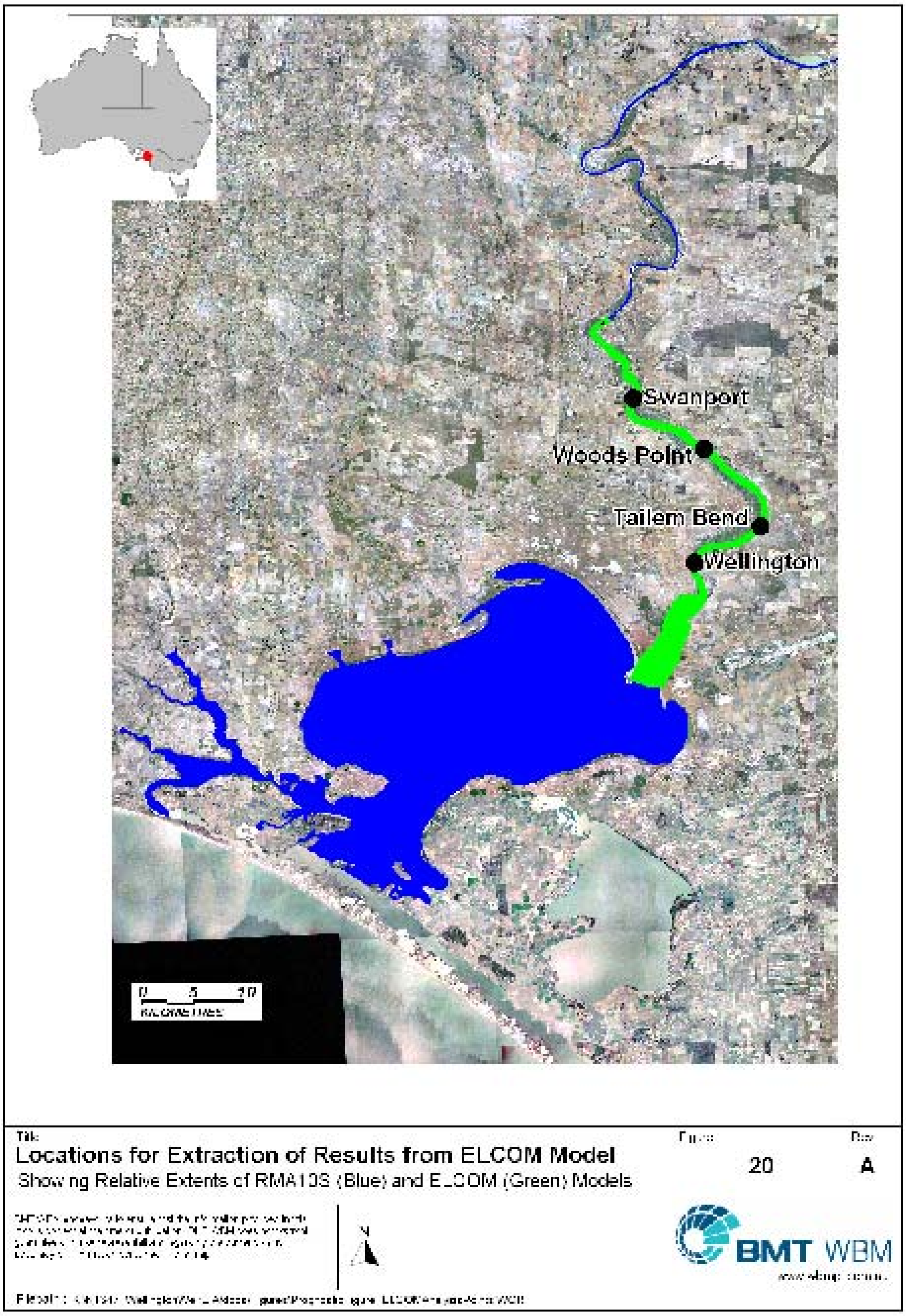

Figure 17 Locations for Extraction of ELCOM model results

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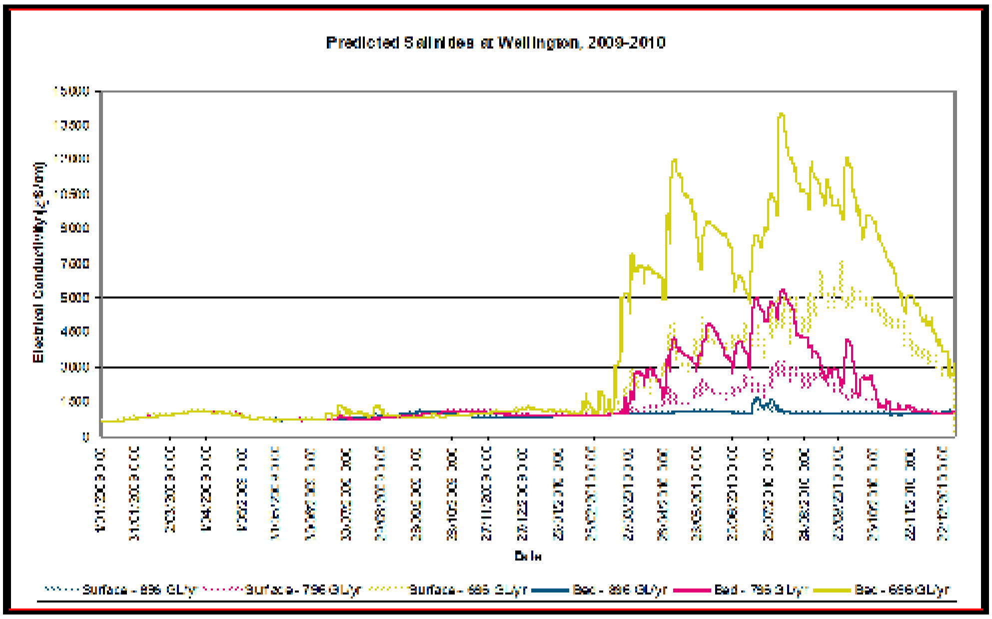

Figure 18 Simulated Top and Bottom Salinities at Wellington

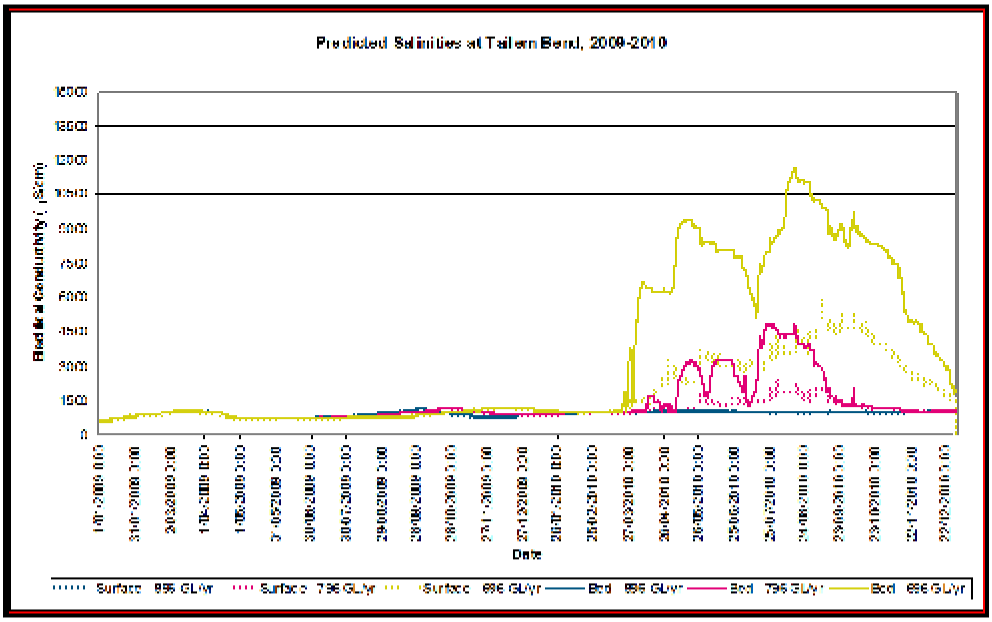

Figure 19 Simulated Top and Bottom Salinities at Tailem Bend

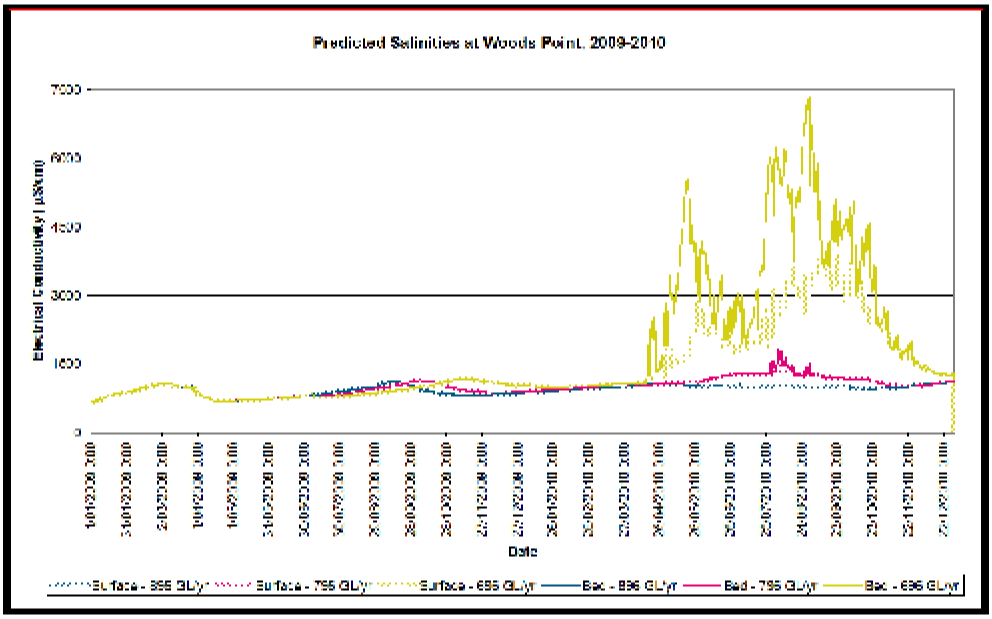

Figure 20 Simulated Top and Bottom Salinities at Woods Point

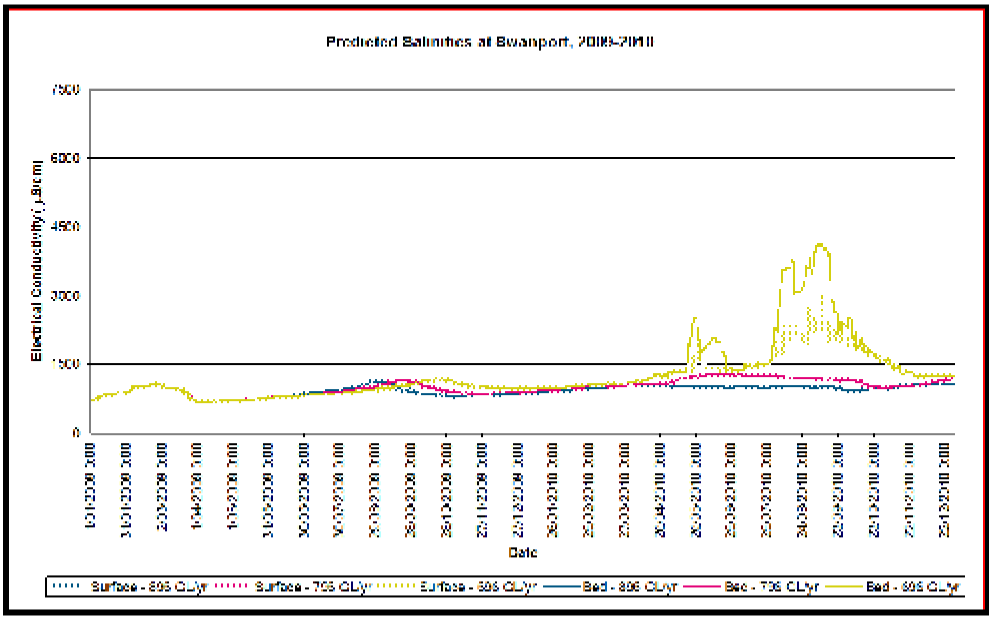

Figure 21 Simulated Top and Bottom Salinities at Swanport

Conclusions

This most recent set of model simulations illustrates a clear potential for salt to migrate upstream along the Murray River towards Murray Bridge, if a virtual weir management scenario were to be adopted. The 696 GL/yr scenario illustrates that impacts could begin being felt at Swanport (around 5 km downstream of Murray Bridge), within six months of the tidal barrages being opened. Such an impact only corresponds to the boundary conditions that have been applied, which also include severely dry weather over the next two years. Given severely dry weather, if the water levels in Lake Alexandrina were to be kept above -1.3 m AHD by introducing seawater, it would seem likely that tidal barrages will need to be opened at some stage between the middle of October and the end of 2009, dependent upon the amount of flow making its way down the River over the next 12-14 months.

We trust that these analyses meet the present expectations of DEH and the South Australian Government. Should you require any further information, please contact the undersigned on 4940 8882.

Yours Faithfully
BMT WBM Pty Ltd

David Wainwright
Associate

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