

A long, straight pier with metal railings extends from the foreground into the distance, leading the eye towards the horizon. The pier is flanked by calm water, and the sky above is a mix of orange, yellow, and light blue, indicating a sunset or sunrise. The overall mood is serene and contemplative.

An analysis of MDBA modelling outputs for the draft Basin Plan: Hydrodynamic modelling of the Coorong and Murray Mouth

Assessing the implications for the Murray Mouth and biota of the region

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Foreword

The Coorong, Lakes Alexandrina and Albert wetland is one of Australia's most important wetlands, having been designated a Wetland of International Importance under the Ramsar Convention on Wetlands in 1985.

In addition to the conservation and environmental importance of the site, the well-being of the Ngarrindjeri people is linked to its health with nationally important middens, burial sites and other sacred places which provide evidence of Ngarrindjeri occupation over many thousands of years.

Years of drought and over-use of water resulted in these significant wetlands being severely affected: the lakes disconnected from the Coorong; communities and industries were put under significant stress and native species risked being lost forever.

The extremes of climate and rainfall, and the history of drought in our nation, are well known. While the extent of the problems facing the Coorong, Lower Lakes and Murray Mouth region (CLLMM) may have only become obvious relatively recently, ecological degradation has been taking place for decades.

Everyone should be concerned with the state of the Murray-Darling Basin – and the Coorong and Lower Lakes in particular.

Over-allocation of water across the entire Murray-Darling Basin has played a significant part in the degradation of the CLLMM. Because the issue is so contested South Australia believes the development of a Murray-Darling Basin Plan must be based on sound science.

To this end, the South Australian Government has undertaken its own scientific analysis of the implications for the Coorong, Lower Lakes and Murray Mouth of the Murray-Darling Basin Authority's proposed 2750 GL water recovery target. This analysis will be used to inform the South Australian Government's response to the draft Basin Plan.

The Australian and State Governments have together already allocated more than \$186 million in funding to support the projects and actions outlined in the State Government's Long-Term Plan for the Coorong, Lower Lakes and Murray Mouth. For the Long-Term Plan to be effective, the need to secure adequate environmental flows through a Basin Plan is vital.

A healthy Coorong, Lower Lakes and Murray Mouth region will depend on everyone accepting responsibility for its future. This document has been written to allow the draft Basin Plan to be assessed as to whether it will protect the essential attributes of this internationally important wetlands.

Allan Holmes
Chief Executive,
Department of Environment and Natural Resources

Executive Summary

The Draft Basin Plan was released by the Murray-Darling Basin Authority (MDBA) for consultation in November 2011. As part of the development of the South Australian Government response, a scientific review was undertaken to assess the hydrological and ecological consequences of the proposed 2750 GL water recovery scenario on key ecological assets for South Australia.

This report presents an analysis of MDBA modelling and examines the potential implications of the proposed 2750 GL water recovery scenario for the Murray Mouth, the Coorong and its biota over the 114-year period modelled by the MDBA in its development of the Draft Basin Plan. As far as possible, analysis was also undertaken on the 2400 GL and 3200 GL sensitivity analysis provided by the MDBA.

The MDBA provided the outputs of a number of the modelling simulations it undertook for analysis by the South Australian Government. The analyses of the MDBA hydrological modelling outputs undertaken by DENR, which forms the basis of this report, assessed the impacts on three ecological drivers, which have been shown to be related to the distribution and abundance of macroinvertebrates, fish, birds and submerged aquatic plants in the Coorong, namely:

1. Murray Mouth 'openness'
2. Coorong salinity
3. Coorong water levels.

Measures that were used to assess the implications for the Coorong were developed in Lester et al, (2011a).

Murray Mouth openness

Murray Mouth openness influences the ecology of the Coorong by affecting how sea level variations impact on life in the Coorong. Together with the rate of freshwater inflow, and local climate, constriction of the Murray Mouth determines water levels and salinity in the Coorong.

The need to dredge the Murray Mouth is influenced by Mouth depth, barrage flow, and Coorong salinity; together with the prospect of barrage flows through the critical spring-summer period in subsequent years. The combined impacts of these variables are outside the scope of this study and have not been assessed here to permit definitive statements of whether dredging will be required as a result of the recovery of environmental water.

Murray Mouth openness against a Baseline (current) scenario and the water recovery scenarios was assessed using two different measures; total annual flow greater than 2000 GL, and annual average Murray Mouth depth (less than 2 m).

Under the Baseline (current) scenario, the Murray Mouth is constricted for 46 years out of the 114 years modelled (based on annual average Mouth depth) and 36 out of 114 years (based on total annual barrage outflows).

Under the 2750 GL water recovery scenario, average annual Murray Mouth depth indicates the risk that the Mouth will be constricted for 15 years out of 114 years (based on Mouth depth) and 13 years out of 114 years (based on total annual outflows).

The 2750 GL scenario is therefore a noteworthy improvement on the current scenario, but Murray Mouth constriction remains an issue during periods of low total annual barrage outflows, such as in drought.

Modest improvements in Murray Mouth openness occur with the provision of volumes greater than 2750 GL. Reductions in the volume of water provided to the environment have the opposite effect - constricting the Mouth. The actual delivery of flow through the barrages may improve the outcomes modelled.

Coorong water levels

Water level is key driver of the ecology of the Coorong, affecting the habitat, survival, diversity, and abundance of important plant and animal species. *Ruppia tuberosa* is a critical plant species for the ecology of the Coorong and needs to remain permanently inundated to complete its lifecycle and ensure persistence.

To assess the water level requirements for *R. tuberosa*, information on the minimum summer water level to maintain effective inundation of the species is required. This information is not presently available and a relatively crude measure of annual average water level is used.

Analysis of the MDBA modelling outputs undertaken on water levels in the Coorong South Lagoon indicate that under the 'without development' (representation of natural) scenario, average annual water levels would support *R. tuberosa* in the South Lagoon in 88 per cent of years.

Under the Baseline (current) scenario this decreases to 57 per cent of years, and under the 2750 GL water recovery scenario there is only a marginal improvement to 62 per cent of years. This may be increased by altering the delivery profile of water through the barrages to increase minimum summer water levels.

Under the 2750 GL scenario, water levels below the desired annual average target of 0.27m AHD will still be experienced in the Coorong during periods of low total annual barrage outflows, such as in drought. Such water levels reduce the available habitat for submerged *R. tuberosa*, which in turn affects macroinvertebrates, fish and waterbirds in the region. The provision of larger volumes up to 3200 GL marginally reduces this impact.

Coorong salinity

Salinity is a well-defined and accepted indicator of the health of the Coorong, and determines the quality of the habitat throughout the system.

The analysis of MDBA modelling results of the 2750 GL water recovery scenario in the Draft Basin Plan indicates that there are multiple years within the 114 years modelled in which average salinities in the Coorong South Lagoon exceed known thresholds for important plants and animals, reducing the available habitat for submerged vegetation, macroinvertebrates and fish, and affecting waterbirds.

Only the provision of larger volumes (up to 3200 GL) reduces the number and duration of consecutive years when salinity thresholds are exceeded.

Conclusion

Analysis of the hydrodynamic modelling undertaken by the MDBA indicates that implementation of the proposed 2750 GL water recovery scenario in the draft Basin Plan would result in considerable improvement in mouth openness (or more accurately reduced constriction), average annual salinity in the Coorong, and, to a lesser extent, water levels in the Coorong relative to the Baseline (current) scenario.

Even so, under the 2750 GL scenario, average annual salinity in the Coorong South Lagoon still exceeds lethal thresholds for important species and average annual water levels remain below thresholds required to be supportive of the keystone species, *Ruppia tuberosa* in a substantial proportion of years. As such, the Coorong would remain at considerable risk of ecological degradation during dry periods.

Greater volumes of water would ameliorate these risks appreciably, and in this regard a 3200GL water recovery scenario represents the lowest risk to maintaining the Coorong as healthy and resilient wetland of international importance.

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1. Introduction

The Draft Basin Plan was released for consultation by the Murray-Darling Basin Authority (MDBA) in November 2011. As part of the development of the South Australian Government response, a review of the science behind the Plan was undertaken by the Department of Environment and Natural Resources and the Department for Water, in conjunction with the Goyder Institute for Water Research. The aim of the review was to consider the potential hydrological and ecological consequences of the proposed 2750 GL water recovery scenario on key ecological assets for South Australia. This report examines the potential implications for the Murray Mouth, the Coorong and its biota.

The MDBA provided South Australia with outputs of modelling simulations for analysis, which it utilised in development of the draft Basin Plan. These outputs assisted with analysing the implications for the state of the proposed water recovery target.

This section of the report seeks to outline:

- relevant background information and context for analyses
- the scenarios examined (provided by the MDBA)
- the CSIRO hydrodynamic model for the Coorong
- an introduction to the hydrodynamics of the Coorong.

1.1. Aims and Objectives

The aims and objectives of this report are to:

- Analyse the MDBA modelling outputs from the CSIRO Coorong hydrodynamic model to obtain a more detailed understanding of the likely outcomes from the adjustment of water diversions, as outlined by the MDBA.
- Provide a summary of the analysis for an assessment of the potential consequences that could result from the modelling. Specifically describing the salinity and water level regimes that result from various barrage outflows from the Murray-Darling Basin as they are fundamental drivers of the Coorong ecology.
- Consider the impacts on Murray Mouth 'openness' using the relationship outlined in Webster *et. al.*, (2009).

1.2. Background

1.2.1. The Basin Plan

Development of infrastructure to manage the river systems across the Murray-Darling Basin in order to support towns, transportation, and agriculture has occurred since European settlement. The Commonwealth *River Murray Waters Act 1915* was the first legislative agreement between New South Wales, Victoria, and South Australia to share and administer the available water resources, although this was principally to ensure economic and social outcomes as well as to mitigate the impacts of floods and droughts.

The observed environmental impacts of sustained and extensive development have led to a long history of water reform across the Basin. As reforms that include a Cap on Diversions (based on 1993-94 development levels) and *The Living Murray* initiative have been implemented, the impacts and effects of over allocation and extraction have become clearer. The recent drought, at the end of a decade of generally below average water availability, highlighted the need to address these ongoing issues for both the benefit of the environment and consumptive users. This led to the development of the Commonwealth *Water Act 2007*.

The objectives of this Act include the enabling of the Commonwealth, in conjunction with the Basin States, to manage the Basin water resources in the national interest (s3(a)), and to ensure the return to environmentally sustainable levels of extraction for water resources that are over-allocated or overused (s3(d)(i)). The Act establishes the MDBA, with the powers necessary to develop and implement new Basin-wide water planning and management arrangements, including legally enforceable limits on the amount of water that can be taken for consumptive use (MDBA 2011a). The Basin Plan is the mechanism for implementing these new sustainable diversion limits (SDLs), in addition to other measures to allow for the integrated management of the Basin.

The Draft Basin Plan was released in November 2011 and included a water recovery target of 2750 GL per year. This volume represents a reduction in long-term average diversions across the Basin in order to achieve a specified SDL.

1.3. Hydrological Modelling Framework

Heneker and Higham (2012) and MDBA (2012) provide a summary of the hydrological modelling framework used by the MDBA in assessing the proposed water recovery scenario for the draft Basin Plan. *BIGMOD* (MDBC 2002) is a computer model that conceptualises and simulates the River Murray system, its major processes and 'normal' river operations, calibrated to available data. The model produces information on barrage outflows at a daily time-step that permits analysis of barrage flows at this scale or aggregation to a higher level. The outputs from *BIGMOD* are then used as an input for the CSIRO Coorong hydrodynamic model (Webster, 2007). See 1.6. - The Coorong hydrodynamic for further information on this model.

1.4. MDBA modelling scenarios

The MDBA has developed and modelled a number of Baseline and water recovery scenarios to support the Draft Basin Plan. The following model outputs were provided for assessment:

- Without Development (run #844) - represents as near as possible 'natural' conditions
- Baseline Conditions (run #845) - represents the current state of the system
- 2750 GL water recovery (run #865)
- 2400 GL water recovery (run #859)
- 2800 GL water recovery (run #847)
- 3200 GL water recovery (run #863)

Each of these is described in further detail in Appendix 5:

1.5. The Coorong and Lakes Alexandrina and Albert wetland of International Importance

The Coorong, and Lakes Alexandrina and Albert (Lower Lakes) wetland of International Importance, listed in 1985 under the Ramsar Convention, is located at the downstream end of the Murray-Darling River system. The site is approximately 142,500 ha in size, and includes a diverse range of freshwater, estuarine, and marine habitats that supports the unique biota of the region, in the context of the Murray-Darling Basin.

The River Murray terminates in South Australia at the Southern Ocean, having passed through Lake Alexandrina, the Murray estuary, and finally the Murray Mouth (Figure 1). Lake Albert is a terminal lake connected to Lake Alexandrina by a narrow channel. The Coorong is a long, shallow, brackish to hypersaline lagoon more than 100 km in length, and separated from the Southern Ocean by a narrow sand dune peninsula. Saline waters of the Coorong lagoons and Murray Mouth estuary are artificially prevented from entering the lakes and the River Murray by a series of barrages constructed between 1935 and 1940 across barrier islands near the Coorong's inlet. The barrages serve to exclude salty water from Lake Alexandrina but allow fresh water to flow through barrage gates into the Coorong during times of elevated flow in the River Murray (MDBC 2006, Phillips and Muller, 2006 etc).

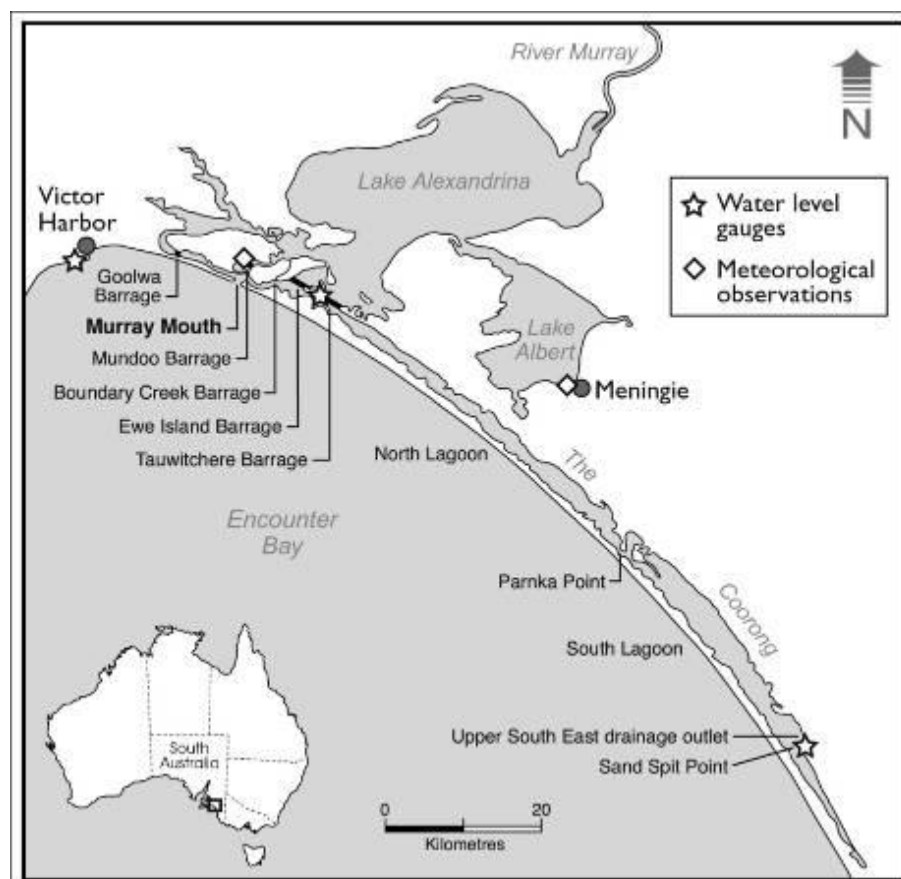


Figure 1: The Coorong showing important landmarks, features and recording locations of relevant information to Coorong hydrodynamics.

The Coorong and Lower Lakes (Alexandrina and Albert) are highly valued for their environmental significance, tourism, and fisheries, and are the traditional home of the Ngarrindjeri Nation. The region was listed in 1985 as a Wetland of International Significance

under the Ramsar Convention. It is of national and international conservation status especially for birds; the Coorong being ranked within the top six waterbird sites in Australia. At least 85 bird species, including the Australasian Bittern (*Botaurus poiciloptilus*), Glossy Ibis (*Plegadis falcinellus*) and Sharp-tailed Sandpiper (*Calidris acuminata*), have been recorded in the site. 25 of these bird species are listed under international migratory bird conservation agreements and are listed as migratory under the *Environment Protection and Biodiversity Conservation Act, 1999*. The Ramsar site supports some threatened ecological communities and species, as well as extensive and diverse waterbird, fish and plant assemblages. Submerged aquatic plant communities with species such as *Ruppia tuberosa* are important components of the food chain, particularly for waders and waterbirds.

Phillips and Muller (2006) identify the Coorong and Lakes Alexandrina and Albert as consisting of:

- a unique mosaic of 23 Ramsar wetland types which include intertidal mud, sand or salt flats, coastal brackish/saline lagoons, permanent freshwater lakes, permanent freshwater marshes/pools, shrub-dominated wetlands, and water storage areas. The site is unique in its wide representation of wetland types within the bioregion
- habitat for the nationally threatened species including; Orange Bellied Parrot (*Neophema chrysogaster*), Australasian bittern (*Botaurus poiciloptilus*), Fairy Tern (*Sterna nereis nereis*), Southern Mount Lofty Ranges Emu Wren (*Stipiturus malachurus intermedius*), Yarra Pygmy Perch (*Nannoperca obscura*), Murray hardyhead (*Craterocephalus fluviatilis*), Murray Cod (*Maccullochella peelii peelii*), and Southern Bell Frog (*Litoria raniformis*)
- parts of the EPBC-listed threatened ecological community (TEC) critically endangered “Swamps of the Fleurieu Peninsula”, the state-listed threatened Gahnia sedgeland ecosystem, and a number of nationally listed plant species.

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region has a mix of industries, primarily dominated by irrigated and dryland agriculture, manufacturing industries centred on wine, machinery and equipment, boat building and maintenance, and recreation and tourism. Sheep, beef, and dairy cattle farming, grain, vegetable, fruit and nut growing, viticulture and fishing are the main primary industries in the area. There is also a significant urban population, with associated housing and service sectors (DEH, 2010).

The gross regional product (GRP) of the region’s economy was estimated to be around \$700 million in 2006-07 (Sobels, 2007). Primary industries directly contributed about \$145 million and directly employed about 2,000 people. Irrigated agriculture employed 1,000 people, contributing more than \$70 million to the GRP (DEH, 2010).

The region occupies a unique place in the Australian psyche as the subject of documentaries and films such as *Storm Boy* (based on Colin Thiele’s cherished Australian classic book). The site is also important given its tourism value (local and overseas), with the South Australian Tourism Commission estimating the number of visitors to the Coorong National Park in 2008 at about 138,000 (DEH 2010). The site is also a key location in South Australia for the pursuit of recreational activities such as sightseeing, bird watching, camping, walking, picnicking, fishing, swimming, boating, canoeing, water skiing and four-wheel driving (DEH, 2010).

There are also less tangible values associated with the region’s natural beauty. People speak of its spiritual value and the sense of freedom and renewal they experience when spending time there (DEH, 2010). The site is acknowledged as culturally vital to the

Ngarrindjeri people, with nationally important middens, burial sites, and other sacred places providing evidence of Ngarrindjeri customs over many thousands of years (DEH, 2010).

“The land and waters must be healthy for the Ngarrindjeri people to be healthy. We say that if Yarluwar-Ruwe (our country) dies, the waters die, our Ngartjis die, then the Ngarrindjeri will surely die”.

Ngarrindjeri Tendi, Ngarrindjeri Heritage Committee and Ngarrindjeri Native Title Management Committee (2006).

The Coorong, and Lakes Alexandrina and Albert wetland of International Importance is a significant site: ecologically, culturally and economically to both South Australia and the Commonwealth.

1.5.1. The Coorong

The Coorong is a long, shallow, estuarine to hypersaline lagoon more than 100 km in length separated from the Southern Ocean by a pair of narrow sand dune peninsulas (Younghusband and Sir Richard Peninsulas). The Coorong is composed of three main elements: the Coorong narrows and shallows near Parnka Point splitting the lagoon into the North and South Lagoons, and the section between Tauwichee and Goolwa barrages which is referred to as the Murray Estuary (Geddes and Butler, 1984; Geddes, 1987; Webster 2005; MDBC 2006, Webster 2007). The South Lagoon extends past Salt Creek where it becomes a series of hypersaline ephemeral lagoons (MDBC 2006).

Because the majority of its freshwater input occurs through the barrages close to the same end as the connection to the sea, the Coorong acts as an inverse estuary in which salinity generally increases away from the Mouth channel (Webster 2005).

Often, particularly during extended periods of low barrage flows, the salinity in the South Lagoon has been observed to considerably exceed the salinity of sea water ($\sim 35 \text{ g L}^{-1}$), a state that is called hypersaline. During the last decade, flows in the River Murray have been low due to irrigation abstraction and prolonged drought in the Murray-Darling Basin. With flows through the barrages being zero for several years, summertime salinity in the South Lagoon exceeded four times that of sea water (Fernandes and Tanner, 2009).

The understanding of the Coorong hydrodynamics is based on published results, and insights provided, by previous investigators including John Noye, Gunther Krause, Michael Geddes, Peter Holloway and David Walker. However, it is enhanced by more recent analyses of measurements collected during the last 10 years by Webster (Webster, 2005, 2007, 2010, 2011). This understanding allows a description of the physical dynamics (hydrodynamics) of the Coorong and how these respond to the system drivers namely:

- Mouth channel depth
- barrage flows
- flows from the Upper South East Drainage scheme (USED) via Salt Creek
- meteorological conditions (evaporation from and precipitation to the water surface, wind blowing over the water surface).
- water level variation in Encounter Bay (including tidal, weather band, and seasonal)

A one-dimensional hydrodynamic model for the Coorong (Webster, 2007) allows diagnosis of system dynamics, thereby providing insight into the function of the important drivers of the physical environment. The conceptual understanding of the Coorong's physical dynamics, encapsulated in a hydrodynamic model, has enabled the evaluation of strategies to alleviate recent degraded conditions and improve future management.

An ecosystem response model was also developed to explore potential future ecological conditions within the Coorong, associated with different climate change and management scenarios (Lester and Fairweather, 2009a, b). This provides a method for exploring the potential effects of proposed and existing management strategies (see Lester *et. al.*, 2011).

1.6. The Coorong hydrodynamic model

The one-dimensional hydrodynamic model developed by the CSIRO (Webster, 2007) simulates water motions, salinity, and water levels in the Coorong as these respond to the system drivers.

At a water level elevation of zero (0 metres Australian Height Datum – AHD), the average widths of the North and South Lagoons are 1.5 km and 2.5 km, respectively, and the average depths are 1.2 m and 1.4 m, respectively (Webster, 2007). The Parnka channel is shallow and narrow relative to the Lagoons and as such represents a considerable restriction for water exchange between the two lagoons.

The key elements of the Coorong from a hydrodynamic perspective are represented in (Figure 2):

- the North and South Lagoons and the Goolwa Channel that are relatively deep and wide
- the narrow Mouth channel connecting the Coorong to the sea
- the channels either side of the Mouth connecting the Coorong and Goolwa Channel basins
- the channel at Parnka Point connecting the Coorong North and South Lagoons.

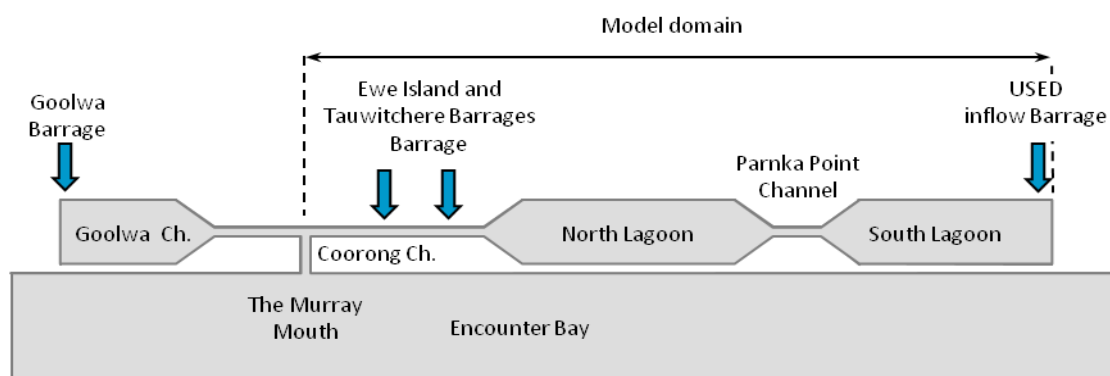


Figure 2: Schematic of major basins, connecting channels, and barrage flows in the Coorong. Not to scale.

The hydrodynamic model domain extends from the Murray Mouth to the south end of the South Lagoon (~5 km past Salt Creek) and is divided into 102 cells, each one km long, in which a momentum equation and an equation describing conservation of mass are solved.

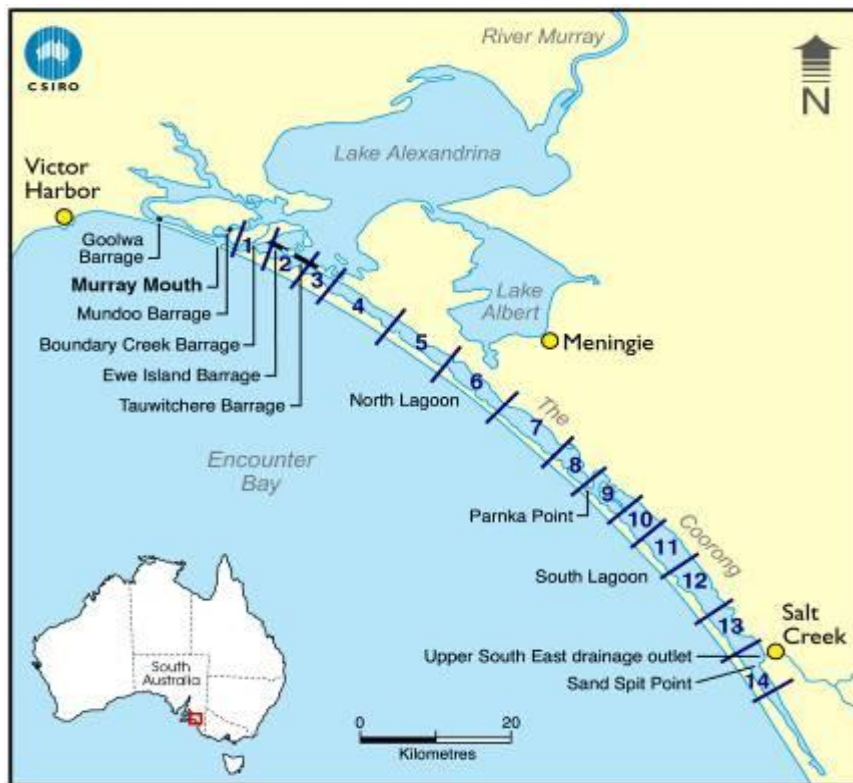


Figure 3: The Coorong, Lower Lakes and Murray Mouth showing the extent of the hydrodynamic model used in the study and the location of salinity cells within that model.

The currents, water levels, and mixing regimes simulated by the basic hydrodynamic model are used to drive a module representing the salinity dynamics. Salinity is modelled in the 14 cells of similar size that extend across groups of the 102 cells used in the base hydrodynamic model (Figure 3). The salinity module solves equations for the conservation of the mass of salt in each cell.

The model itself has been calibrated and validated using the available information for the Coorong (approximately 1976-2007), and was found to be able to simulate features of observed salinity and water level variation at all necessary time and space scales (Webster, 2007). The model structure, calibration, and validation have been described in more detail by Webster (2007, 2011).

The hydrodynamic model has subsequently been used by the MDBA to examine the effect of varying volumes of barrage discharges from the Murray-Darling Basin.

1.6.1. Barrage flows and Mouth channel depth

The Murray Mouth is the connecting channel between the Coorong and the Southern Ocean. Webster (2005) outlines that the degree of Murray Mouth openness is critical to the Coorong because of the way it affects:

- the way the Coorong exchanges water with the sea
- setting water levels within the Coorong and at times, Lakes Alexandrina and Albert.

Additionally, the Murray Mouth is the only path by which pollutants such as salt can be flushed from the entire Murray-Darling Basin, and biota such as diadromous fish can enter and exit the Basin to complete their lifecycles. Its 'openness' is therefore crucial for the health of not only the Coorong but also the whole river system.

The Mouth channel has always been relatively narrow but it has been, and continues to be, extremely dynamic. The width of the Mouth has varied from being several hundred metres during flood flows in the River Murray to being substantially constricted during periods of low flow in drought. The Mouth almost physically closed in 1981 and severely constricted in 2003 when flows out the barrages were very small compared to the long-term average.

Since 2002, the amount of water flowing over the barrages separating the Lower Lakes from the sea had not been enough to naturally keep the Murray Mouth open. Dredging was implemented to maintain a connection and reintroduce tidal variations in the Coorong, while also allowing sea water to enter the Coorong (Campbell, 2008, Brown, 2009).

While much is made of an open Murray Mouth, with many commentators arguing for an 'open Murray Mouth', there is much misunderstanding in the community about what is actually being sought. Many believe that a closed Murray Mouth refers to the accumulation of sand in the Murray Mouth such that a sand bar is created connecting Younghusband and Sir Richard peninsulas. This would result in a physical barrier which disconnects the Southern Ocean from the Coorong as effectively happened in 1981.

Reduced river flows and the associated increased likelihood of Mouth closure are regarded as a threat to the ecological function of the Coorong for a range of reasons (Webster, 2005).

Conversely, an open Murray Mouth is often thought of as a connection between the Coorong and Southern Ocean where water can pass between the two. In the context of the hydrodynamics of the Coorong and the site's ecology, while a physically closed Murray Mouth would be catastrophic, a constricted Murray Mouth could be just as devastating. It would still allow sea water to wash into the Coorong, but by severely restricting tidal penetration and internal mixing along the Coorong, the ability of the lagoon to rid itself of accumulating salt would be greatly diminished and extremely high salinities could occur

A hydraulically restricted (constricted) Murray Mouth is the last step prior to a physically closed Murray Mouth. The more constricted the Mouth is, the more likely a single large storm event is to force enough sand into the Mouth that could result in a physical closure. Once closed, the actions required to re-open the Murray Mouth are complex and costly based on actions required in 1981 (DWLBC, 2002).

As the Mouth progressively constricts, it impacts the ability for animals to migrate into or out of the Murray Mouth to complete their life-cycle or escape degraded water quality conditions in the Coorong.

The consequences of a severely constricted or closed Murray Mouth affect the Coorong's ecology, local industry, and the community. One of the outcomes of the 1981 closure was the decision to undertake dredging of the Murray Mouth. Dredging was an MDBC initiative, agreed by all of the Murray-Darling Basin states (Qld, NSW, ACT, Vic and SA) and the Australian Government, in recognition of the need to export salt and maintain the health of the Coorong.

Webster (2005) outlines the key determinants of the morphological condition of the Murray Mouth Channel as:

- freshwater volume past the barrages
- coastal conditions (wave climate, littoral transport, and sea level).

Aeolian processes have an unknown impact on the morphological condition of the Murray Mouth (Webster, 2005).

The dynamics of the sediment transport in the Mouth is such that flow speed determines whether sand is transported and in which direction. During periods of low or no flow through the barrages, flows through the Murray Mouth are dominated by tidal flows. Tidal water levels and therefore flows are highly asymmetric through the Mouth and estuary region with the flood (rising) tide having a higher current speed and shorter duration than the ebb (falling) tide (Webster, 2007).

During periods of low barrage flow, the tidal flow results in sand entering the Murray Mouth and its subsequent constriction. Substantial flow through the barrages alters the sediment transport by increasing flow out of the Mouth, adding to the falling tide and subtracting from the rising tide. If barrage flows are great enough, outward flow of sand on the ebb tide will be greater than that on the rising tide and the inwards transport of sand will be considerably reduced or stopped. The predominant direction of transport would then be reversed such that the Mouth channel is scoured and deepened.

Even though the bathymetry of the Mouth channel is highly complex, Webster used these dynamics to develop an element of the hydrodynamic model to estimate the effective Mouth size using a technique conceptually similar to that used by Walker and Jessup (1992) (see Webster, 2007). The hydrodynamic model considers the Mouth channel to be of length 1500-m and of uniform 100-m width, but which has a bed elevation which is allowed to vary as the channel is in-filled or scoured (Webster, 2007). The elevation of the bed of the Mouth channel to be used in modelling the Coorong dynamics is adjusted up or down until the observed and modelled attenuation of the tides between the ocean and the Coorong match one another. In effect, this procedure ensures that the Mouth channel has the correct hydraulic connectivity. Note that the Mouth bed elevations (and the depths that are derived from these) calculated in this way are only approximations to physical reality.

The Mouth depths (calculated as bed elevation subtracted from water depth) as determined from the fitting procedure just outlined are shown in Figure 4. The impact that barrage flows have on Mouth depths can be clearly seen. In normal flow years, barrage flows tend to deepen the Mouth channel, typically during spring when they are at their greatest, but when barrage flows cease through much of the year infilling occurs. Between 2002 and 2010, the barrage flows were relatively small, requiring dredging to maintain the Murray Mouth in an

open condition. This program ceased towards the end of 2010 with a return to larger barrage flows.

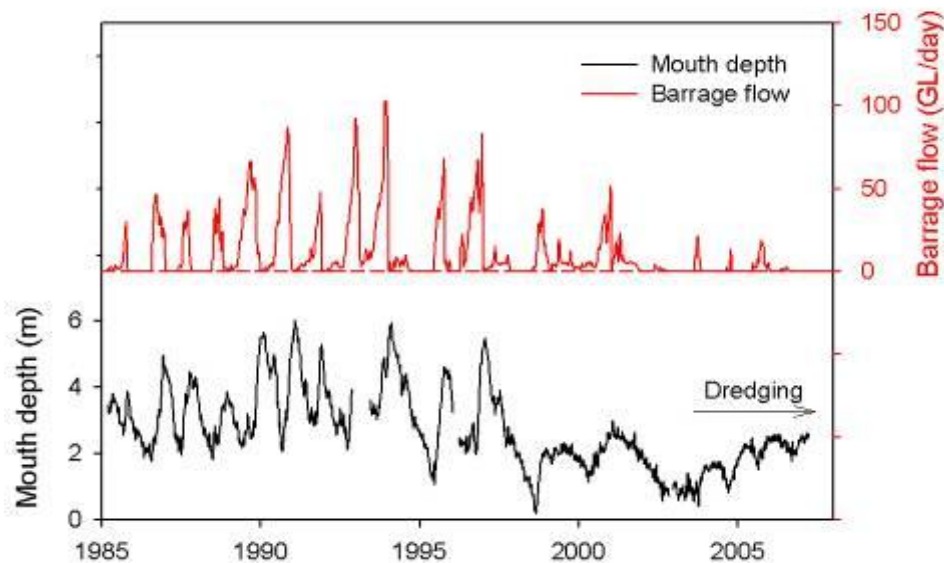


Figure 4: (Top) Barrage flows. (Bottom) Time series of Mouth depth estimated from analyses of water level transmission from ocean (Webster et al 2009).

Although the Mouth openness estimated from comparing water level measurements inside and outside the Coorong is not affected by waves the mathematical algorithm used for estimating Mouth bed elevations assumes a constant infilling rate when barrage flows stop. In reality, individual storm or wind events may be responsible for greatly enhanced infilling for shorter periods of times. If in a particular year there is a greater occurrence of such events then infilling might be considerably greater than normal between barrage flows. The Mouth opening algorithm should therefore be considered to represent an average rate of infilling across many years. Similarly, the rate of scouring of the channel for a particular barrage flow is likely to represent an average rate rather than what will happen with a particular channel configuration in a given year. Comparison between scenarios remains valid because each year of simulation assumes the same local climatic conditions across the scenarios.

Assessing the relative constriction of the Murray Mouth is important in understanding the impact of returning water to the system because of the effect it has on water quality, the ecology of the site, (directly and indirectly) as well as on biota that utilise habitats elsewhere in the Murray-Darling Basin (i.e. diadromous fish and waterbirds). Additionally, assessing the constriction of the Murray Mouth may guide whether it is possible to avoid the costs required to maintain a reasonable level of hydrological connection through dredging in times of insufficient flow.

1.6.2. Barrage flows and salinity in the Coorong

Salinity measurements have been collected sporadically from the Coorong since 1963. During this time, the South Lagoon always had higher salinities than the North Lagoon. In November 1975, salinities in the South Lagoon were measured to be similar to those of sea water, whereas salinities in the North Lagoon were mostly much less than a quarter of those of sea water. These measurements followed a time of very large barrage flows. More recent

barrage flows (2001-2010) have been small and salinities in both lagoons have been much higher than historical salinities as suggested by modelling.

It has been evident for a long time that barrage flows and salinity have been inversely related to one another (Geddes and Butler, 1984). As a general rule, high salinity in both lagoons tends to be associated with periods of reduced barrage flows and *vice versa*. A more complete picture of how salinity responds to barrage flows is achieved by applying the hydrodynamic model. Figure 5 shows that modelled and measured salinity in the South Lagoon are consistent with one another, with both showing enormous variability over recent decades. In both the measurements and model simulation periods of relatively low salinity in the lagoons follow times of relatively high flow through the barrages and *vice versa*.

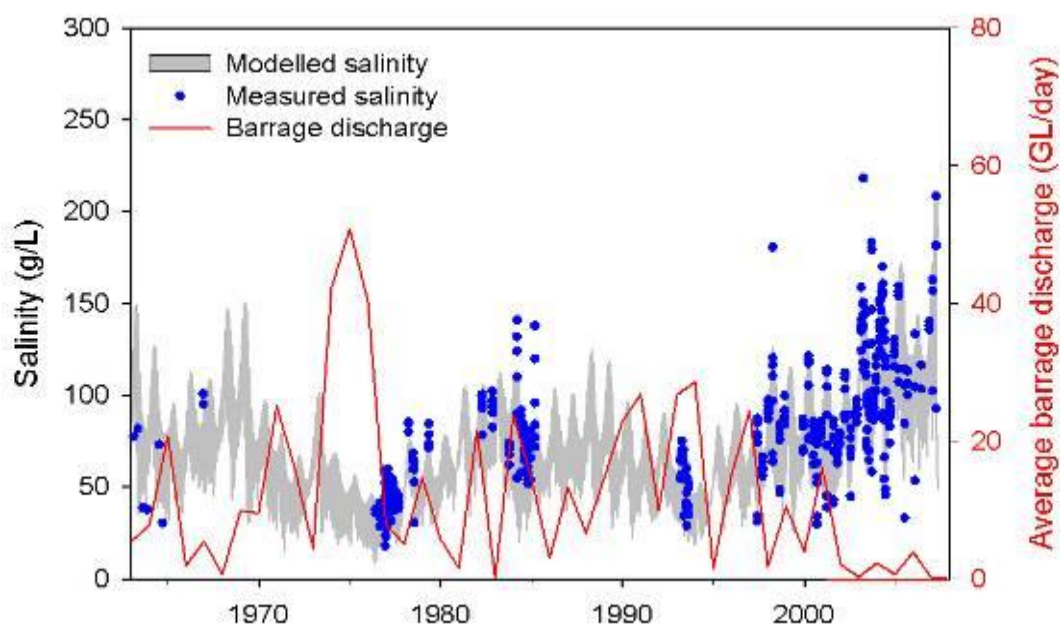


Figure 5: Measured and modelled salinity in the South Lagoon. The grey band shows the range of modelled salinity across the length of the lagoon. Also, shown is yearly averaged (total) barrage flow. Note that for flow, a point plotted at 1/1/1980, for example, represents the average flow for 1/7/1979 to 30/6/1980.

How barrage flows affect salinity in the Coorong can be understood with a conceptual model of the system (Figure 6) taken from Webster (2007). Evaporation from the water surface exceeds precipitation when averaged over a year and causes a net loss of water from both lagoons. To maintain water levels, a steady (advective) current flows along both lagoons from the vicinity of the Mouth towards the south end of the Coorong (Figure 6, top). Back and forth (oscillatory) water motions also occur in both lagoons as a result of sea level changes that propagate through the Mouth and also due to the wind acting on the water surface. Tides in the sea do not propagate very far along the Coorong, but are still an important cause of currents near the Mouth. Other sea level oscillations occur more slowly due to the passage of weather systems across Australia and these are important drivers of water motion (Webster, 2005).

During times of low barrage flows, the advective current of water required to replace evaporative losses derives water from the sea and so carries salt with it. This flow tends to cause salt to accumulate in the inner sections of the Coorong as water evaporates and leaves the salt behind. However, the sloshing of water back and forth associated with oscillatory flows tends to mix the saline water back towards the Mouth so that the system is balanced when the advective transport of salt into the Coorong matches the mixing transport

in the opposite direction. Because sea levels, net evaporation rates, barrage flows, and winds vary seasonally so does the response of the Coorong, so the conceptual model described here applies in an average sense.

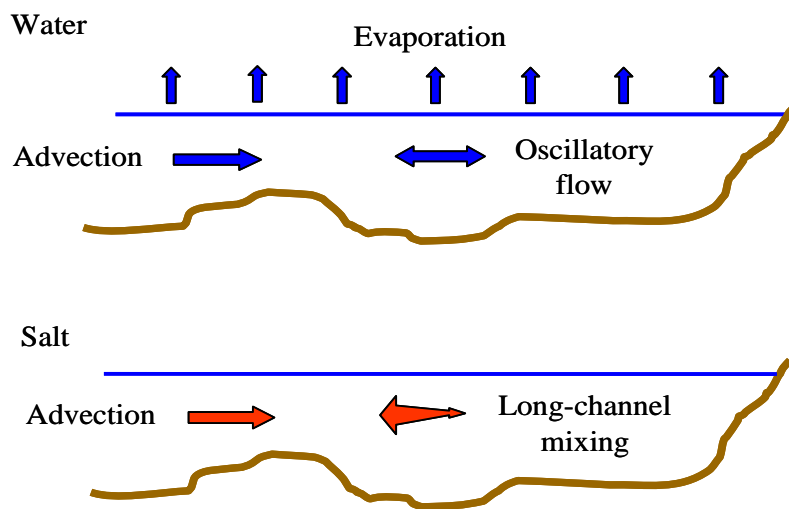


Figure 6: Conceptual model of water motions and salt balance in the Coorong. In the top diagram, the arrows show the direction of water transport. The arrows indicate the directions of salt transport in the bottom diagram (Webster 2005).

Webster (2010) outlines that barrage flows impact on Coorong salinity in three fundamental ways:

1. First, the barrage flows freshen the water between the barrages and the Mouth channel. Any water drawn into the South Lagoon to replace evaporative losses therefore has a lower salt content than it would have if sea water were being drawn in instead. Even after the barrage flows stop, the fresh or brackish water between Tauwichee Barrage and the Mouth takes time to mix out into the ocean.
2. Second, the barrage flows cause scouring and deepening of the Mouth channel. This allows sea level variations to propagate more efficiently from Encounter Bay into the Coorong and so along-lagoon mixing is enhanced. Enhanced along-lagoon mixing accelerates the removal of salt from the South Lagoon.
3. Finally, flow blocking through the relatively-constricted Mouth channel causes water levels to rise in the Coorong during times of strong barrage flows. The raising and lowering of water levels when the barrage flows rise and subside causes water to push into the Coorong and back out and so also contributes to long-lagoon mixing and salinity reduction.

1.6.3. MDBA Modelled Barrage outflows

Heneker and Higham (2012) provide an analysis of the flow volumes and differences between Draft Basin Plan scenarios provided by the MDBA. Table 1 provides a short summary of the comparative statistics for the barrage outflow volumes associated with each scenario and the MDBA modelling runs used in this analysis.

Table 1: flow statistics for scenarios modelled and provided by the MDBA to SA (1895/96-2008/09)

| | Without Development | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|--|---------------------|----------|---------|---------|---------|---------|
| MDBA Model run # | #844 | #845 | #859 | #865 | #847 | #863 |
| Average annual barrage outflow (GL) | 11667.62 | 4862.00 | 6515.70 | 6830.91 | 6837.86 | 7140.33 |
| Additional average barrage outflow relative to baseline (GL) | 6805.62 | 0.00 | 1653.70 | 1968.91 | 1975.86 | 2278.33 |

At the site, the flows from the Murray-Darling Basin pass through the five barrages separating the Coorong from Lake Alexandrina (Figure 1). Most of the flow through the barrages historically occurs through releases from Tauwitchere, Ewe Island and Goolwa barrages. Examination of barrage records between 1962 and 2002 indicated that during this period the barrages were closed approximately 49% of the time (Close, 2002).

In developing the hydrodynamic model, Webster undertook an analysis of gate openings in the barrages between 1982 and 2007. These operations suggested that an average of 58% of the total flow was released through Tauwitchere Barrage and 19% through Ewe Island Barrage, whereas most of the rest flowed through the Goolwa barrage (Ian Webster, pers. comm.). This forms an assumption in the model and that this is indicative of barrage operations throughout the time series.

2. Assessment of Proposed Basin Plan scenarios

2.1. Introduction

The relative merits of the draft Basin Plan scenarios are to be assessed for the Coorong using three ecological drivers:

1. Murray Mouth 'openness'
2. Coorong salinity
3. Coorong water levels

These key elements of the hydrology of the Coorong provide important guidance regarding the relative merits of the proposed water recovery scenarios for the Coorong. This section outlines the literature and studies used to support the hydrological metrics that act as ecological drivers selected for this analysis.

Once the rationale for the metrics is described, the analysis will compare the proposed water recovery scenario (2750 GL) relative to the baseline and 'without development' scenarios. By comparing the proposed 2750 GL water recovery scenario to the sensitivity testing scenarios (2400 GL and 3200 GL), some understanding can be gained of the sensitivity that target outcomes have to assumptions inherent in the modelling, which could affect water availability.

Ecological drivers

An Ecological Driver is defined as a biotic or abiotic element of the environment that causes a change in an organism, community, ecosystem, or other ecological component of the landscape (EPA, 2012).

Salinity, water level, and Mouth openness are important ecological drivers in the Coorong and the Ecological Character of the site (Phillips and Muller, 2006). Salinity is a major determinant of the ecology in the Coorong because it has been demonstrated to influence the abundance and distribution of fish (Brookes et al, 2009), *Ruppia tuberosa* (Rogers and Paton, 2009), macroinvertebrates in the Coorong (Rolston and Dittman, 2009), and indirectly through food availability for waterbirds (Rogers and Paton, 2009).

Water levels are a major determinant of the ecology of the Coorong having been demonstrated to influence submerged aquatic plant community structures (Rogers and Paton, 2009), influence macroinvertebrate distribution and abundance (Rolston and Dittman, 2009), inundate mudflats and alter access to feeding habitats and food availability over space and time for migratory wading birds (Rogers and Paton, 2009), and affect mixing processes and salinity in the Coorong (Webster, 2007).

The 'openness' of the Murray Mouth has been demonstrated to interact with water levels (and therefore salinity) by the way it moderates the propagation of sea level variations from Encounter Bay into the Coorong (Webster, 2007), maintaining tidal fluctuations in the North Lagoon to alter the foraging habitat for wading birds (Campbell, 2008) and also affect

macroinvertebrate species composition (Hirst, 2004; Hastie and Smith, 2006) although this later aspect has not been demonstrated in the Coorong.

2.2. Murray Mouth openness

As outlined previously, constriction of the Murray Mouth can affect the ecology of the Coorong both directly and indirectly by affecting water levels internal mixing along the Coorong, and the ability of the lagoon to rid itself of accumulating salt such that extremely high salinities could occur. An appropriate level of Murray Mouth 'openness' has proven to be difficult to identify with recent studies (Lester et al, 2011) concluding that healthy ecosystem states can only occur with a functional level of Murray Mouth openness, without defining this level except via thresholds for the occurrence of 'healthy' ecosystem states in the Coorong.

The Murray Mouth constricts and 'opens' both within and between years largely in response to flow. The determination of a level of Mouth openness has been made in a practical sense using the Diurnal Tidal Ratio (Walker and Jessup 2002) and this forms the measure by which Mouth openness and dredging performance has been assessed in practice (MDBC, 2005). Metrics describing Mouth openness are really a construct of risk to Mouth closure (Close, 2002) rather than a guarantee the Mouth will physically close, resulting in impacts to water quality of the Coorong and the ecology (DWLBC, 2002).

Determining if the Mouth is unacceptably constricted and at higher risk of closure while a valid assessment in the context of assessing Basin Plan water recovery scenarios is problematic because there is no agreed absolute flow required to achieve this state. A range of investigations have been undertaken to develop measures of Mouth openness (Walker and Jessup, 1992; Walker 2002; Close, 2002 and more recently, Webster et al 2009 and Webster, 2011) but translating these metrics to a flow volume or regime has proved challenging when attempted by these authors.

Webster et al (2009) undertook an analysis of the channel connecting the Coorong with the sea using a derived mathematical algorithm representing the elevation of the bed of this channel (assuming it has uniform width of 100 m and a length of 1500 m) as a surrogate of Mouth depth (listed as mouth bed depth or Z_M). In doing so, they investigated the relative merits of increasing flow volumes for keeping the Mouth clear. The algorithm was not coupled to the fully hydrodynamic model simulated bed elevation of this uniform channel with a sea level set to zero.

In reality, Mouth depth actually varies in response to sea level which shows a seasonal cycle of ~0.3 m. As detailed earlier, changes in the degree of Mouth 'openness' were represented by Webster et. al (2009) as changes in the elevation of the bed of this channel. To account for seasonal sea level changes, the water level in the Coorong is used together with the elevation of the bed of the Mouth channel to calculate the effective Mouth depth.

Webster et al (2009) examined a range of flow volumes from 500 ML/annum up to 2000 GL/annum and a range of different release rates.

In general, Webster et al (2009) found that the scour model indicates:

- high flow rates produce a deeper channel for a given flow volume as would be expected intuitively, but averaged over a whole year, the average Mouth depth is

fairly insensitive to flow volume since a lower flow rate for a given release volume lasts for longer

- higher flow volumes increase the average Mouth channel depth, but the incremental depth increase per increase in flow volume diminishes as the flow volume increases.

The key finding was that to attain an average Mouth channel depth of 2 m (which is approximately what was achieved by the recent dredging effort), a release volume of ~2000 GL/annum is required. This conversion of flow required to achieve the equivalent of a minimum desirable Diurnal Tidal Ratio to Mouth depth forms the basis of the MDBA target for maintaining an open Murray Mouth.

The depth of the Mouth channel is continuously changing in response to barrage flows that scour the channel and infilling associated with processes such as suspension of sands by ocean waves. From analysis of available data, CSIRO developed a robust empirical relationship between flow through the Mouth and its rate of change of depth that represents these two opposing tendencies; depth increases almost directly with flow speed (Webster, 2007). In general, a large barrage flow delivered over a short period of time results in a deeper channel than the same volume of water delivered more slowly over a longer period of time. However, the smaller discharge may result in a channel depth that is similar when averaged over time since it takes longer before infilling commences on cessation of the flow. Importantly, the model also indicates that a lower flow delivered over a longer period achieves a greater salinity reduction than the same volume of water delivered more quickly in a higher flow (Webster et al 2009).

Summary of Mouth openness

The work undertaken by Webster et al (2009) provides a number of coarse metrics to assist with assessing the constriction of the Murray Mouth:

- annual flow from the barrages greater than 2,000 GL/annum
- an annual average mouth bed elevation greater than 2 m.

Classifying the years where average annual Mouth depth is greater or less than 2 m is assumed to provide an indication of the relative Mouth openness. The classification is initially that the Mouth is 'unconstricted' if depth is greater than 2 m, while the Mouth would be classified as 'constricted' if the Mouth depth was less than 2 m. After the initial classification as 'constricted', years where the Mouth has an average annual depth less than 1 m would be classified as 'severely constricted'. Alternatively, the Mouth would be effectively closed at a Mouth depth of 0 m, with only limited tidal exchange between the Coorong and the sea occurring at high tide.

2.3. Target values and thresholds to support Coorong biota

In order to assess local ecological condition within the region, a linked suite of species and assemblages were developed that could indicate the achievement of the desired ecological outcome of a healthy and resilient Wetland of International Importance (Lester et al, 2011). Through this work, an attempt was made to include species and assemblages that were:

- likely to be directly affected by hydrodynamic parameters (e.g. water levels and water quality)
- considered to be key species or assemblages within the region (primarily based on previous research or expert opinion)
- threatened and thus considered to be a matter of National Environmental Significance under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act)
- considered to be sensitive to environmental change (i.e. analogous to the canary in the coalmine).

This information largely has been selected here for use in determining threshold values to assess the Draft Basin Plan scenarios and report on possible consequences. For further information on the indicator selection methodology, the species included, or the linkages to the various objectives and outcomes sought to demonstrate a healthy and resilient wetland of international importance, see Lester et al (2011).

In the framework of this report, the term threshold is used as a value of an environmental parameter at which it is determined from studies that biota can be exposed to without adverse health effects (i.e. threshold values likely to result in harm to the ecology).

In ecological risk assessments, if the maximum value of a contaminant is compared to an eco-toxicologically-based benchmark (Ecotox threshold) for a 'receptor' and the concentration exceeds the benchmark, further assessment is warranted to determine the ecological risk posed by the contaminant (EPA 1996). It is assumed that the events modelled are likely to occur in the future such that if thresholds of ecological drivers are exceeded, the consequence is high and therefore the risk is high.

Where Lester et al (2011) considered indicators were to be representative of ecological outcomes, the available literature was searched and collated (in addition to expert opinion where necessary and/or possible) on the environmental requirements of each indicator to a suite of environmental conditions that were thought to be flow related. These included:

- salinity
- turbidity
- annual return frequency (ARF) of barrage flows inundation
- connectivity (hydraulic and population)
- water levels
- the timing of events.

Information relating to the functional grouping (e.g. feeding groups for invertebrates) and location of each within the region are detailed in Lester et al (2011).

This information was then used to identify thresholds for each of the flow-related parameters for the region, and to construct tables ('trade-off tables') that provided a summary of the known tolerances for each indicator for several of the parameters where most information was available. These tables provide some indication of the consequences of different water recovery volumes on the biota of the site to guide an assessment of the likely implications of one water recovery scenario compared to another and relative to the do-nothing scenario.

2.4. Coorong salinity

The salinity of the Coorong generally increases with increasing distance from the Murray Mouth, but varies over time, mainly in response to barrage outflows from the Murray-Darling Basin (MDBC 2006). The salinity variation - representing estuarine, marine, and hypermarine habitats - supports differing ecological communities (Brookes et al, 2006).

The United States EPA recognises that salinity is a common habitat indicator (abiotic condition indicator) for use in estuaries. Salinity is well-defined, measurable, has ecological significance, and encompasses a number of estuarine properties and processes (Jassby et al, 1995). Based on preferred or lethal concentrations listed in the literature and the historical distribution of the biota in the Coorong (either from the North or South Lagoon), an assessment of the implications to the Coorong biota can be made.

Vegetation

Lester et al (2011) selected ten vegetation indicator species and assemblages for the entire site. While paperbark (*Melaleuca halmaturorum*) and samphire will tolerate elevated salinities and lignum (*Muehlenbeckia florulenta*) tolerates salinities up to 100 ppt (van der Sommen, 1980 cited in Lester et al., 2011), they occur in the vicinity of the Coorong not in the waterbody per se.

The two species of *Ruppia* (sea tassels; *Ruppia megacarpa* and *Ruppia tuberosa*) are the primary vegetation indicators for the Coorong. Lester et al (2011) similarly to other authors, including the MDBA, indicated that these two species of *Ruppia* are key to the ecological functioning of the region. Phillips and Muller (2006) state that *Ruppia* sp. in the Coorong can be considered as 'Ramsar significant biota' for the region, given their role in the aquatic community. The species act as habitat for the saline-tolerant small-mouthed hardyhead (*Atherinosoma microstoma*), macroinvertebrates and meiofauna that act as a food source for this fish, as well as a direct food source for waterbirds including Black Swan (*Cygnus atratus*), a number of migratory shorebird *Calidris* species, (Paton 2005), while small-mouthed hardyhead are an important food source for the endangered Fairy Tern (*Sternula nereis nereis*) and other piscivorous bird species in the region (Rogers and Paton, 2009). It is noted that the diversity and coverage of these species has been declining in recent years as a result of prolonged drought and low-flow conditions with *R. megacarpa* not detected in surveys and the range of *R. tuberosa* severely contracted (see Rogers and Paton, 2009 for further information).

Salinity in the Coorong that permits the growth of *Ruppia* spp. may also lead to increased competition through the growth of the green algae *Enteromorpha* spp. which was predicted to have a negative impact on distribution of *Ruppia* spp. (Rogers and Paton, 2009). *Enteromorpha* is not a taxon that was considered in Lester et al (2011), but should be

considered in future determination of conditions to support *Ruppia* populations in the Coorong to ensure salinities are not too low this species prohibits the restoration of *Ruppia*.

Of the vegetation indicators relevant to the Coorong, the majority had salinity thresholds of $\sim 45 \text{ g L}^{-1}$, with *R. megacarpa*, tolerant of up to $\sim 50 \text{ g L}^{-1}$ and *R. tuberosa* tolerating salinities up to $\sim 230 \text{ g L}^{-1}$ (Brock, 1982). Although it must be noted that at these extreme salinities there would be little active plant growth and salinity reduction would be required to permit recruitment. Hence its use as an upper threshold should be treated with great caution as persistence is not always the most appropriate measure of ecological health. Paton and Bailey (2010) indicate *Ruppia tuberosa* will re-establish in a salinity range of $32\text{--}110 \text{ g L}^{-1}$, although highest abundances would be expected at sites experiencing a salinity range between $72\text{--}98 \text{ g L}^{-1}$ (Rogers and Paton, 2009). Research suggests that growth, flowering, seed set, and turion growth in *R. tuberosa* is severely curtailed at salinities above 120 g L^{-1} (Paton and Bailey, 2010). As such, the time required to complete flowering and seed set is considerably extended relative to lower salinities, truncating its growing season particularly if water levels decline sufficiently prior to seed set. Brock (1982) identified that Laboratory trials indicated extreme salinities resulted in senescence of plant growth. These findings have subsequently been supported by similar findings for another *Ruppia* species, *R. polycarpa* (Sim *et al.*, 2006). This is important given Coorong water levels vary seasonally such that rapid water level changes or low water levels may prevent the species completing its lifecycle and potentially, over time, serially deplete the propagule bank of the population by preventing its replenishment (Nicol, 2005; Paton, 2010).

This indicates that the maximum salinity for *Ruppia tuberosa* is 120 g L^{-1} and the preferred maximum is 100 g L^{-1} assuming water levels remain appropriate for the growth season.

Macroinvertebrates

Macroinvertebrates were not assessed as a part of the site's Ramsar ecological character description (Phillips and Muller, 2006), however they form a vital part of the Lakes and Coorong aquatic ecosystem and contribute to the ecological character of the region (Lester *et al.*, 2011).

Lester *et al.*, (2011) selected 19 macroinvertebrate indicator taxa to cover the gradient of freshwater, estuarine, marine, and hypersaline habitats within the region. The estuarine and/or marine indicator species included:

- tubeworm (*Ficopomatus enigmaticus*)
- various polychaete worms (i.e. *Nephtys australiensis*, *Simplisetia aequisetis* and *Capitella* spp.)
- the microbivalve (*Arthritica helmsi*)
- Goolwa cockle (*Donax deltoides*).

The hypersaline macroinvertebrate indicator considered was brine shrimp (*Parartemia zietziana*).

In addition to these indicator species identified by Lester *et al.*, (2011), Chironomids (*Tanyarsus barbitarsus*) are an appropriate hypersaline biotic indicator given their status as a food item for small-mouthed hardyhead and some wading birds (Phillips and Muller, 2006; Paton, 2010), Chironomids live on the surface of submerged sediments and graze on surface algae (Paton, 2010).

Based on observed distribution and abundance in the Coorong, *T. barbitarsus* has one of the highest salinity tolerances of the previously abundant microinvertebrates of the Coorong with a preferred salinity of less than $\sim 90 \text{ g L}^{-1}$ although it has been recorded at salinities up to $\sim 120 \text{ g L}^{-1}$ (CLLAMMecology Research Cluster, 2008). Although Kokkinn (1986) identified 100 g L^{-1} as the lethal salinity for 50% of the test subject larvae of this species and therefore represents the upper limit for the species in this assessment.

Most of the macroinvertebrate indicators selected by Lester et al, (2011) did not occur in the Coorong (i.e. were freshwater taxa), but of those that occurred there, the majority had preferred salinity ranges of up to approximately $\sim 45 \text{ g L}^{-1}$. Only the polychaete worms, Chironomids and brine shrimp had higher preferred tolerances ($\sim 70 \text{ g L}^{-1}$, $\sim 100 \text{ g L}^{-1}$ and $>200 \text{ g L}^{-1}$, respectively).

Of the macroinvertebrate indicators that were found in the Coorong, most preferred an ARF of less than one for barrage flows, with marginal tolerance to ARFs of up to three. Only *Amphipoda* and brine shrimp had higher preferred ranges, of three and greater than three, respectively.

Fish

Lester et al (2011) selected 17 indicator species to cover the range of freshwater, estuarine, and marine habitats across the site, as well as different strategies for using the site (e.g. migratory versus resident). Many of the fish indicators were either rare visitors to parts of the region (e.g. the Lakes) and/or were tolerant of elevated freshwater salinities (particularly common carp), but were not indicators of relevance to Coorong water quality. The fish indicator species that were considered relevant to the estuarine and/or marine environments of the Coorong included:

- congolli (*Pseudaphritis urvillii*)
- yellow-eyed mullet (*Aldrichetta forsteri*)
- black bream (*Acanthopagrus butcheri*)
- Small-mouthed hardyhead (*Atherinosoma microstoma*)
- mullet (*Argyrosomus japonicus*)
- sandy sprat (*Hyperlophus vittatus*)
- Australian salmon (*Arripis truttacea*)
- bronze whaler shark (*Carcharhinus brachyurus*).

Diadromous fish species, have been considered in Heneker and Higham (2012).

For the fish indicators found in the Coorong, most had preferred salinities ranges of ~ 36 to $\sim 50 \text{ g L}^{-1}$. Lethal Concentration Values (LC50) for these species (e.g. congolli, bony herring, yellow-eyed mullet and black bream) tended to be less than $\sim 100 \text{ g L}^{-1}$. The most tolerant fish indicator (small-mouthed hardyhead) had a preferred salinity range up to $\sim 90 \text{ g L}^{-1}$ or greater (Lester et al, (2011), although the upper limit identified for this species is $\sim 108 \text{ g L}^{-1}$. It is also interesting to note that for some fish species (e.g. small-mouthed hardyhead) the salinity tolerance in the field was actually substantially higher than the lowest known LC50 value, further complicating the use of LC50 values in setting target thresholds (cf. Wedderburn et al, 2008; Bice 2010).

For barrage flows, most of the fish indicators were not found in the Coorong and/or were not estuary-dependent. For those that were, ARIs >5 for the return of barrage flows tended to result in populations for which persistence was possible, but such a long time without connection and exchange would put the majority of these species at risk (e.g. bony herring, mullet and small-mouthed hardyhead).

‘Trade-off’ tables for salinity in the Coorong

In order to summarise the available information relating to the comprehensive list of indicators with the flow-related parameters, Lester et al (2011) developed a set of tables illustrating known thresholds and tolerances similar to CLAMMecology Research Cluster (2008). These tables were developed to allow the relationships between indicator taxa, assemblages and processes and hydrologic conditions to be easily visualised. For the Coorong, Lester et al, (2011) identified critical thresholds, where possible, for water quality (focusing on salinity), flow regime (indicating an ARF), connectivity (specifying intra-site connections and timing). This allowed the indicators for ecological function to be directly related to the hydrodynamics and flow regime of the region, and the various trade-offs associated with increasing salinities and decreasing flows to be highlighted. Therefore, the different outcomes, in terms of the biota and processes supported, arising from a range of possible environmental watering decisions can be assessed.

Applicable information from the trade-off tables from Lester et al (2011) is presented for the salinity tolerance of relevant vegetation (Table 2), macroinvertebrate (Table 3) and fish (Table 4) indicators in the Coorong. Lester et al, (2011) were unable to identify sufficient information to link Coorong water levels to any indicator set.

Table 2: Salinity tolerances of vegetation indicators in the Coorong from Lester et al, (2011)

Note: Dark grey shading denotes preferred ranges, light grey shading denotes marginal ranges and no shading denotes outside of range.

| Indicator | Coorong Salinity (g L ⁻¹ ; ‰ TDS) | | | | | | | | References and comments |
|-------------------------|--|----|----|----|-----|-----|-----|-----|--|
| Vegetation | 0 | 36 | 60 | 90 | 120 | 150 | 180 | 200 | |
| Samphire & saltmarsh | | | | | | | | | Nicol 2007; Short & Colmer 1999; Purvis <i>et al.</i> 2009 |
| Paperbark | | | | | | | | | van der Moezel <i>et al.</i> 1991 |
| <i>Ruppia megacarpa</i> | | | | | | | | | Brock 1982a |
| <i>Ruppia tuberosa</i> | | | | | | | | | Brock 1982a |

Note: the increments of increase in salinity across the columns are not uniform.

Table 3: Salinity tolerances of macroinvertebrate indicators in the Coorong from Lester et al, (2011)

Note: Dark grey shading denotes preferred ranges, light grey shading denotes marginal elevations and no shading denotes outside of range.

| Indicator | Coorong Salinity (g L ⁻¹ ; ‰ TDS) | | | | | | | | References and comments |
|--------------------|--|----|----|----|-----|-----|-----|-----|--|
| Macroinvertebrates | 0 | 36 | 60 | 90 | 120 | 150 | 180 | 200 | |
| Amphipoda | | | | | | | | | Geddes 2005; Kangas & Geddes 1984 |
| Tubeworms | | | | | | | | | Geddes & Butler 1984 |
| Bivalve | | | | | | | | | Kanandjembo <i>et al.</i> 2001 |
| Polychaete worms | | | | | | | | | Dittmann <i>et al.</i> 2006 |
| Brine shrimp | | | | | | | | | Geddes 1976 |
| Chironomids | | | | | | | | | Geddes & Butler 1984, Kokkinn, 1986 |
| Goolwa cockle | | | | | | | | | Murray-Jones & Johnson 2003; Nell & Gibbs 1986 |

Note: the increments of increase in salinity across the columns are not uniform.

Table 4: Salinity tolerances of fish indicators in the Coorong from Lester et al, (2011)

Note: Dark grey shading denotes preferred ranges, light grey shading denotes marginal ranges and no shading denotes outside of range.

| Indicator | Coorong Salinity (g L ⁻¹ ; ‰ TDS) | | | | | | | | References and comments |
|-------------------------|--|------------------------|---------------------------|-----------|-----|-----|-----|-----|--|
| Fish | 0 | 36 | 60 | 90 | 120 | 150 | 180 | 200 | |
| Congolli | Dark grey | | | | | | | | SKM 2003; Clunie <i>et al.</i> 2002; Hart <i>et al.</i> 1991 |
| Common galaxias | Dark grey | | | | | | | | Chessman & Williams 1974; Bice 2010a |
| Yellow-eyed mullet | Dark grey | | | | | | | | Juvenile salinity tolerance <86 g L ⁻¹ ; adults < 35 g L ⁻¹ ; Chubb <i>et al.</i> 1981 |
| Black bream | Light grey | Dark grey | | | | | | | Bice 2010; Bice pers. comm. |
| Small-mouthed hardyhead | Dark grey | | | Dark grey | | | | | Hart <i>et al.</i> 1991 |
| Mulloway | | Dark grey Juveniles | | | | | | | Bice 2010 |
| Sandy sprat | | Dark grey | | | | | | | prefers less than marine salinities |
| Australian salmon | | Light grey | | | | | | | SARDI unpub. Data |
| Bronze-whaler shark | | | Dark grey Rare visitor | | | | | | PIRSA unpub. Data |

Note: the increments of increase in salinity across the columns are not uniform.

Discussion of salinity targets for Coorong biota - Summary of relevant thresholds

Lester et al (2011) found it difficult to identify critical thresholds for some indicators because the available information varied widely across the different indicators. Lester et al (2011) caution the “illustrated thresholds should be interpreted as being maxima, and a conservative approach to interpreting the tables, wise” (i.e. exceeding the thresholds proposed poses increased risk, particularly when co-occurring stressors act).

Much of the published work relating to species and assemblage tolerances reviewed by Lester et al (2011) concentrated on environmental conditions under which those species and assemblages have been found in the field, or on the lethal concentration values (LC50). The LC50 value for a species or an assemblage is an extremely coarse measurement of a tolerance (as 50% of the individuals would already be dead), so it is not appropriate for use in setting target environmental conditions to maintain and restore the Ramsar-listed ecological character.

LC 50 values have most use as an upper limit to demonstrate a high risk of impact to the species in question. Conditions under which the species and assemblages have been detected in the field are a better basis upon which to set target thresholds, but persistence is not always the most appropriate measure of ecological health, particularly for long-lived species which may persist in unfavourable conditions for many years or even decades while suffering substantial sub-lethal impacts (Lester et al, 2011).

Sub-lethal stress (or sub-lethal impacts) has been defined as stress that changes the condition of an organism, without causing mortality (Barton and Iwama 1991 cited in Lester et al, 2011). Such changes may include increased incidence of disease, slower or lower levels of growth, failure to reproduce successfully or changes in tissue, organ or cellular functions (e.g. changes in osmoregulation) (Hassell et al, 2006 cited in Lester et al, 2011). In some instances, behavioural change is also possible (Lester et al, 2011). Behavioural changes such as avoidance and movement from preferred habitats can have follow-on impacts to the higher order trophic ecology (i.e. the habitat use of Fairy Terns in the Coorong is linked to Small-mouthed hardyhead distribution and abundance - see Rogers and Paton, 2009) indicating changes in hardyhead populations habitat use in the Coorong can result in broader, system level impacts on the ecology.

There is in effect, a continuum of severity of sub-lethal impacts, tending to increase as the lethal threshold for a stressor (or combination of stressors) is approached (Lester et al, 2011). Where environmental conditions resulting in sub-lethal impacts persist for long periods, and where they are severe enough, they are capable of causing the loss of the species or assemblage in the long term (e.g. due to a failure to successfully reproduce), even though conditions may not be severe enough to kill all individuals outright. Thus, any assessment of environmental conditions suitable to support a healthy, productive, and resilient wetland of international importance needs to consider the variables for which sub-lethal impacts may be important and set thresholds to minimise the likelihood of their occurrence (Lester et al, 2011).

Assessing the consequences for vegetation, macroinvertebrates, and fish without considering the impacts to birds may seem counterintuitive initially for a Ramsar site. Given these elements of the ecology respond directly to aquatic environmental conditions whereas birds arguably may not, instead responding to the impacts on these primary responses the

approach is valid. This argument is supported by the work of Paton (2010) who demonstrated that during the past 10 years, piscivorous species such as the Australian pelican, Fairy tern, Whiskered tern, Common greenshank and White-faced heron have been steadily declining during the past 10 years as the abundance of small-mouthed hardyhead has declined. Other species have changed their foraging areas and feeding habitats (Paton, 2010). The reliance of wading birds on the presence of chironomid larvae and *Ruppia tuberosa* act as further indicators of food resources being available. As such, the working hypothesis for this assessment is that the condition of the Coorong, as denoted by these indicators, provides an assessment of consequences to higher order species without directly assessing the requirements of these species. Information presently doesn't permit the assessment of wading bird habitat directly by linking Coorong water levels over the year. This, together with the assessment of direct and indirect consequences to waterbirds within the site, should form an element of any future evaluation of proposed water provision to the site.

Based on published literature summarised in the trade-off tables for salinity, the target salinities for:

North Lagoon biota are:

- | | | |
|------------------------------|-------------------|---|
| • Polychaete worms | Maximum | ~70 g L ⁻¹ (Geddes, 2003) |
| • <i>Arthritica helmsi</i> | Lethal Maximum | ~55 g L ⁻¹ (Wells & Threlfall, 1982) |
| • <i>Ruppia megacarpa</i> | Lethal Maximum | ~50 g L ⁻¹ (Lester <i>et. al.</i> , 2011) |
| • Estuarine fish communities | Preferred Maximum | ~50 g L ⁻¹ (Lester <i>et. al.</i> , 2011) |
| • Macroinvertebrate taxa | Preferred maximum | ~45 g L ⁻¹ (Lester <i>et. al.</i> , 2011) |
| • Polychaete worms | Preferred maximum | ~40 g L ⁻¹ (Dittman <i>et. al.</i> , 2006) |

In summary, the target salinity threshold for the North Lagoon should be to not exceed 45 g L⁻¹ so as to avoid sub-lethal effects on target biota. Lethal salinities for target species begin to manifest at salinities greater than 50 g L⁻¹. Although some species will persist at salinities higher this, it is likely to pose considerable risk to elements of the ecology.

South Lagoon biota are:

- | | | |
|---------------------------|-------------------|---|
| • <i>Ruppia tuberosa</i> | Lethal Maximum | ~230 g L ⁻¹ (Brock, 1982) |
| • Small-mouthed Hardyhead | Lethal Maximum | ~108 g L ⁻¹ (Lui, 1969) |
| • Chironomids | Lethal Maximum | ~100 g L ⁻¹ (Kokkinn, 1986) |
| • <i>Ruppia tuberosa</i> | Preferred maximum | ~110 g L ⁻¹ (Paton, 2010) |
| • Small-mouthed Hardyhead | Preferred maximum | ~94 g L ⁻¹ (Molsher et al, 1994), |
| • Chironomids | Preferred maximum | ~90 g L ⁻¹ (Geddes & Butler, 1984) |

In summary, the target salinity threshold for the South Lagoon should be to not exceed 90 g L⁻¹ so as to avoid sub-lethal effects on target biota in the South Lagoon. Lethal salinities for target species begin to manifest at salinities greater than 100g L⁻¹. It is worth noting that growth, flowering, seed set, and turion growth in *R. tuberosa* is severely curtailed at salinities

above 120 g L⁻¹ (Paton and Bailey, 2010) at which point the mobile species would have been excluded from the relevant habitat.

2.5 Coorong water levels

Coorong water levels (specifically, water levels that result in exposure of the plant to the air) have been demonstrated to have an impact on submerged macrophytes (Rogers and Paton, 2009; Lester and Fairweather, 2009a, b; Paton, 2010; Overton, 2009) as well as macroinvertebrates (Rolston and Dittman, 2009) because the water levels result in exposure and desiccation, reducing diversity and abundance. In addition to these impacts, water levels have also been demonstrated to affect foraging behaviour of wading birds by excluding access to food resources due to depth as well as indirectly by effecting the presence of food resources through exposure (Rogers and Paton, 2009).

Coorong water levels vary seasonally but rapid changes in water level or inappropriately low water levels (that result in exposure to the air) resulting in mortality prevent species from completing their lifecycle. Over time, if reproduction is prevented, this can serially deplete the propagule bank of *Ruppia* by preventing its replenishment (Nicol, 2005; Paton, 2010). However, the availability of high resolution bathymetric information presently limits the ability to define target water levels or rates of change beyond generic minimum levels of inundation that prevent exposure of *Ruppia tuberosa*. Additionally, no water-level thresholds for the macroinvertebrate indicators of the Coorong have been identified despite their functional role. Studies presently underway are seeking to correlate species presence to bathymetric information to permit identification of Coorong inundation requirements on a seasonal basis.

Existing bathymetric and hydrological information in the Coorong have permitted researchers such as Overton et al 2009, Rogers and Paton, 2009, and Lester et al 2009 to demonstrate the linkage between average annual water level and *Ruppia* distribution and abundance. Overton et al (2009) found *R. tuberosa* distribution in South Lagoon correlates most strongly with average annual water level of about 0.27 m AHD, with the relationship with *R. tuberosa* presence being weaker than for salinity. Lester et al (2009) found that the occurrence of degraded states in the Coorong is correlated to water level but in a hierarchical arrangement, subservient to salinity.

The influences of Coorong water levels on a seasonal basis for *R. tuberosa* and any associated thresholds have not yet been established as outlined above, however a model for the annual inundation requirements of *Ruppia* has been described in Paton and Rogers (2007). The annual average water level threshold identified by Overton et al (2009) to support the distribution of *R. tuberosa*, (greater than 0.27 m AHD in the South Lagoon of the Coorong) provides a useful guide to inundation requirements in the Coorong, although further work should be undertaken. No target for water levels has yet been determined for the North Lagoon of the Coorong.

2.6 Summary of hydrological metrics to be used in analysis

Murray Mouth 'Openness'

To indicate constriction of the Murray Mouth, average annual Murray Mouth (Mouth) depth reduced to:

- less than 2 m (constriction)
- less than 1 m (severe constriction).

An additional surrogate indicator for Mouth openness is years where total barrage flow is less than 2000 GL/annum (MDBA, 2011).

Coorong Salinity

The maximum salinity for the North Lagoon should be to not exceed 45 g L^{-1} so as to avoid sub-lethal effects on target biota. Lethal salinities for target species begin to manifest at salinities greater than 50 g L^{-1} .

The maximum salinity for the South Lagoon should be to not exceed 90 g L^{-1} so as to avoid sub-lethal effects on target biota. Lethal salinities for target species begin to manifest at salinities greater than 100 g L^{-1} . Maximum salinities of 108 g L^{-1} and 120 g L^{-1} will also be assessed to examine the ability to avoid extreme salinities expected to impact on Small-mouthed hardyhead and *R. tuberosa* populations in the South Lagoon.

Water Level

The target average annual water level in the South Lagoon to support *Ruppia tuberosa* populations is $>0.27\text{m AHD}$.

2.7 Assessment of scenarios

Given the indicative nature of the modelling undertaken by the MDBA and the range of untested assumptions used, interpretation of absolute outcomes should be avoided. Instead, the focus should be on assessing average outcomes and percent of years where modelled values exceed target threshold values (e.g. maximum salinity in the Coorong South Lagoon). It is also important to examine the events in the time series where thresholds are exceeded as being indicative of events that could reasonably be expected in the future and should be accommodated by the Basin Plan as a component of climate variability as opposed to climate change.

Events where thresholds are breached (being indicative of climate variability) require an analysis of their occurrence to fully understand the implications of the various water recovery options and their ability to mitigate events that occur under the baseline.

While in principle the assessment of averages and percentage of years is appropriate, the assessment of the absolute outcomes, specifically maximum salinities and duration of exceeding a given threshold in the Coorong, provide valuable insights into the ecological impacts that would manifest under the proposed recovery volume if delivered as modelled.

By selecting appropriate threshold values for ecological drivers (primarily salinity and water level), it is expected that an assessment of whether the flow recovery scenarios will avoid events that are likely to affect biota can be identified. Thereby screening the flow scenarios and permitting a comparison of relative benefits or a simplistic assessment of risk of adverse impact occurring to the ecology of the Coorong.

3. Methodology

In order to provide a clear description of the analyses undertaken of the MDBA supplied modelling outputs, the following information seeks to outline the information used in the analyses, any transformation or aggregation undertaken, and how the information has then been analysed. No statistical analysis has been undertaken except the reporting of simple descriptive statistics such as mean, median, minimum, maximum and percentiles for values.

All analyses are undertaken on a financial year basis to maximise the use of the information provided by the MDBA.

2.8 Analysis of Murray Mouth ‘openness’

Analysis of outputs from the hydrodynamic model for average daily Mouth depth and average daily water level at the Mouth were combined for each scenario to determine the actual depth of the Mouth opening. Webster et al (2009) report Z_M (the elevation of the bed channel) as a negative number because this elevation is almost always below AHD (elevation = 0). Mouth depth as reported here is bed elevation subtracted from the modelled water level and is therefore virtually always positive and reported as Mouth depth as opposed to bed elevation in the way Webster et al, (2009) reported it.

This daily value is then averaged for each month or for each financial year for each scenario and compared between scenarios, reporting on the number and duration of events (number of days) where depth reduced to:

- less than 2m to indicate constriction
- less than 1m to indicate severe constriction.

A mouth depth of zero (0 m AHD) would equate to a Murray Mouth that is physically closed.

Webster et al (2009) in analysing the recent historical Mouth depth between 1985 and 2008, indicated that dredging occurred in 2002 when elevation of the bed channel was estimated to be approximately 1 m. As such, this will be used in the analysis as an indicator of severe constriction. Importantly, although this value may occur, this does not equate to an automatic trigger for implementation of dredging as the implementation of such an intervention is complex and likely to be based on not only effective Mouth depth and the prevailing salinity conditions in the Coorong, but also on future water availability and potential barrage outflows. As such, it provides an indication of elevated risk but may not result in dredging

The average monthly and average annual Mouth depth can then be represented as either a frequency plot to examine time for constriction at the various levels as an average, or as the examination of individual events represented by the modelling to provide guidance for assessing the implications of one flow scenario relative to another.

2.9 Analysis of salinity in the Coorong Lagoons

The analysis of the salinity outputs from the hydrodynamic model have been used to ascertain the average salinities within a given year. These values have been determined by examining the daily outputs from the hydrodynamic model for the cells representative of the

geographic extent of the North and South Lagoons to permit reporting at these spatial units. The daily salinity outputs are then aggregated to the relevant temporal scale (daily, monthly or annual statistic) to permit analysis and reporting.

Statistics for maximum daily average salinity and minimum daily average salinity for each year are the average maximum (or minimum) salinity simulated by the model for either the North Lagoon or the South Lagoon that occurs in that financial year, for the given flow scenario. If the maximum is greater than the target range for key biota, the duration of the event is then gauged by examining the number of days from the start of the threshold being exceeded as a daily average salinity to the date when the modelled average daily value declines below the threshold as part of a continuous series of dates. The continuous duration of each event is then collated for analysis and reporting of the number of events, their average and median duration as well as the maximum duration of the exceedances that occur over the time series 1895/96-2008/09. Although a more conservative estimate would be to examine the events in a cumulative fashion, it is assumed that events are non-cumulative and recovery from each event of sub-lethal or lethal impacts is 'instantaneous'.

Events less than five days are excluded from the analysis as it is assumed that events of duration less than this may not result in effects to species (i.e. they may be able to persist and withstand an event shorter than this whereas longer events could be expected to result in sub-lethal or lethal effects). Additionally, events less than five days are assumed to not be part of any larger events. This assumption remains to be tested.

Annual average salinities for the North or South Lagoon of the Coorong are determined by averaging the annual salinity for the relevant cells of the model on a daily basis as outlined above, and then averaging the salinity for all the days in that financial year. The maximum, minimum, and average annual statistics for each lagoon is then determined by examining the descriptive statistics for the annual averages for each financial year in the time series and then reporting these statistics on that basis rather than a daily basis.

Delineation of Coorong Lagoons for analysis

Salinity in the Coorong east of the Murray Mouth is reported in the hydrodynamic model via 14 cells of similar size that extend across groups of the 102 cells used in the base hydrodynamic model. The salinity module solves equations for the conservation of the mass of salt in each cell to provide a daily salinity for each of these cells. The geographic representation of the cells is"

- Cells 4 (22km) - 8 (58km) represent the geographic extent of the North Lagoon
- Cells 9 (64km) -14 (98km) represent the geographic extent of the South Lagoon
- Cells 8 (58km) and 9 (64km) include the constriction between the two lagoons referred to as Parnka Point.

Historically, the North Lagoon of the Coorong has been represented by the MDBA as cells 5 (31km) to 7 (50km), excluding cell 8 from analyses of average salinity or water levels. Additionally, the MDBA has then included cells 9 (64km) -14 (98km) as representative of the South Lagoon.

To provide a conservative estimate of average South Lagoon salinities, South Australia has sought to classify the South Lagoon as excluding cell 9 (64 km) and cell 14 (98 km) from its assessment of average salinities of the South Lagoon and include cell 4 (22 km) in its determination of salinities in the North lagoon. This is represented in Figure 7 below.

The South Australian delineation of the South Lagoon uses a smaller subset of the hydrodynamic model outputs to provide a more conservative estimate of average salinity. Average daily salinity provides an indication of the salinity in the lagoon with approximately half being less than the value reported while half the lagoon exceeds that value and as such, the likelihood that there is an impact occurring is partially masked by using averages. A more constrained and conservative assessment of average salinity that removes the extremes arguably provides a more conservative estimate of indicative impacts.

Adopting the delineation proposed by South Australia permits the effects of the USED inputs and also the effect of Parnka Point to be excluded more completely than the MDBA analyses. Based on previous work undertaken by South Australia, the USED inputs may introduce local pooling of fresh water at times which could distort the average salinity statistics of the South Lagoon as a whole, whereas the Parnka Point region displays salinity conditions which are really a transition between the two lagoons, hence should be excluded from analyses of average salinities in the South Lagoon.

Statistics for the both the delineations are included in the report with the South Australian delineation being included in the body of the report and the MDBA delineation included in the appendices.

| | | | | | | | |
|---------------------|-------|-------------------|-----------------|-------|-------|-------|-------|
| Cell number | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Distance from mouth | 58 Km | 64 Km | 70 Km | 76 Km | 83 Km | 90 Km | 98 Km |
| MDBA delineation | | MDBA South Lagoon | | | | | |
| SA delineation | | | SA South Lagoon | | | | |

Figure 7: representation of the Coorong Lagoons and features in the Hydrodynamic model - aggregation of outputs to provide assessment of the average values in the North and South Lagoons

4. Results

4.1 Mouth Openness

4.1.1 Total annual average flow greater than 2000 GL

Table 5 summarises the analysis of total annual flow through the barrages for the Baseline, 2750 GL and without development scenarios. This analysis indicates that for the Baseline scenario, total annual flow through the barrages is less than 2000 GL in approximately one-third of all years (36%), while under the 'without development' scenario a much smaller proportion (3%) of years sees flows less than 2000 GL. In comparison, the 2750 GL scenario results in considerable improvement, with annual flow being greater than 2000 GL, 89% of years. The three years under 'without development' are the same years where flow is less than 2000 GL under the 2750 GL scenario. Ten of the 41 years (where flow is less than 2000 GL) under Baseline also occur under the 2750 GL scenario, which is a substantial improvement.

Table 5: Number of years and percent of years in the series where total annual barrage flow is less than 2000 GL for without development, 2750 GL and baseline scenarios

| | Scenario | | |
|------------|----------|--------|-----|
| | Baseline | 2750GL | WOD |
| # of years | 41 | 13 | 3 |
| % of years | 36% | 11% | 3% |

An examination of the sequence of years where flows are less than 2000 GL (Figure 8) indicates that under the Baseline scenario, there are nine sequences where two or more years are concurrent while under 'without development' there are no concurrent sequences. In contrast, under the 2750 GL scenario, one sequence (2006-2009) results in three concurrent years where flows are less than 2000 GL (Figure 8). Several of the sequences under baseline are for four years or more with one sequence up to eight years in duration (2001-02 to 2008-09).

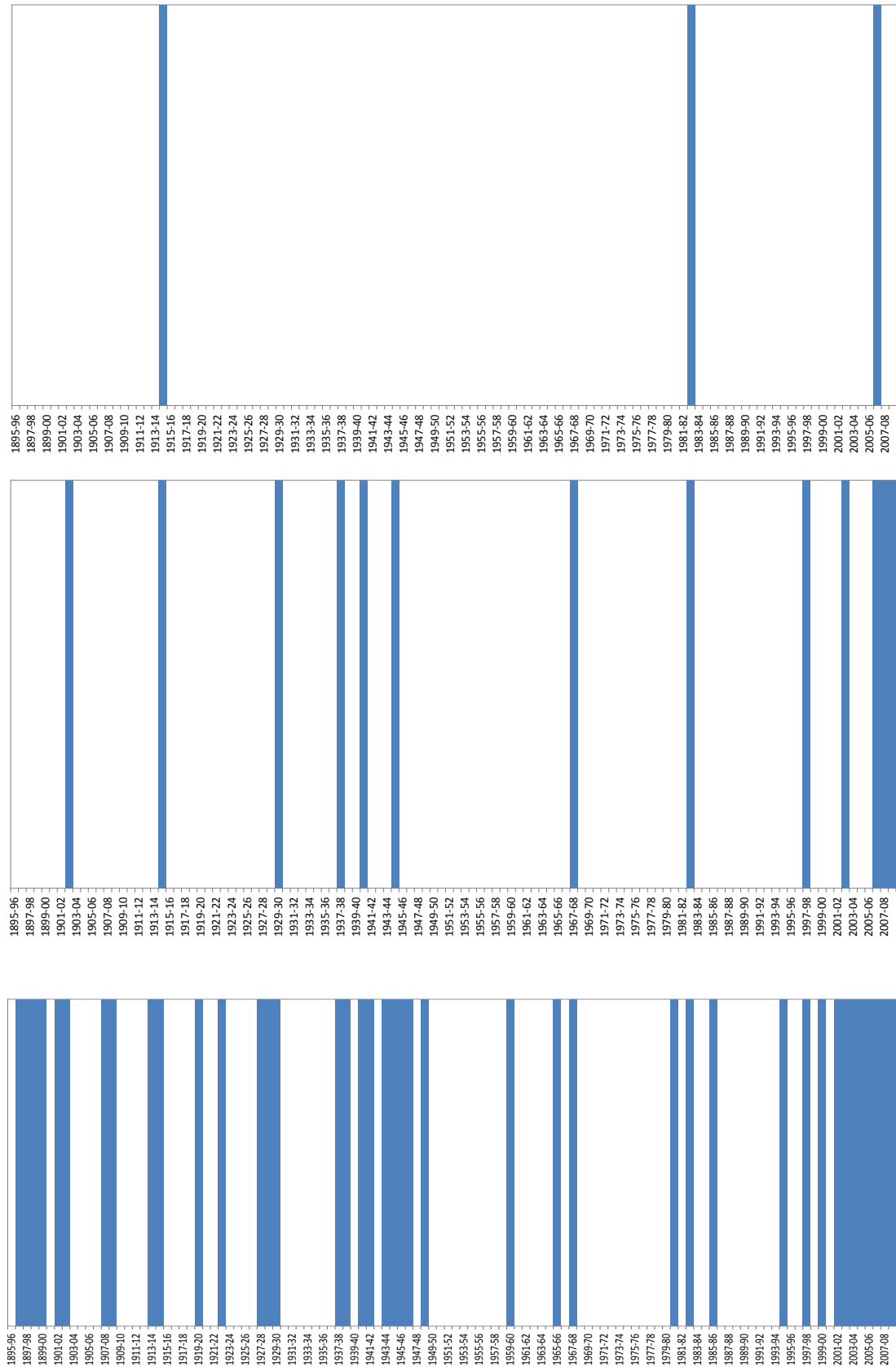


Figure 8: Sequence of years where total modelled barrage flow is less than 2000 GL in that year. Without development (top) 2750 GL scenario (middle), Baseline (Bottom)

The analysis of total annual flow through the barrages for the sensitivity scenarios shows flows are less than 2000 GL in an additional three years under the 2400 GL scenario, while there is no improvement in the number of years under the 3200 GL scenario, relative to the 2750 GL scenario (Table 6). Although the number of years where total annual flow is the same under the 2750 GL and 3200 GL scenario, total annual flow volume does increase in most years under the 3200 GL scenario, relative to 2750 GL scenario, but not enough to exceed the 2000 GL threshold (see Heneker and Higham, 2012).

Table 6: Number of years and percent of years in the series where total annual barrage flow is less than 2000GL for the 2400GL, 2750GL and 3200GLscenarios

| | Scenario | | |
|------------|----------|--------|--------|
| | 2400GL | 2750GL | 3200GL |
| # of years | 16 | 13 | 13 |
| % of years | 14% | 11% | 11% |

An examination of the sequence of years where flows are less than 2000 GL (Figure 9) indicates that under the 2750 and 3200 GL scenarios, there is one sequence where two or more years are concurrent where flow is less than 2000 GL/annum. In contrast, under the 2400 GL scenario, one additional sequence occurs as a result of this reduction in total barrage outflow resulting from a decline in the recovery target (Figure 9).

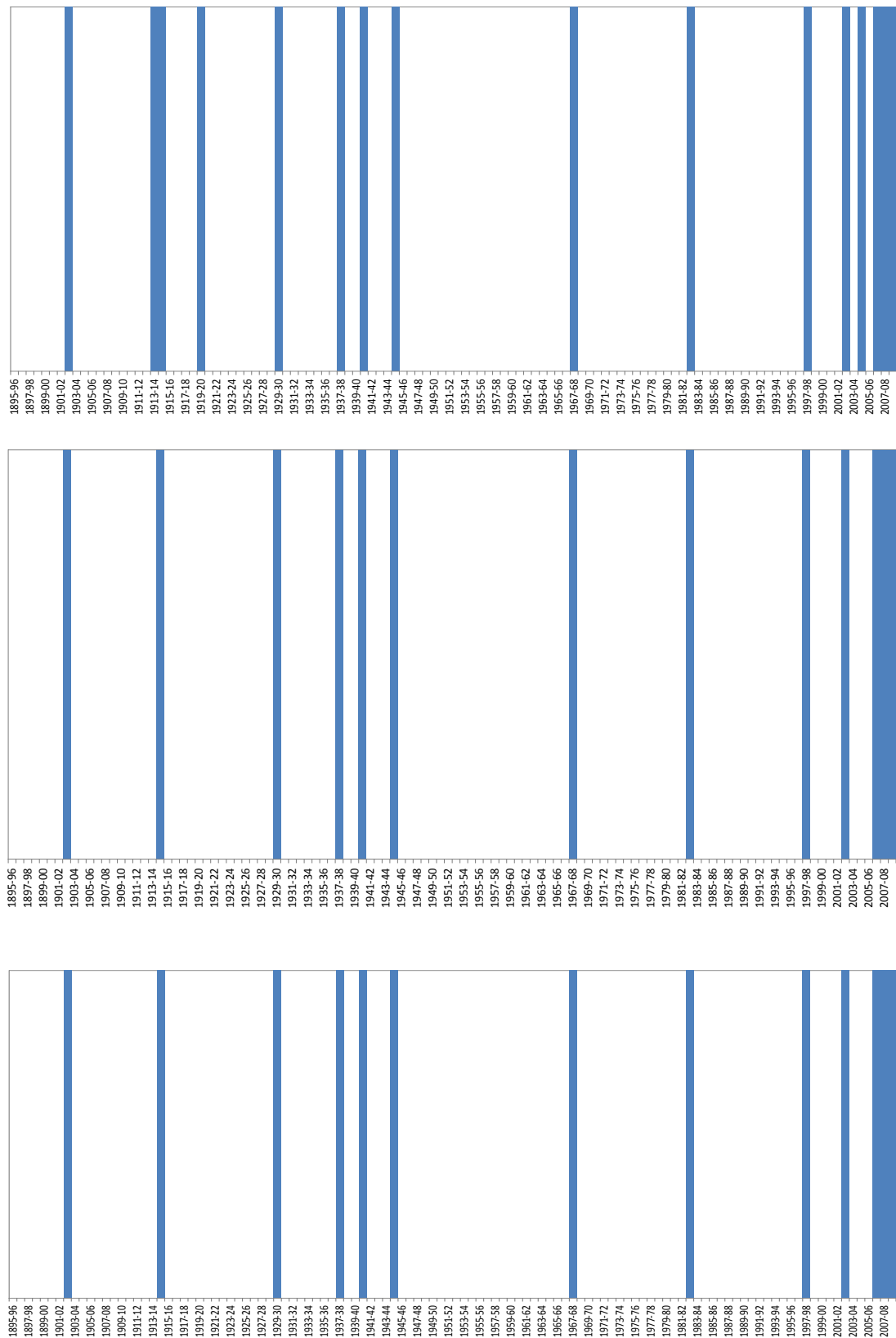


Figure 9: Sequence of years where total modelled barrage flow is less than 2000 GL in that year. 2400 GL scenario (top) 2750 GL scenario (middle), 3200 GL scenario (bottom)

4.1.2 Analysis of annual average Murray Mouth depth

The analysis of annual average effective Mouth depth compares the average annual effective Mouth depth (relative to the water's surface) as calculated from the hydrodynamic model outputs, for the various water recovery scenarios. The analysis reveals a substantial improvement between all scenarios assessed relative to the baseline, but remains less than that estimated under the 'without development' scenario (Figure 10).

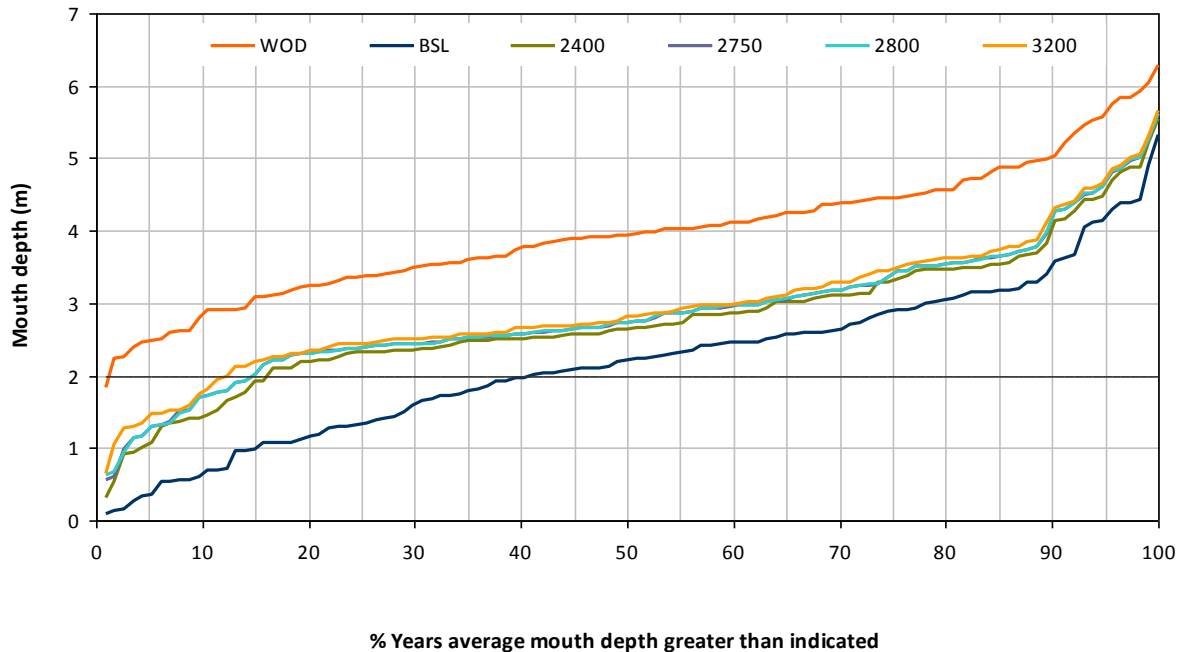


Figure 10: frequency distribution plot of Mouth depth averaged for each financial year over the time series with a depth of 2 m indicated by the dark grey line (1895/96-2008/09)

The analysis reveals some important variation of Mouth depth between years, providing a frequency distribution plot for Mouth depth during the 114-year time series modelled (Figure 10). The analysis of effective Mouth depth during the full time series on an average annual basis indicates that the Murray Mouth is constricted approximately 40% of years for the Baseline scenario (using the 2-m average annual depth criterion). This is in contrast to approximately 2% of time for the 'without development' scenario.

Relative to the Baseline scenario, all water recovery scenarios show a large amount of relative improvement:

- 2750 GL scenario indicating constriction occurring approximately 14% of years
- 2400 GL scenario indicating constriction occurring approximately 16% of years
- 3200 GL scenario indicating constriction occurring approximately 12% of years.

The level of improvement between scenarios indicates that Mouth openness is altered by increases or reductions in the provision of water linked to the recovery volume. The originally proposed 2800 GL scenario indicated an imperceptible difference to the outcome achieved by 2750 GL on an annual average basis.

Annual average Mouth depth statistics

An analysis of annual Mouth depth greater or less than 2 m was undertaken for each available scenario. Table 7 shows that the water recovery scenarios proposed result in the Mouth being 'unconstricted' (average annual depth greater than 2 m) between 84% and 88% of years for the water recovery scenarios, which is a considerable improvement relative to the baseline where approximately 60% of years sees the Murray Mouth 'unconstricted' and the without development scenario seeing is unconstricted approximately 99% of years.

Relative to the baseline, there is improvement in the annual Mouth depth for all water recovery scenarios examined. The number of years where the Mouth is classified as unconstricted is improved as the recovery volume increases with 2750 GL improving relative to 2400 GL and 3200 GL improving relative to 2750 GL (Table 7). None of the scenarios result in conditions improving to the equivalent of the 'without development' scenario.

Table 7: summary of percentage years where the Murray Mouth is classified as constricted or unconstricted (1895/96-2008/09)

| | Without Development | Baseline | 2400GL | 2750GL | 3200GL |
|---------------|---------------------|----------|--------|--------|--------|
| unconstricted | 99.1% | 59.6% | 84.2% | 86.0% | 87.7% |
| constricted | 0.9% | 40.4% | 15.8% | 14.0% | 12.3% |

Further classifying the years where average annual Mouth depth is initially classified as constricted (average annual depth less than 2 m) and as severely constricted (average annual depth less than 1 m) is expected to provide greater insight into the level of constriction that is estimated to occur and the benefits of additional flow.

The results summarised in Table 8 indicate that the number of years where the Mouth on average is classified as severely constricted reduces with increasing volume provided to the environment, but not to the level seen under the 'without development' scenario. No difference was observed in the annual statistics for the 2750 GL and 2800 GL scenarios regarding events where average annual Mouth depth is less than 1 m.

Table 8: summary of number of years where Murray Mouth is constricted under each water recovery scenario (1895/96-2008/09)

| | Without Development | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|----------------------|---------------------|----------|--------|--------|--------|--------|
| unconstricted | 113 | 68 | 96 | 98 | 98 | 100 |
| constricted | 1 | 29 | 15 | 13 | 13 | 13 |
| severely constricted | 0 | 17 | 3 | 3 | 3 | 1 |

Comparison of the annual average Mouth depth in the four most constricted events illustrates the improvement between the water recovery scenarios. The four most constricted were chosen to illustrate the same four years in the sequence where the average annual Mouth

depth is most constricted. A consistent improvement can be seen in all years examined as flow volume increases (Table 9)

Table 9: minimum depth (m) of the Murray Mouth for the worst 4 years of the time series for 2400GL, 2750GL, 2800GL and 3200GL scenarios

| | 2400 | | 2750 | | 2800 | | 3200 | |
|------|---------|-------------------|---------|-------------------|---------|-------------------|---------|-------------------|
| rank | year | Minimum depth (m) | year | Minimum depth (m) | year | Minimum depth (m) | year | Minimum depth (m) |
| 1 | 2008-09 | 0.31 | 2008-09 | 0.56 | 2008-09 | 0.63 | 2008-09 | 0.66 |
| 2 | 2007-08 | 0.54 | 2007-08 | 0.61 | 2007-08 | 0.68 | 2007-08 | 1.05 |
| 3 | 1902-03 | 0.92 | 2006-07 | 0.99 | 2006-07 | 0.94 | 2006-07 | 1.27 |
| 4 | 2006-07 | 0.94 | 1902-03 | 1.14 | 1902-03 | 1.14 | 1902-03 | 1.30 |

4.2 Average annual water levels in the South Lagoon

Annual average water levels were analysed for each of the scenarios on a financial year basis. The analysis contained in Table 10, indicates that under the ‘without development’ scenario, water levels in 12% of years would not support *Ruppia tuberosa* in the South Lagoon. Under the Baseline scenario, this increases to 43% of years where the average annual water level in the South Lagoon does not support *R. tuberosa*. Under the proposed water recovery scenario, there is some improvement with an additional 5% of years with water levels supporting the distribution of *R. tuberosa* in South Lagoon. Improvement occurs under all scenarios, however the improvement is relatively small at between 3% and 8% of years (Table 10).

Table 10: table summarising number of years average annual water depth is greater or less than 0.27m AHD for 2400GL, 2750 GL and 3200 GL scenarios (1895/96-2008/09)

| | Without Development | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|------------|---------------------|----------|--------|--------|--------|--------|
| # of years | 14 | 49 | 46 | 43 | 43 | 40 |
| % of years | 12% | 43% | 40% | 38% | 38% | 35% |

Figure 11 shows the time series of average annual South Lagoon water levels. In some years, water levels in the Coorong are better under the Baseline scenario, however not in all years.

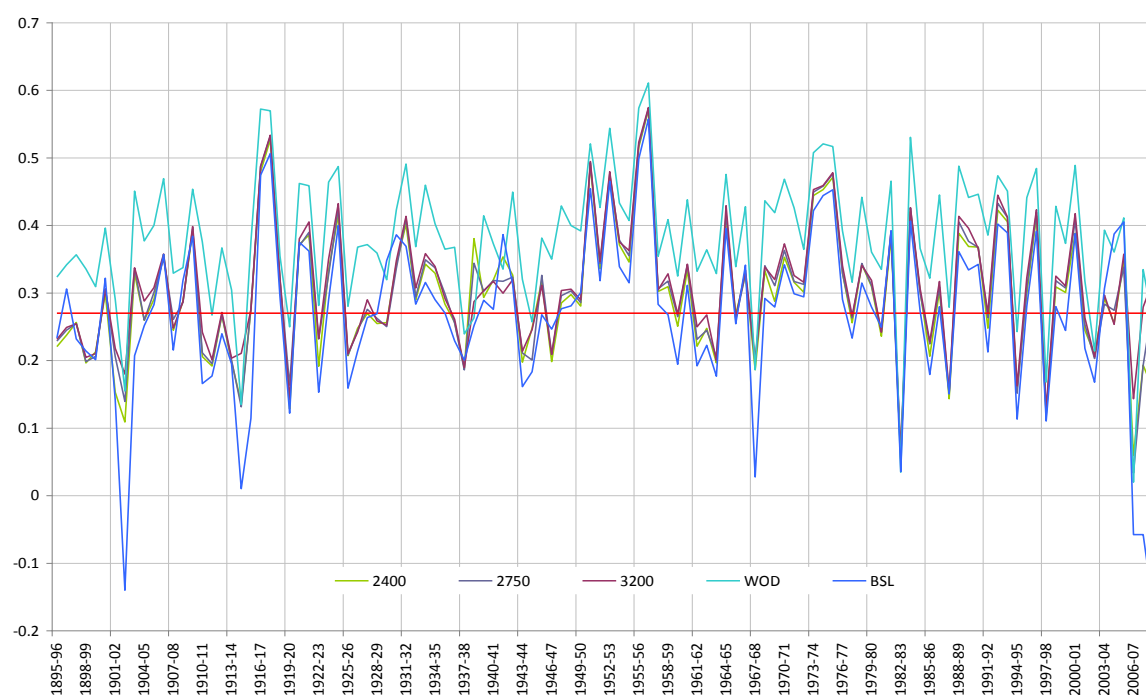


Figure 11: time series of annual average water levels in the South Lagoon for 2400 GL, 2750GL, 3200 GL and ‘without development’ scenarios (1895/96-2008/09). Target annual average water level in the South Lagoon is indicated in red.

4.3 Coorong North Lagoon average salinities

Table 11 summarises the modelled North Lagoon average annual salinity for the 114 years modelled by the MDBA. It shows important variation between years in response to barrage outflow volumes. The 'without development' scenario has a substantially constrained salinity range relative to the Baseline. Maximum average annual salinity in the North Lagoon under the Baseline scenario is extreme relative to the 'without development' scenario at over 148 g L^{-1} (in 2008/09), although 95% of average annual North Lagoon salinities are less than $\sim 51 \text{ g L}^{-1}$. The average and median values are considerably greater for the Baseline scenario relative to the 'without development' scenario.

The 2750 GL scenario indicates an average annual salinity for the North Lagoon ranging between $\sim 2 \text{ g L}^{-1}$ and $\sim 59 \text{ g L}^{-1}$. Average annual average salinity achieved by 2750 GL is nearly 1/4 lower than the Baseline scenario. The maximum annual average salinity observed under the 2750 GL scenario is considerably better than the Baseline scenario. The average annual salinity statistics show a response to higher or lower volumes relative to 2750 GL with larger recovery volumes resulting in lower average annual descriptive statistics (Table 11).

The most notable difference is the impact water recovery scenarios have on the maximum annual average salinities (the highest average annual North Lagoon salinity experienced in a given year across the 114 years), with maximum annual average salinity reducing from $\sim 75 \text{ g L}^{-1}$ under the 2400 GL scenario to $\sim 47 \text{ g L}^{-1}$ under the 3200 GL scenario. Interestingly, the 50 GL increase of the 2800 GL scenario relative to 2750 GL has little effect on the annual average statistics but reduces the maximum annual average salinity observed (Table 11).

Table 11: statistics of average annual salinity (g L^{-1}) for the North Lagoon under the different scenarios (1895/96-2008/09)

| | without development | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|-----------------|---------------------|----------|--------|--------|--------|--------|
| Minimum | 1.8 | 3.5 | 2.5 | 2.4 | 2.4 | 2.3 |
| 5th percentile | 4.0 | 11.1 | 8.5 | 7.8 | 7.8 | 7.5 |
| 10th percentile | 4.8 | 14.0 | 10.5 | 9.6 | 9.6 | 9.0 |
| Median | 11.6 | 28.9 | 22.3 | 20.8 | 20.8 | 19.6 |
| Average | 9.6 | 27.7 | 22.2 | 20.6 | 20.6 | 19.4 |
| 90th percentile | 21.4 | 42.4 | 32.7 | 31.4 | 31.4 | 30.1 |
| 95th percentile | 27.5 | 51.2 | 36.2 | 34.5 | 34.5 | 32.0 |
| Maximum | 49.5 | 148.4 | 75.1 | 58.5 | 55.8 | 47.2 |

Figure 12 illustrates the range of average North Lagoon salinities for each year from 1895/96 - 2008/09, resulting from the 'without development', 2750 GL and Baseline scenarios. In comparison to the Baseline scenario, the 2750 GL scenario shows a reduced range of average salinities in each year; minimum average and maximum average salinities in the North Lagoon in all years are lower with a sizeable reduction in the range of average salinities experienced in a year. As might be expected, although peak salinities in corresponding years are lower relative to the baseline, they are not the equivalent of the 'without development' scenario.

Figure 13 illustrates the range of annual average North Lagoon salinities for each year from 1895/96-2008/09, resulting from barrage flows for the 2400, 2750 and 3200 GL scenarios,

highlighting further reductions in peak salinities experienced and the level of variation within a year as flows increase.

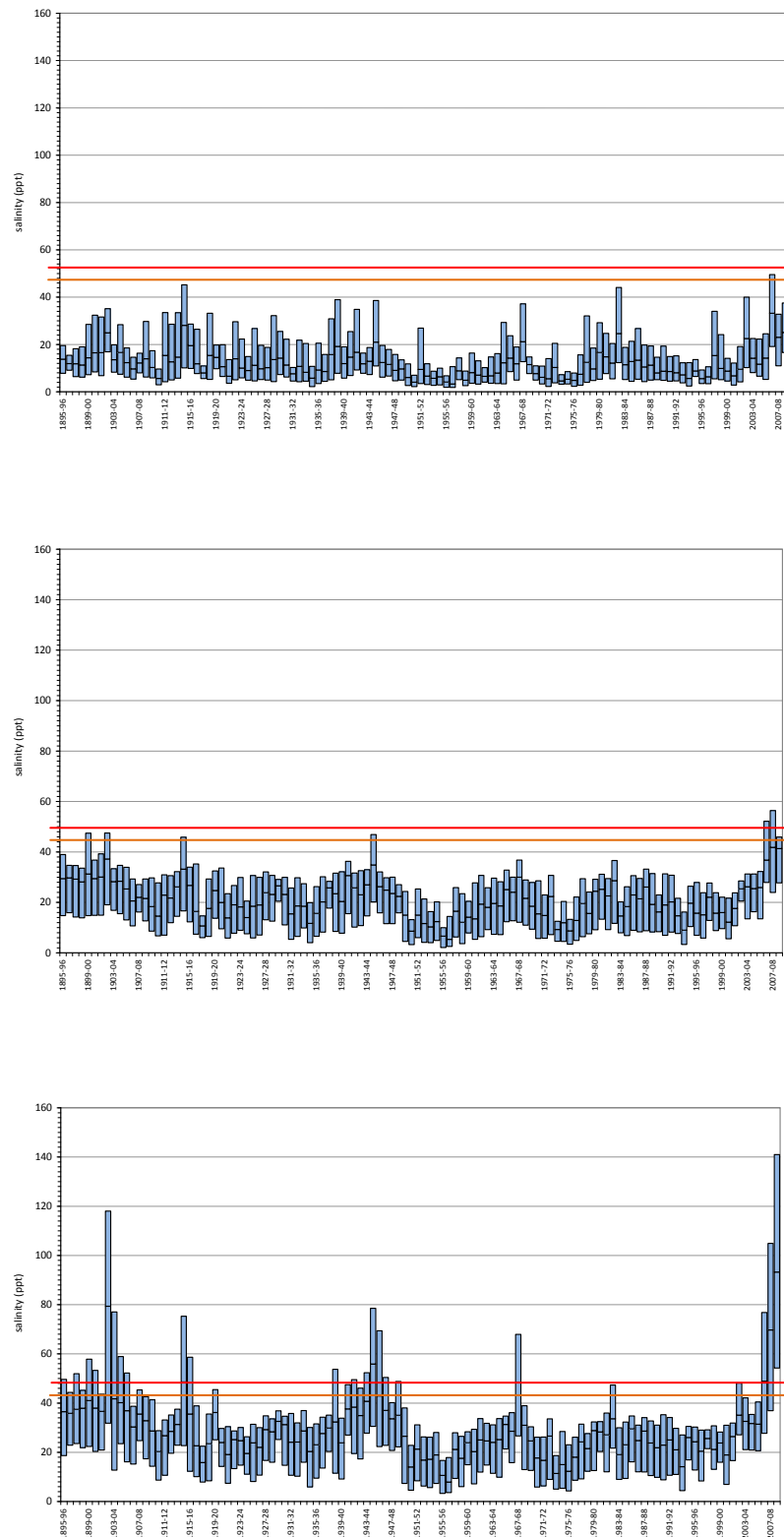


Figure 12: comparison of annual average daily salinity and average daily salinity ranges in the North Lagoon for ‘without development’ (top), 2750 GL scenario (middle) and Baseline scenarios (bottom) (1895/96-2008/09). Note salinity scale is 160g L⁻¹ maximum. Sub lethal maxima for target biota of 45 g L⁻¹ indicated in orange and upper lethal tolerance for *Ruppia megacarpa* in red (50 g L⁻¹).

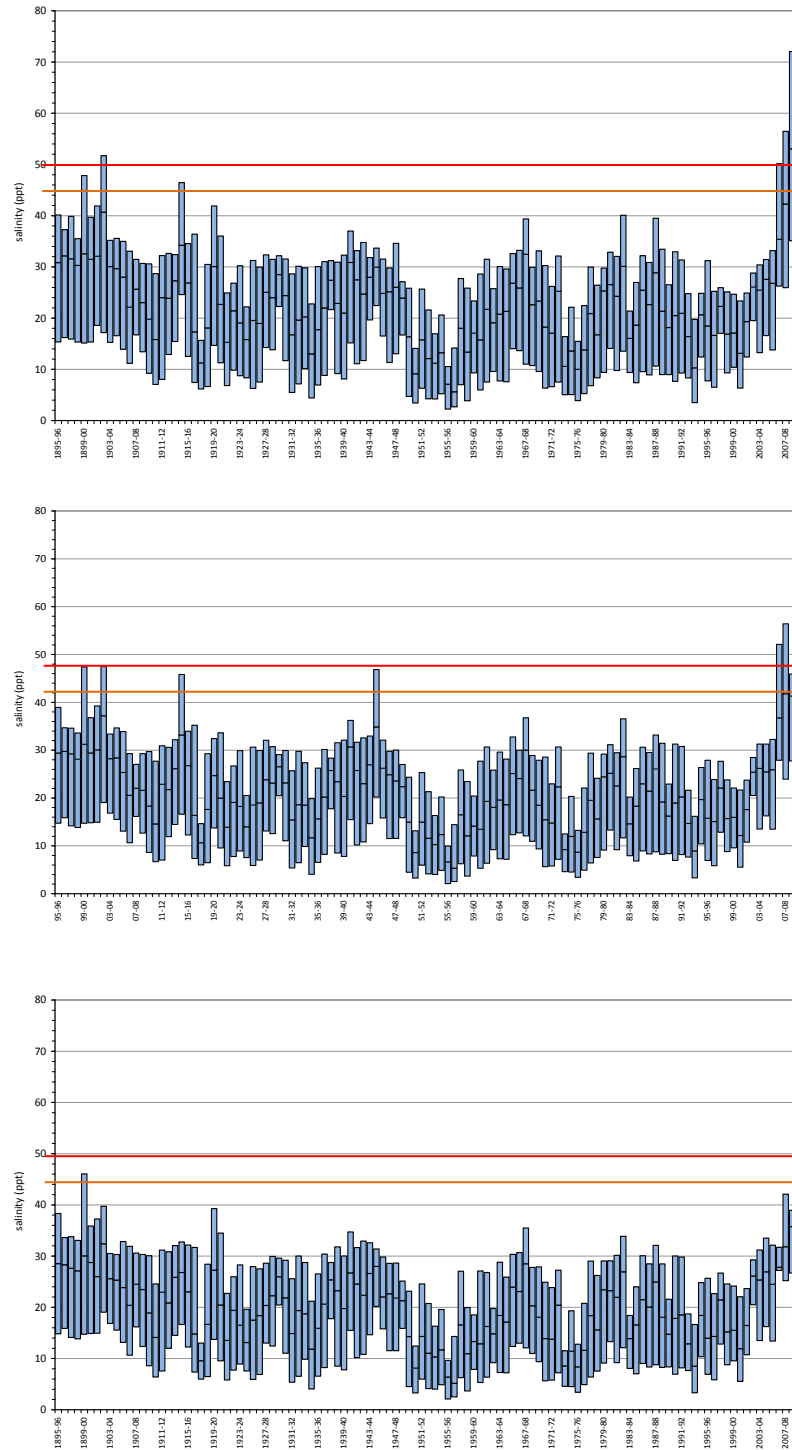


Figure 13: comparison of annual average daily salinity and average daily salinity ranges in the North Lagoon for 2400 GL (top), 2750 GL (middle) and 3200 GL (bottom) scenarios (1895/96-2008/09). Note salinity scale is 80 g L^{-1} maximum. Sub lethal maxima for target biota of 45 g L^{-1} indicated in orange and upper lethal tolerance for *Ruppia megacarpa* in red (50 g L^{-1})

Despite the improvement relative to the baseline, there remains years where average North Lagoon salinity exceeds the sub-lethal salinity thresholds for target biota under all water recovery volumes modelled (Figure 12). The average annual average salinity exceeds the sub-lethal threshold under the 2400 GL scenario, whilst the average annual average salinity in the North Lagoon under the 2750 GL and 3200 GL scenario does not exceed the sub-lethal threshold (Figure 13).

Daily average salinities within a year indicate that average salinities in the North Lagoon exceed the sub-lethal threshold seven times under the 2750 GL scenario, as opposed to six times under the 2400 GL scenario, and once under the 3200 GL scenario. These are substantial improvements relative to the baseline where the sub-lethal threshold would be exceeded 24 times with average annual average exceeding it seven times (Figure 17). The average and maximum duration of these exceedances of the sub-lethal threshold generally reduces as the volume provided to the environment increases with the number of events greater than five days reducing (Table 12). Of note is the increase of average and mean duration of events under the 2800 GL scenario. A single event is evident in the 'without development' conditions (2007).

Table 12: Average daily salinity exceeding the 45g L⁻¹ threshold for sub-lethal impacts on key biota in the North Lagoon

| | Without Development | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|--------------------------|---------------------|----------|--------|--------|--------|--------|
| # events longer than 5 d | 1 | 42 | 8 | 9 | 9 | 1 |
| Mean duration | 77 | 79 | 70 | 48 | 48 | 18 |
| Median duration | 77 | 30 | 48 | 50 | 50 | 18 |
| Maximum duration | 77 | 624 | 180 | 112 | 102 | 18 |

The exceedance of the higher 'lethal' thresholds for North Lagoon biota decreases as volume recovered increases in terms of the number of times the threshold is exceeded, the average duration and maximum duration (Table 13). No events occur under either the 'without development' scenario or the 3200 GL scenario.

Table 13: Average daily salinity exceeding the 50g L⁻¹ threshold for lethal impacts on *Ruppia megacarpa*

| | Without Development | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|--------------------------|---------------------|----------|--------|--------|--------|--------|
| # events longer than 5 d | 0 | 29 | 4 | 2 | 2 | 0 |
| Mean duration | 0 | 77 | 79 | 69 | 66 | 0 |
| Median duration | 0 | 16 | 70 | 69 | 66 | 0 |
| Maximum duration | 0 | 604 | 163 | 91 | 75 | 0 |

4.4 Coorong South Lagoon average salinities

Table 14 summarises the modelled average salinity in the South Lagoon for the period 1895-2009. The average salinity for the Coorong South Lagoon shows sizeable variation between years in response to changes in barrage outflow volumes. The 'without development' scenario has a more constrained salinity range relative to the baseline, with maximum average salinity less than the average salinity experienced under baseline conditions. Maximum annual average salinity in the Baseline scenario is extreme at over 298 g L⁻¹, although 95% of years, average South Lagoon salinities is less than 109 g L⁻¹.

Considerable improvement in average annual salinity relative to the baseline is observed for all water recovery scenarios, with the 2750 GL scenario showing an average annual salinity for the South Lagoon ranging between ~12 g L⁻¹ and ~124 g L⁻¹. Salinity statistics show a response to higher or lower volumes relative to 2750 GL, with an important and noteworthy impact on the maximum average salinities experienced as volume changes. The range of average salinities experienced is constrained as the volume of water recovered and provided to the environment increases principally through a reduction in the maximum average annual salinities experienced. Once again, the 50 GL increase in water of the 2800 GL relative to 2750 GL has little effect on the average statistics for the South Lagoon except the maximum salinity observed. This indicates that the maximum annual average salinity of the South Lagoon is sensitive to the volume provided (as modelled here).

Table 14: statistics of annual average salinity (g L⁻¹) for the SA delineation of the South Lagoon under the different scenarios (1895/96-2008/09)

| | without development | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|-----------------|---------------------|----------|--------|--------|--------|--------|
| Minimum | 7.2 | 18.3 | 12.7 | 11.9 | 11.9 | 11.5 |
| 5th percentile | 12.2 | 33.5 | 25.8 | 23.2 | 23.2 | 22.3 |
| 10th percentile | 13.2 | 38.6 | 29.8 | 27.3 | 27.2 | 25.7 |
| Median | 24.1 | 62.7 | 47.8 | 44.7 | 44.6 | 41.8 |
| Average | 23.0 | 55.8 | 45.4 | 42.0 | 42.0 | 40.2 |
| 90th percentile | 36.3 | 94.8 | 68.6 | 65.5 | 65.5 | 60.5 |
| 95th percentile | 43.1 | 108.5 | 78.9 | 74.2 | 74.2 | 66.9 |
| Maximum | 68.5 | 298.1 | 140.3 | 123.8 | 121.4 | 99.7 |

Figure 14 illustrates the range of annual average South Lagoon salinities for the 'without development', 2750 GL and Baseline scenarios, providing some indication of the range of salinities experienced in the lagoon in response to flows and the relative benefit of 2750 GL in comparison to the Baseline scenario. As might be expected, although peak salinities in corresponding years are lower relative to the baseline, they are not the equivalent of the 'without development' scenario. The range of salinities experienced in a year is also substantially reduced.

Despite the improvement relative to the baseline, there remains years where average South Lagoon salinity exceeds the sub-lethal salinity thresholds for target biota under all water recovery volumes modelled (Figure 15). The average annual average salinity exceeds the sub-lethal threshold under 2750 GL once as does the 2400 GL scenario (to a greater degree), while the average annual average salinity in the South Lagoon under the 3200 GL scenario does not exceed the sub-lethal threshold (Figure 15).

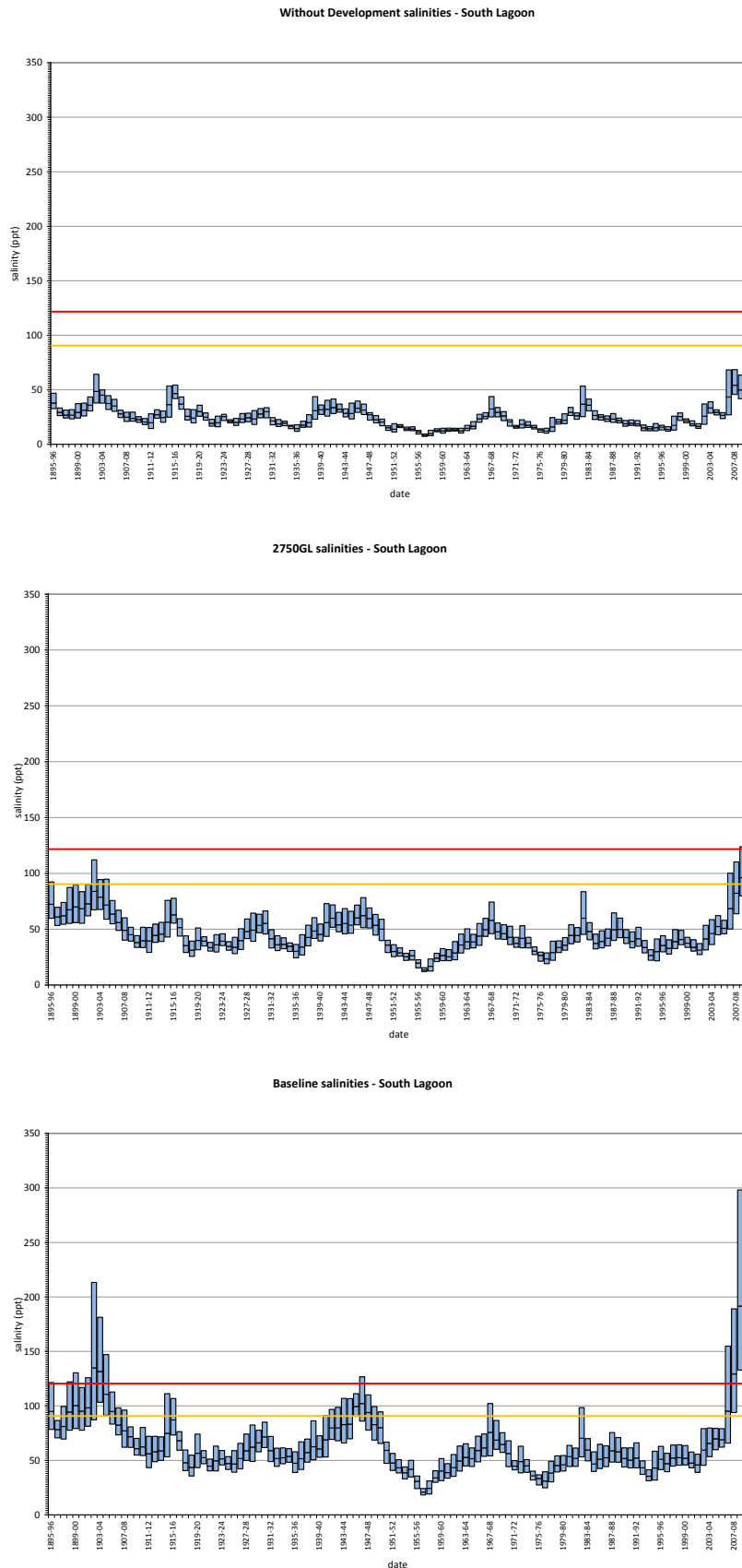


Figure 14: comparison of annual average daily salinity and average daily salinity ranges in the South Lagoon for ‘without development’, 2750 GL recovery and Baseline scenarios (note salinity scale is 350 g L⁻¹ maximum) (1895/96-2008/09). Sub lethal maxima for target biota of 90 g L⁻¹ indicated in orange and upper tolerance for *Ruppia tuberosa* growth indicated in red (120 g L⁻¹).

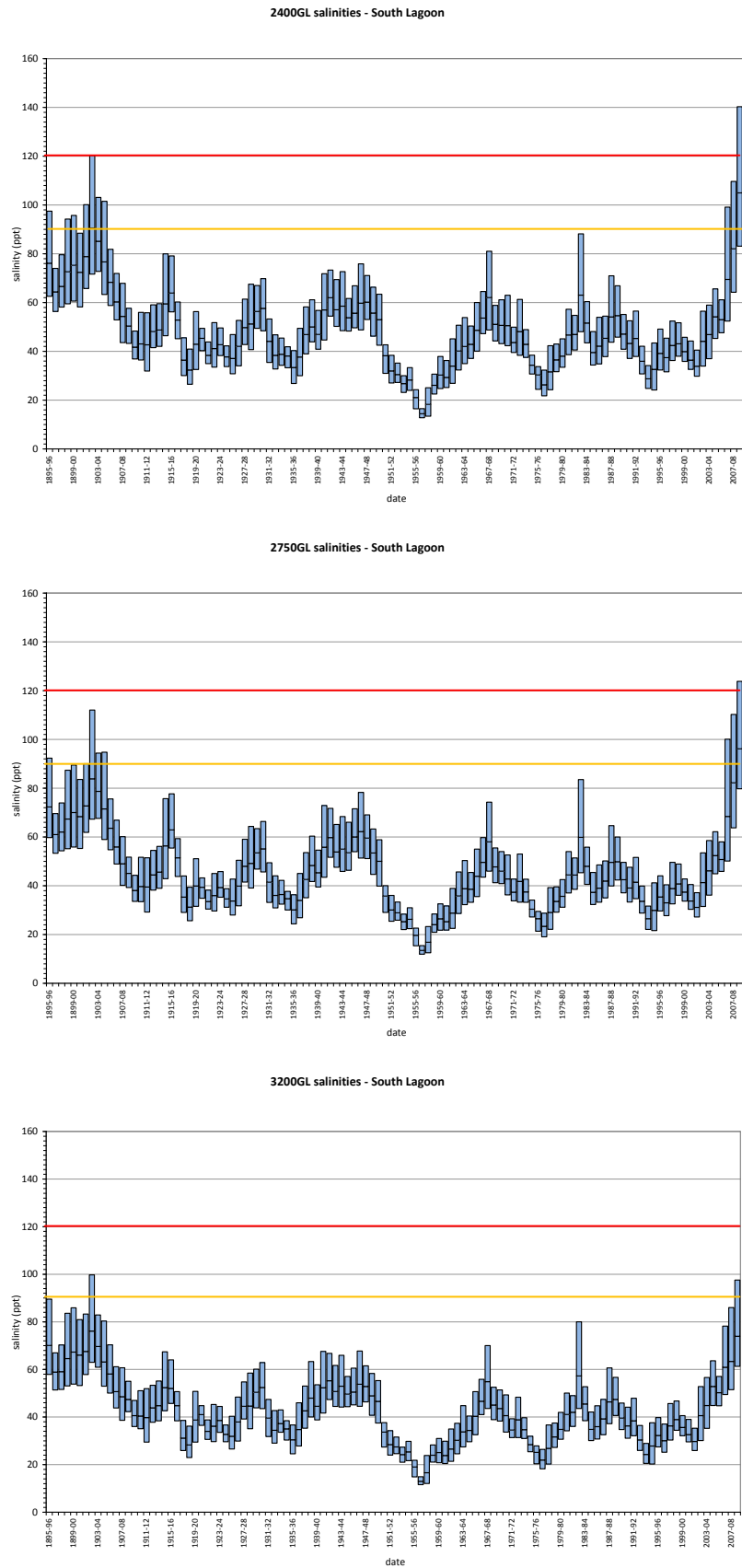


Figure 15: comparison of annual average daily salinity and average daily salinity ranges in the South Lagoon for 2400 GL, 2750 GL and 3200 GL recovery scenarios (note salinity scale is 160g L^{-1} maximum) (1895/96-2008/09). Sub lethal maxima for target biota of 90 g L^{-1} indicated in orange and upper tolerance for *Ruppia tuberosa* growth indicated in red (120 g L^{-1})

Daily average salinities within a year indicate that average salinities in the South Lagoon exceed the sub-lethal threshold six times under the 2750 GL scenario, as opposed to ten times under the 2400 GL scenario, and twice under the 3200 GL scenario (Figure 15: comparison of annual average daily salinity and average daily salinity ranges in the South Lagoon for 2400 GL, 2750 GL and 3200 GL recovery scenarios (note salinity scale is 160 g L^{-1} maximum) (1895/96-2008/09). Sub lethal maxima for target biota of 90 g L^{-1} indicated in orange and upper tolerance for *Ruppia tuberosa* growth indicated in red (120 g L^{-1})). These are all substantial improvements relative to the baseline where the sub-lethal threshold would be exceeded 29 times with average annual average exceeding it 15 times (Figure 15). The average and maximum duration of these exceedances of the sub-lethal threshold reduces as the volume provided to the environment increases with the number of events greater than five days reducing (Table 15). The modelled average annual salinity does not exceed target thresholds at all under the 'without development' conditions.

Table 15: Average daily salinity exceeding the 90 g L^{-1} threshold for sub-lethal impacts on key biota in the South Lagoon

| | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|--------------------------|----------|--------|--------|--------|--------|
| # events longer than 5 d | 25 | 11 | 8 | 8 | 2 |
| Mean duration | 211 | 85 | 75 | 70 | 57 |
| Median duration | 123 | 64 | 38 | 41 | 57 |
| Maximum duration | 1030 | 209 | 198 | 182 | 78 |

The exceedance of the higher 'lethal' thresholds for South Lagoon biota decreases as volume recovered increases in terms of the number of times the threshold is exceeded, the average duration and maximum duration (Table 16, Table 17, Table 18).

Table 16: Average daily salinity exceeding the 100g L⁻¹ threshold for lethal impacts to Chironomids

| | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|--------------------------|----------|--------|--------|--------|--------|
| # events longer than 5 d | 18 | 6 | 3 | 4 | 0 |
| Mean duration | 146 | 57 | 74 | 71 | 0 |
| Median duration | 114 | 14 | 84 | 79 | 0 |
| Maximum duration | 599 | 168 | 129 | 111 | 0 |

Table 17: Average daily salinity exceeding the 108g L⁻¹ threshold for lethal impacts to small mouthed hardyhead

| | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|--------------------------|----------|--------|--------|--------|--------|
| # events longer than 5 d | 15 | 3 | 3 | 2 | 0 |
| Mean duration | 142 | 84 | 49 | 50 | 0 |
| Median duration | 86 | 91 | 41 | 50 | 0 |
| Maximum duration | 554 | 148 | 81 | 59 | 0 |

Table 18: Average daily salinity exceeding the 120g L⁻¹ threshold impacting on *Ruppia tuberosa* growth

| | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|--------------------------|----------|--------|--------|--------|--------|
| # events longer than 5 d | 11 | 1 | 1 | 1 | 0 |
| Mean duration | 100 | 121 | 18 | 9 | 0 |
| Median duration | 47 | 121 | 18 | 9 | 0 |
| Maximum duration | 534 | 121 | 18 | 9 | 0 |

4.5 Spatial representation of salinity in the Coorong South Lagoon - Monthly salinity maxima

Further analysis of Coorong salinities is required to understand the implications of assessing average annual and average daily salinities to identify periods of risk to the ecology of the Coorong, specifically the South Lagoon. Figure 16 and Figure 17 provide some insight into the spatial and temporal salinity in the Coorong during a period in the time series when flows are at their lowest and identified as a period of risk based on average salinity exceeding threshold values (2006/07-2008/09). This period was chosen to examine the reliability of annual average values to represent salinities of concern spatially within the South Lagoon of the Coorong and the effect the recovery volume has in mitigating this issue.

| Year | month | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km |
|---------|-----------|--------------|-------|-------|-------|-------|-------|-------|
| 2006-07 | July | 54.4 | 62.1 | 64.7 | 66.8 | 69.0 | 69.8 | 70.3 |
| | August | 49.6 | 59.4 | 64.2 | 65.5 | 67.3 | 68.0 | 68.5 |
| | September | 54.0 | 62.6 | 66.3 | 67.3 | 68.8 | 69.5 | 70.1 |
| | October | 53.6 | 64.6 | 69.3 | 70.6 | 72.5 | 73.1 | 73.8 |
| | November | 60.4 | 72.3 | 76.8 | 77.7 | 78.9 | 79.0 | 79.8 |
| | December | 72.4 | 81.8 | 87.6 | 88.8 | 89.6 | 89.7 | 90.2 |
| | January | 82.1 | 93.3 | 98.2 | 98.9 | 99.2 | 99.3 | 100.0 |
| | February | 101.7 | 114.2 | 117.6 | 117.3 | 116.6 | 115.7 | 116.7 |
| | March | 120.4 | 135.5 | 138.2 | 137.8 | 136.5 | 135.5 | 135.9 |
| | April | 137.2 | 154.6 | 157.9 | 156.6 | 153.3 | 151.5 | 150.8 |
| | May | 84.8 | 98.9 | 125.3 | 131.7 | 137.3 | 139.1 | 139.5 |
| | June | 72.6 | 90.8 | 106.7 | 114.8 | 124.4 | 129.1 | 131.6 |
| 2007-08 | July | 66.3 | 83.9 | 100.5 | 106.4 | 114.1 | 117.3 | 119.0 |
| | August | 72.2 | 87.7 | 94.1 | 97.7 | 104.2 | 107.3 | 109.1 |
| | September | 65.1 | 82.1 | 92.3 | 96.2 | 100.8 | 102.6 | 103.9 |
| | October | 77.6 | 90.6 | 95.2 | 96.8 | 99.6 | 100.9 | 102.1 |
| | November | 88.0 | 97.7 | 102.3 | 103.3 | 104.4 | 104.7 | 104.9 |
| | December | 92.4 | 104.7 | 110.7 | 112.0 | 112.6 | 111.9 | 112.0 |
| | January | 114.8 | 126.7 | 129.9 | 130.2 | 130.1 | 129.6 | 130.3 |
| | February | 136.7 | 146.7 | 150.4 | 150.3 | 149.7 | 148.9 | 148.5 |
| | March | 169.8 | 179.3 | 182.2 | 181.0 | 179.3 | 178.1 | 178.1 |
| | April | 158.1 | 174.5 | 186.5 | 189.0 | 190.3 | 190.2 | 190.8 |
| | May | 124.9 | 144.3 | 178.9 | 184.0 | 188.4 | 190.0 | 191.6 |
| | June | 99.4 | 126.6 | 150.7 | 161.8 | 174.4 | 180.3 | 183.4 |
| 2008-09 | July | 89.0 | 115.0 | 140.1 | 148.7 | 159.8 | 164.3 | 166.7 |
| | August | 94.2 | 118.5 | 128.8 | 134.8 | 144.6 | 149.3 | 152.1 |
| | September | 96.5 | 119.9 | 131.1 | 134.5 | 140.1 | 142.2 | 143.9 |
| | October | 110.6 | 129.5 | 136.8 | 139.3 | 142.7 | 144.2 | 145.6 |
| | November | 124.7 | 139.9 | 146.8 | 148.4 | 150.0 | 150.5 | 151.6 |
| | December | 131.4 | 150.6 | 161.7 | 164.1 | 166.3 | 166.4 | 168.1 |
| | January | 170.6 | 190.5 | 195.2 | 195.5 | 195.2 | 194.3 | 196.4 |
| | February | 203.0 | 222.6 | 228.1 | 227.5 | 225.9 | 224.1 | 224.8 |
| | March | 272.5 | 285.5 | 287.2 | 283.5 | 277.0 | 274.0 | 273.4 |
| | April | 246.5 | 277.9 | 297.4 | 300.0 | 298.6 | 297.1 | 297.1 |
| | May | 178.4 | 211.7 | 279.1 | 280.2 | 295.5 | 297.6 | 300.1 |
| | June | 132.9 | 178.6 | 216.6 | 240.4 | 267.2 | 278.5 | 284.2 |
| | | South Lagoon | | | | | | |

| Year | month | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km |
|---------|-----------|--------------|-------|-------|-------|-------|-------|-------|
| 2006-07 | July | 44.4 | 48.5 | 49.8 | 51.1 | 52.2 | 52.6 | 52.8 |
| | August | 40.3 | 46.7 | 49.5 | 50.2 | 51.4 | 51.9 | 52.2 |
| | September | 45.2 | 50.0 | 51.8 | 52.4 | 53.1 | 53.5 | 53.9 |
| | October | 47.9 | 53.7 | 55.7 | 56.2 | 56.9 | 57.1 | 57.5 |
| | November | 50.5 | 55.5 | 60.3 | 61.5 | 62.6 | 62.7 | 63.3 |
| | December | 54.5 | 62.9 | 68.0 | 69.2 | 70.3 | 70.5 | 71.1 |
| | January | 55.7 | 66.9 | 73.7 | 75.7 | 77.1 | 77.3 | 77.9 |
| | February | 66.8 | 79.0 | 84.5 | 85.2 | 86.0 | 85.9 | 86.7 |
| | March | 73.8 | 86.1 | 92.3 | 94.2 | 96.1 | 96.5 | 97.1 |
| | April | 68.9 | 87.2 | 96.8 | 99.3 | 101.9 | 102.7 | 103.4 |
| | May | 53.6 | 59.5 | 76.8 | 84.8 | 92.3 | 95.1 | 95.6 |
| | June | 53.2 | 64.5 | 68.9 | 70.6 | 76.6 | 81.4 | 84.4 |
| 2007-08 | July | 49.4 | 59.8 | 68.2 | 70.5 | 73.6 | 75.1 | 76.1 |
| | August | 48.1 | 57.6 | 63.1 | 66.3 | 69.7 | 71.2 | 72.1 |
| | September | 55.3 | 62.1 | 64.4 | 65.5 | 67.4 | 68.1 | 68.9 |
| | October | 54.8 | 62.9 | 65.9 | 67.0 | 68.7 | 69.3 | 69.9 |
| | November | 63.8 | 68.8 | 70.9 | 71.3 | 71.7 | 71.8 | 72.0 |
| | December | 63.5 | 70.0 | 73.3 | 74.9 | 76.4 | 76.4 | 76.6 |
| | January | 67.3 | 79.1 | 83.0 | 84.1 | 85.3 | 85.5 | 86.1 |
| | February | 79.5 | 93.3 | 94.1 | 94.9 | 95.4 | 95.3 | 95.7 |
| | March | 90.9 | 103.0 | 107.8 | 108.6 | 109.0 | 109.1 | 109.4 |
| | April | 83.6 | 98.2 | 106.6 | 109.2 | 112.2 | 113.0 | 113.7 |
| | May | 72.2 | 85.9 | 102.3 | 106.8 | 110.6 | 112.0 | 112.8 |
| | June | 60.7 | 76.9 | 85.6 | 93.0 | 101.6 | 105.6 | 107.8 |
| 2008-09 | July | 59.2 | 74.7 | 84.5 | 88.4 | 93.8 | 96.3 | 97.8 |
| | August | 64.3 | 76.1 | 80.8 | 84.4 | 88.5 | 90.4 | 91.5 |
| | September | 61.8 | 74.4 | 80.9 | 83.0 | 86.4 | 87.7 | 88.7 |
| | October | 63.3 | 74.9 | 80.8 | 83.3 | 86.1 | 87.4 | 88.5 |
| | November | 75.0 | 82.8 | 86.0 | 86.7 | 87.9 | 88.4 | 89.1 |
| | December | 75.0 | 85.0 | 89.8 | 92.1 | 94.5 | 95.1 | 96.1 |
| | January | 75.4 | 92.7 | 100.2 | 102.7 | 105.1 | 105.8 | 108.0 |
| | February | 87.6 | 100.2 | 109.0 | 112.1 | 115.2 | 116.3 | 117.6 |
| | March | 85.9 | 108.8 | 119.9 | 122.9 | 126.6 | 127.8 | 129.0 |
| | April | 61.3 | 83.9 | 108.9 | 117.2 | 124.8 | 127.0 | 128.5 |
| | May | 56.5 | 78.8 | 99.5 | 106.3 | 115.5 | 119.7 | 122.0 |
| | June | 69.0 | 85.9 | 92.7 | 95.2 | 103.4 | 108.3 | 111.2 |
| | | South Lagoon | | | | | | |

Figure 16: maximum monthly salinity in the Coorong with a spatial delineation of the Coorong depicted for the baseline (left) and 2750 GL scenario (right) (2006/07-2008/09). Cells in green indicate less than 90 g L⁻¹, yellow indicates 90-100 g L⁻¹, orange indicates 100-120 g L⁻¹, while red indicates maximum salinity exceeds 120g L⁻¹.

Figure 16 illustrates both the likely extent of salinity conditions (while over representing the duration) of elevated salinities under baseline conditions by representing maximum daily values for each month in the South Lagoon of the Coorong and the Parnka Point region. Under baseline conditions, the maximum daily salinity in each month exceeds that of the upper salinity threshold linked to *Ruppia tuberosa* growth, as well as the lethal salinity for the remaining target biota of chironomids and small-mouthed hardyhead for the entire South Lagoon. In contrast, the 2750 GL indicates that the maximum daily salinity in each month in the majority of the Coorong during this same period is below the maximum target threshold spatially and temporally except in 2008-09 where over 50% of the Coorong exceeds the maximum salinity threshold for approximately 2 months.

| Year | month | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km |
|--------------|-----------|-------|-------|-------|-------|-------|-------|-------|
| 2006-07 | July | 46.2 | 50.6 | 52.1 | 53.4 | 54.7 | 55.2 | 55.4 |
| | August | 41.6 | 48.5 | 51.6 | 52.4 | 53.7 | 54.2 | 54.6 |
| | September | 46.8 | 52.0 | 54.0 | 54.6 | 55.4 | 55.9 | 56.3 |
| | October | 49.1 | 55.5 | 57.8 | 58.4 | 59.2 | 59.5 | 59.9 |
| | November | 52.0 | 57.4 | 62.3 | 63.6 | 65.0 | 65.2 | 65.8 |
| | December | 52.9 | 62.4 | 68.8 | 70.7 | 72.4 | 72.8 | 73.5 |
| | January | 52.5 | 65.5 | 73.8 | 76.4 | 78.5 | 78.9 | 79.8 |
| | February | 64.4 | 77.9 | 84.2 | 85.2 | 86.4 | 86.5 | 87.3 |
| | March | 71.9 | 85.0 | 91.6 | 93.7 | 95.8 | 96.3 | 96.9 |
| | April | 67.7 | 85.5 | 95.8 | 98.2 | 101.3 | 102.1 | 102.8 |
| | May | 51.0 | 57.3 | 75.2 | 83.7 | 91.7 | 94.6 | 95.3 |
| | June | 52.9 | 64.1 | 68.3 | 69.9 | 75.6 | 80.5 | 83.6 |
| 2007-08 | July | 49.0 | 59.3 | 67.6 | 69.8 | 72.8 | 74.3 | 75.3 |
| | August | 47.1 | 57.1 | 62.7 | 65.9 | 69.2 | 70.6 | 71.5 |
| | September | 55.7 | 62.2 | 64.5 | 65.6 | 67.3 | 67.9 | 68.7 |
| | October | 55.8 | 63.2 | 66.3 | 67.4 | 68.7 | 69.3 | 69.9 |
| | November | 63.0 | 68.3 | 70.6 | 71.1 | 71.6 | 71.8 | 71.9 |
| | December | 62.4 | 69.7 | 73.0 | 74.6 | 76.1 | 76.1 | 76.3 |
| | January | 66.9 | 73.5 | 82.4 | 83.5 | 84.8 | 85.0 | 85.6 |
| | February | 78.4 | 88.3 | 93.1 | 94.0 | 94.5 | 94.5 | 94.9 |
| | March | 91.0 | 102.2 | 106.9 | 107.4 | 107.9 | 107.9 | 108.2 |
| | April | 85.1 | 98.4 | 106.4 | 108.8 | 111.4 | 112.0 | 112.7 |
| | May | 73.2 | 86.7 | 102.3 | 106.5 | 109.9 | 111.2 | 111.9 |
| | June | 62.6 | 77.9 | 88.8 | 95.3 | 102.5 | 105.8 | 107.7 |
| 2008-09 | July | 60.5 | 75.6 | 86.0 | 89.8 | 95.1 | 97.4 | 98.8 |
| | August | 68.0 | 78.6 | 82.8 | 85.5 | 89.7 | 91.5 | 92.7 |
| | September | 63.6 | 76.4 | 82.4 | 84.8 | 88.0 | 89.2 | 90.1 |
| | October | 67.4 | 78.6 | 83.0 | 84.6 | 87.5 | 88.9 | 90.0 |
| | November | 73.6 | 83.3 | 87.8 | 89.0 | 90.4 | 90.9 | 91.6 |
| | December | 72.8 | 85.7 | 90.3 | 92.9 | 96.1 | 97.1 | 98.2 |
| | January | 86.8 | 100.8 | 105.4 | 106.6 | 107.8 | 108.1 | 110.2 |
| | February | 98.2 | 111.9 | 118.4 | 119.7 | 120.8 | 121.1 | 122.1 |
| | March | 116.1 | 130.6 | 136.6 | 137.4 | 137.9 | 138.0 | 138.4 |
| | April | 108.9 | 126.5 | 136.1 | 139.2 | 142.6 | 143.4 | 144.3 |
| | May | 94.2 | 112.8 | 131.8 | 136.6 | 140.8 | 142.4 | 143.0 |
| | June | 81.1 | 101.2 | 115.3 | 122.6 | 131.3 | 135.4 | 137.6 |
| South Lagoon | | | | | | | | |

| Year | month | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km |
|--------------|-----------|-------|-------|-------|-------|-------|-------|-------|
| 2006-07 | July | 43.9 | 47.9 | 49.2 | 50.4 | 51.5 | 51.9 | 52.1 |
| | August | 40.0 | 46.2 | 48.9 | 49.6 | 50.7 | 51.2 | 51.6 |
| | September | 44.1 | 49.0 | 51.0 | 51.5 | 52.3 | 52.7 | 53.1 |
| | October | 44.7 | 51.5 | 54.3 | 54.9 | 55.7 | 56.0 | 56.4 |
| | November | 48.0 | 53.8 | 58.9 | 60.0 | 61.2 | 61.3 | 61.9 |
| | December | 50.8 | 59.5 | 65.6 | 67.2 | 68.5 | 68.8 | 69.4 |
| | January | 49.4 | 60.8 | 67.8 | 70.8 | 73.8 | 74.5 | 75.5 |
| | February | 52.6 | 63.3 | 71.7 | 74.6 | 77.7 | 78.4 | 79.5 |
| | March | 45.7 | 62.7 | 73.1 | 76.5 | 81.0 | 82.3 | 83.5 |
| | April | 34.3 | 50.5 | 65.8 | 71.9 | 79.2 | 81.6 | 83.1 |
| | May | 31.4 | 44.7 | 53.3 | 60.9 | 69.9 | 73.9 | 75.6 |
| | June | 45.9 | 52.8 | 55.4 | 56.4 | 59.7 | 63.1 | 65.3 |
| 2007-08 | July | 43.1 | 50.2 | 54.7 | 56.3 | 58.2 | 59.1 | 59.7 |
| | August | 41.2 | 47.6 | 51.7 | 53.8 | 55.7 | 56.6 | 57.1 |
| | September | 43.7 | 49.6 | 51.7 | 52.5 | 54.1 | 54.8 | 55.4 |
| | October | 47.7 | 52.2 | 53.4 | 53.9 | 54.8 | 55.3 | 55.8 |
| | November | 53.1 | 56.5 | 57.7 | 57.9 | 58.0 | 58.0 | 58.0 |
| | December | 53.1 | 56.9 | 59.8 | 61.1 | 62.3 | 62.2 | 62.5 |
| | January | 54.2 | 64.4 | 68.2 | 69.3 | 70.2 | 70.4 | 70.8 |
| | February | 63.9 | 72.7 | 77.1 | 78.1 | 78.6 | 78.6 | 79.0 |
| | March | 64.0 | 75.8 | 83.4 | 85.8 | 88.0 | 88.6 | 89.3 |
| | April | 47.0 | 56.1 | 72.8 | 79.3 | 85.6 | 87.8 | 88.9 |
| | May | 39.6 | 51.1 | 64.7 | 70.2 | 77.2 | 80.6 | 82.6 |
| | June | 52.1 | 60.3 | 63.2 | 64.4 | 68.2 | 71.6 | 73.6 |
| 2008-09 | July | 49.4 | 57.9 | 62.7 | 64.3 | 66.3 | 67.3 | 68.0 |
| | August | 51.3 | 57.9 | 60.6 | 62.4 | 64.3 | 65.1 | 65.6 |
| | September | 51.4 | 58.3 | 61.4 | 62.4 | 64.1 | 64.7 | 65.3 |
| | October | 50.5 | 58.4 | 61.5 | 62.8 | 64.9 | 65.7 | 66.4 |
| | November | 60.9 | 65.1 | 66.6 | 66.9 | 67.3 | 67.5 | 67.9 |
| | December | 61.0 | 66.9 | 70.3 | 71.7 | 73.2 | 73.4 | 74.1 |
| | January | 61.7 | 74.1 | 79.2 | 80.7 | 82.1 | 82.6 | 84.7 |
| | February | 71.2 | 79.9 | 86.4 | 88.9 | 91.3 | 92.1 | 93.4 |
| | March | 68.3 | 83.6 | 93.5 | 96.7 | 100.1 | 101.3 | 102.3 |
| | April | 47.5 | 64.9 | 83.6 | 90.8 | 98.0 | 100.2 | 101.6 |
| | May | 43.5 | 60.2 | 76.4 | 81.9 | 89.6 | 93.1 | 95.1 |
| | June | 56.6 | 66.6 | 73.3 | 75.0 | 80.7 | 84.2 | 86.4 |
| South Lagoon | | | | | | | | |

Figure 17: maximum monthly salinity in the Coorong with a spatial delineation of the Coorong depicted for the 2400GL (left) and the 3200 GL scenario (right) (2006/07-2008/09). Cells in green indicate less than 90 g L⁻¹, yellow indicates 90-100 g L⁻¹, orange indicates 100-120 g L⁻¹, while red indicates maximum salinity exceeds 120g L⁻¹.

Figure 17 illustrates the relative impact of both less and additional water than the proposed recovery target of 2750 GL on maximum daily salinity in each month in the South Lagoon. For the 2400 GL scenario, salinity in the South Lagoon degrades considerably in the last year (although it is still substantially better than the baseline conditions). In contrast, the 3200 GL scenario demonstrates the benefits of the additional volume provided in the low flow periods by mitigating the peak monthly salinities observed in both 2750 GL and the baseline conditions.

The figures provide an over estimate of the duration of events described previously in Section 4.4 and analysed on the basis of average daily salinity but provide a useful visual aid in examining the comparative spatial and temporal effect of flow on salinities of concern in the South Lagoon of the Coorong, screening periods of concern and the benefits of additional flow recovery relative to 2750 GL.

5 Discussion

Mouth openness

While an appropriate level of Murray Mouth ‘openness’ has proven difficult to identify, recent studies (Lester et al, 2011) conclude that a healthy ecosystem in the Coorong can only occur with a functional level of Murray Mouth openness.

The examination of total annual barrage outflows and average annual Mouth depth indicates that there is a considerable improvement in Mouth openness (or more accurately a reduction in constriction) with increased flows. Conversely, periods of low barrage outflow correspond with periods of constriction and continue to pose a risk to ecology of the site.

Webster et al (2009) demonstrated that an indicative total annual barrage outflow volume of 2000 GL is required to maintain an annual average Mouth bed elevation of -2.0m AHD and reduce the risk of dredging.

Total annual barrage outflows for the Baseline scenario shows that flows are less than 2000 GL in approximately one-third of all years (36%). In comparison, the 2750 GL scenario results in considerable improvement with total annual barrage outflows being greater than 2000 GL in 89 per cent of years.

Comparison between the 2400 GL and 2750 GL water recovery scenarios reveals that total annual barrage outflows are less than 2000 GL for an additional three years, while there is no improvement in the number of years under the 3200 GL scenario.

Importantly, although there is no improvement in the number of years where flow is greater than 2000 GL under the 2750 GL and 3200 GL scenarios, the total annual barrage outflow volume does increase under the 3200 GL scenario relative to 2750 GL scenario, but not enough to exceed the 2000 GL threshold. It will, however, improve average annual Mouth depth.

Under the Baseline (current) scenario, there are nine sequences where total annual barrage outflows in two or more consecutive years are less than 2,000 GL. In contrast, under the 2750 GL scenario, there is only one sequence of two or more consecutive years where total annual barrage outflows are less than 2000 GL (2006-2009). This is also the case for the 2400 GL and 3200 GL scenarios.

Two or more consecutive years where total annual barrage outflows are less than 2000 GL will not necessarily lead to the Murray Mouth physically closing. Instead, the most appropriate interpretation is that there is increased risk of physical closure during these periods. Avoiding physical closure may be possible in the absence of significant total annual barrage outflows by dredging the Murray Mouth, as was the case in the most recent drought (2002-2010).

Any improvement in the number of sequences of two or more consecutive years where total annual barrage outflows are less than 2000 GL during the time series and reduced risk of Murray Mouth closure does not imply that the likely requirement for dredging has reduced from nine events to one. This would be an inappropriate extrapolation of results given the

inability of this study to categorically identify dredging as being required and the complexity of any decision to dredge in reality.

The recovery of water and its provision to the environment reduces the risk of Murray Mouth closure by not only increasing the number of years where total annual barrage outflows is greater than 2000 GL across the time series, but by also reducing the instances of two or more concurrent years where total annual barrage outflows are less than 2000 GL.

The analysis of outputs from the hydrodynamic model for daily Mouth depth reporting on the number of years where the annual average depth reduced to less than 2 m or less (classified as constricted) or 2 m or more (unconstricted). The years where the average Mouth depth reduced to less than 2 m were then further classified as 'severely constricted' where the Mouth depth reduced to less than 1 m. This classification applied to annual average Mouth depths only.

The examination of the hydrological modelling results undertaken indicates that the number of years where the Mouth is classified on average as severely constricted reduces with increasing volume provided to the environment. A comparison of the annual average Mouth depth in the four most constricted events across the time series illustrates improvement between the water recovery scenarios. Although there is no improvement in the number of years where total annual barrage outflows is greater than 2000 GL under the 2750 GL and 3200 GL scenarios, average annual Mouth depth is greater, reducing the risk of Mouth closure. The impact of this on any requirement to dredge is unknown at this stage.

The risk of severe constriction and reduced annual average depth is consistently reduced as total annual barrage outflows increased. The 2750 GL scenario results in the Murray Mouth being constricted in approximately 14 per cent of years (three years of which are severely constricted). By contrast, under the Baseline (current) scenario, 40 per cent of years are constricted (17 years of which are severely constricted).

Modest improvements in average annual mouth depth occur with the provision of additional water (up to 3200 GL) relative to 2750 GL, while reductions in the volume of water provided to the environment (2400 GL) has the opposite effect, constricting the Murray Mouth relative to 2750 GL. The significance of that difference is debatable on its own, but is likely to be important when considering the other effects that result on peak salinities and minimum water levels in the region or levels of biotic connectivity that result in harm to the environment.

Assessment of Mouth 'openness' by either the coarse measure of years where total annual barrage outflows are greater than 2,000 GL or annual average Mouth depth is greater than 2 m (or 1 m) constitutes a measure of risk that the Mouth could close as a result of local climate and wave conditions. It therefore acts as a guide to management, rather than a definitive estimate. The shallower the Mouth, the more likely that it would close as a result of a single weather event.

The risk of needing to implement dredging is increased by a severely constricted Murray Mouth, reduced Mouth depth, and periods of low barrage flow and high Coorong salinity, coupled with limited prospects of barrage flow through the spring-summer period in subsequent years.

A reduction in the number of years or periods where these risks are observed provides a useful measure of proposed water recovery scenarios. Any periods of risk identified are likely

to result from consecutive years of low/deficient barrage flows. Future analysis and reporting should therefore seek to develop a rolling average approach to flow volume in combination with an analysis of Mouth depth.

In addition, flow duration and daily discharge rate also affect the degree to which a given flow volume will scour the Mouth and improved average annual outcomes may be possible by altering the barrage flow delivery profile. This should be the focus of future work.

It is possible to analyse model outputs of Murray Mouth depth at smaller time-steps. This was not undertaken in this study because of the interaction with other processes, including seasonal changes to Mouth depth that occurs and would need to be accounted for, as well as the time scales for the mixing processes that govern the salinity dynamics in the Coorong.

The relationship between Mouth openness and flow is complex, but does not plateau. That is, small flows will open the Mouth to a small degree (and not at all, below a threshold), while larger flows will open the Mouth to a larger degree. Seasonal differences in the degree of Mouth openness are natural and a desirable part of the variability in the region (Lester et al, 2011). The minimum Mouth depth that occurs and its implications for the migration of fish and macroinvertebrate larval supply remains an important issue. Future work should seek to examine these relationships further.

The results of the monthly time step analysis undertaken are presented in Appendix 1. They provide a proportion of the months where the Murray Mouth is classified as constricted. This does not effectively consider local climactic information and is therefore presented for information only.

The estimation of Mouth openness due to flow encompassed in the hydrodynamic model is a simplified assessment of the dynamics of the Murray Mouth. This assessment and any conclusions must therefore be treated with caution and with the express understanding that it only provides guidance to South Australia on Mouth response during periods of increased risk. Because of the additional complexity of local processes that cannot be included in this model, it does not fully estimate the actual Mouth depth.

Critically, no assessment has been made as to whether a Murray Mouth depth of 1 m constitutes a realistic value for constriction that equates to a closed Murray Mouth. Although it is unlikely that an adaptive management experiment would be undertaken to validate this assessment, the fact that the value poses an increased risk of an actual physical closure is not in dispute. The modelling of the flow recovery scenarios identifies periods where the annual average Mouth depth declines to less than 1 m but this does not necessarily result in the Mouth actually achieving a daily Mouth depth of 0 m (physically closed) within that year (or sequence of years, but it does in some). Hence the caution expressed herein directly linking identification of severe constriction to Mouth closure.

The occurrence of a Mouth depth of 1 m is an untested metric, and is not the same as a physically closed Mouth or the implementation of dredging to avoid a closed Mouth.

With the recovery of the proposed volumes of water, periods of constriction (elevated risk) of the Murray Mouth closing will still occur and likely require some dredging to ensure it is kept open sufficiently during periods of low barrage flow (drought), although based on this analysis the provision of larger volumes reduce this risk.

Given the complexities in determining whether dredging would be required based on this analysis, it is not possible to definitively state whether the Murray Mouth will be maintained in an open configuration 95% of years through flow alone as desired by South Australia.

Water Levels in the South Lagoon

Rapidly changing water level can adversely affect macroinvertebrates in the Coorong (Rolston and Dittman, 2009). Similarly, low water levels which expose *Ruppia tuberosa* to desiccation for even short periods may prevent the species completing its lifecycle (Rogers and Paton, 2009, Paton, 2010) and over time, serially deplete the seedbank of the population by preventing its replenishment. As such, water levels are critical to the Coorong's ecological function. Research undertaken on *R. tuberosa* in the Coorong South Lagoon indicates that its distribution correlates most strongly with average annual water level greater than 0.27 m AHD (Overton, et al, 2009).

The analysis undertaken here indicates that under the 'without development' scenario, water levels would not support *Ruppia tuberosa* in the South Lagoon in 12 per cent of years. Under the Baseline (current) scenario, this increases to 43 per cent of years. Improvement *R. tuberosa* occurs under all water recovery scenarios, with the 2400 GL, 2750 GL and 3200 GL scenarios supporting increased distribution of the species in 3, 5 and 8 additional years respectively.

It is likely that the actual differences between the annual average water level for each scenario is a couple of centimetres at most. This is because the value is averaged across the year, and water level in the Coorong is driven by local climatic conditions; the seasonal response to sea level interacts with the effect of flow to achieve the water levels modelled.

The occurrence of a large proportion of years where the annual average water level in the South Lagoon is below 0.27 m AHD indicates that water levels resulting from the delivery of the recovery water as described here is not conducive to maximising the response in *Ruppia tuberosa* in the Coorong South Lagoon. It is postulated that this is because barrage outflows are not linked to achieving desired water levels in the Coorong, and instead flows are provided in response to upstream environmental and consumptive use.

While it is recognised that both minimum and variable water levels are important to the ecology of the Coorong, an understanding of seasonal minimum water level sufficient to maintain effective inundation of *Ruppia tuberosa* to complete its life-cycle and ensure persistence is lacking. Future understanding of this vital information would permit a more sensitive analysis of benefits and opportunities of environmental water delivery on the ecology of the Coorong. Averaged over the whole year, the annual water level target of 0.27m AHD is relatively crude. The primary period where water levels are required to be maintained for *Ruppia tuberosa* to complete its lifecycle is in summer, following the spring seasonal peak in flows. Better understanding these inundation requirements is the focus of work currently underway as a part of South Australia's Murray Futures CLLMM Recovery Project, funded by the Australian Government.

Delivery of flow through the barrages (timing, rate of release, volume and distribution of volume between barrages), can impact on water levels in the Coorong (Webster et al, 2009) As such there may be the potential to improve the average annual water level achieved by each scenario by altering the delivery of water during each year to increase water levels in

summer, thereby improving the average annual water level. It is likely that flow delivery as modelled here will not maximise benefits for the target species *Ruppia tuberosa*.

In addition, future work should seek to undertake hydrological modelling for the Basin that uses the CLLMM as a driver of environmental water provisions in the Basin to improve the number of years where water levels support the needs of Coorong biota, specifically *Ruppia tuberosa* in the Coorong South Lagoon.

Salinity in the Coorong

The Coorong is a reverse estuary, in that generally the salinity increases with distance from the Murray Mouth. Salinity does vary over time, but mainly in response to freshwater inflows over the barrages. The United States EPA recognises that a common habitat indicator or use in estuaries is salinity. Salinity is well-defined, measurable, has ecological significance, and encompasses a number of estuarine properties and processes (Jassby et al, 1995). A series of threshold values for salinity that would affect target biota of the Coorong were determined from published literature (see Section 2). These threshold values permitted an assessment of the Coorong salinity.

The maximum salinity values used for the North Lagoon is essentially the same as those used by the MDBA ($\sim 50 \text{ g L}^{-1}$), with an intermediate sub-lethal value assessed to report on any implications. South Australia adopted a series of intermediate salinity thresholds to assess the implications of South Lagoon salinity. These values were lower in quantum than the single value reported on by the MDBA ($\sim 130 \text{ g L}^{-1}$). The upper value represents a threshold where there is a likelihood of significant decline in *Ruppia tuberosa* (MDBA 2012b).

The South Australian values were linked to salinity that indicated growth in *Ruppia tuberosa* would be effectively prevented ($\sim 120 \text{ g L}^{-1}$). In both lagoons, South Australia also identified threshold values that permitted an assessment of whether sub-lethal impacts were being avoided in most years ($\sim 45 \text{ g L}^{-1}$ in the north lagoon and $\sim 90 \text{ g L}^{-1}$ in the South Lagoon).

The indicator or receptor species of macroinvertebrates (chironomids), *Ruppia*, and Small-mouthed hardyhead were chosen because of their role in the ecology of the Coorong as habitat or food resources for higher order organisms (Paton, 2010). Implications on these populations could be expected to affect organisms such as the piscivorous birds (Australian Pelican and Fairy tern), obligate herbivorous species such as the Black Swan (Rogers and Paton, 2009), and international migratory shorebirds (Sharp-tailed Sandpiper, Red-necked Stint).

The 2750 GL scenario indicates the modelled average annual salinity remains below the target thresholds in the North Lagoon in all years and below the target thresholds in the South Lagoon in all but a single year (2008/09). The daily average salinity observed under the 2750 GL scenario in each year is considerably better than the baseline scenario. However, the daily average salinity in the South Lagoon and the North Lagoon both exceed the target thresholds and illustrate that while annual average salinities are a useful guide, they should not be relied on to determine if impacts to the Coorong ecology are avoided.

The duration of events where daily average salinity exceeded thresholds provides additional information to assess the implications of salinity in the Coorong. This is despite it being an average of salinity and a coarse indicator of habitat remaining within the geographic boundaries of the lagoon (50% of the lagoon will be above the maximum daily average).

Despite the improvement relative to the baseline, there remain years where salinities that result from 2750 GL scenario exceeds the sub-lethal salinity thresholds for target biota in the North Lagoon. It is assumed that the average salinities are lower than the baseline and more likely to support populations at a 'healthier' and therefore more resilient level. Multiple years do exceed the lethal threshold for *Ruppia megacarpa* under all scenarios except 3200GL indicating a sizeable risk to the Coorong ecology in the North Lagoon during dry periods.

Daily average salinities within a year indicate that average salinities in the South Lagoon exceed the lethal thresholds under all water recovery scenarios except the 3200 GL scenario. There are substantial improvements relative to the baseline for all scenarios. The exceedance of the lethal thresholds for South Lagoon biota decreases as volume recovered events increases (the number of times the threshold is exceeded). This further supports the findings from analysis of the North Lagoon; namely that during dry periods there is major risk to the ecology of the South Lagoon as well.

Given the average daily modelled salinity concentration in the Coorong lagoons is compared to, and exceeds, the published, peer review based benchmark, further assessment and determination of the consequences by the MDBA appears warranted for the 2750 GL and other scenarios. Given concentrations below the threshold should not result in sizeable adverse effects to ecological receptors when appropriately conservative benchmarks are used (EPA, 1996), the analysis here indicates that 3200 GL scenario indicates the lowest risk to the ecology.

A key finding is the impact water recovery scenarios have on the maximum annual average salinities. The 50 GL increase in water relative to 2750 GL (as represented by the originally proposed 2800 GL scenario) was assumed to have little effect on the Coorong, with little effect observed on the annual average statistics. However, it was found that the impact on maximum average salinity observed in any one year in both the North and South Lagoons decreased by approximately 2 g L^{-1} between scenarios. While not major within themselves, the results are noteworthy, indicating that maximum average salinities are sensitive to even modest changes in barrage outflows (see Heneker and Higham, 2012 for a description of these changes).

It is plausible that the way water is delivered differs sufficiently between these scenarios (i.e. watering events upstream are different such that this altered not only the volume of water delivered to the Coorong but potentially even more importantly the timing between years). Any changes in the final volume to be recovered for the environment should be assessed against the effect on daily average salinities in the Coorong relative to the target threshold values.

Interactions between thresholds – implications for recommendations

Where information was available, thresholds were identified for key species and communities in the Coorong. For most, water properties examined by Lester et al (2011) were considered separately, as very few studies considered multiple factors simultaneously. Where tolerances are known, for almost all taxa, only a single stressor (or condition) has been considered. This limited the ability to examine the synergistic implications of these factors. Further work should be undertaken to examine the interaction between stressors.

The selection of lethal concentration values for biota is not conservative and does not account for interactions with other water quality properties ie inundation (water levels) and turbidity. The exceedance of these salinity threshold values would have to be characterised

as indicating considerable risk, even if they are based on an assessment using daily averages for the lagoon, such that 50% of the lagoon being examined may still be able to support the target biota. Given the maximum modelled salinity has been compared to an eco-toxicologically based lethal concentration and that the value is exceeded, at the very least further assessment is warranted to determine the ecological risk posed by the contaminant (EPA 1996).

Given recovery from a mortality event linked to a lethal threshold could take years of optimal conditions to recover (assuming the species isn't locally extirpated), South Australia's target is to not exceed these thresholds.

The analysis of the salinity in the Coorong resulting from the MDBA modelling indicates that there remains appreciable risk to important plants and animals of the Coorong with the recovery of 2750 GL, due to the exceedance of salinity thresholds as well as water levels not being suited to supporting the distribution of *Ruppia*.

6 Conclusions and Recommendations

South Australia welcomes the potential for increased water to be returned to the environment as outlined under the Draft Basin Plan and its associated water recovery scenario of 2750 GL. However, analysis of the hydrological modelling outputs provided by the MDBA raises concerns that the Coorong, Lower Lakes and Murray Mouth - a unique environmental asset in the Murray-Darling Basin - is still at considerable risk during times of extended drought.

Analysis of estimated Murray Mouth depth using the scenario of 2750 GL indicates that the Mouth depth would likely be less constricted relative to the baseline representing present conditions. The number of years where total annual flow is greater than 2000 GL is improved, as well as the number of years where the average annual Mouth depth is greater than 2 m. Using a threshold of Mouth depth being greater than 2 m, the Mouth is constricted more than 90% of years as targeted by the MDBA. Importantly however, given the complexities in determining whether dredging would be required based on this analysis, it is not possible to definitively state whether the Murray Mouth will be maintained in an open configuration 95% of years through flow alone as desired by South Australia.

There are still events where average salinities in the Coorong South Lagoon exceed the upper thresholds for key species in the South Lagoon. These exceedances are greater than five days, and given they represent over half of the Lagoon habitat being unsuitable, they are of significant concern. This is compounded by average annual water levels in the South Lagoon not meeting the requirements of *Ruppia tuberosa* (a key species in the Coorong) in a large proportion of years.

The analysis of the water recovery scenarios (sensitivity scenarios – 2400 GL and 3200 GL) demonstrates that the outcomes are sensitive to the volume provided to the site as a long term average. Reductions in the outcomes occur under the 2400 GL scenario relative to 2750 GL scenario, while improvements are seen under the 3200 GL scenario. Critically, the exceedance of salinity thresholds in the South Lagoon is indicatively eliminated under the 3200 GL scenario, indicating that a modest increase in the provision of water can have significant benefits that reduce the risks to the site.

Based on the analysis of average daily salinity in the Coorong, these risks as characterised by the adopted thresholds, are highest during periods of drought when barrage flows are at their lowest.

Analysis of all the available water recovery scenarios indicates that daily average salinity in the North and South Lagoons is sensitive to an increase of as little as 50 GL in environmental provision.

Further modelling and analyses is recommended regarding improving the delivery of water to the site and optimisation of outcomes achieved through operations, to confirm whether exceedance of thresholds can be avoided through the proposed water recovery scenarios.

The preliminary examination of annual average water levels in the South Lagoon would indicate that water levels are not being managed to support *Ruppia tuberosa* even though salinities potentially are at the upper sensitivity level. River and barrage operations will be

critical to achieve the target outcomes over the season, and further work should be undertaken by the MDBA with assistance from South Australia to:

1. At a minimum, use the Coorong as a driver of water delivery, with timing linked to the volumes available from this work.

Or, more preferably:

2. Use the Coorong seasonal and lakes volumetric requirements to drive water recovery volume AND delivery timing.

Based on previous studies (i.e. Webster et al, 2009) altering the timing and rate of barrage flows can have a major impact on water level and salinity outcomes in the Coorong. It may be possible to achieve better outcomes than has been modelled by the MDBA by optimising the delivery strategy which is a task that remains.

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APPENDIX 1: Murray Mouth depth duration and event analyses – monthly time step

In order to examine the effect of the Draft Basin Plan scenarios, the modelled daily Murray Mouth depth was calculated and a monthly average of this value taken for each scenario. This information was then examined as a frequency distribution plot and as a figure illustrating the Murray Mouth depth over time.

Murray Mouth depth duration and event analyses - monthly

A frequency distribution for average monthly effective Mouth depth was developed from the MDBA outputs to examine the number of months whereby the constriction of the Murray Mouth can be assessed in finer detail (Figure 18). A daily frequency analysis was not undertaken due to the limitations of Microsoft Excel as an analysis tool, and given the duration of events undertaken on a daily basis provides a more effective tool for analysis of the duration of specific events.

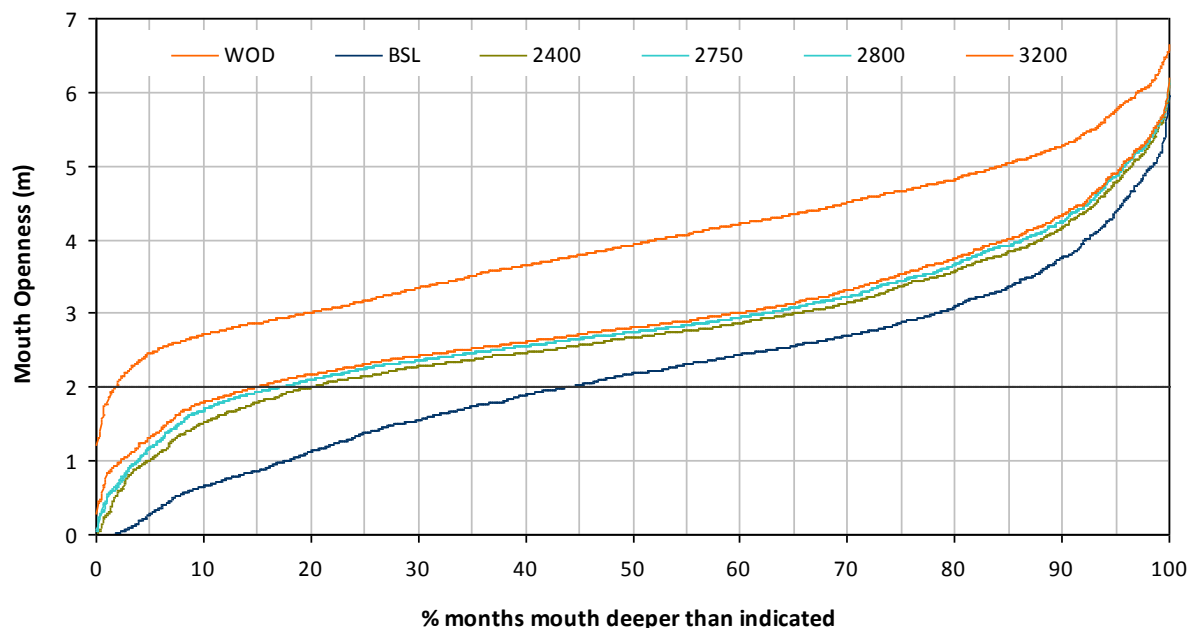


Figure 18: frequency distribution plot of Mouth depth averaged for each month over the time series with a depth of 2 m indicated by the dark grey line (1895/96-2008/09)

The analysis of effective Mouth depth over the full time series on a monthly average basis indicates that the Murray Mouth is constricted approximately 45% of months for the Baseline scenario, as opposed to less than 3% of time for the ‘without development’ scenario. Relative to the Baseline scenario, all water recovery scenarios show a large amount of relative improvement:

- 2750 GL scenario indicating constriction occurring approximately 17% of months
- 2400 GL scenario indicating constriction occurring approximately 20% of months
- 3200 GL scenario indicating constriction occurring approximately 15% of months.

The 2800 GL scenario indicated an imperceptible difference to the outcome achieved by 2750 GL.

Without Development scenario

For the 'without development' scenario, constriction of the Murray Mouth occurred on a number of occasions such that the effective Mouth depth reduced to values less than 2 m for five periods.

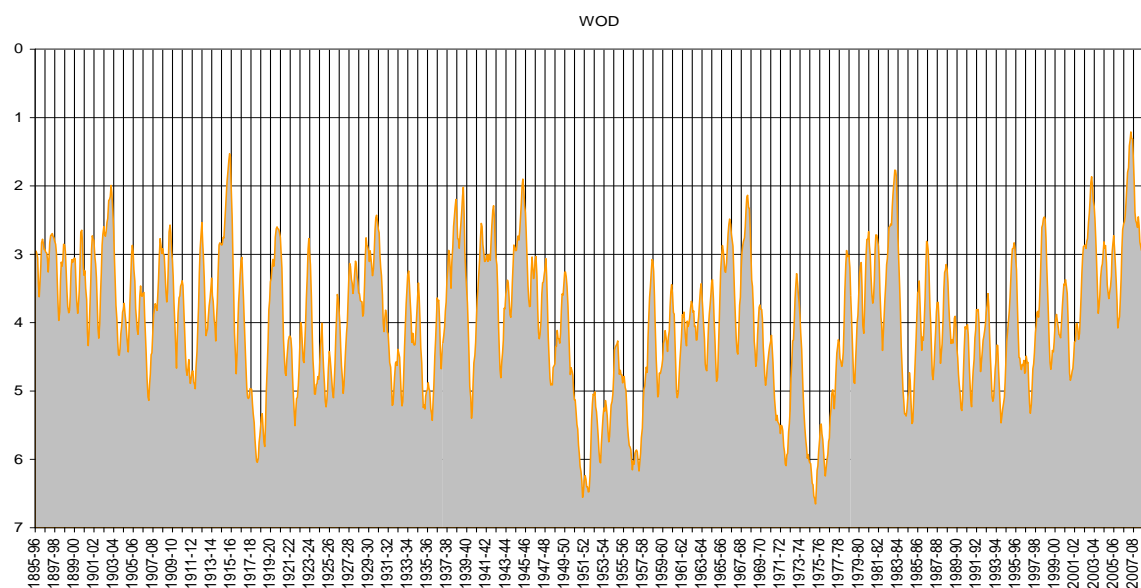


Figure 19: time-series of monthly average effective Mouth depth as calculated by the hydrodynamic model for the 'without development' scenario (1895/96-2008/09).

Baseline scenario

For the Baseline scenario, constriction of the Murray Mouth occurred on a number of occasions such that the effective Mouth depth reduced to values less than 2 m for 20 periods.

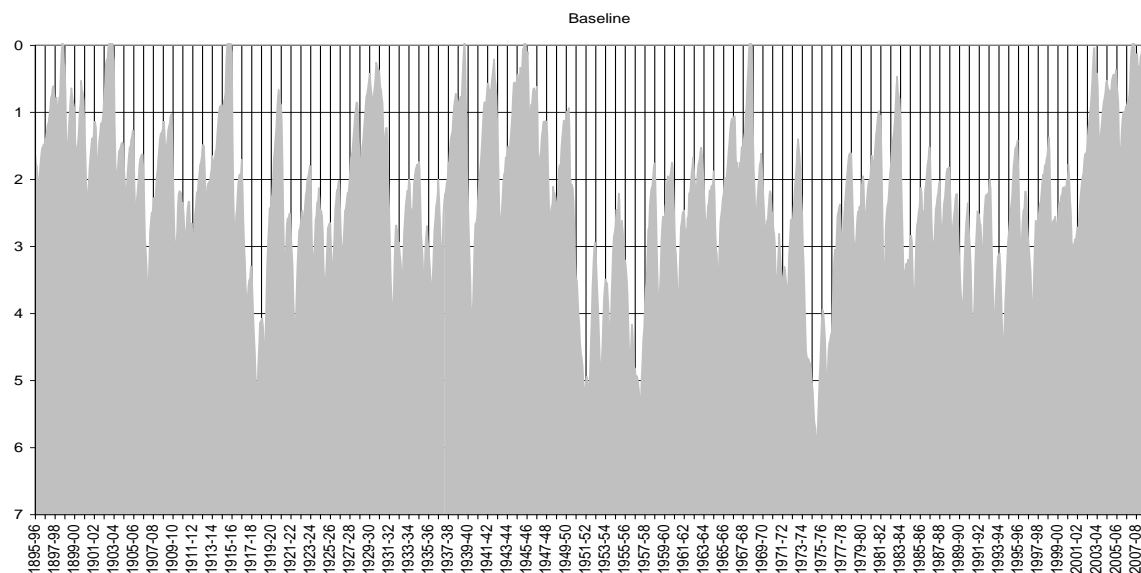


Figure 20: time-series of monthly average effective Mouth depth as calculated by the hydrodynamic model for the Baseline scenario (1895/96-2008/09).

2400 GL scenario

For the 2400GL scenario, constriction of the Murray Mouth occurred on a number of occasions such that the effective Mouth depth reduced to values less than 2 m for 27 periods.

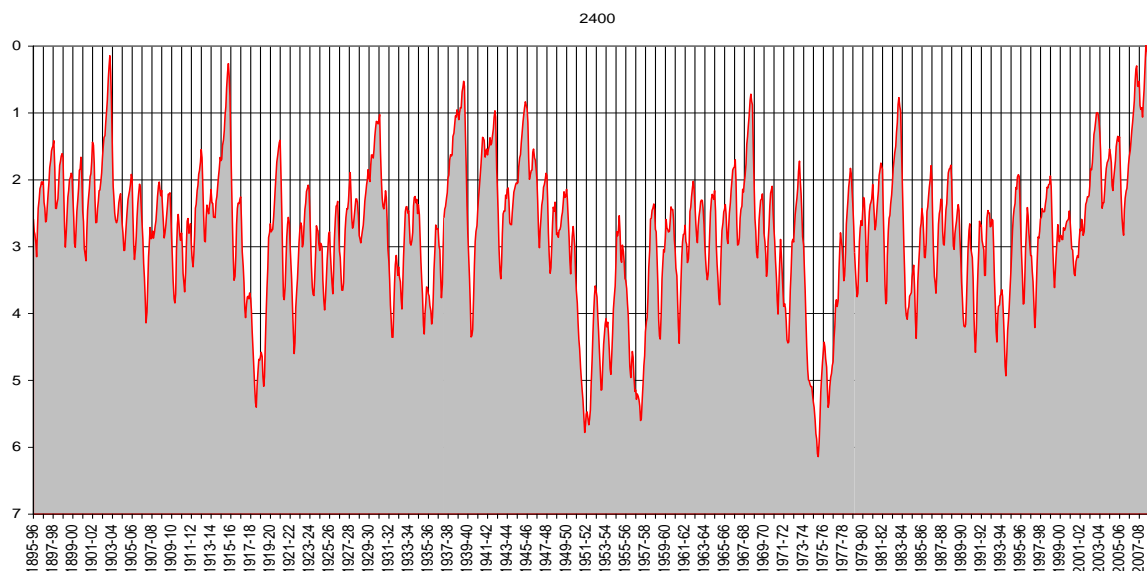


Figure 21: time-series of monthly average effective Mouth depth as calculated by the hydrodynamic model for the 2400 GL scenario (1895/96-2008/09).

2750 GL scenario

For the 2750GL scenario, constriction of the Murray Mouth occurred on a number of occasions such that the effective Mouth depth reduced to values less than 2 m for 24 periods.

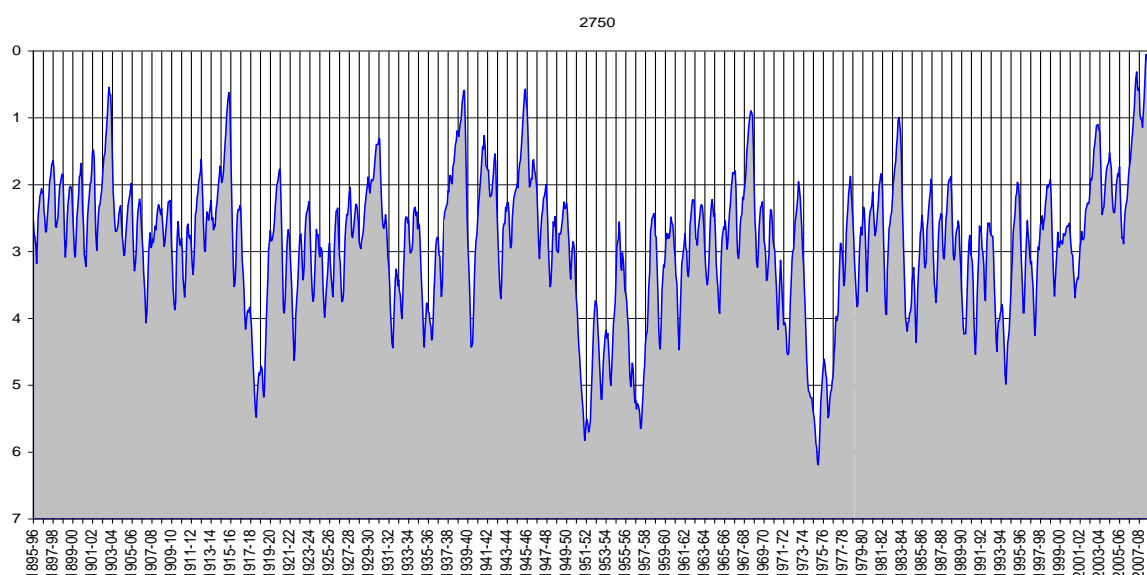


Figure 22: time-series of monthly average effective Mouth depth as calculated by the hydrodynamic model for the 2750 GL scenario (1895/96-2008/09).

3200 GL scenario

For the 3200 GL scenario, constriction of the Murray Mouth occurred on a number of occasions such that the effective Mouth depth reduced to values less than 2 m for 23 periods.

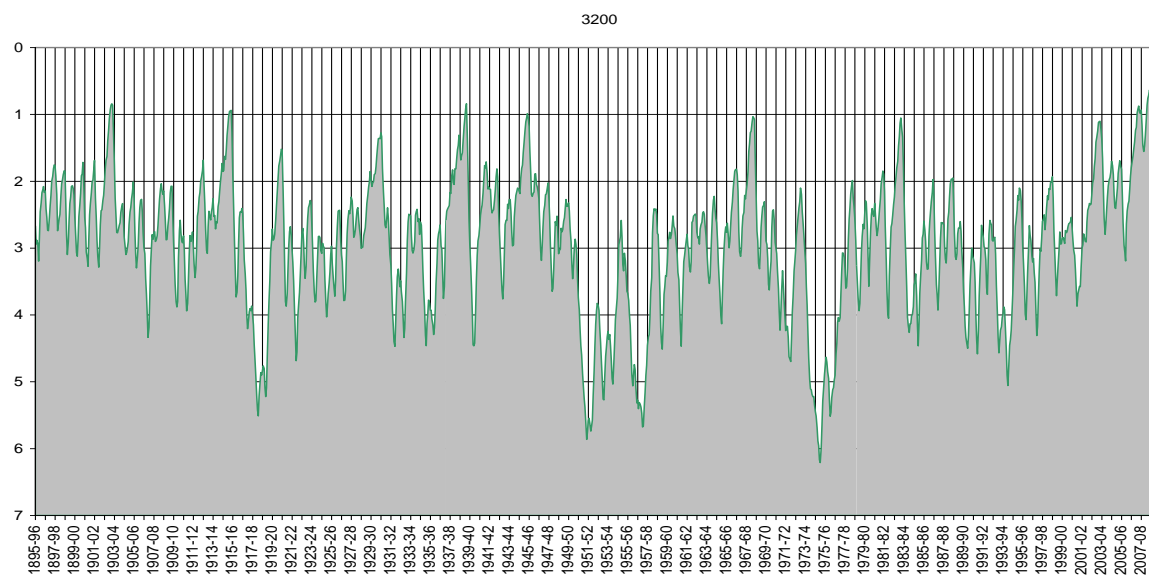


Figure 23: time-series of monthly average effective Mouth depth as calculated by the hydrodynamic model for the 3200 GL scenario (1895/96-2008/09).

APPENDIX 2: Modelled average daily salinity statistics for each cell of the hydrodynamic model

Table 19: 'without development' scenario modelled salinity statistics for each cell in the hydrodynamic model (1895/96-2008/09)

| | | | | | MDBA North Lagoon | | | | MDBA South Lagoon | | | | | |
|-----------------|-------|-------|-------|-------|-------------------|-------|-------|-------|-------------------|-------|-------|-------|-------|-------|
| | | | | | SA North Lagoon | | | | SA South Lagoon | | | | | |
| | 4 km | 10 km | 15 km | 22 km | 31 km | 40 km | 50 km | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km |
| Minimum | 0.13 | 0.13 | 0.41 | 0.69 | 1.16 | 1.65 | 2.43 | 3.19 | 4.71 | 6.52 | 7.02 | 7.46 | 7.64 | 7.71 |
| 5th percentile | 0.47 | 0.44 | 1.31 | 1.87 | 2.63 | 3.66 | 5.51 | 7.40 | 9.85 | 11.40 | 11.95 | 12.47 | 12.61 | 12.70 |
| 10th percentile | 0.60 | 0.53 | 1.72 | 2.41 | 3.31 | 4.44 | 6.37 | 8.56 | 11.10 | 12.62 | 13.02 | 13.58 | 13.79 | 13.90 |
| Average | 10.81 | 6.94 | 8.57 | 9.12 | 9.95 | 11.20 | 13.59 | 16.81 | 20.41 | 22.85 | 23.71 | 24.81 | 25.22 | 25.49 |
| Median | 7.43 | 3.09 | 5.51 | 6.41 | 7.55 | 9.14 | 11.95 | 15.41 | | 21.71 | 22.60 | 23.68 | 24.00 | 24.22 |
| 90th percentile | 27.26 | 19.64 | 20.07 | 19.82 | 20.16 | 21.07 | 23.27 | 26.71 | 30.79 | 34.26 | 35.57 | 37.23 | 38.02 | 38.55 |
| 95th percentile | 32.66 | 27.57 | 27.45 | 27.19 | 27.08 | 27.29 | 28.80 | 31.86 | 36.69 | 40.75 | 42.30 | 44.19 | 44.95 | 45.54 |
| Maximum | 40.39 | 42.02 | 43.74 | 44.72 | 46.70 | 49.11 | 52.68 | 58.22 | 62.90 | 67.00 | 68.20 | 72.17 | 74.56 | 76.23 |

Table 20: Baseline scenario modelled salinity statistics for each cell in the hydrodynamic model (1895/96-2008/09)

| | | | | | MDBA North Lagoon | | | | MDBA South Lagoon | | | | | |
|-----------------|-------|-------|--------|--------|-------------------|--------|--------|--------|-------------------|--------|--------|--------|--------|--------|
| | | | | | SA North Lagoon | | | | SA South Lagoon | | | | | |
| | 4 km | 10 km | 15 km | 22 km | 31 km | 40 km | 50 km | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km |
| Minimum | 0.17 | 0.17 | 0.60 | 1.34 | 2.26 | 2.94 | 5.12 | 7.03 | 11.14 | 16.87 | 17.86 | 18.99 | 19.12 | 18.64 |
| 5th percentile | 1.13 | 0.89 | 3.59 | 5.16 | 7.38 | 10.16 | 15.27 | 20.93 | 27.78 | 31.64 | 32.93 | 34.34 | 34.79 | 34.86 |
| 10th percentile | 2.43 | 1.50 | 5.22 | 7.10 | 9.53 | 12.92 | 18.89 | 25.02 | 31.77 | 36.68 | 38.13 | 39.38 | 39.89 | 39.97 |
| Average | 21.10 | 17.17 | 20.41 | 21.97 | 24.38 | 27.77 | 34.42 | 43.08 | 52.61 | 59.37 | 61.59 | 64.35 | 65.31 | 65.84 |
| Median | 23.24 | 17.45 | 20.89 | 22.35 | 24.30 | 26.75 | 31.81 | 38.86 | 47.20 | 53.02 | 54.91 | 57.36 | 58.19 | 58.74 |
| 90th percentile | 33.73 | 29.60 | 30.40 | 31.55 | 35.10 | 40.75 | 51.73 | 65.18 | 79.85 | 89.91 | 93.15 | 97.37 | 98.83 | 99.66 |
| 95th percentile | 38.36 | 39.26 | 40.96 | 42.26 | 45.21 | 49.69 | 60.40 | 76.61 | 90.82 | 102.59 | 106.22 | 112.14 | 114.65 | 116.49 |
| Maximum | 86.49 | 94.57 | 111.34 | 119.29 | 131.52 | 145.12 | 168.92 | 272.50 | 285.48 | 297.39 | 300.01 | 298.64 | 297.58 | 300.08 |

Table 21: 2400GL scenario modelled salinity statistics for each cell in the hydrodynamic model (1895/96-2008/09)

| | | | | | MDBA North Lagoon | | | | MDBA South Lagoon | | | | | |
|-----------------|-------|-------|-------|-------|-------------------|-------|-------|--------|-------------------|--------|--------|--------|--------|--------|
| | | | | | SA North Lagoon | | | | SA South Lagoon | | | | | |
| | 4 km | 10 km | 15 km | 22 km | 31 km | 40 km | 50 km | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km |
| Minimum | 0.16 | 0.16 | 0.53 | 1.02 | 1.58 | 2.23 | 3.49 | 4.97 | 7.81 | 11.67 | 12.46 | 13.22 | 13.40 | 13.06 |
| 5th percentile | 0.84 | 0.70 | 2.80 | 4.00 | 5.68 | 7.85 | 11.62 | 16.07 | 21.46 | 24.57 | 25.38 | 26.41 | 26.69 | 26.73 |
| 10th percentile | 1.53 | 1.05 | 3.87 | 5.30 | 7.25 | 9.67 | 14.29 | 19.29 | 24.63 | 28.08 | 29.21 | 30.57 | 30.98 | 31.13 |
| Average | 17.81 | 13.47 | 16.08 | 17.26 | 19.04 | 21.58 | 26.35 | 32.91 | 40.20 | 45.29 | 47.01 | 49.17 | 49.93 | 50.37 |
| Median | 19.39 | 12.76 | 15.95 | 17.29 | 19.12 | 21.57 | 26.17 | 31.88 | 38.45 | 43.12 | 44.63 | 46.55 | 47.22 | 47.55 |
| 90th percentile | 31.92 | 26.64 | 27.73 | 28.38 | 29.74 | 31.99 | 37.72 | 47.37 | 57.67 | 64.95 | 67.28 | 70.71 | 72.08 | 73.07 |
| 95th percentile | 34.05 | 29.47 | 29.69 | 30.17 | 32.02 | 35.36 | 42.17 | 53.71 | 65.48 | 74.06 | 77.20 | 80.98 | 82.24 | 83.43 |
| Maximum | 49.48 | 53.32 | 60.15 | 62.83 | 67.24 | 73.31 | 84.98 | 116.11 | 130.59 | 136.64 | 139.15 | 142.55 | 143.36 | 144.28 |

Table 22: 2750GL scenario modelled salinity statistics for each cell in the hydrodynamic model (1895/96-2008/09)

| | | | | | MDBA North Lagoon | | | | MDBA South Lagoon | | | | | |
|-----------------|-------|-------|-------|-------|-------------------|-------|-------|-------|-------------------|--------|--------|--------|--------|--------|
| | | | | | SA North Lagoon | | | | SA South Lagoon | | | | | |
| | 4 km | 10 km | 15 km | 22 km | 31 km | 40 km | 50 km | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km |
| Minimum | 0.16 | 0.16 | 0.52 | 0.98 | 1.49 | 2.09 | 3.28 | 4.69 | 7.34 | 10.93 | 11.66 | 12.38 | 12.54 | 12.23 |
| 5th percentile | 0.79 | 0.66 | 2.59 | 3.68 | 5.23 | 7.16 | 10.58 | 14.56 | 19.40 | 22.19 | 22.88 | 23.79 | 24.13 | 24.31 |
| 10th percentile | 1.41 | 0.98 | 3.60 | 4.95 | 6.68 | 8.85 | 12.93 | 17.44 | 22.41 | 25.65 | 26.72 | 27.98 | 28.31 | 28.44 |
| Average | 17.00 | 12.54 | 15.04 | 16.14 | 17.79 | 20.14 | 24.58 | 30.68 | 37.48 | 42.25 | 43.86 | 45.89 | 46.61 | 47.04 |
| Median | 17.87 | 10.93 | 14.21 | 15.47 | 17.34 | 19.89 | 24.23 | 29.66 | 35.56 | 39.69 | 41.18 | 42.98 | 43.59 | 43.95 |
| 90th percentile | 31.33 | 25.83 | 26.94 | 27.58 | 28.81 | 30.73 | 35.89 | 45.21 | 55.13 | 62.23 | 64.38 | 67.43 | 68.73 | 69.59 |
| 95th percentile | 33.29 | 28.31 | 28.66 | 29.19 | 30.86 | 33.68 | 40.18 | 51.09 | 61.99 | 69.88 | 72.89 | 76.56 | 78.30 | 79.75 |
| Maximum | 42.77 | 44.91 | 48.62 | 50.23 | 52.99 | 57.21 | 65.77 | 90.87 | 108.79 | 119.92 | 122.88 | 126.80 | 127.82 | 128.95 |

Table 23: 2800GL scenario modelled salinity statistics for each cell in the hydrodynamic model (1895/96-2008/09)

| | | | | | MDBA North Lagoon | | | | | MDBA South Lagoon | | | | | |
|-----------------|-------|-------|-------|-------|-------------------|-------|-------|-------|--------|-------------------|--------|--------|--------|--------|--|
| | | | | | SA North Lagoon | | | | | SA South Lagoon | | | | | |
| | 4 km | 10 km | 15 km | 22 km | 31 km | 40 km | 50 km | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km | |
| Minimum | 0.16 | 0.16 | 0.52 | 0.98 | 1.49 | 2.09 | 3.27 | 4.68 | 7.33 | 10.91 | 11.64 | 12.35 | 12.51 | 12.20 | |
| 5th percentile | 0.79 | 0.66 | 2.59 | 3.68 | 5.22 | 7.16 | 10.57 | 14.56 | 19.38 | 22.17 | 22.85 | 23.77 | 24.09 | 24.27 | |
| 10th percentile | 1.41 | 0.98 | 3.59 | 4.94 | 6.67 | 8.84 | 12.91 | 17.42 | 22.37 | 25.62 | 26.70 | 27.94 | 28.28 | 28.42 | |
| Average | 16.99 | 12.53 | 15.03 | 16.12 | 17.77 | 20.13 | 24.56 | 30.67 | 37.47 | 42.24 | 43.85 | 45.88 | 46.61 | 47.03 | |
| Median | 17.87 | 10.96 | 14.24 | 15.51 | 17.36 | 19.90 | 24.28 | 29.69 | 35.61 | 39.74 | 41.20 | 42.99 | 43.57 | 43.95 | |
| 90th percentile | 31.30 | 25.79 | 26.93 | 27.57 | 28.78 | 30.72 | 35.86 | 45.14 | 55.12 | 62.19 | 64.36 | 67.45 | 68.75 | 69.61 | |
| 95th percentile | 33.26 | 28.27 | 28.60 | 29.19 | 30.77 | 33.60 | 40.15 | 50.95 | 61.87 | 69.95 | 72.94 | 76.67 | 78.34 | 79.78 | |
| Maximum | 42.81 | 44.86 | 48.40 | 49.62 | 51.72 | 54.51 | 63.04 | 87.23 | 104.07 | 116.99 | 120.43 | 124.50 | 125.74 | 126.93 | |

Table 24: 3200GL scenario modelled salinity statistics for each cell in the hydrodynamic model (1895/96-2008/09)

| | | | | | MDBA North Lagoon | | | | | MDBA South Lagoon | | | | | |
|-----------------|-------|-------|-------|-------|-------------------|-------|-------|-------|-------|-------------------|-------|--------|--------|--------|--|
| | | | | | SA North Lagoon | | | | | SA South Lagoon | | | | | |
| | 4 km | 10 km | 15 km | 22 km | 31 km | 40 km | 50 km | 58 km | 64 km | 70 km | 76 km | 83 km | 90 km | 98 km | |
| Minimum | 0.16 | 0.16 | 0.52 | 0.96 | 1.46 | 2.04 | 3.17 | 4.55 | 7.12 | 10.57 | 11.27 | 11.96 | 12.07 | 11.77 | |
| 5th percentile | 0.74 | 0.63 | 2.44 | 3.47 | 4.94 | 6.81 | 10.04 | 13.84 | 18.36 | 21.18 | 22.01 | 22.92 | 23.22 | 23.32 | |
| 10th percentile | 1.29 | 0.91 | 3.37 | 4.63 | 6.29 | 8.34 | 12.20 | 16.41 | 21.17 | 24.17 | 25.16 | 26.39 | 26.84 | 27.04 | |
| Average | 16.36 | 11.82 | 14.20 | 15.22 | 16.74 | 18.94 | 23.08 | 28.75 | 35.10 | 39.55 | 41.07 | 42.98 | 43.67 | 44.08 | |
| Median | 16.88 | 9.88 | 13.09 | 14.32 | 16.12 | 18.76 | 23.00 | 28.16 | 33.95 | 38.05 | 39.45 | 41.24 | 41.78 | 42.08 | |
| 90th percentile | 30.77 | 25.18 | 26.29 | 26.86 | 27.97 | 29.64 | 33.83 | 41.91 | 50.85 | 57.41 | 59.51 | 62.42 | 63.73 | 64.65 | |
| 95th percentile | 32.53 | 27.17 | 27.64 | 28.08 | 29.33 | 31.41 | 36.32 | 45.85 | 55.83 | 63.00 | 65.55 | 69.17 | 70.64 | 71.67 | |
| Maximum | 39.28 | 40.54 | 41.70 | 42.55 | 44.37 | 46.67 | 52.09 | 71.20 | 83.65 | 94.53 | 98.11 | 102.67 | 104.41 | 105.97 | |

APPENDIX 3: SA delineation of the South Lagoon – additional salinity statistics and reporting against thresholds

Annual average statistics for the SA delineation of the South Lagoon is listed in section 4.4

Table 25: average daily salinity exceeding the MDBA defined 130g L⁻¹ upper limit (MDBA 2012b)

| | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|--------------------------|----------|--------|--------|--------|--------|
| # events longer than 5 d | 5 | 1 | 0 | 0 | 0 |
| Mean duration | 189 | 71 | 0 | 0 | 0 |
| Median duration | 113 | 71 | 0 | 0 | 0 |
| Maximum duration | 516 | 71 | 0 | 0 | 0 |

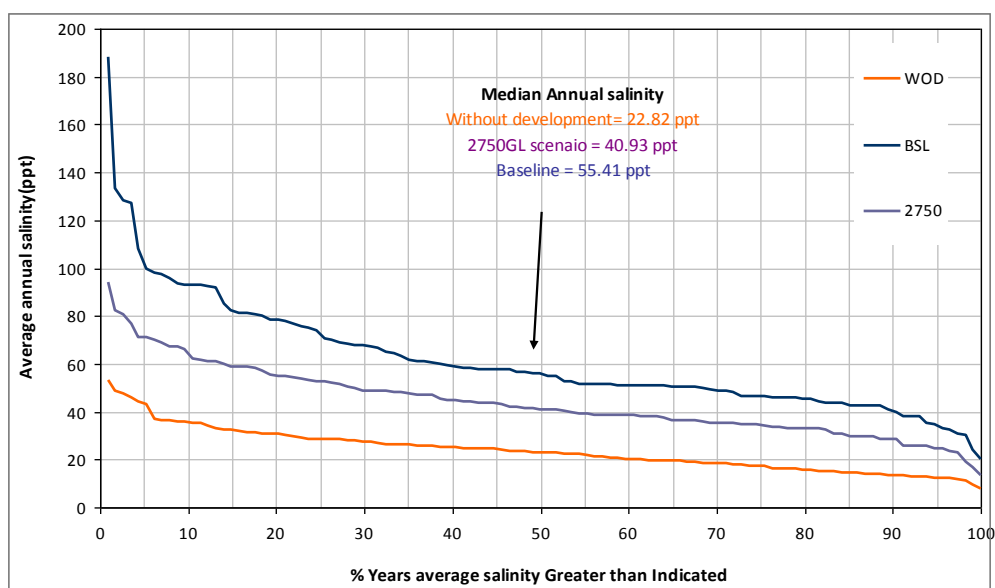


Figure 24: frequency curve for modelled average annual average South Lagoon salinity (1895/96-2008/09)

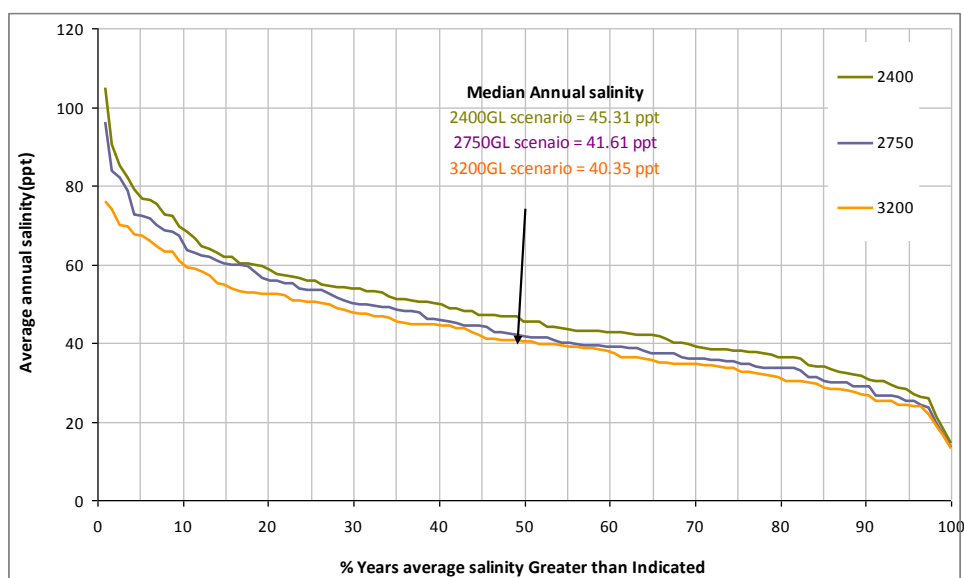


Figure 25: frequency curve for modelled average annual average South Lagoon salinity (1895/96-2008/09)

APPENDIX 4: MDBA delineation of the South Lagoon – salinity statistics and reporting against thresholds

Table 26: statistics of annual average salinity (g L^{-1}) for the MDBA delineation of the South Lagoon under the different scenarios (1895/96-2008/09)

| | without development | Baseline | 2400GL | 2750GL | 2800GL | 3200GL |
|-----------------|---------------------|----------|--------|--------|--------|--------|
| MINIMUM | 6.9 | 17.8 | 12.3 | 11.5 | 11.5 | 11.2 |
| 5th percentile | 11.9 | 33.0 | 25.4 | 23.0 | 23.0 | 22.0 |
| 10th percentile | 13.0 | 38.0 | 29.2 | 26.7 | 26.7 | 25.2 |
| AVERAGE | 23.7 | 61.5 | 47.0 | 43.9 | 43.8 | 41.1 |
| MEDIAN | 22.6 | 54.8 | 44.6 | 41.3 | 41.3 | 39.5 |
| 90th percentile | 35.6 | 93.2 | 67.4 | 64.4 | 64.4 | 59.3 |
| 95th percentile | 42.3 | 105.8 | 77.3 | 72.8 | 72.8 | 65.6 |
| MAXIMUM | 67.1 | 290.7 | 138.0 | 121.8 | 119.1 | 97.4 |

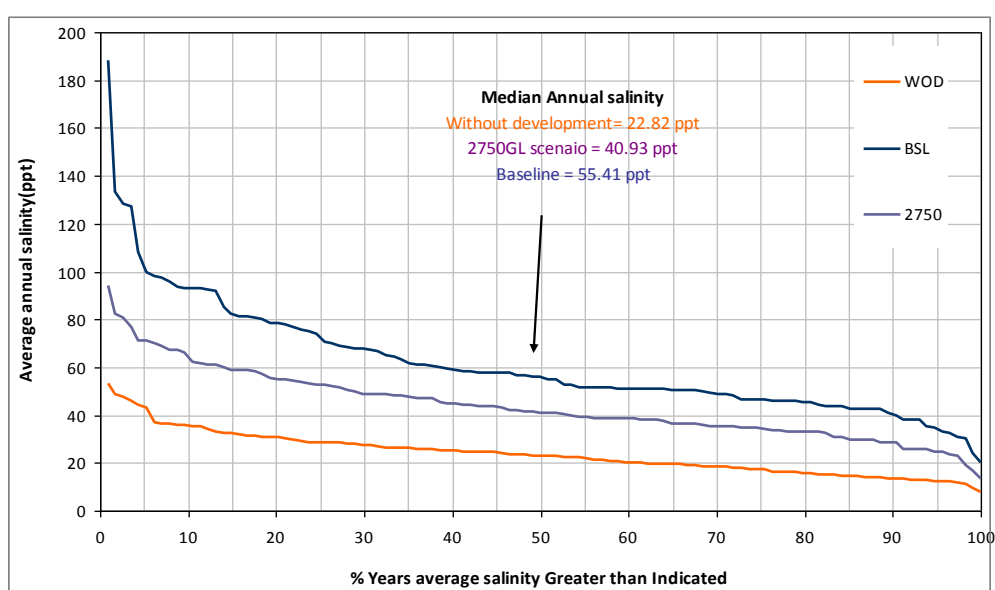


Figure 26: frequency curve for modelled average annual average South Lagoon salinity (1895/96-2008/09)

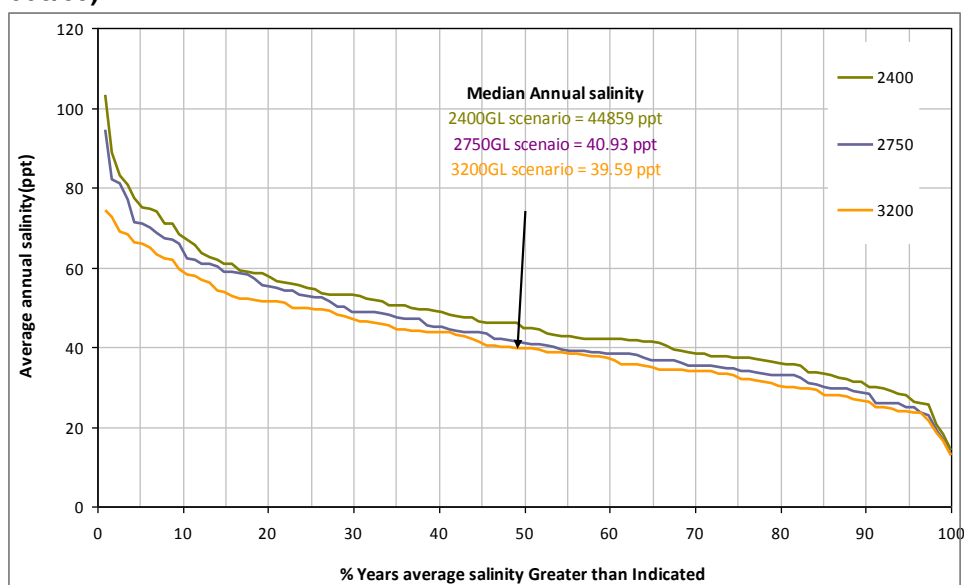


Figure 27: frequency curve for modelled average annual average South Lagoon salinity (1895/96-2008/09)

Average daily South Lagoon salinity statistics

The exceedance of salinity thresholds for target biota in the South Lagoon was assessed for the MDBA delineation of the South Lagoon as well as that of the SA delineation. The statistics are presented here in Table 27 to Table 31 for comparison to those presented in Section 4.4 and Appendix 3.

Table 27: average daily salinity exceeding the 90g L⁻¹ upper limit

| | Baseline | 2400 GL | 2750 GL | 2800 GL | 3200 GL |
|--------------------------|----------|---------|---------|---------|---------|
| # events longer than 5 d | 33 | 12 | 5 | 5 | 2 |
| Mean duration | 138 | 68 | 96 | 91 | 40 |
| Median duration | 83 | 49 | 115 | 101 | 40 |
| Maximum duration | 910 | 188 | 184 | 181 | 54 |

Table 28: average daily salinity exceeding the 100g L⁻¹ upper limit

| | Baseline | 2400 GL | 2750 GL | 2800 GL | 3200 GL |
|--------------------------|----------|---------|---------|---------|---------|
| # events longer than 5 d | 18 | 6 | 3 | 4 | 0 |
| Mean duration | 160 | 66 | 99 | 71 | 0 |
| Median duration | 118 | 47 | 87 | 79 | 0 |
| Maximum duration | 599 | 168 | 129 | 111 | 0 |

Table 29: average daily salinity exceeding the 108g L⁻¹ upper limit

| | Baseline | 2400 GL | 2750 GL | 2800 GL | 3200 GL |
|--------------------------|----------|---------|---------|---------|---------|
| # events longer than 5 d | 16 | 2 | 2 | 2 | 0 |
| Mean duration | 119 | 115 | 43 | 26 | 0 |
| Median duration | 76 | 115 | 43 | 26 | 0 |
| Maximum duration | 551 | 147 | 74 | 40 | 0 |

Table 30: average daily salinity exceeding the 120g L⁻¹ upper limit

| | Baseline | 2400 GL | 2750 GL | 2800 GL | 3200 GL |
|--------------------------|----------|---------|---------|---------|---------|
| # events longer than 5 d | 9 | 1 | 1 | 0 | 0 |
| Mean duration | 127 | 101 | 9 | 0 | 0 |
| Median duration | 73 | 101 | 9 | 0 | 0 |
| Maximum duration | 532 | 101 | 9 | 0 | 0 |

Table 31: average daily salinity exceeding the 130g L⁻¹ upper limit

| | Baseline | 2400 GL | 2750 GL | 2800 GL | 3200 GL |
|--------------------------|----------|---------|---------|---------|---------|
| # events longer than 5 d | 6 | 1 | 0 | 0 | 0 |
| Mean duration | 151 | 64 | 0 | 0 | 0 |
| Median duration | 149 | 64 | 0 | 0 | 0 |
| Maximum duration | 323 | 64 | 0 | 0 | 0 |

APPENDIX 5: MDBA modelling scenarios

Without Development

‘Without development’ represents flow and system conditions that are as near to natural conditions as possible. It is generated by removing all infrastructure (including locks and weirs, dams, storages, barrages, and irrigation and environmental works) as well as all diversions for consumptive purposes (including irrigation, direct stock and domestic, town water supply, and industrial) from the system. However, the input flow data has not been corrected for land use changes and on-farm development. This data is largely generated from rainfall-runoff models and with limited or no availability of data on which to model these conditions, the effects are largely included implicitly in the measured data used to calibrate the models.

Baseline Conditions

A standard approach for the objective evaluation of different water management scenarios is to use hydrological modelling (Heneker and Higham, 2012). This approach requires the generation of a set of ‘Baseline’ conditions that represents the current state of the system, which then provides the basis against which changes to that system can be assessed. In terms of the Draft Basin Plan, comparisons between possible water recovery scenarios and Baseline conditions can show potential outcomes and benefits as a result of changes to the level of diversions (Heneker and Higham, 2012).

The Baseline conditions generally apply the current parameters of a system such as infrastructure (e.g. dams, locks, barrages), operating rules, water sharing rules under the Murray-Darling Basin Agreement, and diversions across the full modelled period. A number of key assumptions are as follows (MDBA, 2011b):

- In terms of diversions, the Baseline conditions for the Draft Basin Plan reflect water usage at June 2009 water sharing arrangements: that is, the Murray Darling Basin Ministerial Cap level of development for all States unless current water sharing arrangements have a usage level lower than the Cap level, for example, the New South Wales Water Sharing Plans.
- Water recovery under *The Living Murray* (TLM) and Water for Rivers for the Snowy River is included; however, Water Recovery under other programs such as the Commonwealth Government programs of Sustainable Rural Water Use and Infrastructure and Restoring the Balance in the Murray-Darling Basin, New South Wales Government River Environmental Restoration program and Northern Victorian Irrigation Renewal Program are not included.

Given the nature of baseline conditions and the water recovery assumptions above, there are a number of important points when considering the results:

- Model outputs will not necessarily be an exact replica of what was actually observed at a given time. Most of the current infrastructure and operating rules have only been in place since 1975, from which point the majority of observed data is available. In general, modelled data will more closely represent more recent observations.
- The inclusion of water recovery under TLM means that conditions observed in the Lower Lakes under baseline conditions will not be as severe as what actually

occurred. This is particularly so for the recent drought and water levels are not likely to be as low, nor salinities as high, as those observed due to the assumed delivery of additional TLM environmental flows.

- The difference between the model scenarios is as important as the absolute values. This is because it is expected that any model errors will cancel each other out and provide a good estimates of expected changes.

Critically, the nature of 'baseline' conditions means that model outputs produced for the assessment of the Draft Basin Plan will not necessarily be an exact replica of what was actually observed at a given time due to a combination of factors including changing infrastructure, operating rules or changed flow conditions such as the provision of additional water through programs such as TLM (Heneker and Higham, 2012). Nonetheless, 'baseline' provides an opportunity to assess the relative benefits and indicative consequences of any changes should they be adopted.

Water Recovery Scenarios

The MDBA has modelled a number of 'Basin Plan Scenarios' intended to represent the changes in the flow regimes that can be achieved through the recovery and use of water for the environment under the Basin Plan (MDBA, 2012a). The four key water recovery scenarios modelled and provided to South Australia by the MDBA were:

- BL-2750 - 2750 GL/y reduction in consumptive use basin wide
- BP-2800 - 2800 GL/y reduction in consumptive use basin wide
- BP-2400 - Alternative scenario of 2400 GL/y reduction in consumptive use basin wide
- BP-3200 - Alternative scenario of 3200 GL/y reduction in consumptive use basin wide.

The figure of 2750 GL that was finally included in the Draft Basin Plan represented a reduction of 50 GL in the water to be recovered from parts of the Northern Basin, upstream of Menindee Lakes.

2800 GL Water Recovery

Prior to the release of the Draft Basin Plan in November 2011, the MDBA proposed and modelled a water recovery target of 2800 GL. In this scenario, 450 GL/y was recovered from the northern connected Basin, 2288 GL/y was recovered from the southern connected Basin, and 69 GL/y from the disconnected rivers (MDBA 2012a). The SDL for each valley is proposed to consist of reduction required for in-valley environmental water requirements and sourcing of a proportion of shared reduction required from Northern (catchment upstream of Menindee lakes) and Southern basins required to meet the Barwon-Darling and River Murray environmental requirements. The contribution from each valley towards the shared reduction is based on a pro-rata recovery for each Entitlement Type (high security, low security and supplementary) but is only a scenario used for modelling. The actual contribution by individual valleys to the shared reduction will be dependent on the outcomes of water recovery programs.

2750 GL Water Recovery

The MDBA decision-making process led to a Draft Basin Plan containing a 2750 GL reduction as opposed to the previously suggested 2800 GL reduction. The change between scenarios was to one northern valley (Condamine-Balonne) expected to have “little impact on the environmental flow indicators downstream of its confluence with the Barwon-Darling” (MDBA 2012a). This is the main scenario for assessment.

2400 GL and 3200 GL Water Recovery

As a means of gauging the capacity to meet environmental outcomes with varying level of water availability for environmental use and informing the determination of the Environmentally Sustainable Level of Take (ESLT), two additional scenarios of +/- 400 GL/y (or a basin-wide scale of change of 2400 GL/y and 3200 GL/y) were also modelled by the MDBA (MDBA, 2012a) and are assessed in this report.

These two additional scenarios maintained the same SDLs in the northern connected basin and adjusted SDLs in the Southern Connected System, in recognition that the majority of the potential reduction in diversions will be in the Southern Basin, and it is most important to understand the sensitivities in these valleys, particularly in the Murray where environmental water needs are the largest in the basin (MDBA, 2012a). Accordingly, in the BP-2400 scenario, 1890 GL/y is recovered from the southern connected basin, whilst in BP-3200 scenario, 2691 GL/y is recovered from the southern connected basin.