Australian Government

Commonwealth Environmental Water

ENVIRONMENTAL WATER DELIVERY

River Murray—Coorong, Lower Lakes and main channel below Lock 1

MAY 2012 V1.1

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Mouth of the Murray River, Coorong National Park
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Pelicans at Long Point, Coorong National Park
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ENVIRONMENTAL WATER DELIVERY

River Murray—Coorong, Lower Lakes and main channel below Lock 1

JANUARY 2012 V1.0

Environmental water delivery: River Murray – Coorong, Lower Lakes and main channel below Lock 1

Increased volumes of environmental water are now becoming available and this will allow us to pursue a larger and broader program of environmental watering. It is particularly important that managers of environmental water seek regular input and suggestions from the community as to how we can achieve the best possible approach. As part of the consultation process for Commonwealth environmental water we are seeking information on:

- community views on environmental assets and the health of these assets
- views on the prioritisation of environmental water use
- potential partnership arrangements for the management of environmental water
- possible arrangements for the monitoring, evaluation and reporting (MER) of environmental water use.

This has been prepared to provide information on the environmental assets and potential environmental water use in the River Murray system below Lock 1. As the first version of the document, it is intended to provide a starting point for discussions on environmental water use. As such, suggestions and feedback on the document are encouraged and will be used to inform planning for environmental water use and future iterations of the document.

The River Murray system below Lock 1 supports significant ecological values as well as internationally recognised wetland systems. Potential water use options for the system include providing flows to establish a variable lake level regime for Lakes Alexandrina and Albert to support riparian and floodplain vegetation; providing flows to improve connectivity between the Lower Lakes and the Coorong for the migration of fish species; and providing barrage flows to maintain water quality in the Lower Lakes suitable for salt-sensitive flora and fauna species.

A key aim in undertaking this work was to prepare scalable water use strategies that maximise the efficiency of water use and anticipate different climatic circumstances. Operational opportunities and constraints have been identified and delivery options prepared. This has been done in a manner that will assist the community and environmental water managers in considering the issues and developing multi-year water use plans.

The work has been undertaken by consultants on behalf of the Australian Government Department of Sustainability, Environment, Water, Population and Communities. Previously prepared work has been drawn upon and discussions have occurred with organisations such as the South Australian Department of Environment and Natural Resources, South Australian Department for Water, SA Water and the Murray-Darling Basin Authority.

Management of environmental water will be an adaptive process. There will always be areas of potential improvement. Comments and suggestions including on possible partnership arrangements are very welcome and can be provided directly to: ewater@environment.gov.au. Further information about Commonwealth environmental water can be found at www.environment.gov.au/ewater.

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Contents

Figures

Tables

List of acronyms

ADF	Additional Dilution Flows
AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment Conservation Council
ARI	Annual Return Interval
ASS	Acid Sulfate Soils
AWD	Available Water Determination
BDBSA	Biological Data Base of South Australia
CAMBA	China–Australia Migratory Bird Agreement
CEWH	Commonwealth Environmental Water Holder
CLLMM	Coorong, Lower Lakes and Murray Mouth
CMA	Catchment Management Authority
COAG	Council of Australian Governments
DFW	South Australian Department for Water
DENR	South Australian Department of Environment and Natural Resources
EC	Electrical conductivity units
EMLR	Eastern Mt Lofty Ranges
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)
FSL	Full Supply Level
g/L	Grams per litre
GL/year	Gigalitres per year
IUCN	International Union for Conservation of Nature
JAMBA	Japan–Australia Migratory Bird Agreement
mAHD	metres Australian height datum
MDB	Murray-Darling Basin
MDBA	Murray-Darling Basin Authority
ML/day	Megalitres per day
$\mu S\ cm^{-1}$	microSiemens per centimetre
MM	Murray Mouth
Murray CMA	Murray Catchment Management Authority
RoKAMBA	Republic of Korea-Australia Migratory Bird Agreement
SA MDB NRM Board	South Australian Murray-Darling Basin Natural Resources Management Board
SARDI	South Australian Research and Development Institute
SEWPaC	Australian Government Department of Sustainability, Environment, Water, Population and Communities
TLM	The Living Murray program
USED	Upper Southeast Drainage scheme
WAP	Water Allocation Plan

PART 1:
Management Aims

1. Overview

1.1 Scope and purpose of this document

Information provided in this document is intended to help establish an operational planning framework that provides scalable strategies for environmental water use based on the demand profiles for selected assets. This document outlines the processes and mechanisms that will enable water use strategies to be implemented in the context of river operations and delivery arrangements, water trading and governance, constraints and opportunities. It specifically targets large-scale water use options for the application of large volumes of environmental water.

To maximise the system's benefit, three scales of watering objectives have been expressed:

1. Water management area (individual wetland features/sites within an asset).
2. Asset objectives (related to different water resource scenarios).
3. Broader river system objectives across and between assets.

Information provided focuses on the environmental watering objectives and water use strategy for the River Murray including the Coorong, Lower Lakes and main channel below Lock 1.

As part of this project, assets and potential watering options have been identified for regions across the Murray-Darling basin. This work has been undertaken in three steps:

1. Existing information for selected environmental assets has been collated to establish asset profiles, which include information on hydrological requirements and management arrangements necessary to deliver water to meet ecological objectives for individual assets.
2. Water use options have been developed for each asset to meet watering objectives under a range of volume scenarios. Use of environmental water will aim to maximise environmental outcomes at multiple assets, where possible. Water use options will provide an `event ready' basis for the use of environmental water. Options are expected to be integrated into a five-year water delivery program.

3. Processes and mechanisms required to operationalise environmental water delivery have been documented and include:
    - delivery arrangements and operating procedures
    - water delivery accounting methods (in consultation with operating authorities) that are either currently in operation at each asset or methodologies that could be applied for accurate accounting of inflow, return flows and water ‘consumption’
    - decision triggers for selecting any combination of water use options
    - approvals and legal mechanisms for delivery and indicative costs for implementation.

1.2 Catchment and river system overview

The Murray-Darling Basin has an area of 1,042,730 square kilometres and includes parts of Queensland, New South Wales, Victoria, South Australia and the Australian Capital Territory (Figure 1-1). The headwaters of the Murray and Darling rivers and most of their tributaries rise in the Great Dividing Range. Most of the run-off comes from these higher rainfall areas of the Basin with very little entering the River Murray from run-off within the Murray region.

The natural environment of the Basin includes vast floodplains at the heart of a system of over 30,000 wetlands. These wetlands and floodplains support biodiversity of national and international significance. The Basin has one World Heritage site (the Willandra Lakes Region), 16 wetlands listed under the Convention on Wetlands of International Importance (the Ramsar Convention), and in excess of 200 wetlands listed in the Directory of Important Wetlands of Australia (CSIRO 2008). The Coorong and Lower Lakes area which forms part of this water delivery document is one of the Ramsar Convention wetlands within the Basin.

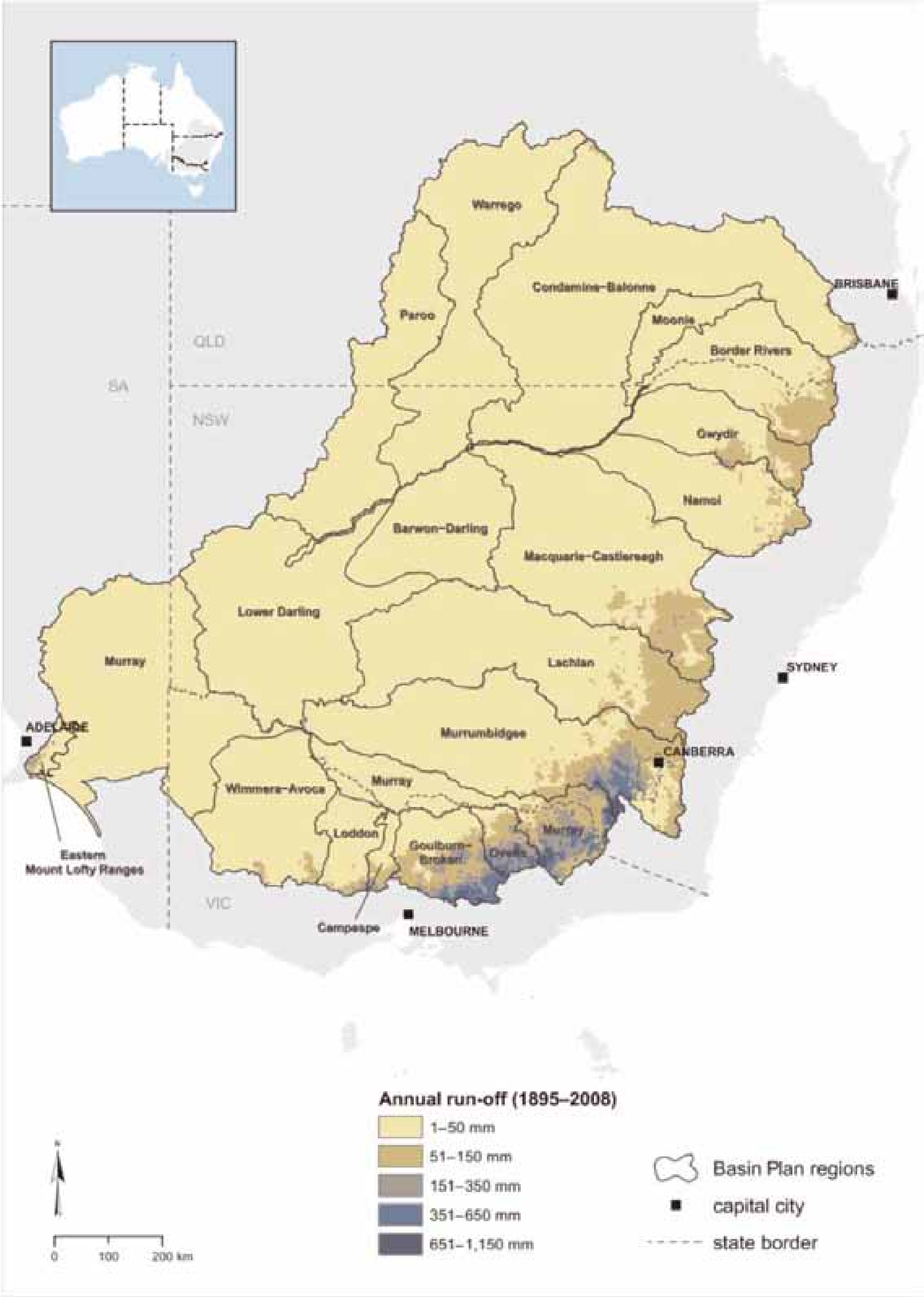


Figure 1-1: Overview map of the Murray-Darling Basin including annual run-off.

Source: Mean annual run-off modelled using the method in the CSIRO Murray-Darling Basin Sustainable Yields Project (Chiew et al. 2008; CSIRO 2008), cited in Figure 2.3 MDBA (2010c)

The last major tributary of the River Murray is the Darling River which joins the River Murray just upstream of the Wentworth Weir (and Lock 10). Lock 10 is located just over 832 river kilometres from the Murray Mouth. The Murray enters the Southern Ocean at the Murray Mouth near Goolwa, having first flowed through Lake Alexandrina.

Below Wentworth, the river has a very low gradient (e.g. 89 per cent of the length of the river downstream of Wentworth has a channel slope of less than 0.017 centimetres per kilometre) with relatively little sinuosity, low stream power, and highly cohesive bank materials. Flow velocities are correspondingly slow and the travel time for water flowing from the South Australian border to the Lower Lakes is approximately one month. However, the actual travel time varies significantly between flow events and can be much shorter than this. At higher flow rates travel time is usually reduced but this is highly variable and dependent on such factors as the rate of rise of a flood peak and the rate of flow. For example, in the 2010–11 floods the time for flow between locks was in the order of three days (D Jones 2011, pers. comm., 13 April). Travel time from Lock 1 to Wellington (200 river kilometres) at flows less than 50,000 ML/day would typically take around three days (D Jones 2010, pers. comm., 5 December).

There are three distinct sections of river downstream of the Darling River confluence. Thoms et al. (2000) describe the river from Wentworth to Overland Corner as being situated in a 5 to 10 kilometre-wide valley, with the channel flanked by a broad floodplain. From Overland Corner to Mannum the river channel is confined to a limestone gorge 2 to 3 kilometres wide and 30 to 40 metres deep. Flows in the lower sections of the River Murray are therefore slow moving and the lateral extent of flooding is constrained by the limestone gorge. From Mannum the river passes through swamplands before reaching Lake Alexandrina.

Flows in the lower sections of the River Murray are heavily regulated. Upstream of the South Australian border, flows are managed through the large water storages (mainly Hume Dam, Dartmouth Dam, Menindee Lakes and Lake Victoria). The river is further regulated by weirs with associated locks, which allow boat passage past the weirs. Weirs are used to maintain stable water levels along the lower sections of the River Murray. The last of these weirs and associated locks is Lock 1 which is located at Blanchetown in South Australia. Lock 1 represents the upstream boundary of the area of interest for this water delivery document, which focuses on the area downstream of Lock 1.

There are two other key features in this area: Lake Albert and the Coorong. Lake Albert is a terminal lake connected to Lake Alexandrina by a narrow channel. Lake Albert and Lake Alexandrina are often referred to as the Lower Lakes. The Coorong is a 140 kilometre long lagoon system that receives inflows from Lake Alexandrina, the Southern Ocean and the upper south-east area of South Australia. The Coorong and Lower Lakes were designated as wetlands of international importance under the Ramsar Convention in 1985. The Coorong, Murray Mouth and Lower Lakes are proposed as a hydrological indicator site in the Murray-Darling Basin having met all five of the Murray-Darling Basin Authority (MDBA) key proposed environmental asset criteria (MDBA 2010). They are also an icon site under The Living Murray initiative.

There are five barrages that separate Lake Alexandrina from the Coorong and the Murray Estuary—Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere. With the exception of Goolwa, the barrages are built on a natural sill of calcium sediments (the remnants of the last interglacial shoreline), which separates Lakes Alexandrina and Albert from the Murray Estuary and the Coorong (Gell & Hayes 2005). Historically, this sill, in conjunction with flow down the River Murray, is hypothesised to have impeded the ingress of seawater into the Lower Lakes in addition to the Murray Mouth itself acting as a constriction reducing the effect of local tides. Built by the Engineering and Water Supply Department of South Australia for the River Murray Commission between 1930 and 1940, the barrages are constructed from reinforced concrete and have 593 independent operable gates (Phillips & Muller 2006).

Figure 1-2: Regional context for Coorong, Lower Lakes and lower River Murray.

(Source: SEWPaC 2011)

SA Water operates the barrages for, and on behalf of, the governments of South Australia, New South Wales, Queensland, Victoria and Australia, subject to funding and direction from the Murray-Darling Basin Authority (MDBA). Water released from Lake Alexandrina through the barrages exports salt, sediment, nutrients and organic matter to the Coorong and Southern Ocean and facilitates the movement of fish species between the Basin and the ocean.

The barrages maintain a weir pool from Lock 1 at Blanchetown to the Lower Lakes, a distance of about 270 kilometres. This weir pool supports the four major public water supply pumping stations that are located downstream of Lock 1. These supply the Swan Reach to Stockwell, Mannum to Adelaide, Murray Bridge to Onkaparinga, and Tailem Bend to Keith pipelines which provide water to Adelaide, parts of the mid-north and Yorke Peninsula, and the south-east of South Australia. The weir pool also provides water that is directly extracted for town supply and agriculture around the Lower Lakes and River Murray up to Lock 1.

1.3 River operating environment

1.3.1 Overview

Inflows to this section of river are primarily governed by River Murray flows past Lock 1 and these in turn are governed by the flow to South Australia.

There are opportunities to manipulate flows to South Australia by the management of Lake Victoria (and storages further upstream), but once below Lake Victoria the only opportunities to manipulate flows are though weir pool manipulations. While these can be effective in managing water levels and spatial spread of water for flows below 50,000 ML/day (the maximum river discharge at which weirs 3 and 5 can be elevated—with lower volumes for the rest of weirs (Cooling 2010)), their impact on actual flows are very limited (due to the relatively small storage volume behind each lock and weir).

For much of the time the water level in the River Murray below Lock 1 is controlled by the water level in Lake Alexandrina and levels are relatively stable. The river level does vary through flooding and drying events, and with wind direction and strength or seiching, exposing and inundating the river margin and connected wetlands, on a seasonal and short-term irregular basis.

Historically, the key water levels in the Lower Lakes, measured by metres with respect to the Australian height datum (mAHD), have been:

- +0.60 mAHD: preferred minimum level
- +0.75 mAHD: target full supply level (FSL)
- +0.85 mAHD: surcharge level (water begins to spill over the spillways associated with the barrages as surcharge level is achieved)
- +0.87 mAHD: inundation of surrounding land commences.

Past management of lake levels primarily focused on meeting the requirements of water extractors, and subsequently compromised the environmental values of the Lower Lakes. The need to adopt operational arrangements that better meet the ecological need of the area has been recognised. Strategies have been proposed that would permit more variable inter and intra-annual lake levels (MDBC 2006).

Under typical conditions (i.e. those prior to winter 2006, after which time the combined drought and river regulation impacted upon water levels), Lakes Alexandrina and Albert fill during winter/spring from a low of approximately +0.60 mAHD, typically attained in April/May, to a high of +0.75 mAHD (FSL). If inflows are adequate, the lakes are surcharged to +0.85 mAHD by the end of spring, primarily for water supply purposes to prevent lake levels falling below +0.60 mAHD in the following autumn as water is lost through evaporation. Some incidental watering of fringing wetlands may have occurred through this process. This process (in combination with grazing practices) also contributed to accelerated lake shore erosion causing detriment to some wetland areas and loss of farming land.

Water in the Lower Lakes has been maintained above +0.60 mAHD to:

- Minimise the ingress of seawater into the lakes via the barrages.
- Reduce the potential for saline groundwater discharge into the lakes.
- Facilitate irrigation diversions (but this is no longer critical since the construction of pipelines around both sides of the Lower Lakes in response to the recent drought).

Saline groundwater intrusion and acid sulphate soils can present management issues at thresholds below +0.6 mAHD. These are further detailed in Section 1.3.3.

Wind effects can result in localised water levels ± 0.30 metres different from the average for the Lower Lakes as a whole (Webster et al. 1997).

The flow through the barrages separating the Coorong from Lake Alexandrina can be controlled individually by raising or lowering gates, but for low flow periods, particularly over summer when evaporation rates are high there can be extended periods of zero flow and occasionally seawater can leak through the barrages or splash over them creating localised areas of salty water over short periods of time. Releases of water depend very much on flow conditions in the River Murray and in recent years these flows have been reduced due to drought conditions. Most releases occur through the three main barrages namely Goolwa, Ewe Island and Tauwitchere (Webster 2007).

In recent years additional discharge to the Coorong has occurred through Salt Creek, near the southern end of the South Lagoon. This water is surface drainage water from the upper south-east drainage scheme (USED) that has been collected via a network of channels into Morella Basin where it is stored. The inflow volumes from this source have been minor in comparison to the volume of the Coorong and the volumes of historic flows through the barrages.

Within the body of the North Lagoon, at weather timescales (10 days or less), water level variations are driven in equal measure by wind, which tilts the water level one way or another depending on wind direction, and by sea level variations (Webster 2007). Tidal water level variations at the diurnal and semi-diurnal frequencies are thought to dominate within approximately 15 kilometres from the mouth, but the importance of these depends very much on the degree to which the mouth channel is open (Webster 2007). The depth of the Murray Mouth channel is clearly related to outflow rates through the mouth (Webster 2007). When the mouth is constricted, fluctuations in sea level penetrates less effectively into the Coorong and the exchange flows associated with these fluctuations are reduced. As a consequence, mixing of salt back towards the mouth is less effective and salinity tends to increase in both lagoons.

There are several channel sections on either side of Parnka Point that are very narrow (approximately 100 metres) and shallow, which represent the main restriction for water exchange between the two lagoons. This limits the movement of water between the North and South Lagoons resulting in a markedly higher salinity in the South Lagoon.

A more detailed description of the operating environment for each key system component follows.

1.3.2 River Murray: Lock 1 to Wellington

The section of river below Lock 1 extends 200 river kilometres south before it flows into Lake Alexandrina which is five kilometres south of the township of Wellington. Lock 1 and the associated weir were completed in 1922. This infrastructure maintains the water level upstream of the weir at 3.20 mAHD. A fishway was constructed in 2009 at Lock 1 to facilitate fish passage past the weir.

Between Lock 1 and Mannum the River Murray is confined to a limestone gorge two to three kilometres wide and thirty to forty metres deep (Thoms et al. 2000) and the floodplain is relatively limited in extent (Ecological Associates 2010a). From Mannum the river passes through swamplands before reaching Lake Alexandrina. This section of the River Murray receives minor inflows from Reedy Creek (near Mannum) and Marne River (south of Swan Reach).

Lock 1 and its associated weir are operated to maintain a target pool level for irrigation and navigation. A constant level is maintained at a variety of flows by varying the passing flow. As flows increase during a flood, opening the weir or removing stop logs increases the passing flow. The weir is closed or stop logs are replaced as flows decrease. Under flood flow Weir 1 is generally removed between flows of 49,000 and 59,000 ML/day to allow flood flows to pass downstream. The weir is usually reinstated at flows representing the recession of the flood peak (from 74,000 to 84,000 ML/day) (Cooling 2010).

As flow over Lock 1 increases, the river surface slopes as it flows downstream from the weir towards the barrages. This slope increases as flow increases. Back waters and fringing wetlands are supplied with water as the water level below the lock increases. While most of these wetlands are connected directly to the river (at normal pool level) some have regulator structures on them and can be manipulated to create wetting and drying cycles as well as to hold water post flood recession.

There are a few temporary wetlands inundated once flows exceed 30,000 ML/day but the volumes of water needed to fill these is small and hence these are not the primary focus for this water delivery document. The management of these smaller systems are either done by the South Australia Murray-Darling Basin Natural Resources Management Board or by community groups under guidance from the BoardFloodplain inundation between Lock 1 and Wellington commences at flows above 55,000 ML/day and significant inundation occurs at 75,000 ML/day (Ecological Associates 2010).

For much of the time, in the absence of high river flows (e.g. less than 30,000 ML/day), water level in the lower sections of the river is controlled by the water level in Lake Alexandrina and levels are relatively stable (Lake Alexandrina has been typically maintained at a level of +0.6 to +0.85 mAHD). River level does vary through flooding and drying events, and with wind direction and strength, or seiching, it exposes and inundates the river margin and connected wetlands on a seasonal and short-term irregular basis.

During high flows water levels downstream of the Lock 1 weir increase with flow, but the effect diminishes with distance.

After barrage construction, and as a consequence of floodplain development for irrigation, much of this river section developed an ecological character very different from its historical condition. The maintenance of relatively stable water levels has reduced habitat heterogeneity (Phillips & Muller 2006). In the past it has been important to maintain stable water levels in the Lower Lakes for water supply and ferry operation purposes. These requirements are now largely met over a wider range of water levels than in the past as a result of infrastructure that was installed in response to the recent drought.

The main channel and connected wetlands are thus highly regulated by the barrages, and through stream regulation, upstream of Lock 1.

1.3.3 The Lower Lakes

The Lower Lakes are large, freshwater lakes, physically separated from the Murray Mouth and estuary and the Coorong by a series of islands and the system of five barrages. The barrages were designed to exclude seawater from the Lower Lakes and to regulate lake water levels in spite of upstream development (Sim & Muller 2004).

Construction of the barrages caused a barrier to fish migration. Fish movement from the lakes to the Coorong remained possible but was restricted to periods when the barrage gates were open. Movement in the reverse direction was restricted due to the high flow velocities and physical structure of the gates. Such movement is particularly important for diadromous and migratory species that require access to both marine and freshwater habitats to complete their life cycles, and to freshwater vagrants that may be washed downstream and need to return to freshwater habitats (Jennings et al. 2008). Since 2002, five fishways have been constructed to facilitate fish passage. A rock ramp fishway and two vertical slot fishways are located at the Tauwitchere Barrage and vertical slot fishways are located at the Goolwa Barrage and Hunters Creek. The MDBA Fish Passage Taskforce has also recommended fishways at Mundoo and Boundary Creek barrages. Recent 2010–11 monitoring indicates that fishways have effectively enabled passage of a large abundance and diversity of fish, including size ranges (A Frears (DFW) 2011, pers. comm.).

Water levels in the Lower Lakes fluctuate seasonally—they are generally higher in late spring and lower in late summer/autumn because of seasonal variability in the River Murray and smaller local tributary inflows, as well as climatic factors such as evaporation (Phillips & Muller 2006).

Under current conditions, long-term average annual outflows through the Murray Mouth have been estimated to be around 5,100 GL/year, but more recently the three-year rolling average for 2006–07 to 2008–09 was 100 gigalitres (MDBA 2010).

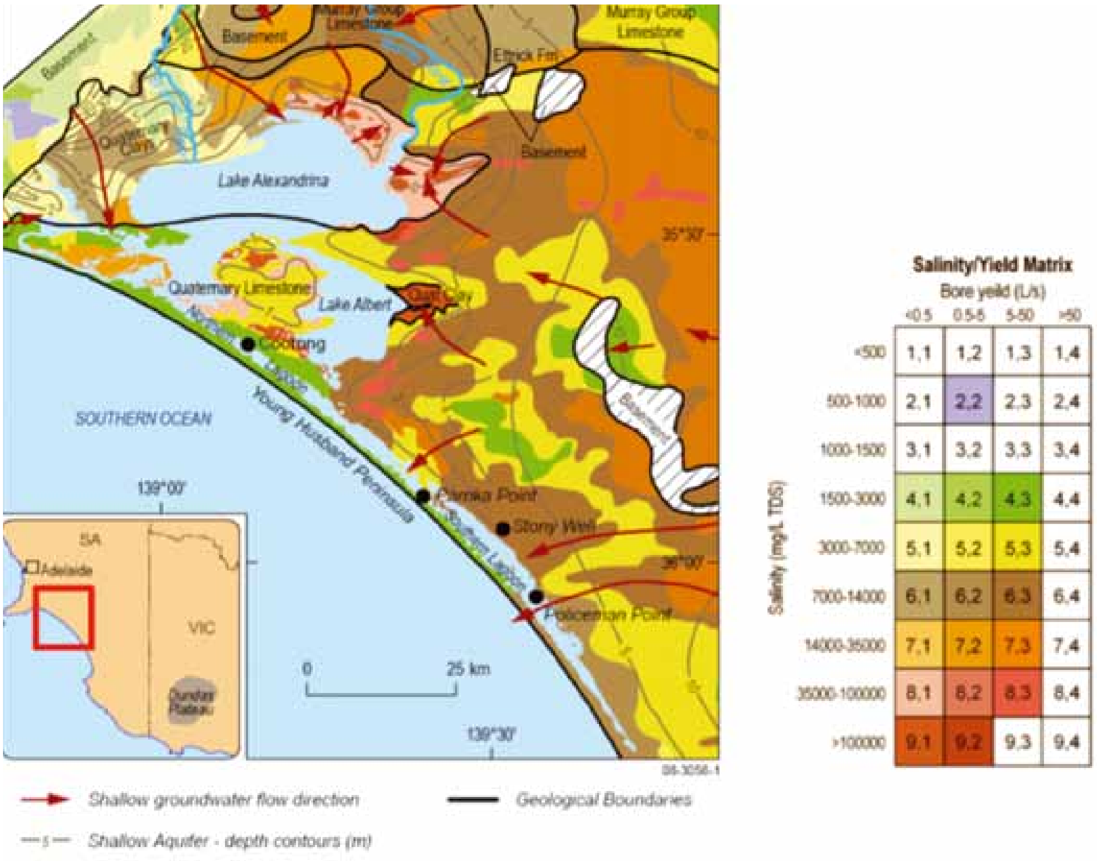
There are a number of small tributaries from the Eastern Mount Lofty Ranges (the main ones being the Finniss River, Currency Creek and the Angas and Bremer Rivers) that contribute inflows to Lake Alexandrina of 35 to 110 GL/year, with a median inflow of 50 to 60 GL/year (DEH 2010). While these are minor in volume they are considered ecologically important because they support species listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC), and species of conservation significance to South Australia.

Until recently town and irrigation supplies were taken directly from the Lower Lakes. Extreme low water levels (less than 0.0 mAHD) between 2007 and 2010 resulted in water supply pipelines being constructed along both sides of Lakes Alexandrina and Albert. This has removed the need for most irrigators to rely directly on water extraction from the lakes. Water for these irrigators and for town supply is now extracted from upstream of the lakes on the River Murray near Tailem Bend. When lake levels are high enough and water quality appropriate it is cheaper for irrigators to extract water directly from the lakes, and some still prefer to do so.

Both Lake Alexandrina and Lake Albert, and many of the wetlands along the River Murray floodplain between Lock 1 and Wellington, have potentially high levels of acid sulfate soils (ASS) (Fitzpatrick et al. 2008a, 2008b, 2009). Water levels in the Lower Lakes below 0.0 mAHD will expose ASS, creating the potential for pH to decline below Australian and New Zealand Environment Conservation Council guideline levels (ANZECC 2000). This has implications for the maintenance of the ecological character of the water body and individual wetlands. If low water levels allowed sufficient acidification of ASS in the lakes for the alkalinity buffer in the remaining lake water to be lost, and the pH shifted below 6.5, then a suite of flora and fauna could be put at risk.

Saline groundwater underlies the Lower Lakes and can impact on water quality, however groundwater inflow volumes are believed to be negligible compared with river inflows (Lester, Fairweather & Higham 2011a). The most significant risk to salinity levels in the Lower Lakes is low inflows from upstream (resulting in a lack of dilution flows and low water levels leading to evapo-concentration), rather than groundwater inflow.

Shallow saline aquifers impact on the northern and eastern sides of Lake Alexandrina and on Lake Albert (Figure 1-3). On the western side of Lake Alexandrina, the watertable is within Quaternary clay which overlies and semi-confines the limestone aquifer (Haese et al. 2009). Elsewhere in low-lying areas around the Lower Lakes, the watertable occurs in organic-rich clays, which were deposited when the Lower Lakes expanded in response to a higher sea level about 6,000 years ago (Haese et al. 2009). These low-lying areas contain highly saline groundwater (where salinity is greater than 100,000 milligrams per litre) due to strong evaporative discharge, which has lowered the watertable below sea level (Haese et al. 2009). The watertable contours show that these areas are the focus for regional groundwater discharge in preference to the Lower Lakes when the lakes are at a higher level of +0.75 mAHD. The risk of salinisation is most prevalent where depth to the watertable is less than 2 metres. Mean monthly salt inflows from groundwater into Lake Alexandria vary between 300 and 800 tonnes per day (Heneker 2010).



	<0.5	0.5-5	5-50	>50
<500	1,1	1,2	1,3	1,4
500-1000	2,1	2,2	2,3	2,4
1000-1500	3,1	3,2	3,3	3,4
1500-3000	4,1	4,2	4,3	4,4
3000-7000	5,1	5,2	5,3	5,4
7000-14000	6,1	6,2	6,3	6,4
14000-35000	7,1	7,2	7,3	7,4
35000-100000	8,1	8,2	8,3	8,4
>100000	9,1	9,2	9,3	9,4

Figure 1-3: Hydrogeological map of the Coorong Lagoon and Lower Lakes region.

(Source: Haese, Murray & Wallace 2009)

Lake Alexandrina is a broad and shallow (mean depth 2.86 metres, maximum depth 4.75 metres), well-mixed, freshwater, regulated waterbody, with a surface area of approximately 650 square kilometres and volume of approximately 1,620 gigalitres at +0.75 mAHD. It is a large open water body that supports little or no macrophyte vegetation beyond a depth of approximately 0.5 metres. It is likely that high turbidity, water movement, carp and excessive depth all contribute to an unfavourable environment for submerged, floating-leaved and emergent macrophytes.

Depth volume and area information for Lake Alexandrina and Lake Albert is provided in Appendix 5.

The level of Lake Alexandrina is highly regulated by the five barrages that separate the lake from the Coorong. Average water levels have historically been maintained at between +0.60 and +0.85 mAHD (Figure 1-4). The lake levels vary seasonally with flooding and drying events, and in the short-term with wind direction and strength, and seiching. Together, these processes expose and inundate the lake margin, on both a seasonal and a short-term irregular basis. Water levels at any one time may vary across the lake by as much as 0.6 metres as a consequence of wind strength and seiching. Lake Alexandrina is a freshwater system, with salinity usually varying between 400 and 1,500 electrical conductivity units (EC) (Phillips & Muller 2006; Heneker 2010). Salinity in Lake Alexandrina is primarily controlled by lake inflows from the River Murray and Eastern Mount Lofty Ranges' (EMLR) tributaries, and outflows through the barrages (Heneker 2010).

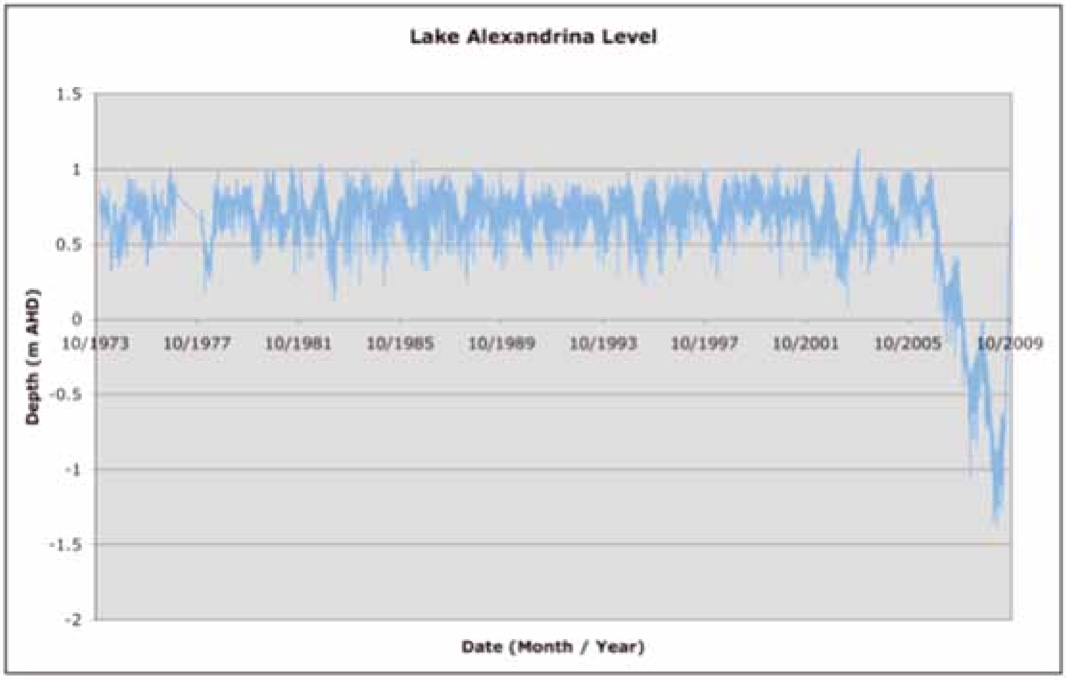


Figure 1-4: Lake level (mAHD) of Lake Alexandrina at the Goolwa Barrage (Site A4261005 Upstream Goolwa Barrage Daily) November 2002 to November 2009.

(Source: DWLBC)

Lake Albert is a terminal lake of the River Murray linked to Lake Alexandrina by a narrow channel (The Narrung Narrows) between Point Malcolm and Narrung Peninsula, via which it receives the majority of its inflows. The lake is broad and shallow, a maximum depth 1.7 metres and covers an area of 168 square kilometres. Like Lake Alexandrina, it is an open water body that supports little or no macrophyte vegetation beyond a depth of approximately 0.5 metres.

Water levels in Lake Albert are governed by the water levels in Lake Alexandrina and also by wind and evaporation. During the recent extended period of low flow into the two lakes (spring 2006 to spring 2010), the lakes were separated by a temporary bund (2008 to 2010), to allow control of water levels in Lake Albert. This bund was removed in 2011.

The lake supports complex and extensive fringing vegetation and an array of sand and mud islands, providing important habitat to a variety of bird species (Seaman 2003). In the recent drought, and as a consequence of the record low flow into the lake and the historic low lake levels, much of this fringing habitat was disconnected from the lake shoreline for an extended period, effectively removing habitat from the lake for many fauna species. The subsequent exposure of mud flats fringing the lake created extensive foraging habitat for migratory waders (Ecological Associates 2010b).

A shallow and saline aquifer (Figure 1-3) also discharges into the lake (Heneker 2010), particularly during periods of low water levels, creating seasonal and permanent saltwater marshes in depressions or swales around the lake's edge (Phillips & Muller 2006).

Lake Albert acts as a sink for salt and sediment for inflows from the River Murray and groundwater (Phillips & Muller 2006). As a terminal lake it has no through-flow mechanism and consequently is more saline than Lake Alexandrina (Heneker 2010). Salinities typically range between 1,000 to 2,300 EC (Heneker 2010), but can be higher. It is not practical to manage salinity levels within Lake Albert independently of Lake Alexandrina (Heneker 2010).

Extensive siltation from river inflows and lakeshore erosion is reducing water depth and topographical diversity (Aldridge et al. 2009). This has resulted in a retreat of lake perimeter at an average of 1 metre per year (Coulter, 1992), with deposition rates of around 3 millimetres per year (Herzeg et al. 2001). The nature of Lake Albert, as a terminal lake with its narrow connection with Lake Alexandrina, means that flow into and out of this lake is controlled by water level, wind and evaporation. Prior to European settlement, Lake Albert is believed to have been significantly fresher than today, supporting relatively extensive submerged aquatic plant beds and diverse emergent fringing vegetation communities (Sim & Muller 2004).

Before river regulation the Lower Lakes are believed to have been essentially an estuarine and freshwater system, with freshwater submerged aquatic plants extensive in Lake Alexandrina, spreading for several kilometres into the lake (Sim & Muller 2004). These habitat types are now restricted to the lake fringe and EMLR tributary deltas. Lake Alexandrina has developed an ecological character different from its pre-regulation condition.

After barrage construction, as a consequence of the maintenance of relatively stable water levels, the lake habitat heterogeneity has been reduced, with the extent of fringing and emergent vegetation significantly contracted when compared with historical values, and communities such as *Phragmites australis* and *Typha domingensis* have flourished while species dependent on variable water levels (E.g. *Eleocharis* spp and *Baumea* spp) have become restricted to fringing wetlands and tributaries (Phillips & Muller 2006).

1.3.4 Murray Estuary

The Murray Estuary (area approximately 3,400 hectares) includes the region around the Murray Mouth from the Goolwa barrage to Pelican Point and the Goolwa, Coorong and Mundoo channels which are separated from Lake Alexandrina by the Goolwa, Boundary Creek, Mundoo, Ewe Island and Tauwitchere Barrages.

The area is naturally estuarine. Salinity levels fluctuate widely when there is flow across the barrages. When flow ceases, a salinity gradient from seawater at the mouth to hypersaline conditions in the Northern Lagoon, develops (Lester et al. 2011b).

A diurnal tidal prism is evident as far as Pelican Point, but it is relatively small in extent, with the deepest mouth channel attenuating the largest tides (approximately 1 metre range for spring tides) by a factor of three by the Tauwicherie Barrages compared with that in the nearby sea (Webster 2007).

The Murray Mouth has always been relatively narrow, but it has been and continues to be extremely dynamic (Webster 2005). The width of the mouth has varied from being several hundred metres during flood flows (Walker 2002), to closed off completely in 1981 and almost closed in 2003. The degree of opening of the Murray Mouth is governed by a flood-tide delta (a delta landward of the mouth) that is present in the estuary and is formed as a result of the micro-tidal conditions and domination of wave energy along the coast (Harvey 1996). Modelling indicates that barrage outflows are the controlling agent for maintaining the mouth in an open condition (Webster 2007). River Murray flows over the barrages maintain an open mouth by exporting accumulated silt from the tidal sedimentation imbalance (more silt is imported from the incoming tide than is exported by the outgoing tide). The channel is subject to infilling and scouring on a seasonal basis. The frequency and duration of periods of zero or very low river flows since 2002 has meant that this imbalance has not been redressed naturally, and the mouth began to close. From October 2002 to December 2010 the mouth was kept open by dredging. Long-term effects of high flow events are not seen, as the majority of freshwater passes through the mouth, and seasonal siltation processes do not allow a deep mouth to persist through time.

Maintenance of an open Murray Mouth is important as many species depend on movement from the ocean into the estuary and freshwater Lower Lakes for reproduction and recruitment (MDBC & DWLBC 2002). An open mouth is also vital to the Coorong's ecosystem, as the tidal variation provides habitat for waders and maintains water levels and salinity for many other species.

Modelling (MSM-Bigmod) of River Murray natural series flows (for the period 1891 to 2000) over the barrages and out of the mouth, found that flows exceeding 2,000 ML/day would have occurred more than 95 per cent of the time (Sim & Muller 2004). This is no longer the case with much reduced flows over the barrages and extended periods of no flows leading to the constriction of the Murray Mouth.

1.3.5 The Coorong

The Coorong is a coastal lagoon complex separated from Encounter Bay and the Southern Ocean by two narrow coastal dune barriers, the Younghusband Peninsula to the southeast and the Sir Richard Peninsula to the northwest of the Murray Mouth.

The system is classified as an inverse estuary, which means that freshwater inflows enter from the same end as the mouth, rather than the more-usual configuration of having fresh inflows enter at the opposite end to the connection to the sea. The terminal set of lagoons that form the Coorong gradually grade up over its length becoming progressively shallower towards the southern end of the Southern Lagoon before forming a series of ephemeral lagoons. This creates a salinity gradient from usually estuarine conditions around the Murray Mouth through to hypersaline conditions in the South Lagoon.

The Coorong receives seawater inputs via tidal exchange through the Murray Mouth, which is the main mechanism by which seawater enters and leaves the Coorong, and it receives freshwater input from River Murray flows over the barrages into the Goolwa and Coorong Channels (Figure 1-5).

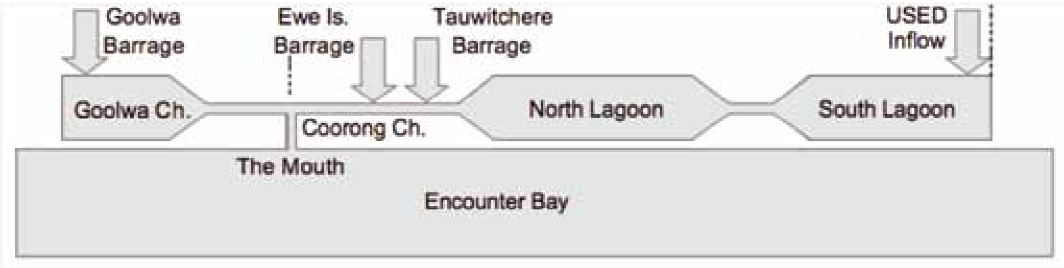


Figure 1-5: Summary of Coorong connectedness, including inflows.

(Source: Webster 2007)

Fresh water also enters the Coorong by distributed local run-off, groundwater inputs and small, irregular volumes of water from the Upper South East Drainage Scheme (USED Scheme) via Salt Creek located at the southern end of the Coorong system.

The conceptual model that underlies water movement and salt balance in this estuary type is illustrated in Figure 1-6 and Figure 1-7 (Webster 2006). Water is lost from along the length of the estuary through evaporation. To maintain the water level within the estuary, seawater flows in either from the estuary mouth or from flows over the barrages. The salt that is carried with the seawater tends to accumulate within the estuary. Back-and-forth water motions (oscillatory flows) within the estuary arise due to sea-level variations including the tides as well as water mounding due to varying winds blowing over the water surface. These motions serve to mix the salt accumulating within the estuary back towards its mouth (long-channel mixing). Over the long term the inflow of salt associated with evaporated water loss balances the transport of salt in the opposite direction due to oscillatory mixing. Super-imposed on this model of long-term salt transport within the Coorong are seasonal variations associated with the annual cycle of sea-level variation, relatively fresh water inflows from the River Murray over the barrages, and of evaporation (and precipitation) rate, but fundamentally this underlying salt balance pertains on an average basis (Lester et al. 2011b).

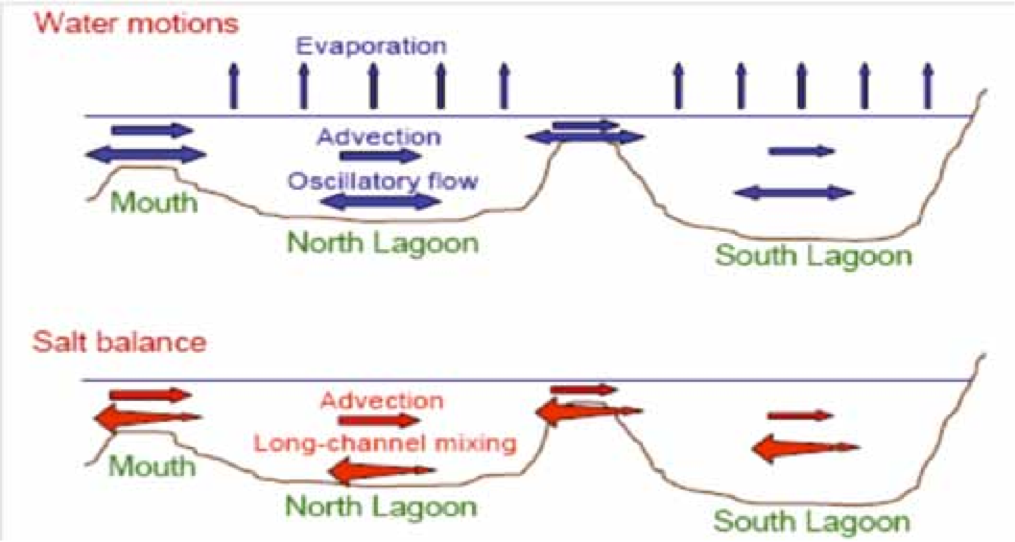


Figure 1-6 : Conceptual model of the Coorong.

(Source: Webster 2006)

Water levels in the Coorong undergo a seasonal cycle of up to approximately 0.7 metres in range, higher levels tending to occur in late winter to early spring and lower in late summer to early autumn (Webster 2005). This seasonal variation is due to a combination of variation in sea level outside the mouth, seasonal variations between the two lagoons and the back-up due to discharge through the barrages. Webster (2005) also found that shorter term water level variations of ±0.05 metres in the Coorong are typically due to the tilting of the water surface by the wind (Figure 1-7). Tidal level variation is important near the mouth.

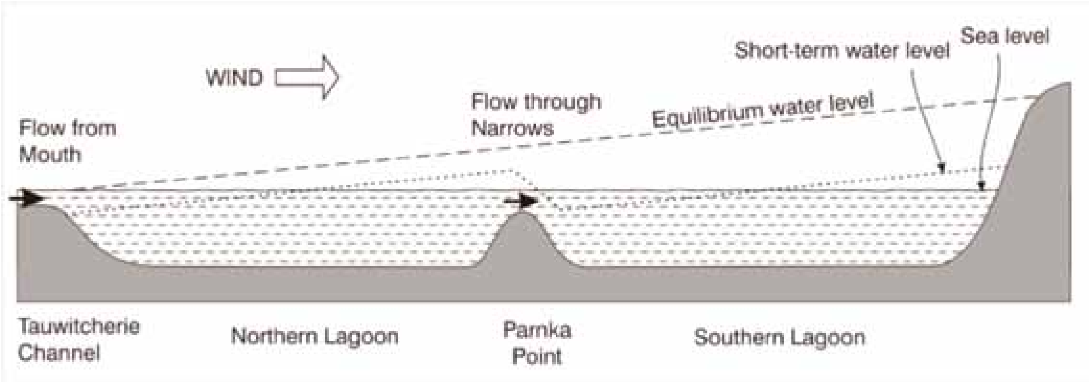


Figure 1-7: Water level response in the Coorong to an along channel (south easterly wind) wind stress.

(Source: Webster 2005)

The movement of water in and out of the South Lagoon associated with seasonal water level variation is a key determinant of the salinity there (Webster 2005).

Flows over the barrages maintain water levels within the Coorong at a higher level than the sea level in Encounter Bay (Webster 2005). This reduces seasonal disconnections between the lagoons and thus enhances long-channel mixing within the system, tending to result in higher water levels and lower salinities. In addition, the water that flows along the Coorong to replace evaporative loss has a lower salinity than seawater, so the overall input of salt into the system is lower, again reducing the salinity of Coorong waters.

Webster (2007) found that the barrage flows influence the salinity dynamics in the Coorong in at least three important ways. Periods of elevated barrage flows deepen the mouth channel which in turns allows more active mixing along the length of the Coorong. By freshening the water at the northern end of the North Lagoon (compared to seawater) the water that flows along the Coorong to replace evaporative losses has a lower salinity. When the barrages flow, the water level in the whole system tends to increase and water is pushed along the Coorong. Webster found that, generally, variations in discharge cause the water level in the Coorong to rise and fall causing back-and-forth water exchange along the system, which enhances longitudinal mixing.

For barrage flows less than 1,225 GL/year there is a high likelihood that the entire Coorong will fall into degraded ecosystem states, with more than 6,000 GL/year required to minimise the likelihood of more than 50 per cent of sites being in a degraded ecosystem state (Lester et al. 2011b).

Key characteristics for the north and south lagoons are further described in the sections that follow.

1.3.5.1 North Lagoon

Water quality in the North Lagoon has recently been characterised by similar conditions as presented in the Murray Estuary (Dittman et al. 2006), with barrage releases controlling salinity. Typically, the salinity gradient increases southwards along the North Lagoon, which extends from Pelican Point to Parnka Point. The Coorong naturally splits into North and South Lagoons at Parnka Point, where it reduces to a 100 metre wide section (Hells Gate). There are several channel sections on either side of Parnka Point that are very narrow (approximately 100 metres) and shallow, and that represent the main restriction for water exchange between the two lagoons (Webster 2007). The distance from the southerly end of the North Lagoon to the mouth is approximately 60 kilometres (Webster 2007). At 0 mAHD, the average width of the North Lagoon is 1.5 kilometres, the average depth is 1.2 metres, the volume of the North Lagoon is 86 gigalitres (Webster 2007) and its area is approximately 11,069 hectares (Phillips & Muller 2006).

Prior to barrage construction the North Lagoon was dominated by tidal input of marine water and River Murray inputs at its northern end (Gell & Haynes 2005), but since then the extent of estuarine habitat has been severely reduced, with a transition to higher turbidity and hypersaline conditions, and the loss of extensive beds of submerged vegetation, which was naturally dominated by *Ruppia megacarpa* (Phillips & Muller 2006).

Although the North Lagoon is a permanent water body, the area of inundation varies both diurnally and seasonally with the tides and inflows, resulting in the exposure of mudflats and intertidal marshes along the shoreline (Boon 2000). This area provides important habitat for a large number of waterbirds, including migratory shorebirds in spring and summer (Paton et al. 2009; Paton 2010).

1.3.5.2 South Lagoon

South of Parnka Point, the South Lagoon extends past Salt Creek where it ultimately becomes a series of hypersaline ephemeral lagoons to the south. The length of the South Lagoon is approximately 40 kilometres (Webster 2007). At 0 mAHD, the average width of South Lagoon is 2.5 kilometres and the average depth is 1.4 metres, the volume of the Lagoon is 140 gigalitres (Webster 2005) and it has an area of approximately 9,440 hectares (Phillips & Muller 2006).

Typically, water levels within the South Lagoon vary seasonally by approximately 0.9 metres (Lamontagne et al. 2004), being higher in winter and lower in summer, resulting in the seasonal exposure of mudflats which provide extensive areas of foraging and nesting habitat for large numbers of birds (Phillips & Muller 2006).

Salinity levels vary from estuarine to hypersaline. Salinity in the South Lagoon is controlled by the exchange of water with the North Lagoon, rainfall on the lagoon surface, evaporation, openness of the Murray Mouth, the depth of channels at Hells Gate, and inflows from Salt Creek (from the USED scheme).

During the summer months, the water level in the Coorong drops as sea level drops and barrage flows diminish (Webster 2005). Once the water level drops to 0 mAHD, the channel connecting the lagoons becomes shallow enough that it cannot support a flow sufficient to replenish the evaporation loss from the South Lagoon (Webster 2007). Consequently, the water level in the South Lagoon continues to drop below the level in the North Lagoon. Under these conditions, water level in the South Lagoon is determined by both the evaporation rate and by the height of the Parnka Point channel bottom (Webster 2007).

1.3.5.2.1 Upper south-east dryland salinity and flood management program (USED scheme)

The upper south east is a region situated immediately east of the Southern Lagoon of the Coorong. The region features a drainage network designed to prevent saline groundwater from rising to the land surface and affecting the health of agricultural and native vegetation. Surface water is also captured within the drains and diverted away from the region. Morella Basin, near Salt Creek, is the receiving basin for all flows from the USED scheme. Water held within Morella Basin is released into the Southern Lagoon of the Coorong via Salt Creek.

Release volumes from 2000 to 2009 ranged from a low of 33.6 ML/year (2002) to a high of 13,660 ML/year (2003) (a mean of 6,619 ML/year). Release volumes for 2010 by the end of October were 21,317 megalitres. The salinity of water released from Morella (2000 to 2005: 6,685 to 59,673 EC; September 2009 to October 2010: 10,708 to 30,291 EC), has been much lower than that of the Southern Lagoon of the Coorong (up to 380,000 EC) (MDBC 2006).

The decision to release water from Morella Basin is currently based on factors independent of flows down the River Murray, and at the discretion of the South Australian Department for Water (DWLBC 2009). Considerations for decision include:

- a release should be considered in October while there is still some flow occurring through the south eastern floodways; this allows the release of the freshest water before evapo-concentration occurs
- if there is an extreme rainfall event, a release may be considered earlier
- if a dry year has occurred, a release may be postponed until December or January or cancelled.

Releases from the USED scheme can potentially contribute to the mitigation of hypersaline conditions in the Coorong, associated with low River Murray flows. However, release volumes in the long term will depend on the development of further infrastructure and seasonal outcomes in the south east of South Australia.

A conceptual flow diversion system in the upper south east, to maximise inflows to the Coorong, indicates that estimated annual inflows could vary between 1.5 and 161 gigalitres, depending on channel capacities and diversion routes, with median annual volumes of between 30 and 40 gigalitres (AWE 2009). It is uncertain whether this volume of water alone would have a significant impact on the condition of the South Lagoon and hence this source of water should only be considered as being potentially complementary and not an alternative to increased River Murray flows over the barrages.

2. Ecological values, processes and objectives

2.1 Introduction

The Coorong and Lakes Alexandrina and Albert (the Lower Lakes) are recognised both nationally and internationally as significant in their role in supporting critical aquatic ecosystems within the Murray-Darling Basin, and for providing habitat for migratory avifauna listed under various international agreements. This recognition includes:

- their designation as a wetland of international importance under the Ramsar Convention in 1985
- the designation of the Coorong National Park
- the identification of the Coorong, Lower Lakes and Murray Mouth as one of six designated icon sites in the Murray-Darling basin under The Living Murray initiative
- the identification of the Coorong, Murray Mouth and Lower Lakes as a proposed hydrological indicator site in the Murray-Darling Basin—these sites also meet all five of the Murray-Darling Basin Authority's (MDBA) proposed key environmental asset criteria.

Listed under the Ramsar Convention as 'The Coorong and Lakes Alexandrina and Albert Wetland', this asset meets eight of the nine Ramsar criteria used to quantify wetlands of international importance (Phillips & Muller 2006). The justification against these criteria includes:

- it represents a unique wetland system, with 23 different wetland types
- it partially supports the critically endangered swamps of the Fleurieu Peninsula ecological community and provides habitat for nine nationally endangered fauna and six nationally endangered flora specieit supports populations of 20 fish species, five bird species, one plant species and the vulnerable *Gahnia* spp. vegetation association important for maintaining the biological diversity of the region
- it supports 20 fish and 49 plant species at a critical stage in their life cycle, or provides refuge during adverse conditions; it supports large waterbird populations at times of 200,000 to 400,000 birds
- it regularly supports 16 species in numbers exceeding 1 per cent of the total species population
- it provides significant habitat for 49 fish species; and of these, 43 rely on it as an important source of food, spawning grounds, nursery and/or migration path (refer to the Australian Wetlands Database; http://www.environment.gov.au/water/topics/wetlands/database/index.html).

The Coorong, Murray Mouth and Lower Lakes also meet all five of the ecological values used to identify key environmental assets within the Murray-Darling Basin (Table 2-1).

Table 2-1: Summary of the key environmental asset values in the Coorong and Lakes Alexandrina and Albert identified by the Murray-Darling Basin Authority.

Criterion number	Description	Values
1	The asset is recognised in and/or is capable of supporting species listed in international agreements.	• Approximately 140,500 ha of the Coorong and Lakes Alexandrina and Albert were listed under the Convention on Wetlands of International Importance (the Ramsar Convention) in 1985. • The Coorong and Lower Lakes site meets eight of the nine nominating criteria for Ramsar listings (Phillips & Muller 2006). • Species listed in the Japan–Australia, China–Australia and/or Republic of Korea–Australia migratory bird agreements have been recorded at and are supported by the site.
2	The asset is natural or near-natural, rare or unique.	• The site consists 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 (Phillips & Muller 2006). • The site is unique in its wide representation of wetland types within the bioregion. • The site includes the only estuarine system in the Murray-Darling Basin.
3	The asset provides vital habitat.	• This site supports a large number of fish and bird species during critical stages of their life cycles. Of the 49 species of native fish recorded, 20 species utilise the site at critical stages of their life cycle. This includes seven diadromous fish species such as common galaxias and estuary perch that move between fresh, estuarine and marine waters at various stages of their life to breed (Phillips & Muller 2006). • A total of 77 bird species have been recorded at the site, most being waterbirds (Phillips & Muller 2006). The site is important as waterbird habitat at a global, national and state scale. Of these, 49 species of birds including 25 species listed under international migratory conservation agreements, rely on the wetland at critical life stages, such as migration stop-over, for breeding habitat or as refuge during times of drought. • This site is considered significant because of the diversity of its fish species and the diversity of their form, structure and breeding styles, including their migration habits between fresh, estuarine and marine waters (Phillips & Muller 2006).
4	The asset supports Commonwealth, state or territory-listed threatened species and/or ecological communities.	• The site supports species listed as threatened under Commonwealth and/or state legislation.

Criterion number	Description	Values
5	The asset supports, or is capable of supporting, significant biodiversity.	• The site is one of Australia's iconic wetlands and a biodiversity hot spot supporting critically endangered, threatened and vulnerable species and ecological communities. It also supports extensive and diverse waterbird, fish and plant assemblages, which are reliant on its complex mosaic of wetland types (Phillips & Muller 2006). • The Department of Sustainability, Environment, Water, Population and Communities has identified the Coorong as part of one of 15 national biodiversity hot spots. The biodiversity hot spot covers an area of South Australia's south-east and Victoria's south-west. • A significant number of waterbirds use this Ramsar site, at times reaching 200,000 to 400,000 individuals—far in excess of 20,000 or more waterbirds required to meet the Ramsar criteria (Phillips & Muller 2006). A number of species that frequent this site regularly occur in abundances greater than 1,000 individuals. Sixteen species of waterbirds have been recorded in numbers greater than 1 per cent of the global population, including the Cape Barren goose (*Cereopsis novaehollandiae*), curlew sandpiper (*Calidris ferruginea*), red-necked avocet (*Recurvirostra novaehollandiae*) and fairy tern (*Sterna nereis*) (Phillips & Muller 2006). • The site also supports the Gahnia sedgelands, Swamps of the Fleurieu Peninsula as well as several species of note that contribute to the site's biological diversity, including the Murray hardyhead (*Craterocephalus fluviatilis*), Yarra pygmy perch (*Nannoperca obscura*), southern bell frog (*Litoria raniformis*), Australasian bittern (*Botaurus poiciloptilus*) and hooded plover (*Thinornis rubricollis rubricollis*) (Phillips & Muller 2006).

(Source: MDBA 2010)

The Coorong, Lower Lakes and Murray Mouth supports 58 identified vegetation communities of which two ecological communities are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act); Gahnia sedgeland ecosystem, and the Swamps of the Fleurieu Peninsula. Based on a search of the Biological Database of South Australia (BDBSA) data set and published literature, the habitat types presently support 117 fauna species meriting a significant international (IUCN Red List), national (EPBC Act) or state (National Parks and Wildlife Act 1972) conservation rating (Appendix 4). These include 20 fish, 90 bird, three amphibian, one reptile and three mammal species.

The Coorong and Lower Lakes represents important breeding habitat for waterbirds. Brandis et al. (2009) found that there were 470 records of colonial waterbird breeding in the Murray-Darling Basin from 1899 to 2008, with breeding recorded in 115 unique wetlands. Of these wetlands the Coorong and Lower Lakes wetland complex ranked fifth in the total number of breeding events, with 34 known events in the period, making it one of the most important colonial waterbird wetland breeding sites in Australia.

The diversity in ecological character of the River Murray from Lock 1 to Wellington, Lower Lakes, and the Coorong, broadly consists of four freshwater habitat components (the main channel and fringing wetlands between Lock 1 to Wellington; Lake Alexandrina; Lake Albert; and tributary wetlands associated with the lower reaches of the Finniss River, Currency Creek and Tookayerta Creek), and three estuarine-saline components (Murray Mouth and estuary; North Coorong Lagoon; and South Coorong Lagoon). Descriptions of the ecological values of each of these components are below.

2.1.1 Lock 1 to Wellington

The area between Lock 1 and Wellington is comprised of two distinct geomorphic areas: the limestone Murray Gorge and associated limited floodplain; and the swamplands extending from Mannum to Wellington.

Between Lock 1 and Mannum, wetland and watercourse features make up more than one-third of the area of the river corridor. Over half of the wetlands are permanently inundated and most of the remaining wetland areas are inundated at flows of 30,000 ML/day (Ecological Associates 2010). Below Mannum there are eight wetlands more than 50 hectares in size, representing two-thirds of the total wetland area in this section of the river, but less than 10 per cent of the total number of wetlands. Most of the floodplain below Mannum has been highly modified from its natural state for irrigation and agriculture. All large wetlands are inundated at pool level and most wetlands are permanently inundated. Additional areas are inundated by flows exceeding 30,000 ML/day (Ecological Associates 2010).

These wetlands support remnants of diverse herbland and sedgeland vegetation communities in South Australia, and in doing so, support species of significant conservation status in South Australia. These include the critically endangered purple-spotted gudgeon (*Morgurnda adspersa)* (Hammer et al. 2009) and cryptic waterbird species, the little bittern (*Ixobrychus minutus dubius)*, latham's snipe (*Gallinago hardwickii*) and spotless crake (*Porzana tabuensis)*. These wetlands also support the species listed under the EPBC Act, including small-bodied fish, such as the Murray hardyhead, and migratory/cryptic waterbird species, such as the lewin's rail (*Lewinia pectoralis)* and painted snipe (*Rostratula australis)*.

Fluctuations in water level, due to wind seiching (also known as wind tides) contribute to the maintenance of these wetlands by increasing breadth of the littoral zone, transporting nutrients and providing flow, enhancing ecological diversity.

Two conservation parks are associated with the main river channel below Weir 1 (Mowantjie Willauwar Conservation Park (143 hectares) and Ngaut Ngaut Conservation Park (49 hectares)).

2.1.2 Lake Alexandrina

Lake Alexandrina supports a complex fringing vegetation, 14 wetland types (Table 2-2), ecologically valuable habitat on Hindmarsh Island, and an array of sand and mud islands providing important habitat to a variety of bird species (Seaman 2003). The lake supports extensive and highly significant *Phragmites australis* and *Typha domingensis* reedbeds, which provide excellent shelter habitat for a range of fish and other vertebrate species, as well as long-term waterbird rookeries for a range of species at a variety of sites around the lake perimeter (Phillips & Muller 2006). The most complex wetland flora is found near confluences, channels and drains where the localised water regime is relatively variable (Phillips & Muller 2006).

Three state game reserves (Currency Creek Game Reserve (128 hectares), Mud Islands Game Reserve (125 hectares) and Tolderol Game reserve (427 hectares)), one conservation park (Salt Lagoon Islands Conservation Park (76 hectares)) and the Mosquito Point Sanctuary, all established under the *National Parks and Wildlife Act 1972* (SA), are located around the perimeter of Lake Alexandrina. To the south, Lake Alexandrina abuts the Coorong National Park, and in 2001, the private property Wyndgate (a third of Hindmarsh Island) was added to the National Park.

Table 2-2: Overview of wetland habitat and community diversity across the Coorong and Lower Lakes Ramsar site.

Wetland types found within the Ramsar site	Freshwater			Estuarine/saline			Total area (ha)
	Lake Alexandrina	Lake Albert	Tributary Wetlands	Murray Mouth and Estuary	North Lagoon	South Lagoon	
Marine/coastal wetlands							
Permanent shallow marine waters				X			50
Rocky marine shores	X			X	X	X	788
Sand, shingle or pebble shores	X	X		X	X	X	1,020
Estuarine waters				X			2,200
Intertidal mud, sand and salt flats				X	X	X	3,142
Intertidal marshes				X	X		536
Intertidal forested wetlands				X			4
Coastal brackish/saline lagoons				X	X	X	10,128
Coastal freshwater lagoons				X	X		41
Inland wetlands							
Permanent rivers/stream/creeks	X		X			X	221
Seasonal/intermittent/irregular rivers/streams/creeks	X						200
Permanent freshwater lakes	X	X	X				79,480
Seasonal/intermittent freshwater lakes	X						120
Seasonal/intermittent saline/brackish/alkaline lakes and flats	X	X				X	1,729
Seasonal/intermittent saline/brackish/alkaline marshes/pools	X	X	X			X	1,289
Permanent freshwater marshes/pools	X	X	X				4,474
Seasonal/intermittent freshwater marshes/pools	X		X				1,037
Shrub-dominated wetlands	X	X				X	4,875

Wetland types found within the Ramsar site	Freshwater			Estuarine/saline			Total area (ha)
	Lake Alexandrina	Lake Albert	Tributary Wetlands	Murray Mouth and Estuary	North Lagoon	South Lagoon	
Freshwater, tree-dominated wetlands	X		X			X	1,470
Freshwater springs; oases						X	<10
Human-made wetlands							
Seasonally flooded agricultural land	X		X				1,235
Water-storage areas			X				1
Canals and drainage channels, ditches	X	X	X				44

(Source: Phillips & Muller 2006)

2.1.3 Lake Albert

Lake Albert supports seven wetland types (Table 2-2). It contains remnant patches of *Gahnia filum* and extensive and highly significant *Phragmites australis* and *Typha domingensis* reedbeds, which provide excellent shelter habitat for a range of fish and other vertebrate species, as well as long-term rookery sites for ibis, spoonbill and cormorants (Phillips & Muller 2006).

2.1.4 Tributary wetlands

The tributary wetlands (Table 2-2) associated with three Eastern Mount Lofty Ranges' streams—Finniss River, Tookayerta Creek and Currency Creek—are nationally significant, supporting dense and diverse wetland flora and significant fauna such as the Mount Lofty Ranges' southern emu wren and pygmy perches (Phillips & Muller 2006). In the recent drought, and as a consequence of the associated record low flow into the lake and low lake levels, much of this fringing habitat was disconnected from the lake shoreline for an extended period. As such, habitat for many species was temporarily lost, and fauna such as the Yarra pygmy perch are now believed to be extinct from the River Murray (Bice 2010), but captive populations are held.

2.1.5 Murray Mouth and Estuary

The Estuary and Murray Mouth provide a diversity of habitats within nine wetland types (Table 2-2).

2.1.6 North and South Coorong Lagoons

The South Lagoon of the Coorong provides a diversity of fauna habitats associated with 10 wetland types, and the North Lagoon provides six wetland types (Table 2-2).

Historically, the submerged annual plant *Ruppia tuberosa* (*R. tuberosa*) dominated the South Lagoon, forming the primary diet of a number of waterbird species and together with other submerged aquatic plants such as *Lamprothamnion* sp. once provided habitat for a variety of species. *R. tuberosa* is a major contributor to primary production to the Coorong ecosystem, driving the system's capacity to support higher organisms, as well as providing physical habitat important for juvenile fish (Phillips & Muller 2006).

Prior to the hypersalinisation of the South Lagoon in the first decade of the 20th century *R. tuberosa* occurred predominantly in the Coorong Southern Lagoon (Phillips & Muller 2006). However, as of early 2009 it was effectively absent from the South Lagoon. This was a consequence of a combination of extended periods of hypersaline conditions and low water levels possibly acting in synergy to deplete seedbanks and cause multiple impacts on the plant's life cycle. In 2009 it appeared to be slowly increasing in distribution and abundance in the North Lagoon (Rogers & Paton 2009). Loss of *R. tuberosa* has resulted in the loss of the associated community from the South Lagoon. Within the systems in which *R. tuberosa* dominates there are no species that have an equivalent role. It has a particular role in ecosystem stability, providing critical habitat and food sources, which form the basis of a low-complexity food web sustaining a diversity of high trophic level organisms (Thompson & Starzomski 2007).

Although not a "keystone species" in the strictest sense (Power et al. 1996), *R. tuberosa* does exert a strong effect on biodiversity (Duffy et al. 2007), by virtue of its large biomass and trophic position, because of the complex microhabitat array it provides for other species, and because of the diversity of waterbirds known or suspected to feed on it.

2.1.7 Key indicators of functioning ecological processes

A suite of indicators are used by Lester et al. (2011a, b) to describe the key ecological processes of the Lower Lakes and Coorong region. The maintenance of these processes, the associated components and ecosystem services, are the foundation of the ecological character of the system and represent the basis for management objectives. These indicators include:

1. Vegetation (including phytoplankton): including 13 vegetation indicator species and assemblages, between them, that covered a range of aquatic vegetation communities from the terrestrial edge of the floodplain to the lower edge of the euphotic zone (see Muller (2010) for further information).
2. Fish: including 17 indicator fish species, between them, that covered the range of freshwater, estuarine and marine habitats across the site, as well as different strategies for using the site (e.g. migratory and resident). Pest species (i.e. common carp *Cyprinus carpio*) were also included as an indicator of decline in site conditions and/or fish communities.
3. Macroinvertebrates: including 19 macroinvertebrate indicator species that were chosen to cover the gradient of freshwater, estuarine, marine and hypersaline habitats within the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. The level of knowledge regarding their functional role within the region varied significantly among species. One of the main limitations in using macroinvertebrates as indicators for this region was the lack of specific knowledge and local data, particularly for the Lower Lakes, so much of the rationale for this group was drawn from research and management that was undertaken.
4. Ecological processes: including 10 key ecological processes that were used to indicate the overall health and productivity of an ecosystem without the need to monitor every species that is present. Ecological processes selected as indicators included basic ecological functions such as photosynthesis, decomposition, nutrient cycling, along with ecological responses to changing environments such as responses to salinity, acid/base and sediment dynamics, water clarity, terrestrialisation (or re-wetting), food-web functionality and functional connectivity. Other ecological processes considered included colonisation (including invasive issues) and bioaccumulation (both of potential pollutants but also carbon sequestration).

Lester et al. (2011a) summarises the identified links between each process and the ecological indicators.

2.2 Ecological management objectives

The CLLMM icon site objectives, as set by the Murray-Darling Basin Ministerial Council (see Lower Lakes, Coorong and Murray Mouth Icon Site Environmental Management Plan 2006–2007 (MDBC 2006)), are:

- An open Murray Mouth.
- Enhanced migratory wader habitat in the Lower Lakes and Coorong.
- More frequent estuarine fish spawning and recruitment.

A series of 17 specific ecological targets have been developed relating to native fish (including freshwater, diadromous and estuarine/marine), freshwater and estuarine vegetation, benthic invertebrates, mudflats, waterbirds, water quality and connectivity to inform progress against these three high-level objectives, as per MDBC (2006).

The objective for the CLLMM region specified by the most-recent draft of the long-term plan for the site is that it continues to be a "healthy, resilient wetland of international importance" (DEH 2010).

The Murray-Darling Basin Authority (MDBA 2010) notes six broad objectives for the CLLMM:

1. To conserve the Ramsar site consistent with its ecological character at the time of listing.
2. To protect and restore ecosystems that support migratory birds listed under international agreements.
3. Protect and conserve natural, or near-natural, rare or unique water-dependent ecosystems (in their current state).
4. To protect and restore water-dependent ecosystems that provide vital habitat.
5. To protect and restore water-dependent ecosystems that support Commonwealth, state or territory-listed threatened species and communities.
6. The asset supports, or is capable of supporting, significant biodiversity.

Each of these objectives is linked to at least one Ramsar criterion.

In order to determine an environmental water requirement for the Lower Lakes and Coorong with explicit links between hydrodynamic and ecological outcomes, Lester et al. (2011a) identified eight ecological objectives necessary to achieve a healthy resilient wetland for the CLLMM region. A detailed rationale for each of these objectives is outlined in Lester et al. (2011a). These ecological objectives are:

1. The region supports a range of species that persist without major and/or ongoing management intervention.
2. A range of species are able to successfully breed and recruit in the region without interruption.
3. Water links the various habitats and management units at the site.
4. A range of habitats exist within the region.
5. A suitable salinity gradient is maintained across the site.
6. Both flows and water levels vary through time.
7. A variety of ecological functions are supported at appropriate levels.
8. Links exist between aquatic and terrestrial ecosystems.

For the purpose of this document, the ecological objectives for targeted water use in each of the main water management areas are outlined below (Table 2-3).

Table 2-3: Ecological objectives for targeted water use

Water management area	Broad-scale system objective	Ecological objectives
Lock 1 to Wellington: main channel, permanent and semi-permanent wetlands and floodplain	Flood peak enhancement.	Promote: • productivity, health and diversity of floodplain vegetation • connection between wetland and riverine aquatic habitats • broader and more productive littoral vegetation • more diverse and productive flood-dependent fauna • temporary seasonal habitats.
Lakes Alexandrina and Albert	Enable export of salt and nutrients from the Murray-Darling Basin through an open Murray Mouth.	Maintain water quality required by salt-sensitive flora and fauna species.
	Variable inter and intra-annual lake level regime.	Promote: • productivity, health and diversity of riparian and floodplain vegetation • connection between fringing wetland and lake aquatic habitats • broader and more productive littoral vegetation • more diverse and productive flood-dependent fauna • annual fauna reproductive events • diverse epiphyte community • temporary seasonal habitats. • Maintain lake levels at sufficient heights to avoid acidification.
	Maintain longitudinal connectivity.	• Allow annual migration of fish between lakes and estuary.
The Coorong and River Murray Estuary	Minimum inter and intra-annual over barrage flow.	Promote: • ongoing estuary-ocean connectivity • productivity, health and diversity of fringing and submerged aquatic vegetation • connection between fringing wetland and lake aquatic habitats • broad and productive estuarine, marine and hypersaline habitats • more diverse and productive flood-dependent fauna • annual fauna reproductive events • temporary seasonal habitats.

3. Watering management objectives

3.1 Asset objectives

3.1.1 Lock 1 and Wellington

Most floodplain wetlands between Lock 1 and Wellington have become permanently wet with little change in water regime. Water levels can increase or decrease by around 0.5 metres on a daily basis through wind seiching, though these fluctuations are typically short periodic fluctuations. Regulators have been installed on some small individual wetlands to enable wetting and drying cycles to be introduced to these wetlands.

Cooling et. al. (2010) describes the inundation of floodplain and floodplain wetlands throughout the South Australian River Murray. The document presents this information according to the river's three key geomorphic stretches; the broad floodplain from the border to Lock 3, the gorge section with the constrained floodplain corridor from Lock 3 to Mannum (located between Lock 1 and Wellington), and the heavily altered floodplains from Mannum to Wellington. In order to discern flow figures for inundation between Lock 1 and Wellington, it was therefore necessary to interpret the figures from both the Lock 3 to Mannum, and Mannum to Wellington sections of the document.

Therefore, from Cooling et. al. (2010) it can be understood that additional wetland areas are inundated at flows exceeding 30,000 ML/day with minimal further increases in inundation once flows exceed 75,000 ML/day. Significant floodplain inundation occurs at flows above 55,000 ML/day, with inundation is largely complete at 100,000 ML/day.

Water management objective: to generate flows within the flow band of 30,000 to 75,000 ML/day, for a duration of between 30 to 90 days, commencing late spring to support inundation of floodplain wetlands and floodplains between Lock 1 and Wellington. Antecedent conditions will determine the frequency with which these flows are generated as both wet and dry years will be required.

Thus, this watering objective aims to achieve two key things—a flow band that will support the inundation of additional floodplain wetland areas, and a flow band that includes volumes large enough to begin significant inundation of the floodplain itself. This objective does not target maximum floodplain inundation, but provides for a significant extent of inundation to occur.

This flow regime should be targeted downstream of Lock 1 to benefit the floodplain through associated increased productivity, health and diversity of floodplain vegetation, improved connection between wetland and riverine aquatic habitats, creation of a broader and more productive littoral vegetation, with the result of a more diverse and productive flood-dependent fauna and maintenance of temporary seasonal habitats.

Where possible benefits can be achieved by adding volumes to existing flows to either increase the peak of smaller flows above the 30,000 ML/day threshold, and/or extend the period over which flows greater than 30,000 ML/day are maintained.

3.1.2 Lakes Alexandrina and Albert

Under natural conditions, water levels in Lake Alexandrina and flows to the sea would have been closely linked to River Murray flows, with substantial seasonal and annual variability (see Muller 2010). Increasing regulation within the MDB has enabled water levels to be held relatively constant for approximately the past 50 years for water extraction, transport and recreational purposes. Historically, the key levels in the Lower Lakes have been: +0.60 mAHD as a preferred minimum level and +0.75 mAHD for full supply level. The surcharge level of +0.85 mAHD is the height at which water begins to spill over the barrage spillways, and at +0.87 mAHD inundation of surrounding land commences.

As a result of this loss of variability in lake levels there has been a simplification of riparian ecosystems and the accumulation of sulfidic soils over time (Lester et al.2011a). To support the ecological requirements of the Lower Lakes, as presented above, and in accord with objectives established by the MDBA, three key water management objectives have been identified and are being proposed for the purpose of this document.

Water-management objectives:

1. **Provide sufficient flows to enable export of salt and nutrients from the Basin through an open Murray Mouth:**
   - **Salt export: 2 million tonnes per year.**
   - **Water quality target: salinity less than 700 µS cm^{-1} at Tailem Bend.**
   - **Barrage flow: Rolling 10-year average greater than 3,200 GL/year.**
2. **Provide a variable lake level regime to support a healthy and diverse riparian vegetation community while maintaining lake levels above 0.0 mAHD to manage acidification issues.**
3. **A minimum flow of 150 ML/day[1] through the existing barrage fishways (J Higham [DENR] 2011, pers. comm.) be provided at all times to promote fish passage between Lake Alexandrina and the River Murray estuary. This volume will need to be increased as more fishways are installed.**

Increased water level variability and improved water quality are key water management objectives for the River Murray below Lock 1 including Lake Alexandrina and Lake Albert (Lester et al. 2011b; MDBA 2010). The identification of a target water level envelope for Lake Alexandrina was largely based on the requirements of vegetation indicator species and assemblages (Muller 2010). These targets are described in Section 4.2.

The salinity target at Tailem Bend is designed to achieve a water quality suitable for raw drinking water, to facilitate extraction for domestic purposes. Lester et al. (2011b) also propose a salinity target of 700 µS cm^{-1} in Lake Alexandrina. This is a conservative target proposed for Lake Alexandrina because of the strong relationship between salinity in Lake Alexandrina and Lake Albert.

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[1] This is a minimum flow requirement to meet fishway operation at the barrages, with preferred optimum flow rates to include sufficient volumes for supporting multiple objectives, such as the provision of attractant flows for fish, and with consideration of water management objectives for the Coorong and Murray Mouth.

The salinity level in Lake Albert is consistently higher than that of Lake Alexandrina because of evapo-concentration effects which are exacerbated because there is no through flow; water can only enter and leave the lake via the Narrung Narrows which are of relatively limited capacity (Heneker 2010). Inspection of the observed salinity data presented in Heneker (2010) (refer Figure 3-1) highlights that the salinity in Lake Albert rarely falls below 1,000 µS cm^{-1}.

When Lake Alexandrina salinity exceeds 700 µS cm^{-1} it is likely that the salinity in Lake Albert will exceed 1,500 µS cm^{-1}. This salinity threshold is approaching the upper end of the tolerances of some of the identified key aquatic plant species in this system and where sub-lethal effects to a range of fauna species are likely.

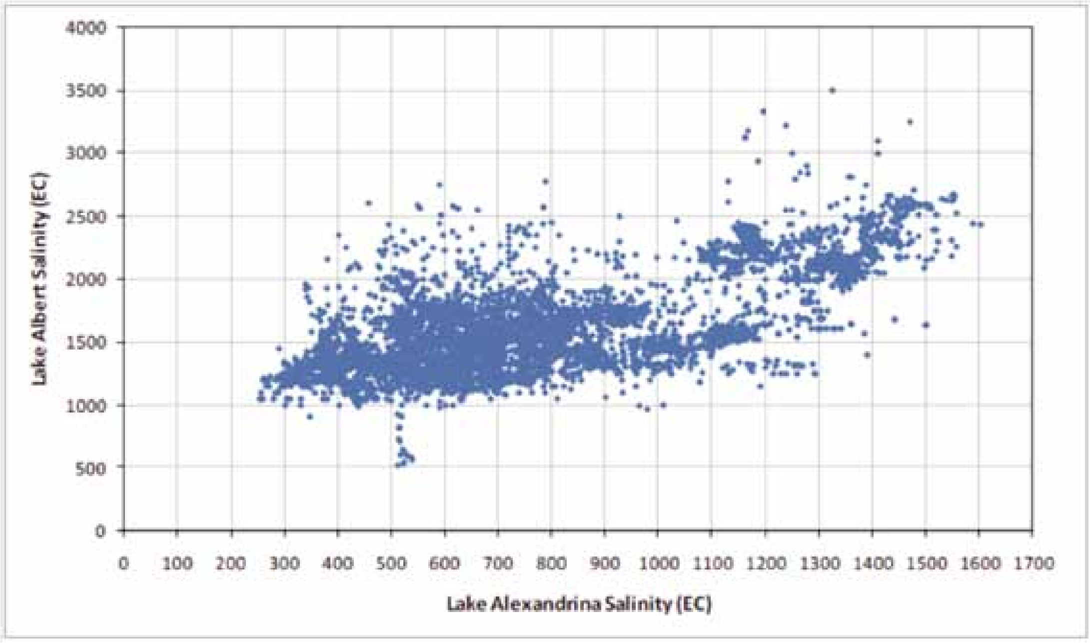

Figure 3-1: Relationship between observed salinity in Lake Alexandria and Lake Albert (pre- April 2007).

(Source: Heneker 2010)

Some data on key habitat species with low salinity tolerances is currently unpublished and subject to current monitoring programs. This information is expected to be published in the near future and this will add to the knowledge of the Lower Lakes' ecosystem. One such species of interest is *Myeariophyllum caput-medusae*, extensive beds of which have been present historically providing core native fish habitat. This species has a low salinity tolerance and has disappeared under recent drought and high lake salinity conditions (J Nicol 2011, pers. comm.).

Thus, 700 µS cm^{-1} is currently considered a reasonable target for lake management, and setting a higher salinity target for Lake Alexandrina would be highly likely to affect the ecological character of Lake Albert.

3.1.3 Murray Estuary

Implicit in the objectives for the South and North Lagoon is the following proposed objective for the Murray Mouth (also identified in MDBA 2010).

Water management objective: provide sufficient flows to enable export of salt and nutrients from the Basin through an open Murray Mouth.

3.1.4 Coorong North Lagoon

To meet the key ecological objectives identified in Section 2, and the broad-scale objectives as identified in MDBA (2010), the following water management objective and associated management targets are proposed.

Water management objective: maintain a range of estuarine, marine and hypersaline conditions in the Coorong, to support healthy populations of 'keystone' species such as *Ruppia megacarpa* in the North Lagoon.

The targeted characteristics for Northern Lagoon salinity required to achieve this objective are:

a. **Average annual salinity less than 20 g/L (35,700 μS cm^{-1}) in a proportion of years.**

b. **Maximum salinity less than 50 g/L (89,000 μS cm^{-1}).**

3.1.5 Coorong South Lagoon

To meet the key ecological objectives identified in Section 2, and the broad-scale objectives as identified in MDBA (2010), the following water management objective and associated management targets are proposed.

Water management objective: maintain a range of estuarine, marine and hypersaline conditions in the Coorong, to support healthy populations of 'keystone' species such as *Ruppia tuberosa* in the South Lagoon.

The targeted characteristics for Southern Lagoon salinity required to achieve this objective are:

- **Average long-term salinity less than 60 g/L (107,000 μS cm^{-1})**
- **Maximum salinity less than 100 g/L (179,000 μS cm^{-1}) in 95 per cent of years**
- **Maximum salinity less than 130 g/L (232,000 μS cm^{-1}) in 100 per cent of years**.

Water level is also understood to be an important consideration for ecological health in the South Lagoon. However, water level objectives are yet to be established and require further investigation.

4. Environmental Water Requirements

A substantial body of knowledge exists on the ecology of the CLLMM region. This has been collected over many years by a variety of researchers and government agencies (see Department of Environment and Planning 1990; Sloan 2005; Ferguson 2006a,b,c,d; Phillips & Muller 2006; Ferguson, Ward & Geddes 2008; Jennings et al. 2008; Bice & Ye 2009; Brookes et al. 2009; Noell et al. 2009; and Bice 2010).

In addition, literature reviews summarising information on the ecology of the region have recently been compiled as a part of the development of the *Securing the Future: a long-term plan for the Coorong, Lower Lakes and Murray Mouth* (the Long-Term Plan) (e.g. Fluin et al. 2009; Aldridge et al. 2010; Bice 2010; Ecological Associates 2010; Gehrig & Nicol 2010; Napier 2010; Shiel 2010; Rolston et al. 2010) and external to that process Lester et al. (2008).

This recent work on the Long-Term Plan has been the culmination of investigation work associated with the CLLMM Murray Futures project and represents more than four years of research and investigations. It has formed the technical basis for much of this environmental water use document.

4.1 Main Channel Lock and Weir 1 to Wellington

Flow Volumes

As mentioned in Section 3, most wetlands along this stretch of the river are permanently inundated with a small additional area inundated by flows exceeding 30,000 ML/day and minimal additional increases once flows exceed 75,000 ML/day.

On the floodplain along the main river channel between Lock 1 and Wellington, significant floodplain inundation does not commence until flows exceed 55,000 ML/day and is largely complete at a discharge of 100,000 ML/day (Ecological Associates 2010a). The total area of inundation across watercourses, wetlands and floodplains in this reach of the River Murray is shown by Figure 4-1.

The main flow band where change in inundation area occurs for floodplain wetlands is between 30,000 ML/day and 75,000 ML/day. Hence, increased inundation could be achieved where the opportunity arises to augment small natural floods to increase flows once they are going to exceed 30,000 ML/day. The required volume would be flood specific, but typically would require additional flows of 5,000 to 10,000 ML/day for one to three months in late spring. By targeting flows in this flow band above 55,000 ML/day, environmental watering would also ensure that significant floodplain inundation commences.

There is relatively little floodplain vegetation remaining and little to distinguish the flow thresholds of the vegetation types. The 115 hectares of remnant river red gum forest is largely inundated by flows between 40,000 and 60,000 ML/day, but river red gum woodland, samphire, lignum shrublands and black box woodlands are all gradually inundated between flows of 50,000 and 90,000 ML/day (Ecological Associates 2010a).

There are regulators on some small individual wetlands within this part of the system that can be operated to allow drying of these wetlands and control of wetting/drying cycles. Other than introducing regulated drying and refilling cycles (back to pool level) there are only limited opportunities to manipulate water levels other than through flow augmentation. The majority of wetlands throughout this reach of the river do not have management plans that describe individual site water management regimes.

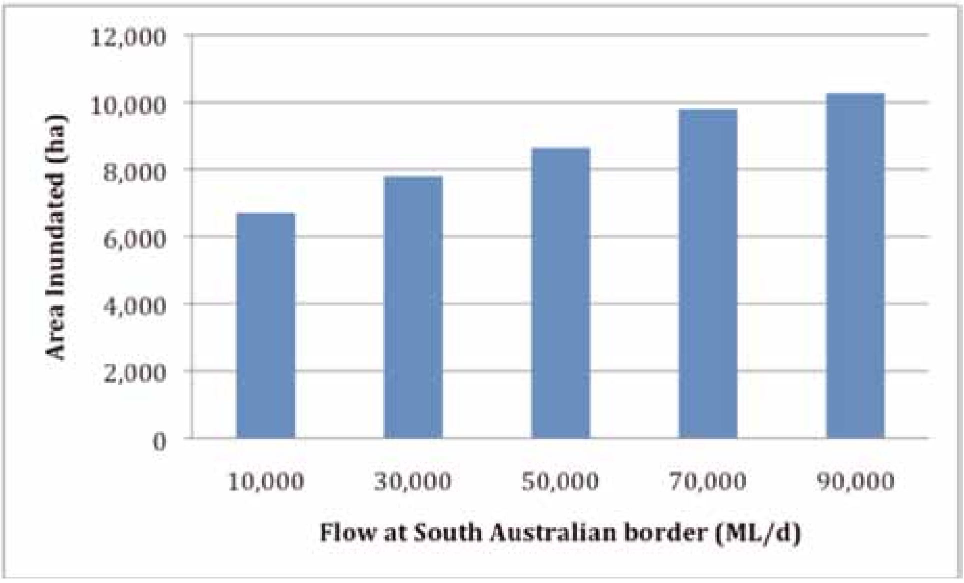

Figure 4-1: Inundation of watercourses, wetlands and associated floodplains with increasing flow from Lock 1 to Wellington.

(Source: DFW Floodplain Inundation Model)

4.2 Lakes Alexandrina and Albert

Flow volumes and salinity targets

The majority of recommendations regarding environmental flows for the Lower Lakes focus on a two or three-year return interval (Jensen et al. 2000). This is partly due to the relatively short 'memory' (i.e. the length of time in which the influence of a large flow is apparent) both for the Lower Lakes and the Coorong, but also partly due to the unregulated nature and thus limited control that can be exerted over high flow events (Lester et al. 2011).

Large flows have the ability to lower the salinity of the system for up to three years, after which they would begin to rise again. Thus, rules were developed (Heneker 2010, Lester et al. 2011b) to specify the minimum volume of water needed to pass over the barrages (thus commencing the flushing of salt from Lake Alexandrina) over a three-year period.

Flows sufficient to achieve the long-term average annual salinity of 700 µS cm^{-1} in Lake Alexandrina should be the target for most years (Lester et al. 2011b); requiring flows in excess of the minimum requirement. A maximum salinity of 1,000 µS cm^{-1} in Lake Alexandrina should be maintained in 95 per cent of years, and never exceeding 1,500 µS cm^{-1}.

Heneker (2010) determined that to meet the more conservative target of 700 µS cm^{-1} in Lake Alexandrina—which represents a high degree of certainty for maintaining the Ramsar site's ecological character—flows over the barrages in any given year should be the maximum of:

1. 3,150 gigalitres
2. 8,000 gigalitres—F_{X-1} or
3. 12,000 gigalitres—$F_{X-1} – F_{X-2}$.

   where F_{X-2} is equal to the lesser of the actual outflow two years prior to the current year and 4,000 gigalitres, and where F_{X-1} is the flow volume from the previous year.

In dry years (up to 5 per cent of the time) where the 700 µS cm^{-1} target cannot be met, in order to meet the salinity target of a maximum of 1,000 µS cm^{-1} in Lake Alexandrina, flows over the barrages in any given year should be the maximum of:

1. 650 gigalitres
2. 4,000 gigalitres—F_{X-1}, or
3. 6,000 gigalitres—$F_{X-1} - F_{X-2}$.

   where F_{X-2} is equal to the lesser of the actual outflow two years prior to the current year and 2,000 gigalitres, and where F_{X-1} is the flow volume from the previous year.

Modelling was undertaken to determine if the above targets could be met by existing management arrangements and water allocations. For the salinity targets in Lake Alexandrina of 1,000 and 700 µS cm^{-1}, additional average flows of 1,427 and 2,622 gigalitres were required for 44 and 78 out of 117 years respectively (Lester et al. 2011b). This identifies that in nearly half of all modelled years the 1,000 µS cm^{-1} could not be achieved without additional flows.

Further, Heneker (in Lester et al. 2011b) determined that additional flow volumes of 850 GL/year were required to ensure that the absolute maximum (sub-lethal) annual salinity level of 1,500 µS cm^{-1} in Lake Alexandrina was not exceeded. This additional flow was required in 25 out of 117 years. The recommended annual maximum of 1,500 µS cm^{-1} for Lake Alexandrina should be thought of as an absolute maximum, to be avoided wherever possible in order to maintain a healthy ecosystem. This salinity figure does not replace the desired salinity target of 700 µS cm^{-1} in Lake Alexandrina but rather is designed to provide guidance for operators for periods when flow and salinity targets cannot be met for what the system can tolerate for short periods.

Should lower flow volumes be delivered, it is unlikely that healthy marine or hypersaline ecosystems would become established, in the Lower Lakes in particular. This is because low water levels and large fluctuations in salinity mean conditions are likely to be regularly outside the tolerance limits of the associated biota. Thus the fluctuations, and the rate at which these changes occur, are likely to be problematic.

The implications of delivering less water than has been recommended were demonstrated under predicted median and dry future climate conditions for Lakes Alexandrina and Albert, and for the Coorong. Salinities were predicted to rise dramatically in both lakes and in the two lagoons of the Coorong (Lester et al. 2011b).

4.2.5.1 Lake level variability

Increased variability was identified by Lester et al. (2011b) as a key requirement for developing a target water level envelope for the Lower Lakes and river below Lock 1.

The pattern of elevating and lowering lake levels is driven by the seasonal requirements of the ecology in and around the Lower Lakes. Generally speaking, gradual drawdown over summer and autumn months aims to expose mudflats and support diverse vegetation. Maintaining the lake at a minimum water level is designed to promote diverse littoral and riparian vegetation diversity and support biogeochemical cycling. Gradual winter–spring refilling of the lake supports growth of new vegetation shoots while ensuring fauna have access to vegetation for food, shelter and recruitment. Water levels are kept high during spring to ensure fauna access to habitat (Lester, Fairweather & Higham 2011a).

Target ranges for water levels in Lake Alexandrina on an annual return interval (ARI) of 1 (i.e. water levels to be achieved each year; Figure 4-2) and also at an ARI of 3 (i.e. levels to be achieved every three years on average, which are over and above those levels specified with the ARI of 1; refer to Figure 4-3) have been determined. The water levels that have been specified are monthly averages across the site. Topography and wind seiching mean that there will be significant variability in water levels across the lake and at shorter temporal scales (e.g. daily).

The target temporal water level envelopes identified by Lester et al. (2011a, b) are based on the requirements of vegetation indicator species and assemblages around Lake Alexandrina (Muller 2010; see Lester et al. 2011a). Lester et al. (2011a) offer further explanation on the ecological benefits from seasonal lake level variation for both ARI scenarios.

For the water level envelope with an ARI of 1, lower limits for these water levels have been set with disconnection points within the region in mind (e.g. Hindmarsh Island streams), as well as seasonal requirements for water and connectivity (e.g. fish passage through the Coorong to coincide with migration events). The upper limit for the ARI of 1 water level envelope was determined based on the water requirements of the riparian zone and its position relative to the floodplain. Differences between the water level envelopes for ARI's of 1 and 3 are largely focused on achieving occasional flooding of the surrounding floodplains. For detailed information regarding the seasonality of the lake level envelopes, including detailed information on minimum and maximum lake levels, see Lester et al. (2011a).

An understanding of other environmental management issues that exist outside of these lake envelopes is also critical. These include the intrusion of saline groundwater, and the exposure of acid sulphate soils at, and below, 0.0 mAHD (see Section 1.3.3). Concerns around lowering lake levels to such a point that risks the ability to fill the lake to within its target envelope in the subsequent year are also present. This concern plays a role in influencing the minimum lake level of +0.35 mAHD specified in the ARI 1 envelope (Lester et al. 2011a). These management issues will also play a role in managing lake level variability.

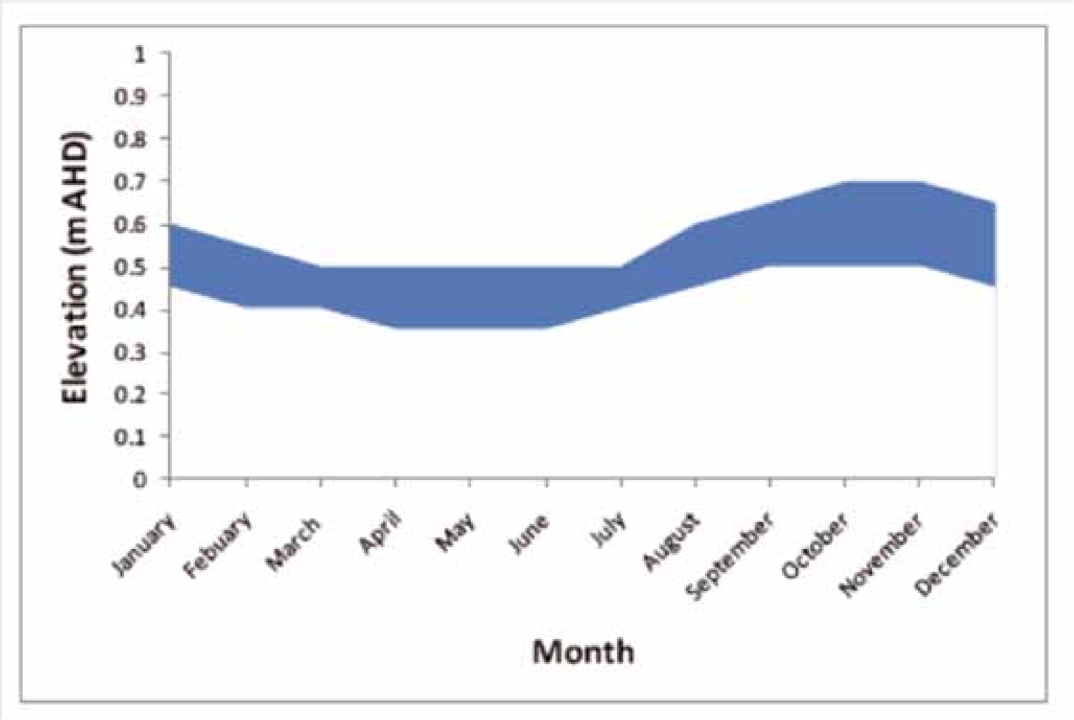

Figure 4-2: Proposed target envelope for water level in Lake Alexandrina at an ARI of one year showing upper and lower limits.

(Adapted from Muller 2010, in Lester et al. 2011b)

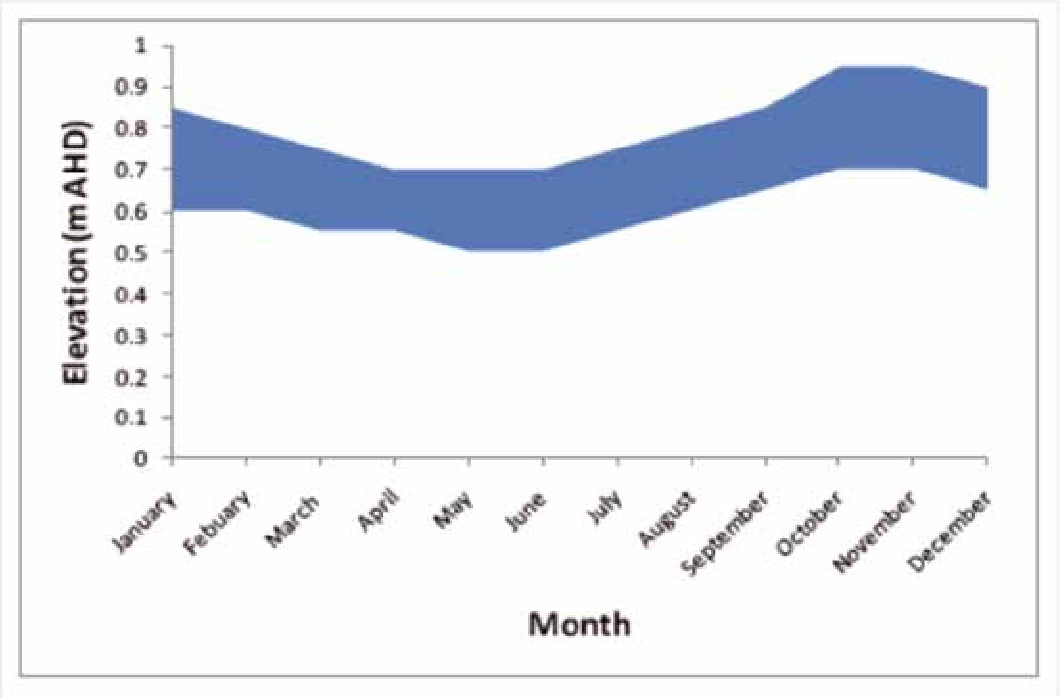

Figure 4-3: Proposed target envelope for water level in Lake Alexandrina at an ARI of three years showing upper and lower limits.

(Adapted from Muller 2010 in Lester et al. 2011b)

Lake level management is key to wetting and drying fringing wetlands of the Lower Lakes. However, several wetlands in this region can be hydrologically managed via the use of existing flow-control structures. These wetlands include Narrung wetland, Waltowa swamp and Tolderol wetland.

Maintaining the water level of the Lower Lakes within the target envelope of seasonal variability has only a minor implication for water allocation. Under the historical water level management regime for the benchmark scenario (1995 level of development assuming historical climate), the monthly variability in losses from the Lower Lakes was high, with the average ranging from less than 1 gigalitre in June to around 140 gigalitres in December and January. Analysis of the lake bathymetry data indicates that the surface area of the Lower Lakes varies by only approximately 3 per cent over the normal water level range of +0.4 to +0.9 mAHD (refer to Appendix 1), indicating that seasonal variation in loss was driven by climate (mainly evaporation) seasonality, not variation in lake surface area. Most of the time the water level in the lakes is controlled by barrage operation rather than River Murray inflows, although lake levels will fall if inflows are insufficient to offset losses (including releases).

Compared with the benchmark scenario, the proposed lake level target regime produces overall lower lake levels. This regime would produce a lower volume of losses than under benchmark conditions, however the difference would be small.

4.2.5.2 Barrage flow volumes

A key further consideration for the management of the Lower Lakes is to ensure there are sufficient flows though the barrages to promote connectivity between the lakes, ocean and Coorong.

Construction of the barrages caused a barrier to fish migration. Fish movement from the lakes to the Coorong remained possible when the barrage gates were open, but movement in the reverse direction was restricted due to the high flow velocities and physical structure of the gates. Such movement is particularly important for diadromous and migratory species that require access to both marine and freshwater habitats to complete their life cycles. Since 2002, five fishways have been constructed to facilitate fish passage. Minimum flow requirements at the barrages for the purpose of maintaining broader fish passage targeting diadromous fish species is estimated to be 150 ML/day which equates to 55 gigalitres over a full water year (J Higham (DENR) 2011, pers. comm.).

Similarly, flows through the barrages to establish estuarine conditions within Boundary Creek and downstream of Goolwa barrage, as well as provide attractant flows for Goolwa fishway, total a minimum of 164 GL/year. Further attractant flows (at Tauwitchere and Goolwa) total 202 GL/year (DFW 2010).

The minimum flow requirements for maintaining fishways are outlined in Table 4-1.

Table 4-1: Minimum barrage flow requirements to meet the needs of diadromous and migratory fish speciees.

Month	Barrage flows (GL)			
	Fishways	Maintain connectivity with estuary	Attractant flows	Total
Jan	4.7	18.6	37.2	60.5
Feb	4.2	16.8		21.0
Mar	4.7	18.6		23.3
Apr	4.5			4.5
May	4.7			4.7
Jun	4.5			4.5
Jul	4.7	18.6		23.3
Aug	4.7	18.6	18.6	41.9
Sep	4.5	18	36	58.5
Oct	4.7	18.6	37.2	60.5
Nov	4.5	18	36	58.5
Dec	4.7	18.6	37.2	60.5
Year	**55**	**164**	**202**	**421**

(Source: DFW 2010)

4.3 Coorong North and South Lagoons and Murray Estuary

The water requirements are largely driven by managing water salinity to acceptable tolerance levels. Water level is also thought to be a driver for ecosystem health but there is currently insufficient information to effectively describe the water requirements. The systems' requirements are further complicated by the long lag and influences associated with antecedent conditions. For example, an average South Lagoon salinity of greater than 117 g/L (209,000 µS cm^{-1}) has been shown through modelling to be the best predictor of degraded ecosystem states three years in advance (Lester et al. 2011a).

A key requirement is the exchange of water between the sea, the River Murray and the Coorong. These exchanges are primarily driven by wind, seasonal and diurnal tidal variations and flow through the barrages.

Barrage flows from Lake Alexandrina influence the salinity dynamics in the Coorong in at least three important ways (Webster 2007):

- Periods of elevated barrage flows deepen the mouth channel, which in turn allows more active mixing along the length of the Coorong.
- By freshening the water at the northern end of the North Lagoon (relative to seawater) the water with a lower salinity flows along the Coorong to replace evaporative losses further along the system. Even after evaporation increases the salt concentrations in the two lagoons, a lower salinity is maintained.
- When there are flows through the barrages, the water level in the whole system tends to increase and water is pushed along the Coorong. Generally, variations in discharge cause the water level in the Coorong to rise and fall causing back and forth water exchange along the system, which enhances longitudinal mixing.

Sea level variations with periods of elevated water level longer than a few days penetrate into the Coorong more effectively than shorter period fluctuations and can be important drivers of water level fluctuations in both lagoons. Penetration increases as the period increases, as the mouth channel deepens, and increases with higher sea levels.

Coorong hydrodynamics are best correlated with barrage flows at a one-year lag (Lester et al. 2011a). Barrage flows from more than two years prior to the year in question have little impact on the predicted mix of ecosystem states. This is likely to be due to the role of the Murray Mouth in regulating hydrodynamics within the Coorong. Mouth depth influences the transmissivity of water between the Coorong and Encounter Bay, and is primarily a function of barrage flows in the current year (Lester et al. 2011b). Long-term effects of high flow events are not seen, as the majority of fresh water passes through the mouth, and seasonal siltation processes do not allow a deep mouth to persist through time.

Research (Webster 2007, Lester et al. 2011b) has demonstrated that the health of the Coorong is sensitive to closure of the Murray Mouth and it is very unlikely that the Coorong would support predominantly healthy ecosystem states without functional connectivity to the mouth. For barrage flows less than 1,225 GL/year, modelling suggests there is a high likelihood that the entire Coorong will fall into degraded ecosystem states, with more than 6,000 GL/year required to minimise the likelihood of more than 50 per cent of sites in degraded ecosystem states (Lester et al. 2011a).

Management of flows to achieve a healthy state in the Coorong is complex, requiring an iterative approach. Conditions in the preceding years markedly alter the best case scenarios needed to manage flows into the system. Where a nominal volume of water is available, long drawn out releases over autumn or spring achieve a markedly better ecological outcome than a single short flow high volume pulse (Webster et al. 2009).

Notwithstanding this, for the Coorong and Murray Estuary specifically, the following minimum flow requirements over the barrages have been suggested (Lester et al. 2011a):

- There should be no years in which no flow passes over the barrages. The absolute minimum barrage flow should be between 50 GL/year and 120 GL/year (this meets the minimum requirement for maintaining fishways, however, is unlikely to prevent salinity thresholds being exceeded).
- Over any two-year period, at least 600 GL/year should be released to the Coorong to prevent South Lagoon salinity thresholds of 117 g/L (209,000 µS cm^{-1}) to be exceeded.
- At least 2,500 gigalitres over two years as a minimum target (95 per cent of the time) to prevent extreme salinity levels occurring in the South or North Lagoons which would result in the decline in key species such as *Ruppia tuberosa* and small-mouthed hardyhead (*Atherinosoma micrstoma*) fish species.

High flows of 6,000 and 10,000 GL/year should be maintained at a frequency of every three and seven years over the barrages into the Coorong.

Ideally a minimum daily flow regime to reduce the risk of mouth closure is required which has been estimated to be 2,000 ML/day (Close 2002). For the purpose of modelling a daily flow rate of 3,000 ML/day was adopted as a conservative estimate for this document, but it is anticipated this will be updated with a seasonal distribution once a seasonal distribution has been established with confidence.

If the requirements for Lake Alexandria can be met this will also achieve the desired outcomes for the Coorong North and South Lagoons and the Murray Estuary.

4.4 Modelling used to establish requirements for the Lower Lakes and Coorong

Modelling was undertaken by Heneker (2010) and Lester et al. (2011b) to determine the environmental flow requirement for the CLLMM region. The modelling was used to develop environmental water requirements for the Lower Lakes based on ecological first principles (Lester et al. 2011b).

Lester et al. (2011b) described eight ecological objectives (see section 2.1.2) and 33 ecological outcomes that are associated with healthy and resilient wetlands. These objectives are in line with the South Australian Department of Environment and Natural Resources (DENR) stated goal that the region be maintained as a healthy, resilient wetland of international importance.

Lester et al. (2011a) compiled a comprehensive list of species, assemblages and ecological processes that would occur in the CLLMM region under the ecological character described for the Ramsar site (Phillips & Muller 2006). This list was then linked to the ecological objectives and outcomes, and their flow-related requirements (including water quality, water level, connectivity and return intervals for flooding and barrage flows) were assessed from the literature.

In turn, the ecological objectives and outcomes were linked to a suite of indicators specific to the CLLMM region in order to assess ecological condition locally (Muller 2010). Where species and assemblages were selected as indicators, these focused on those that could be considered: keystone species or assemblages in the region; 'canary' species or assemblages (i.e. sensitive species that are likely to be early indicators of change); or threatened species or assemblages as matters of national environmental significance (as defined by the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth)).

Hydrodynamic modelling

The effect of environmental water allocations on the hydrodynamics of the Coorong was investigated using a one-dimensional hydrodynamic model (Webster 2007). This model simulates water levels and salinities along the length of the Coorong, allowing the effect of varying barrage flows to be assessed and compared between scenarios.

The model simulates water movement and levels along the entire domain, as these respond to the driving forces associated with water-level variations in Encounter Bay (including tidal, weather band, and seasonal), winds, barrage inflows, flows in Salt Creek (USED), and evaporation (Lester et al. 2011b). The model simulates the broad response of the system in both salinity and in water level, explaining approximately 90 per cent of salinity changes in the system (Lester et al. 2011b).

The hydrodynamic model was run for 19 scenarios. The scenarios contained combinations of flows to support different salinity targets in Lake Alexandrina, in combination with different climate change scenarios. Current water allocations were modelled under an historical climate, plus median and dry future climate scenarios, as was natural flow (i.e. with no extractions in the Murray-Darling Basin) under historical climate conditions (Lester et al. 2011b).

Ecosystem response modelling

In order to assess ecological condition in the Coorong, Lester et al. (2011b) used an existing ecosystem response model based on "ecosystem states" (Webster et al. 2009). Using the response model the likely mix of ecosystem states in the Coorong that would be supported by the flow regimes designed to meet salinity targets in Lake Alexandrina were identified (Lester et al. 2011a, b).

The ecosystem states model is a statistical model, where data for the region have been statistically analysed and modelled to identify associations and relationships between the biota that occur within the system at any one point in time, and the environmental conditions under which they occur (Lester et al. 2011b). The ecosystem state model developed for the Coorong identified eight distinct ecosystem states. These can be divided into two 'basins of attraction': a marine basin and a hypersaline basin. Within each basin, there are four states, ranging from a healthy state to a degraded state. Thus, the four states within each basin are considered to be a continuum of conditions from a healthy ecosystem to a more-degraded ecosystem, although it should be noted that a diverse range of conditions is the norm for the Coorong region.

The critical thresholds of each of the indicator species and processes were identified, where possible, for water quality; flow regime; connectivity; and water levels (including links to water quality and connectivity) (see Lester et al. 2011a for information).

Lester et al. (2011a) then directly related the identified indicators of ecological condition to the hydrodynamics and flow regime of the Lower Lakes and Coorong and explicit trade-offs were explored regarding the effect of different values of each parameter. Based on this process, and the historical condition of Lake Alexandrina and other similar freshwater lakes, targets were set for use in hydrological modelling in the lakes.

Hydrological modelling

Hydrological modelling used the historical flow record from the River Murray and existing models for the Lower Lakes and Coorong to explore the various flow regimes and likelihood of meeting the desired targets. Flow sequences required to maintain the salinity targets, and thus water levels, were also explored.

Outputs from the hydrological modelling were then used to assess the ecological implications of the recommended flow regime for the ecology of the CLLMM region. This assessment was qualitative for the Lakes. This modelling was used to develop rules for the minimum delivery of water to the Lakes.

Based on the hydrodynamic requirements, as well as the predicted flows required to support ecosystem states in the Coorong, several possible salinity targets for Lake Alexandrina were identified. Salinity was the variable that required the most flow to support in the long term (thus, if flows were sufficient to meet the salinity targets for Lake Alexandrina, other targets such as those associated with water levels should also be met). Three qualitative targets for salinity in Lake Alexandrina were explored: an annual mean of 700 $\mu S\ cm^{-1}$; an annual maximum of 1,000 $\mu S\ cm^{-1}$; and an annual maximum of 1,500 $\mu S\ cm^{-1}$. Flow sequences into Lake Alexandrina were explored to develop rules for additional flow to maintain salinities below the threshold levels in Lake Alexandrina and to achieve water level and/or flow requirements for the suite of indicators.

Annual flow bands

Four bands of annual flow at the barrages have been identified as part of developing this environmental water use document that relate to specific ecological thresholds (Table 4-2). For specific seasonality of flows, refer to Section 4.2 Figure 4-2, Figure 4-3 and Table 4-1. These flow bands all put achieving target lake levels as a first priority which then by default achieves the targets for fringing wetlands and other freshwater components of the Lower Lakes' ecosystem. The flow bands are presented to guide manager responses in any one particular year, however, it is recognised that antecedent conditions are significant and there are long lag times (two to three years).

Table 4-2: Bands of forecast annual flow at the barrages for July to June water year with suggested management responses to meet ecological objectives.

Total flow requirements over the barrages for water year (July-June)	Management response	Ecological objectives	Frequency of implementation of response
0 to 60 GL/year	• Boost flows to at least 60 GL/year. • Further boost flow as required to achieve salinity target. • Manipulate water level of lakes to achieve target regime. • Prioritise flows through fishways.	• Maintain connectivity between the lakes and the estuary. • Achieve salinity lower than or equal to 1,500 μS cm^{-1}. • Achieve water level variability of lakes to maintain health of riparian vegetation.	Annually.
60 to 650 GL/year	• Boost flows to at least 650 GL/year. • Further boost flow as required to achieve salinity target.	• Achieve the minimum flow required to avoid unrecoverable degradation of ecological health, including stimulating fish recruitment through flows for fishways, attractant flows, and maintaining connectivity between the lakes and the estuary. • Achieve a lake salinity lower than or equal to 1,000 μS cm^{-1}. • Maintain functional connectivity at the mouth in the majority of years.	Meet in at least 95 per cent of years, with non-complying years non-sequential.
650 to 2,000 GL/year	• Boost flows to at least 1,000 GL/year (to ensure 1,500 μS cm^{-1} threshold is not exceeded. • Further boost flow as required to achieve salinity target (<1,000 μS cm^{-1}).	• Additionally, achieve an enhanced degree of openness of the Murray Mouth. • Enhanced spring fresh to increase certainty of stimulating fish recruitment. • Additionally, achieve a salinity annual mean of ≤1,000 μS cm^{-1}	Meet mouth maintenance target in at least 90 per cent of months. Meet full spring fresh target in 90 per cent of years.
>2,000 GL/year	Boost flows as required to achieve salinity targets in Lake Alexandrina and Coorong South Lagoon.	• Additionally, achieve a salinity annual mean of ≤700 μS cm^{-1} to prevent degradation of marine states in the Coorong and achieve a high degree of certainty that the Ramsar-nominated ecological character will be maintained.	Maintain as the long-term average (meet in at least 50 per cent of years).
	• Periodically boost flows to at least 6,000 GL/year.	• Additionally, achieve a healthy hypersaline state in the South Lagoon.	Maintain long-term average frequency of every 3.6 years, and maximum interval of 5 years.
	• Periodically boost flows to at least 10,000 GL/year.	• Additionally, achieve a healthy hypersaline state in the South Lagoon.	Maintain long-term average frequency of every 10.4 years, and maximum interval of 17 years.

Note: The objectives of each flow band in table 4-2 are additional to those of the lesser flow band/s.

Summary of justification for the flow bands

The steady state annual flow that will sustain less than 1,500 µS cm^{-1} in Lake Alexandrina is 1,000 gigalitres. However, annual flows less than this (down to 60 gigalitres) are tolerable for individual years provided the flows in the two previous years are sufficient, such that salinity remains less than 1,500 µS cm^{-1}. Hence there is a need to review flow delivery over a three-year rolling average.

The steady state annual flow that will sustain less than 1,000 µS cm^{-1} is 2,000 gigalitres. When annual flows regularly exceed 2,000 gigalitres, available additional water can be used to reduce salinity towards the target of 700 (annual mean). The long-term average salinity target for the Lower Lakes is 700 µS cm^{-1} (Lester et al. 2011a), which would be approximated by achieving an annual mean salinity of 700 µS cm^{-1} in 50 per cent of years.

By providing sufficient steady baseflow over the barrages each month, the flow in the river would tip the balance in the Murray Mouth to a net outward flow that would assist in preventing sediment entering the inlet during a rising tide, and assist in flushing sediment during an ebb tide (Walker 2002). There is an increasing relationship between flow volumes and the relative openness of the mouth (i.e. more flow means that the mouth will be more open). Functional connectivity at the mouth will be maintained in the majority of years by delivering the flows that achieve salinity lower than or equal to 1,000 µS cm^{-1} in the Lower Lakes (Lester et al. 2011a).

Close (2002) modelled the impact on risk of mouth closure of maintaining low flows over the barrages of 2,000 ML/day. It was estimated that providing this baseflow would reduce the frequency of risk of mouth closure to about 6 per cent of years, compared to the benchmark scenario with 31.5 per cent of years (Close 2002). Thus, improved connectivity can be achieved with baseflows of 2,000 ML/day. Target frequencies for these objectives have not been specified in the literature. Logically, the average frequency of year-round low risk of mouth closure occurring jointly with a high certainty of stimulating fish recruitment (through a spring fresh), should fall between that of achieving the 1,000 µS cm^{-1} target (95 per cent of years) and the 700 µS cm^{-1} target (50 per cent of years).

A healthy hypersaline state in the South Lagoon requires regular flows of 6,000 GL/year and 10,000 GL/year (Lester et al. 2011a). According to Lester et al. (2011a), these flows should continue to be exceeded at the long-term average frequencies characteristic of the benchmark scenario, which they calculated to be every three and seven years respectively. The modelling undertaken for this project utilised a MSM-Bigmod TLM scenario extending from July 1895 to June 2009 and all calculations were based on water years. In this scenario, annual flows exceeding 6,000 gigalitres and 10,000 gigalitres occurred at long-term average frequencies of every 3.6 and 10.4 years respectively, so the long-term targets used herein have been reset to these frequencies.

The application of the above water requirements targets for water delivery is discussed further in Section 5.

5. Operating regimes

The supply of water to the region below Lock 1 under a regulated flow regime requires a release(s) to be made from upstream storages, either from storages on the River Murray (e.g. Hume Dam) or from the Darling (e.g. Menindee Lakes) systems. The flow to South Australia can be further manipulated (to a degree) by the control of releases from Lake Victoria. The flow to South Australia is set in the field by officers of SA Water based at Berri, South Australia, acting under the direction of River Murray Operations (RMO).

Flow into South Australia is measured under two scenarios determined at Gauging Station (GS) 426200 on the River Murray downstream of Rufus River. If the river height at Gauging Station 426200 is:

- Less than 5.80 metres then flow to South Australia equals flow at GS 426200 + flow at Mullaroo Creek Offtake – Lindsay River allowance.
- Greater than 5.80 metres then flow to South Australia equals flow at GS 426200.

Lake Victoria is the last storage to provide opportunities to manage or manipulate flows in any significant way upstream of Lake Alexandrina. Lock weir pools can be adjusted to influence water levels but the storage volumes they provide are relatively small and hence any flow adjustments they provide are short lived.

Water levels in Lake Alexandrina and the flow through the barrages can be controlled by any of the five sets of barrages. The distribution of flow across the barrages can have an impact on mixing in the North Lagoon of the Coorong and hence any releases require monitoring and adjustment to avoid unwanted results. In general, releases are spread across the Tauwitchere and Goolwa barrages; these releases are managed in part to preserve navigation channels for boats and prevent the lateral movement of the Murray Mouth. The bathymetry of the system is highly variable and hence an adaptive management approach must be applied throughout each release sequence.

Minimum lake-level targets are based on the requirements of vegetation indicator species and assemblages around Lake Alexandrina, while considering disconnection points and seasonal connectivity requirements. However, other management issues do play a role in influencing minimum lake levels (see Section 4.2 for further information).

The proposed approach relies on forecasting flows over a 12-month period. This period is appropriate given that the ecology of the Lower Lakes (and Coorong) is heavily influenced by antecedent conditions over a one to two year time frame. System health is influenced by the conditions that prevailed one or two years previous (Lester et al. 2011b) and system response is influenced by long term (yearly rather than monthly or weekly time periods). Hence any planning decisions need to be made in recognition of past conditions and a long-term forecasting approach is required.

MDBA and DFW presently prepare long-term monthly flow forecasts for planning purposes for lake levels. These forecasts are based on modelled flows to South Australia and this information can be used to provide estimates of flow over the barrages for different inflow regimes.

5.1 Decision triggers for initiating water delivery

Decision triggers have been outlined below in a series of examples designed for longer term implementation of targeted flow regimes (however, these can be equally applied for the short term once a flow forecast is determined).

Water delivery priorities have been assigned based on advice from DENR (J Higham 2010, pers. comm.), with regard to the work of Lester et al. (2011b), and with regard to the draft Icon Site Management Plan. Priorities for meeting the water management objectives have been established because the work underpinning for this document, including Lester et al. (2011b), has highlighted that in many years the full range of desired watering objectives cannot be met.

Achieving minimum lake level targets is considered of highest priority (as explained in the previous section) followed by ensuring variable levels to provide fringing wetlands and lake ecosystems with the desired seasonal water regime.

Once the lake level objective has been achieved, consideration should first be given to achieving the water quality targets (which are based on supporting the ecological objectives of the Lower Lakes) because if these targets can be met then it is likely that the remaining flow based ecological targets can also be achieved. Maintaining sufficient barrage flows to achieve the salinity targets will therefore also ensure that there is sufficient water for the fishways.

The proposed hierarchy for water delivery is as follows:

1. Maintain seasonal water levels in Lake Alexandrina within target levels.
2. Maintain salinity levels in Lake Alexandrina below target levels.
    a. 700 µS cm^{-1} or, if this is not possible,
    b. below 1,000 µS cm^{-1} or, if this is not possible,
    c. below 1,500 µS cm^{-1}.
3. Maintain minimum flow (1,090 GL/year) over the barrages to keep an open Murray Mouth.
4. Manage fishways:
    a. maintain flow through fishways, plus, if there is sufficient water availability,
    b. maintain connectivity of fresh water flows to the River Murray estuary
    c. provide attractant flows, plus, if there is sufficient water availability
    d. provide spring pulse flows through the barrages to support breeding/recruitment.

    Note: Managing flows through the fishways will be a higher priority in years of low flow, where maintaining connectivity will be the primary aim of environmental watering. However, in years of higher flows, it is expected that targeting flows to achieve water quality objectives will also ensure sufficient flows for the fishways.
5. Allow additional flows through the barrages to facilitate the export of salt from the river system and achieve a healthy hypersaline state in the South Lagoon of the Coorong.

5.2 Capacity to meet ecological objectives for different flow regimes and water availability

The hierarchy outlined above was applied to a range of flow series scenarios. The flow scenarios were all provided by MDBA and included the:

- natural flow scenario (assumes no water resources development)
- benchmark scenario ((BM) assumes 1995 level of water resources development)
- benchmark plus The Living Murray water scenario (BM + TLM) (assumes 1995 level of water resources development and within assumed allocation constraints (i) attempting to meet an ecologically desirable target range of lake water levels and (ii) providing 2,000 ML/day (2,500 ML/day in October to December) over the barrages for maintaining the Murray Mouth in an open state).

The modelling process and results are presented in full in Appendix 1.

Analysis of the frequency with which the ecological objectives were met under the benchmark scenario plus allowance for TLM water indicates there is a significant shortfall in many years between the desired flow over the barrages and that which is available.

As expected, the natural flow scenario showed a high level of compliance with the ecological targets, meeting the salinity needs within the desired long-term frequencies (Table 5-1). The other ecological needs were met in 96 per cent of months, but because the non-complying months were scattered throughout the record, only 74 per cent of years had full compliance with other ecological needs (Table 5-1).

The benchmark scenario had low compliance with ecological targets, failing on all required long-term frequencies for salinity targets, and achieving the targets for other needs in only 9 per cent of years (Table 5-1). The Living Murray allocation (BM + TLM) led to a significant improvement in achievement of other ecological needs, rising to 44 per cent of year targets achieved (Table 5-1). The improvement in achievement of salinity targets was less dramatic. This is because the main objective of the TLM environmental water is to maintain the mouth in an open state.

A scenario was run assuming that there was no constraint on water availability. For this scenario only the rules for achieving the 6,000 and 10,000 GL/year targets were adjusted to achieve the desirable long-term average frequency and no better than the maximum frequency (without this adjustment the frequencies would have been higher than necessary to meet the targets). This scenario revealed the volume of water required in each year to augment the flow with the objective of fully complying with all ecological targets. However, there are some aspects of this scenario that deem it impractical:

- In 22 per cent of years the required water exceeds 1,500 gigalitres, and in 9 per cent of years it exceeds 4,000 gigalitres—these volumes are high compared to the volumes that are likely to be available through environmental water allocations.
- In 19 per cent of years, flow at the barrages has to be more than doubled to achieve the targets.
- In general, larger volumes of environmental water are required in years of lower flow at the barrages. In reality, the availability of environmental water is likely to be lower in such years, dependent on the volumes of carryover from the previous water year.

The other scenarios assumed that the availability of environmental water was constrained (Table 5-1). These are hypothetical scenarios, intended only to illustrate the trade-off between water availability and achievement of ecological health targets. Given the unlikeliness of unconstrained allocations being available, it will not be possible to meet all of the ecological targets all of the time, so it is inevitable that some of the time the health of the CLLMM asset will be affected. Having an effective process for balancing water availability and ecological health will be fundamental to the management of the CLLMM asset.

In the scenarios tested, the targets for specific flow based ecological needs were easier to achieve than the salinity targets. An annual allocation of 500 gigalitres or more, with no carryover, achieved the less than 2,000 GL/year targets in 99 per cent of years. Carryover was of variable importance; it was instrumental in improving compliance with targets for other needs if the annual allocation was low, and it was important in improving compliance with salinity targets if the annual allocation was large (Table 5-1). Success in meeting the 6,000 and 10,000 GL/year targets principally depended on the arbitrary additional volume of environmental water provided for this purpose.

Illustration of how potential supply of allocated environmental water holdings could be distributed to augment the flow under the constrained allocation scenarios is provided for two scenarios: 300 gigalitres with no carryover (up to 300 gigalitres in storage) (Appendix 1, Figure 0-4) and 800 GL/year with carryover permitted (up to 3,000 gigalitres in storage) (Appendix 1, Figure 0-6). These scenarios illustrate how environmental water is required in years of low to moderate flow, which is the fundamental management problem of the CLLMM asset.

Health indicator scores were determined for the modelled scenarios. These scores were calculated as the observed annual flow divided by the annual flow required to fully meet the targets (observed to expected (O/E) scores). The CLLMM asset health indicator scores (Appendix 1, Figure 0-8 and Figure 0-9) were favourable for the entire time series of the natural scenario, except for 2006 to 2008, when the 700 $\mu S\ cm^{-1}$ salinity target was rated very poor. In the benchmark scenario there were periods of high compliance with ecological targets, but overall, the health indicator scores were poor most of the time. The period of worst health was from 2002 to 2008.

Comparing three of the environmental water availability scenarios:

- A scenario with 300 gigalitres annual allocation and no facility for carryover satisfied the other objectives, but the 700 $\mu S\ cm^{-1}$ and 1,000 $\mu S\ cm^{-1}$ targets were only partially met in most years.
- A scenario with 800 gigalitres of annually allocated environmental water and up to 3,000 gigalitres being held in storage almost satisfied all of the targets; the 700 $\mu S\ cm^{-1}$ target was met in approximately half of the years (as desired), and in the non-complying years the health score for this indicator was mostly in the range poor to very poor (O/E score of 0.2 to 0.6).
- A scenario with unlimited allocation available satisfied all of the targets. Note that for good ecological health the 700 $\mu S\ cm^{-1}$ target does not have to be met in every year, as the requirement is for this to be the long-term average salinity. This is the main difference in health achieved by this scenario compared to that of the natural scenario. Although having unlimited allocation available achieved all of the ecological targets, the performance of this scenario was only marginally better than the scenario with allocation constrained to 800 gigalitres per year and carryover available, but at an average annual cost of 268 gigalitres per year in additional water.

Table 5-1: Compliance of flow scenarios with ecological targets and environmental water allocation use.

(BM = Benchmark; TLM = The Living Murray; CEW = Commonwealth environmental water, XXX/YYYY (XXX = annual allocation, YYYY = max allocation that can be held in storage)

Scenario	Salinity targets			Other ecological needs						Other ecological needs combined (for Q < 2,000 GL)		CEW allocation used		
	0 – 60 GL	60 – 650 GL	>650 GL	0 – 60 GL	60 – 650 GL	650 – 2,000 GL		> 2,000 GL						
	1,500 EC % of years met	1,000 EC % of years met	700 EC % of years met	% of years met	% of years met	Mouth open % of mths met	Spring fresh % of years met	6,000 GL max. interval (years)	10,000 GL max. interval (years)	% of mths met	% of years met	% of years called on	Mean (±SD) (GL/ year)	Max. (GL/ year)
Target	100	95	50	100	95	90	90	5 years	17 years	-	-	-	-	-
Natural	100	98	94	100	100	96	96	3	5	96	74	-	-	-
BM	82	63	31	95	88	51	50	11	22	49	8	-	-	-
BM + TLM	89	71	32	97	92	92	46	11	21	86	42	-	-	-
BM + TLM + CEW 200/200	93	75	38	100	92	93	78	7	14	93	68	74	373 (629)	2,888
BM + TLM + CEW 200/1000	94	76	40	100	95	93	84	7	14	94	76	73	425 (702)	3,664
BM + TLM + CEW 200/2000	94	76	42	100	95	93	85	7	14	94	77	73	428 (702)	3,664
BM + TLM + CEW 300/300	96	77	39	100	96	93	91	7	14	96	83	74	417 (619)	2,888
BM + TLM + CEW 300/1000	96	78	44	100	97	93	94	7	14	97	88	73	502 (745)	3,664
BM + TLM + CEW 300/2000	96	78	45	100	97	93	95	7	14	97	89	73	503 (746)	3,664
BM + TLM + CEW 500/500	97	80	39	100	100	96	100	6	14	100	99	73	505 (659)	3,016
BM + TLM + CEW 500/1000	98	80	46	100	100	96	100	5	14	100	99	71	623 (829)	3,664
BM + TLM + CEW 500/2000	98	81	49	100	100	96	100	5	14	100	99	71	643 (840)	3,664
BM + TLM + CEW 800/800	98	82	43	100	100	96	100	6	14	100	100	72	625 (739)	3,475
BM + TLM + CEW 800/1000	98	85	46	100	100	96	100	5	14	100	100	71	709 (875)	3,664
BM + TLM + CEW 800/2000	98	88	50	100	100	96	100	5	14	100	100	71	775 (951)	3,800
BM + TLM + CEW 800/3000	100	92	51	100	100	96	100	5	14	100	100	71	815 (1014)	3,930
BM + TLM + CEW unlimited	100	98	65	100	100	96	100	5	17	100	100	67	1,078 (1713)	8,384

Note: Green shading = target met; red shading = target not met.

5.3 Water allocation and supply decision support

As outlined in Section 4 and above, the targets for flow and salinity all vary depending on antecedent conditions over the previous two years as well as flows during the forecast year. Furthermore, the capacity to achieve the targets is limited by the available environmental water during the current year, including any provisions for carrying over water.

The process for predicting likely environmental water requirements is proposed as follows:

1. Assess the flow forecast for the coming year, consider also:
    a. a lower bound estimate (entitlement flow)
    b. dry scenario (30th percentile monthly flows)
    c. median scenario (50th percentile monthly flows)
    d. wet scenario (assumed to be 70th percentile monthly flows).

    This can be done by forecasting flow to South Australia for the year and then running this through MSM-Bigmod (incorporating provision for TLM water).

2. Calculate the annual flow target forecast for the 700 and 1,000 µS cm^{-1} salinity targets. This includes consideration of flows of previous years.
3. Forecast the environmental water availability for the year, including any carryover.
4. Compare the annual forecast and forecast ranges (dry, wet etc.) including the available environmental water with the target annual flow for the year to determine if that target can be met. If the desired target cannot be met then adopt the highest flow regime target that can be achieved.
5. Run MSM-Bigmod model (incorporating provision for TLM water) through the forecast year to determine if minimum lake level targets will be met and calculate the month and amount of any shortfall.
6. Make provision for meeting the shortfall in lake level (volume) in the monthly distribution of the year's available environmental water.
7. Forecast the required monthly provision of environmental water (once water level requirements are satisfied) based on Table 5-2 and re-run MSM-Bigmod (incorporating provision for TLM water) by applying the proposed environmental water distribution to confirm water level and flow targets are met. Adjust as appropriate.
8. Review each month by updating actual flow data and incorporating revised forecasts as they become available.

Table 5-2: Target flow regime monthly distribution (volumes).

Month	Flow (GL)							
Jul	5	52	93	148	263	348	548	948
Aug	5	52	93	192	330	432	672	1,152
Sep	5	59	90	259	443	579	899	1,539
Oct	5	60	93	285	492	645	1,005	1,725
Nov	5	59	90	259	443	579	899	1,539
Dec	5	60	93	210	348	450	690	1,170
Jan	5	60	93	185	300	385	585	985
Feb	5	46	84	96	1,65	216	336	576
Mar	5	51	93	93	93	93	93	93
Apr	5	50	90	90	90	90	90	90
May	5	51	93	93	93	93	93	93
Jun	5	50	90	90	90	90	90	90
Annual Target	60	650	1,095	2,000	3,150	4,000	6,000	10,000

Table 5-3: Target flow regime monthly distribution (percentages).

Month	Flow Proportion (%)							
Jul	8%	8%	8%	7%	8%	9%	9%	9%
Aug	8%	8%	8%	10%	10%	11%	11%	12%
Sep	8%	9%	8%	13%	14%	14%	15%	15%
Oct	8%	9%	8%	14%	16%	16%	17%	17%
Nov	8%	9%	8%	13%	14%	14%	15%	15%
Dec	8%	9%	8%	11%	11%	11%	12%	12%
Jan	8%	9%	8%	9%	10%	10%	10%	10%
Feb	8%	7%	8%	5%	5%	5%	6%	6%
Mar	8%	8%	8%	5%	3%	2%	2%	1%
Apr	8%	8%	8%	5%	3%	2%	2%	1%
May	8%	8%	8%	5%	3%	2%	2%	1%
Jun	8%	8%	8%	5%	3%	2%	2%	1%
Annual target (GL)	60	650	1,095	2,000	3,150	4,000	6,000	10,000

The flow distribution for target annual flows of 1,095 gigalitres or less are based entirely on criteria described in Table 4-1 and the requirement to maintain a minimum barrage flow of 3,000 ML/day to maintain an open Murray Mouth. In flow years where the achievable flow is above 1,095 gigalitres, the first 1,095 gigalitres is apportioned in accordance with the above requirements with the balance apportioned throughout the year in accordance with the distribution presented in Table 5-4.

Table 5-4: Proposed flow distribution for flows over 1,095 GL/year.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10%	6%	0	0	0	0	10%	12%	16%	18%	16%	12%

The distribution in Table 5-4 is based on the 'natural' flow to South Australia regime reported in Heneker (2010) but adjusted so that the flow over the barrages for the mid-range cases (i.e. between 2,000 GL/year and 4,000 GL/year is similar to the natural flow condition).

The resultant monthly flow sequences for the annual flows presented in Table 5-2 are illustrated in Figure 5-1. The distribution is uniform for the low flow years when only the primary aim is to ensure flow through the fishways and connectivity is maintained between the Lower Lakes and the Coorong. As more water becomes available the proposed approach biases water delivery to the late spring-early summer period in line with the 'natural' flow regime. The mid-flow ranges most closely match the natural flow regimes.

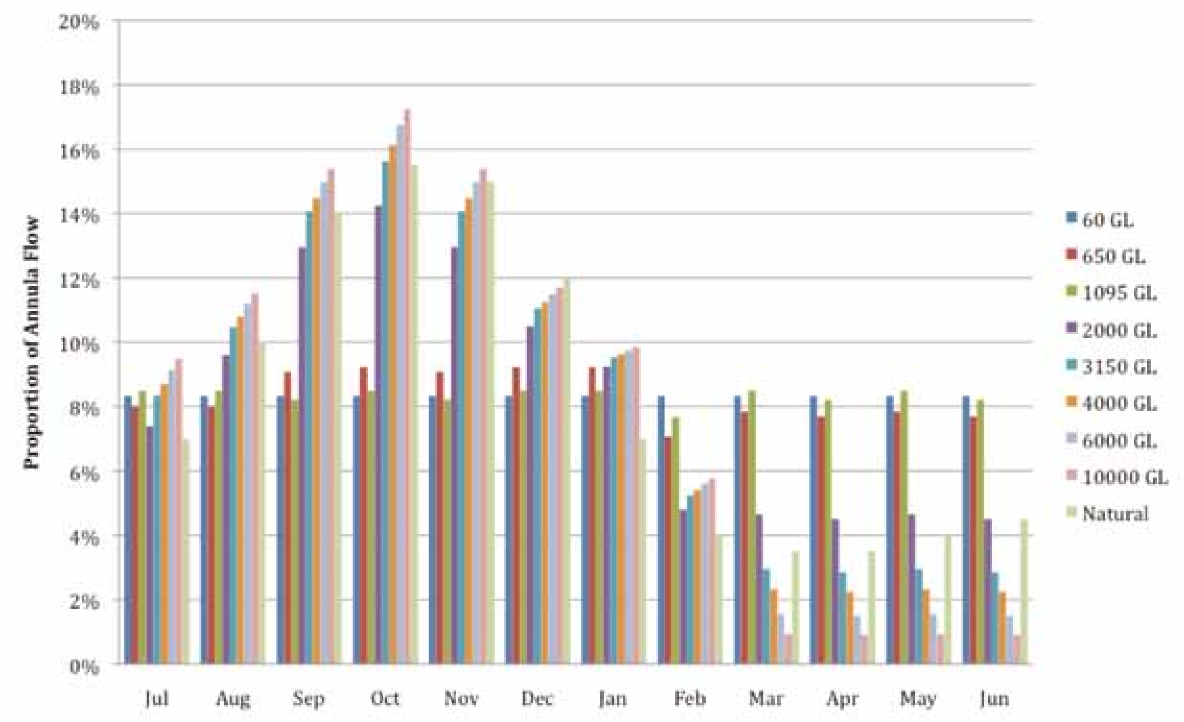

Figure 5-1: Distribution of flow over barrages from proposed watering plan flow allocation for a range of annual flows (as listed in Table 5-2).

As previously discussed, the proposed approach relies on 12-month forecasts. Table 5-5 provides a series of monthly flow sequences based on the MDBA benchmark flow series. These could be used as a starting point in the absence of other forecasting tools in the short term.

Table 5-5: Designated monthly flow bands for flow over the barrages to support interim flow forecasts (GL)*.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Extreme Dry	0	0	0	0	0	0	0	0	0	0	0	0
30th percentile	62	56	62	60	62	60	62	116	199	155	75	62
50th percentile	62	57	62	60	62	107	165	399	490	524	168	79
70th percentile	66	83	132	118	166	298	491	818	964	1,013	723	413

* Note: Percentiles are based on monthly percentiles not annual percentiles

Appendix 2 includes several case studies that illustrate this proposed approach.

5.4 Proposed water-delivery infrastructure

Water delivery would be achieved using existing infrastructure.

Environmental water for the CLLMM is likely to be delivered from Hume Dam, Menindee Lakes and Lake Victoria. To a lesser extent, tributary flows originating in the northern Victorian rivers and the Murrumbidgee River may also contribute. Given the position of the CLLMM at the end of the Murray-Darling system, environmental watering of the asset may be part of a broader multiple-site environmental watering process.

Depending on the desired environmental flow outcome for the CLLMM, there are a number of options for how the water could be delivered. An example delivery option may involve a release of environmental water from Hume Dam as part of managed watering of an upstream environmental asset. Water not used by the upstream sites (i.e. system return flows) would be passed down to the South Australian border, either as a trade or passing flow. The delivery of traded environmental water to South Australia would be the responsibility of the lower River Murray river operator, SA Water. It is likely that part of the environmental water would also be used to water sites upstream of Lock 1, which could include the operation of regulators and weir pool manipulations.

5.5 Water-delivery accounting

Environmental water delivered to South Australia is accurately accounted for at the South Australian border.

There is a velocity index rating gauging station at the town of Morgan that that could be used for water delivery accounting and there are also staged index rating stations at Overland Corner and Lyearup. All of the locks can estimate flow, however, this is more accurate at lower flows, and so flow information through these structures are estimates only. Flow is not measured at the barrages, instead it is estimated based on a rate of 300 ML/day per gate/bay (500 ML/day at Mundoo). However, flows can be significantly less when water levels are elevated in the North Lagoon. Annual barrage flows are determined by assessing the water balance calculation. When flows are less than 50,000 ML/day, the estimates of flow past Lock 1 is considered to be more reliable than the estimates for flows over the barrages. At these flow rates the weir panels at Lock 1 are still in place, whereas at higher flows the weir panels are removed and the lock is 'drowned out'. Ultimately, it is likely that large multiple-site water deliveries will need to be accounted for using a combination of site measurement, hydrological modelling and net loss calculations.

5.6 Operational constraints

The suggested volumes of water can be delivered utilising existing infrastructure and operating regimes.

River channel capacities are generally not a constraint to delivering the recommended flows. The thresholds for significant flooding that would involve significant water loss generally exceed 50,000 ML/day, which is substantially more than regulated flow conditions.

Lake levels in Lake Alexandrina and Lake Albert need to be maintained above +0.35 mAHD to avoid the risk of activating acid sulphate soils with a factor of safety of between 100 to 200 millimetres. This, and the requirements to maintain seasonal variations in lake levels, limits the extent to which these two lakes can be used to provide a balancing storage.

A number of boating regattas are carried out in the summer months in the Lower Lakes. Maintenance of lake levels above +0.35 mAHD is also required to facilitate navigation which would be achieved by maintenance of the minimum target water levels.

6. Governance and planning arrangements

6.1 Strategic delivery partners

The principle delivery partners in involved water to assets within the Coorong, Lower Lakes and main channel below Lock 1 are:

- South Australian Department for Water
- South Australian Department of Environment and Natural Resources
- South Australian Murray-Darling Basin Natural Resources Management Board
- Murray-Darling Basin Authority (River Murray Operations)
- SA Water.

South Australian Department for Water

The South Australian Department for Water (DFW) is the primary authority for the delivery of environmental water in South Australia.

Broadly, the DFW is responsible for water policy, the issuance of water licences and the management of water allocation in South Australia. The Environmental Water Management Team in the DFW is responsible for managing environmental water against Class 9 entitlements (see Section 8.1.4), directing operation of managed pool-level wetlands and coordinating other watering activities in the South Australian Murray. The team is also responsible for developing environmental watering proposals and coordinates input from other agencies, the South Australian Murray-Darling Basin Natural Resources Management Board and local environmental groups.

DFW has joint management of the Lower Lakes, Coorong and Murray Estuary due to its role in The Living Murray icon site management. The South Australian Department of Environment and Natural Resources (DENR) also manage aspects of the site. Both agencies coordinate primarily through a number of committees set up to govern the Lower Lakes and Coorong Recovery Murray Futures project.[2]

South Australian Department of Environment and Natural Resources

The South Australian Department of Environment and Natural Resources (DENR) is responsible for the *National Parks and Wildlife Act 1972* (SA) and manages national parks. The Coorong, Lower Lakes and Murray Mouth group within DENR manages the Lower Lakes and the Coorong Murray Futures project. DENR manages wetlands that are located on crown land and national parks (including areas of the CLLMM).

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[2] Under the Australian Government's *Water for the Future* program up to $200 million will be provided to the CLLMM, which is managed under the state's Murray Futures initiatives.

South Australian Murray-Darling Basin Natural Resources Management Board

The South Australian Murray-Darling Basin Natural Resources Management Board (the Board) is responsible for land and water management on the South Australian Murray. The Board works collaboratively with community groups, Local Action Planning committees and land owners on wetland management (e.g. undertaking works, preparing management plans and monitoring). The Board serves this function from Chowilla Game Reserve through to the Lower Lakes, excluding areas that are managed by DENR (which includes crown land and national parks).

Murray-Darling Basin Authority—River Murray Operations

The Murray-Darling Basin Authority (MDBA) owns barrage and lock infrastructure in South Australia and is responsible for directing their operation.

The supply of environmental water to the CLLMM would likely require a water allocation transfer from interstate to South Australia. River operators will need to be consulted to ensure that the water can be delivered in the required timeframe, and infrastructure can be operated as required.

The MDBA also coordinates the Barrages Operations Advisory Group which advises on the direction of barrage releases. This group includes representatives from MDBA River Murray Operations, DFW, DENR, SA Water and the DSEWPaC. On occasion it may include ecologists from the South Australian Research and Development Institute (SARDI) to provide additional advice on ecological benefits of barrage releases.

SA Water

SA Water is responsible for operating barrage and lock infrastructure in South Australia, as directed by the MDBA.

6.2 Approvals, licences, legal requirements, other administrative issues

Water use approvals

The Australian Government has no Water Resource Works Approvals or Site Use Approvals to enable use of environmental water in South Australia. Thus, for the Australian Government to use environmental water in South Australia, water allocations are traded to an account that has these approvals. These approvals could be obtained through an application process with landholders' consent, or arrangements could be made to utilise existing approvals held by landholders. The current process includes the development of watering options in consultation with the DFW Environmental Water Management Team and utilisation of the South Australian Minister for Water's environmental water account (which has the required approvals).

Relevant trading rules and system accounting

The supply of environmental water to the assets below Lock 1 would likely require a water allocation transfer from interstate. This water holding would be delivered under the operational arrangements that are established with River Murray Operations, in accordance with trading and delivery protocols outlined in the Murray-Darling Basin Agreement (Schedule 1 to the *Water Act 2007* (Cwlth)).

Paragraph 3 of the Murray-Darling Basin Agreement Protocol 2010 (Schedule D—Adjusting Valley Accounts and State Transfer Accounts) prescribes how traded water allocations are delivered between states. Allocations traded to South Australia must be delivered between September and April in a manner that conserves the proportions of the entitlement pattern, however, the MDBA may deliver outside of the entitlement pattern to match expected demands. This exception provides flexibility to enable the delivery of environmental water to the South Australian border when it is required (in the absence of other delivery constraints).

Trades to South Australia are accounted for at the border by the MDBA. This is the primary, accurate accounting point in South Australia and thus water cannot be ordered to a point downstream of the border.

During periods of surplus flow to South Australia (unregulated conditions), water trades to South Australia are first met by the surplus flows. This is a likely constraint to the use of environmental water holdings, as trading water to South Australia during these conditions would not result in additional water in the system. The trade of environmental water to South Australia would be met by the surplus water already in the system, and not by water held in storages. Other ways of releasing water from storages that would result in increased flows at the South Australian border will need to be investigated to overcome this constraint. A possible solution is the use of return flows from upstream watering actions and tributary flows.

Transferability of water holdings

The Australian Government holds Class 1 and Class 3a entitlements in South Australia. Allocations to both these classes can be traded to another person, intra or interstate.

Other approvals

The current approach to use of environmental water in South Australia has been to engage the Environmental Water Management Team of the DFW to implement water delivery. In this role the DFW has been responsible for ensuring that any approvals required for the watering actions are obtained, including for water delivery, works required to enable that delivery, and any environmental approvals.

6.3 Existing water use planning

6.3.1 Environmental water use plans

Coorong and Lower Lakes

Currently there is no dedicated environmental water allocation plan for the Coorong, Lower Lakes and Murray Mouth; however a TLM icon site environmental water management plan is under development. There have been various studies to estimate the environmental requirements of this site to inform the TLM program and planning for the Murray-Darling Basin Plan (MDBA 2010).

River channel and pool-level wetlands below Lock 1

The majority of wetlands below Lock 1 do not have environmental management plans. The pool-level regulated wetlands approved for Class 9 entitlement do have management plans. Other relevant plans include:

- The River Murray Channel icon site environmental management plan 2006–2007 (MDBC 2006). This plan sets out objectives and management actions to protect and enhance the values of River Murray Channel icon sites, along with a monitoring and evaluation program. An environmental water management plan is currently (2011) being developed for this icon site which will describe more explicitly the environmental water requirements.
- The Water Allocation Plan (WAP) for the River Murray Prescribed Watercourse (South Australian Murray-Darling Basin Natural Resources Management Board, July 2009). The WAP specifies that 200 gigalitres is provided for the evaporative losses for pool-level wetlands and provides guidance on the requirements for pool-level managed wetlands to receive allocation (Class 9 entitlements). Details on how water should be used at the pool-level managed wetlands are described in each approved wetland's management plan.

6.3.2 Other water management plans relevant to environmental water use and planning in South Australia

- River Murray System Annual Operating Plan: this annual plan describes the potential delivery volumes and anticipated operation of major infrastructure along the river for the next water year, taking into account forecasted water availability, constraints such as construction works, objectives for the environment and public water supply.
- The South Australian Strategic River Murray Environmental Water Plan 2008–2013 sets out the principles that guide decision-making by the South Australian Government about environmental water priorities in the South Australian Murray (Stribley & Goode 2008).

7. Risk assessment and mitigation strategies

The risk assessment outlined in Table 7-1 provides an indication of the risks posed to the environmental assets in the Coorong, Lower Lakes and main channel below Lock 1 by the water use options proposed in this document. This table specifically does not include operational risks associated with the delivery of environmental water to the focus area (i.e. it does not include any risks to areas upstream of Lock 1). It should be noted that risks are not static and require continual assessment to be appropriately managed. Changes in conditions will affect the type of risks, the severity of their impacts and the mitigation strategies that are appropriate for use. As such, a risk assessment must be undertaken prior to the commencement of water delivery. A framework for assessing risks has been developed by DSEWPaC and is included at Appendix 6.

Table 7-1: Risks associated with environmental water options for the Coorong, Lower Lakes and main channel below Lock

Risk	Description	Likelihood	Consequence	Risk ranking	Mitigation
Water quality and salinity					
Acid sulphate soils (ASS)	ASS are known to occur in Lake Alexandrina and Lake Albert as well as upstream in the Murray channel and associated wetlands (Fitzpatrick et al. 2008a, 2008b, 2009). Any unforseen reduction in flow exposing these soils would present water quality management issues for these areas.	Possible	Moderate	Medium	Undertake a detailed assessment of sites suspected/known to contain ASS to quantify the level of risk and identify appropriate management strategies. If water levels are maintained within the levels proposed in this document, ASS are unlikely to constitute a major risk.
Blackwater (low dissolved oxygen)	Blackwater events in the Murray River generally originate in the upper catchment areas (i.e. central Murray floodplain forests), however, they have the potential to occur anywhere that organic material is mobilised from the floodplain. Blackwater events upstream may carry anoxic waters through to South Australia, and impact local ecology, or, they may be created in South Australia itself.	Unlikely	Moderate	Low	Assess likelihood of high flow volumes creating blackwater events in South Australia and adopt appropriate management strategies for high flow events (e.g. conduct watering outside of the spring-summer period where possible, ensure follow-up flows to the event will occur to flush any anoxic waters). Work with upstream environmental water managers to ensure South Australia is notified of backwater events and develop management strategies to cope with such an event (e.g. ensure follow-up flows to the event will occur to flush any anoxic waters). Blackwater events are likely to be diluted by the time flows reach the South Australian border.
Salt mobilisation during high flows	Salt discharge into the River Murray in South Australia originates from direct groundwater discharge and the mobilisation of accumulated salts in wetlands and from floodplain soils. The risk of salt mobilisation increases with the extent and duration of floodplain inundation. Saline flows may also originate from floodplain inundation occurring upstream of South Australia. Salinity is an ongoing management issue for the Lower Lakes and Coorong, as the receiving water bodies of River Murray flows.	Possible	Major	High	Monitor salinity of flows upstream, and within, South Australia. Ensure appropriate management strategies are in place to manage salt mobilised during and after high river flows (e.g. ensure follow-up flows to the event will occur to flush salts from the river system, and manage lake levels and barrage operations to enable flushing to occur).

Risk	Description	Likelihood	Consequence	Risk ranking	Mitigation
Ecology					
Spread of, or benefit to, non-native vegetation species.	Non-native vegetation species may be spread through the provision of flows.	Possible	Moderate	Medium	Vegetation condition and composition is monitored bi-annually and appropriate management should be instigated should a threat occur. The status and management guidelines for weeds of national significance can be found at: http://www.weeds.gov.au/weeds/lists/index.html. Aquatic weeds likely to occur in the region are listed at: http://www.weeds.org.au/cgi-bin/weedident.cgi?tpl=form.tpl&state=sa&s=&region=sesa&form=water
Spread of, or benefit to, non-native fish species	Environmental water that targets ecological events such as fish spawning and recruitment may also provide benefits to non-native fish species.	Possible	Moderate	Medium	Where possible, the delivery of environmental water should be timed to avoid spawning periods for non-native fish. Allowing connected wetlands between Lock 1 and Wellington to dry could allow removal of carp.
Species impacted by inappropriate flooding regimes	If the environmental flows are interrupted, resulting in a rapid recession/draw-down of river flows then fish may become stranded in off-channel habitats. Also, environmental flows that are inappropriately timed/suddenly stopped may result in a 'false start' to spawning and recruitment processes.	Unlikely	Minor	Low	Environmental watering should be managed to ensure that flows can be provided for the duration required.
Geomorphic impacts					
Erosion	Areas of unstable bank along the North Lagoon could be destabilised by the release of additional flows that could exacerbate these processes by elevating water levels.	Possible	Minor	Low	Monitor areas and if necessary implement bank protection measures before undertaking subsequent releases.
	Areas of unstable bank along the lakes and main river channel could be destabilised by elevating or lowering water levels.	Possible	Minor	Low	Monitor areas and if necessary implement bank protection measures before undertaking subsequent lake level rises. Adjust rates of rise and fall as necessary.
Sedimentation	Increase in sediment transport causing movement in the Murray Mouth and disturbance of navigation channels.	Unlikely	Minor	Low	Considered unlikely at flow rates proposed.

Risk	Description	Likelihood	Consequence	Risk ranking	Mitigation
Hydrology					
Inundation risks	Inundation of semi-permanent wetlands in the area below Lock 1 is likely (to some extent) during the watering actions proposed.	Likely	Minor	Medium	Inundation of semi-permanent wetlands below Lock 1 is targeted as part of the watering actions proposed in this document. Risks to private land or infrastructure, including public inconvenience, should be determined prior to implementation and managed accordingly (including communicating with the landholders and public).
Operational					
Diversionary loss	Landholders may deliberately or inadvertently divert the environmental water for their own personal use.	Unlikely	Minor	Low	Provision of environmental water under regulated river conditions will protect the security of the water from unintentional diversion as it flows from the point of release to the South Australian border. From the border, South Australia will manage water as an environmental flow and it will not be available for consumptive use or capture.
Other risks					
Community perception and reaction	Adverse community reaction to releases of water.	Possible	Minor	Low	Liaise with relevant stakeholders, including SA MDB NRM Board and CLLMM Community Reference Group. Communicate the objectives and benefits of environmental watering through media releases.

8. Environmental water reserves

8.1 South Australian water availability

8.1.1 South Australian entitlement flow

Water availability for the River Murray in South Australia is determined by the Murray-Darling Basin Cap (for South Australia) and the entitlement flow, both prescribed under the Murray-Darling Basin Agreement (Schedule 1 to the *Water Act 2007* (Cwlth)).

The Cap volume determines the volume of water that can be diverted from the River Murray for consumptive purposes (i.e. all other consumptive uses other than the environment). The entitlement flow for South Australia under the Murray-Darling Basin Agreement determines the minimum flows that South Australia will receive across the border.

Under the Murray-Darling Basin (MDB) water sharing rules, South Australia is guaranteed a minimum entitlement flow of 1,850 GL/year. This comprises a consumptive water entitlement of 1,154 GL/year and a dilution and loss entitlement of 696 GL/year (58 gigalitres per month), as summarised in Table 8-1. During periods of low flow, these figures may need to be adjusted by the formal processes outlined in the Murray-Darling Basin Agreement.

Table 8-1: South Australian entitlement flow.

Month	Consumptive share (GL)	Dilution and loss share (GL)	Total entitlement (GL)
July	50.5	58	108.5
August	66	58	124
September	77	58	135
October	112.5	58	170.5
November	122	58	180
December	159	58	217
January	159	58	217
February	136	58	194
March	128	58	186
April	77	58	135
May	35	58	93
June	32	58	90
Annual	**1,154**	**696**	**1,850**

The Murray-Darling Basin Agreement states that if the MDBA decides that flow or prospective flow in the River Murray downstream of its junction with the Great Darling River Anabranch for the month will be in excess of: (a) South Australia's entitlement flow; (b) flows that are required for Lake Victoria; and (c) any use by New South Wales and Victoria downstream of the junction, then surplus (also known as unregulated) flows may occur at the South Australian border. If South Australia receives surplus flow in one month, then it will not alter the entitlement flow for subsequent months.

South Australia's dilution and loss entitlement is fixed and does not match real-time loss and dilution requirements between the border and the Murray Mouth, which typically varies between 950 and 1,350 GL/year. Unregulated flows typically cover any loss and dilution shortfalls in the lower River Murray, and some of the consumptive share may also contribute to meeting these losses. However, during dry periods there is often not enough flow to meet the shortfall (DEH 2010). For example, from March 2007 to September 2010 there was no flow through the barrages as there was not enough water to meet the losses in the system, resulting in water levels in the Lower Lakes reaching record lows.

8.1.2 Additional dilution flow

Since 1989, South Australia has also received additional dilution flows (ADF) from the Menindee Lakes at times when sufficient water is available in the lakes. The intent of the ADF rules is a 'use it or lose it' principle whereby additional water is delivered to South Australia to reduce river salinities, rather than lose the water as evaporation from Menindee Lakes.

Under the ADF rules, South Australia receives 3,000 ML/day above the daily equivalent of the monthly entitlement flow whenever storage levels concurrently exceed both the triggers in the Menindee Lakes and combined Hume/Dartmouth storage (see Table 2 MDBA (2010b)).

Table 8-2: Additional dilution flow storage triggers (GL).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Menindee Storage	1,300	1,300	1,300	1,300	1,300	1,650	1,650	1,500	1,300	1,300	1,300	1,300
Hume & Dartmouth Storage	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000

8.1.3 Regulation of South Australian River Murray flows

Flows of water in the River Murray to South Australia are regulated by releases of water from Hume Weir, Lake Victoria, and Menindee Lakes, with Dartmouth Dam providing inter-annual regulation.

Much of South Australia's entitlement flow is delivered as a regulated release from Hume Dam, the Menindee Lakes and Lake Victoria, particularly during the summer and autumn months when unregulated flows are generally lower and water demands are high. During the winter and spring months, system inflows are generally higher, with high upstream unregulated flows contributing to, and exceeding, South Australia's entitlement flow.

The annual average and median flows of River Murray water to South Australia are 6,750 gigalitres and 4,600 gigalitres respectively (modelled flows under current conditions for the period 1891 to 2000), which are significantly higher than South Australia's entitlement flow of 1,850 GL/year (SA MDB NRM Board 2009).

8.1.4 South Australian River Murray licences

The framework for water planning and management in South Australia is established under the *Natural Resources Management Act 2004* (SA). Under this Act a water resource may be prescribed, and if prescribed, the relevant regional Natural Resource Management Board will prepare a Water Allocation Plan. This plan guides the distribution of water access entitlements, the determination of water allocations and sets conditions for the taking and use of water. In this instance, the relevant plan is the Water Allocation Plan for the River Murray Prescribed Watercourse (the WAP) (SA MDB NRMB 2009).

In 2009, water rights and responsibilities were unbundled in South Australia. This effectively enabled simpler and faster trade of water allocations and water entitlements. Previously, one licence contained all the specifications for entitlement allocation and use of water. Now, four separate pieces of legal authority allow for use of water in the South Australian River Murray (DWLBC undated). These are:

- Water Access Entitlement—ongoing right to a specified share of the water resource, set out on a water licence. This asset can be sold or transferred permanently or for a limited period.
- Water Allocation—right to take a specific volume of water for a given period of time, not exceeding 12 months. This right will specify the actual volume of water able to be used. The actual volume may vary depending on how much water is available, and is determined and announced by the South Australian Minister for the River Murray at the beginning of a water year (financial year). This asset can be sold.
- Water Resource Works Approval—permission to construct, operate and maintain works (such as a pump, well or dam) to take water at a particular location in a particular way. The requirement to meter the water taken from the resource is connected to this approval. This permission is not transferable to another location.
- Site Use Approval—permission to use water at a particular location in a particular way. This permission is not transferable to another location.

The WAP describes nine classes of Water Access Entitlements. These were established to reflect the reliability and transferability of the water. The classes do not necessarily reflect purpose of use, however they align to individual or groupings of the former purpose-based allocations as outlined in Table 8-3 (SA MDB NRM Board 2009).[3]

Table 8-3: South Australian River Murray water access entitlements.

Class No	Former class type	Maximum no. of unit shares	Maximum allocation (GL)	Water access entitlements endorsed on 2011 licences (unit shares)
Class 1	Stock and domestic	8,704,910⁽¹⁾	8.7	8,375,134
Class 2	Urban use—country towns	50,000,000	50.0	50,000,000
Class 3a	Irrigation	565,057,136	565.1	545,009,002
Class 3b	Irrigation			19,765,134
Class 4	Recreation	4,423,526	4.4	4,428,526
Class 5	Industrial and industrial dairy	5,519,841	5.5	5,519,841
Class 6	Urban use—metropolitan Adelaide	130,000,000	130.0⁽²⁾	130,000,000
Class 7	Environment	38,366,550	38.4	38,366,550
Class 8	Environmental land management	22,200,000	22.2	21,426,388
Class 9	Wetlands	200,000,000	200.0	33,421,070
Total		**1,024,271,963**	**1,024.3**	**856,311,645**

(1) Includes contingency of 1,000,000 shares for additional stock and domestic entitlements.

(2) Maximum allocation is 650 gigalitres over rolling five-year period, with allocations in excess of 130 gigalitres in some years.

Characteristics that differ between Water Entitlement Classes (SA MDB NRM Board 2009, DWLBC 2011b, DFW 2011) include:

- Except for Class 6 and Class 9 entitlements, the maximum volume of water that can be made available for allocation is 1 kilolitre per unit share. Class 6 are eligible for more than 1 kilolitre per unit share, as the allocation is provided as a five-year rolling entitlement. Thus, some years may receive less or more than 1 kilolitre per share. Class 9 may receive more than 1 kilolitre per share when flows to South Australia are above entitlement.[4]
- South Australian River Murray licences are essentially all high reliability. However, there is no set relative reliability of classes and during periods of drought classes may be prioritised for allocation by the minister.
- A Water Entitlement Class cannot be converted to another class with the exception of conversion between Class 3a and 3b.

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[3] The former purpose of use class type is no longer applicable since unbundling of water rights that allowed for the separation of use from the access and allocation entitlements.

[4] This exception has not been applied to date.

- Classes may differ in eligibility for carryover. Amendments to the Murray-Darling Basin Agreement in 2008 saw the development of Schedule G that accounts for South Australia's storage right. This schedule came into effect on 1 September 2011 and enables carryover of water for critical human water needs and for private carryover of irrigation entitlements. South Australia is currently developing its rules and policy regarding private carryover.
- Water Allocations and Water Access Entitlements may be traded to another person intrastate (except for Class 6 entitlement water allocations). Class 8 and Class 9 allocations can be traded but water use remains subject to conditions of these classes[5] (SA MDB NRM Board 2009)
- Water Access Entitlements cannot be traded interstate. Water allocations on all Classes except Class 6, 8 and 9 cannot be traded interstate[5].
- Class 8 and Class 9 entitlements are restricted on how and where water can be used: allocations obtained on Class 8 can only be used for environmental land management purposes; and Class 9 entitlements can only be used for approved pool-level wetlands. Any conditions for other Classes would be described on the Water Resource Works Approval or Site Use Approval[5].

8.1.5 Determinations/seasonal allocations

Annual water allocations are issued subject to provisions of the *Natural Resources Management Act 2004* (SA) with the minister determining the volume of water available under each entitlement class, taking into account prevailing conditions, for a 12-month period. Generally, allocation announcements are made twice monthly until the maximum is reached.

8.2 Environmental water holdings/provisions

Environmental water can be allocated to made available for water use actions outlined in this plan from allocations against entitlements held by the Commonwealth and The Living Murray (from a total allocation of 485 gigalitres for the designated icon sites); unregulated flows; and water made available from the South Australian Government to allocate to environmental watering actions.

8.2.1 Commonwealth environmental water holdings

Commonwealth Environmental Water manages water acquired through the *Restoring the Balance in the Murray–Darling Basin Program* and water saved through funding infrastructure and other water delivery efficiencies through the *Sustainable Rural Water Use and Infrastructure Program*. The Australian Government holds water access entitlements under relevant state or territory legislation, and is bound by the same rules, restrictions and fees that apply to all holders of water access entitlement in each jurisdiction (SEWPaC 2011).

It is envisaged that the Commonwealth water portfolio will continue to increase over time. As at 4 October 2011, Commonwealth environmental water included 739,536 megalitres in the southern connected basin and 1,062,066 megalitres in the entire Murray-Darling Basin. Of this volume, the Commonwealth held 72,679 megalitres of South Australian Water Access Entitlements. These entitlements are Class 1 (43 megalitres) and Classes 3a and 9 (72,636 megalitres). Updated information on the Commonwealth's environmental water portfolio can be found at: http://www.environment.gov.au/ewater/about/holdings.html

In order to satisfy the environmental water requirements in South Australia it will be necessary to trade water into the state from upstream. Rules governing how water can be traded and delivered to South Australia are specified in the Murray-Darling Basin Agreement.

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[5] These restrictions do not apply to Class 9 water access entitlements traded to the Commonwealth, and allocations against these entitlements.

8.2.2 South Australian environmental water provisions

Of the South Australian River Murray Water Entitlement Classes, there are two that are relevant to the environment: Class 7 and Class 9 (refer to Table 8-3).

Class 7 licences comprise the South Australian entitlements under The Living Murray entitlements (36,662,218 shares), some private environmental water entitlements (1,699,333 shares), and an entitlement held by the South Australian Minister for the River Murray (4,999 shares) (DFW 2011, pers. comm., 19 May). The minister's entitlement is not necessarily for environmental use, and is not available to be assigned to watering actions.

Class 9 entitlement volume is provided for from the dilution and loss share of South Australia's entitlement flow. The portion of shares associated with this class corresponds to the estimated annual average evaporative loss from all pool-level wetlands (200,000 megalitres) and so Class 9 has been assigned 200,000,000 unit shares.

Of the 200,000,000 Class 9 shares, currently only 33,421,070 are assigned to entitlements, as not all pool-level wetlands are managed and require an allocation. Of these shares, with the exception of a Water Access Entitlement for Banrock Station, are held by the South Australian Minister for the River Murray to enable a coordinated approach to management of the pool-level managed wetlands (DFW 2010, pers. comm.).

A list of current pool-level managed wetlands that are approved for entitlement is provided in Appendix 3. New entitlements may be granted by the South Australian Minister for the River Murray as more pool-level wetlands become regulated. The WAP outlines a number of requirements that must be met for these wetlands to obtain licences, including having a comprehensive management plan. The Environmental Water Management Team of the South Australian Department for Water (DFW) is currently revising the process for managing water allocations for pool-level managed wetlands.

Class 8 Water Access Entitlements may only be used for environmental land management within the Lower Murray Reclaimed Irrigation Area. Allocations are provided for the amelioration of threats such as soil salinisation, subsidence and acidification (SA MDB NRM Board 2009). Generally, Class 8 Entitlements are not used for wetland management or restoration. Paiwalla Wetland (located below Lock 1) has a Class 8 Water Access Entitlement and presents an exception as the wetlands have been restored from an irrigated dairy farm in the Lower Murray Reclaimed Irrigation Area.

The South Australian Government owns limited Water Access Entitlements that can be allocated to environmental watering actions. The use of allocations against Class 9 Water Access Entitlements is limited to managed pool-level wetlands. In the past, water has been purchased on the open market for use on ecological assets and donations have been actively sought (Stribley & Goode 2008).

Water requirements of pool-level managed wetlands (refilling to pool-level and evaporative losses) should be met by the Class 9 shares. During periods of drought these wetlands may not receive water as the wetland may become disconnected from the main channel if river levels drop, or the regulating structures may be closed so that evaporative savings can be made for other water needs in South Australia.

During the recent drought, South Australia made water savings by closing pool-level managed wetlands to assist in meeting water for critical human needs, irrigators and the support of water levels in the Lower Lakes (DEH 2010). During October 2006, all pool-level managed wetlands were disconnected for watering savings. During 2007, six additional un-managed sites were closed (Lake Bonney, Ross Lagoon, Jaeschke Lagoon, Yatco Lagoon, Murbko South wetland and Nelwart Lagoon) following decision by the South Australian senior officials group. Three of these unmanaged sites (Murbko South, Yatco and Nelwart) had permanent management infrastructure installed at this time. While this situation occurred during the drought in the late 2000s, it will not necessarily re-occur should similar conditions arise (DFW 2011, pers. comm.).

8.2.3 Cross-jurisdictional environmental water holdings

The Living Murray program (TLM) is a partnership of all Murray-Darling Basin states and territories. The partner governments committed to recovering 500 gigalitres of water for use at six Living Murray icon sites. Representatives from the partner governments make up The Living Murray Environmental Watering Group which develops an annual (water year) watering plan designed to make best use of available resources. Allocations may not be distributed evenly across sites each year, instead watering will be assigned to associate with natural flooding events. The Environmental Watering Group meets regularly during the year to make recommendations to the MDBA on TLM environmental water use.

8.3 Water availability forecasts

A description of the likely water availability and flows into the lower River Murray is provided fortnightly by the MDBA and DFW. Flood peak estimates within South Australia are provided by DFW based on information supplied through the MDBA River Operations Group, which can provide four to six week projections (assuming no additional system inputs).

Access to this information is available through the following web sites:

- DFW: www.waterforgood.sa.gov.au/news-info/publications/river-murray-flow-advice/
- MDBA: www.mdba.gov.au/water/river_info/weekly_reports

9. Monitoring, evaluation, and improvement

9.1 Existing monitoring programs and frameworks

An extensive range of monitoring programs exist to monitor ecosystem diversity and environmental parameters in the area of the Coorong, Lower Lakes and main channel below Lock 1 in response to watering regimes. These programs are maintained through coordinated efforts between the South Australian Environment Protection Authority (EPA), the South Australian Research and Development Institute (SARDI), SA MDB NRM Board, DENR and the DFW. Funding and project management for monitoring is sourced through DFW (The Living Murray) and DENR (Murray Futures). Monitoring programs are coordinated between both agencies. The monitoring programs are described in Table 9-1 however they are likely to vary with changes to funding availability and monitoring priorities.

These programs would provide sufficient information to monitor the effectiveness of an improved water regime over a long time frame.

Table 9-1: Current monitoring and evaluation in the Coorong, Lower Lakes and main channel below Lock 1

Monitoring parameter	Description	Timing/ frequency of monitoring	Data custodian
Water quality and phytoplankton	Analyses are performed in the field and in the laboratory to assess the condition of the water body against ANZECC guidelines (ANZECC 2000) and predetermined trigger values. **Field analysis**: pH, alkalinity filtered and unfiltered, acidity (if required), temperature, dissolved oxygen, salinity, oxidation reduction potential **Laboratory analysis**: algae, alkalinity as calcium carbonate, acidity as calcium carbonate, aluminium—acid extractable and dissolved, arsenic—total and dissolved, bicarbonate, calcium, chloride, chromium—total and dissolved, cobalt, copper—total and dissolved, conductivity, iron—total and dissolved, magnesium—total and dissolved , manganese—total and dissolved, nickel—total and dissolved, nitrogen—total and nitrate and nitrite and TKN, pH, phosphorus—total and dissolved, potassium—total and dissolved, salinity, selenium—total, sodium—total and dissolved, strontium—dissolved, sulfate, sulfur, and turbidity.	Water quality—fortnightly Phytoplankton—monthly	EPA (SA)
	Between Lock 1 and Wellington the SA MDB NRM Board manages the Community Stream Sampling program that undertakes monitoring of stream tributaries. Monitoring includes water quality testing of ambient water samples as well as macroinvertebrate study and community observations. This monitoring program complements studies undertaken as part of the ongoing monitoring of managed wetlands in the area.	Quarterly—seasonally	SA MDB NRM Board
Benthic macroinvertebrates	At each of the sites, 10 replicate samples are taken haphazardly close to the current water line, and at the locations of the previous water line, which are now submerged. To characterise benthos sediment conditions the samples are taken below, at, and above, current water level. Three samples (to account for small-scale variability) for grain size are taken at each sampling location and pooled into one sample per site. Samples for sediment organic matter are taken at each sampling date again by taking 3 replicate samples that are pooled. Samples for microphytobenthic biomass (Chl-a) are taken. One Chl-a sample is taken per location. All sediment samples are frozen until laboratory analyses are carried out.	Bimonthly, annually	Flinders University
Zooplankton	Three replicate samples are taken in approximately knee-deep water at each site, using a 200 μm mesh plankton net. The sample is scanned by row in a 125 mm^2 gridded Greiner tray. Zooplankton is identified to the lowest taxonomic level as follows: • Rotifera: All known Australian rotifers can be keyed from Shiel (1995) and the more recent guides to the *Identification of the Microinvertebrates of the Continental Waters of the World* series (Backhuys, Netherlands). • Cladocera: Cladocerans may be identified to family and sometimes genus on gross morphology, but to species resolution requires dissection of trunk limbs, post-abdomen or other body parts. • Copepoda: Copepoda can be identified by examination of the dissected limb, antenna or mouthpart structure, depending on group. • Ostracoda: Ostracods require dissection and comparison of furcae, thoracopods and other limb structures. There is no comprehensive key to Australian ostracods, but the papers of De Deckker (2002) provide direction. • Other components: Small macroinvertebrates such as dipteran larvae, hydracarinid mites, barnacle or crab larvae in estuarine conditions, or various other small macroinvertebrates, are identified using appropriate treatment and keys.	Monthly	University of Adelaide

Monitoring parameter	Description	Timing/ frequency of monitoring	Data custodian
Vegetation	The Living Murray Lower Lakes vegetation condition monitoring (Marsland & Nicol 2009) protocol is used. 1x3 m quadrats are established at varying heights on transects running perpendicular to the shore at each site. Cover and abundance of each species present in the quadrat are estimated using the method outlined in Heard and Channon (1997), except that N and T were replaced by 0.1 and 0.5 to enable statistical analyses. The changes in floristic composition through time (seasonal and longer term) are analysed using multivariate analyses, such as clustering, nonmetric multidimensional scaling ordination, PERMANOVA and indicator species analysis.	Spring, autumn each year	SARDI Aquatic Sciences
Fish	Boundary Creek and Mundoo Channel fish assemblages below the barrages.	Bimonthly	University of Adelaide
	This monitoring program samples the 'whole' fish community (i.e. small-bodied and large-bodied and larval life stages) and detects spawning and recruitment. This includes single-wing fyke nets, large mesh gill nets, seine pulls and larval plankton tows. All fish collected from fyke, gill and seine nets are identified to species and counted.	May and Nov each year	SARDI Aquatic Sciences
	Lower Lakes TLM Condition Monitoring of Threatened Fish Species program target Murray hardyhead, Southern pygmy perch and Yarra pygmy perch populations and recruitment using single-wing fyke nets, seine net hauls, box traps and dab nets.	April and Nov each year	University of Adelaide
	Coorong TLM Condition Monitoring for small-mouthed hardyhead, black bream and greenback flounder populations using seine and fyke nets.	Seasonal, depending on species targeted	SARDI Aquatic Sciences

Monitoring parameter	Description	Timing/ frequency of monitoring	Data custodian
Birds	The University of Adelaide—TLM Coorong bird census and habitat monitoring. The Coorong and Murray Mouth is divided into 1 km sections (110 sections): • Murray Mouth estuary (18 sections) • Coorong North Lagoon (44 sections) • Coorong South Lagoon (48 sections). Between 10 to 20 sections are surveyed per day and between 7 and 16 days may be required to complete surveys. Waterbird counts conducted on foot, and by boat. Eastern and western shorelines counted (two observers each). Deeper waterbodies, inaccessible areas and islands counted from a boat (two observers). All waterbirds observed within each 1-km section are recorded. Reported by subsection (e.g. eastern shoreline, western shoreline, centre, island). Behavioural observations recorded (e.g. groupings, distributions), and habitat information relating to chironomid larvae, *Ruppia* spp. and distribution of small mouth hardyhead also collected.	Conducted annually in January	University of Adelaide
	The University of Adelaide also undertakes an annual census of the Lower Lakes, through the TLM program. The lakes are divided into 1 km^2 sections: all birds are counted on foot, using spotting scope and binoculars.	Late January, early February	University of Adelaide
	Australian Wader Studies Group: see Wainwright and Christie (2008), and references therein, for more detail on shorebirds only. North Lagoon, South Lagoon, Murray Mouth Estuary: 25 sections surveyed over two days by land and boat-based teams.	Conducted annually in February	Australasian Wader Studies Group
	Coorong Nature Tours covers fixed sites: • Lake Albert & Alexandrina—23 sites (covering a range of habitats) • Coorong North –10 Sites • Coorong South –10 Sites • Barrage Survey—14 sites. Each site is scanned in an arc radius of approximately 1.5 km. All bird species and numbers viewed are recorded. Special attention is paid to unusual birds for accurate identification (up to 30 mins). All flagged birds observed are recorded and submitted to Birds Australia, a national environmental and research group.	Monthly	SA MDB NRM Board, Coorong Tours Data maintained by DENR in digital database (SVY 177)

Monitoring parameter	Description	Timing/ frequency of monitoring	Data custodian
Frogs	Southern bell frog census of the Lower Lakes: nocturnal surveys are undertaken at sites with suitable habitat using call recognition, call playback and spotlighting techniques. Tadpole surveys undertaken using bait traps and fyke nets.	Nocturnal surveys—October, November and December. Tadpole surveys during January and February	SA MDB NRM Board
Managed wetlands	The SA MDB NRM Board has an ongoing wetland monitoring program at the following Lower Lakes wetlands: Narrung, Teringie, Waltowa, Dunn`s Lagoon, Loveday Bay (Jennie`s Lagoon) and Milang. Wetlands monitored in the river channel below Lock 1 to Wellington include Sweeney’s Lagoon, Morgans Lagoon, Sugarshack wetland, Reedy Creek wetland, Paiwalla, and Rocky Gully wetland. At these wetlands the following parameters are monitored with assistance from community and landholders: water quality and level, groundwater quality and level, photopoints, vegetation, fish, frogs and birds. Monitoring of each parameter does not necessarily occur at each site (depends on site characteristics).	Most parameters quarterly	SA MDB NRM Board
Morella release via Salt Creek (DWLBC 2009): The following monitoring activities will be undertaken for the duration of the release.			
Aquatic habitat and biota monitoring, with quarterly waterbird monitoring.		Quarterly	DFW
Gauging of Morella Basin water levels, temperature and EC (continuous monitoring).		Daily	South Eastern Water Conservation and Drainage Board
Gauging of release volumes, temperature and EC through Morella Regulator (continuous monitoring).		Continuous	South Eastern Water Conservation and Drainage Board
Monitoring of water quality parameters at Morella Basin, Salt Creek and in the mixing zone of the release in the Coorong.		Pre, during and post release	DFW
Nutrient load (Total N and P) monitoring in conjunction with the EPA for the 09/10 release.		Weekly	EPA
Monitoring of Coorong water level, salinity and flow velocity at Snipe Island (A4261165) and Parnka Point (A4260633).		Daily	DFW

9.2 Flow monitoring sites

Hydrological monitoring suitable for environmental water delivery is also incorporated within existing monitoring and operation recording systems. Specifically this includes:

- Continuous flow measurements at Gauging Station 426200 on the River Murray downstream of Rufus River.
- Continuous water level and salinity measurements along the River Murray between Gauging Station 426200 and Wellington, as well as in Lake Alexandrina.
- Regular bathymetry and aerial photography of the Murray Mouth (every six weeks at present).

The only point were environmental water can be accurately accounted for is at the South Australian border.

There is a velocity index rating gauging station at Morgan and also staged index rating stations at Overland Corner and Lyearup. All of the locks can estimate flow however this is more accurate at lower flows, and so flow information through these structures are estimates only. Flow is not measured at the barrages, instead it is estimated based on a rate of 300 ML/day per gate/bay (500 ML/day at Mundoo). However, flows can be significantly less when water levels are elevated in the North Lagoon. Annual barrage flows are determined by assessing the water balance calculation. When flows are less than 50,000 ML/day, the estimates of flow past Lock 1 are considered to be more reliable than the estimates for flows over the barrages. At these flow rates the weir panels at Lock 1 are still in place, whereas at higher flows the weir panels are removed and the lock is 'drowned out'.

9.3 Operational monitoring

Water delivery monitoring is required to record how much water was used, and when and how it was delivered (refer to the DSEWPaC operational monitoring report template at Appendix 7). This information is required to account for environmental water use and to refine the effectiveness and efficiency of future watering events.

References

Aldridge, KT, Deegan, BM, Lamontagne, S, Bissett, A, & Brookes JD (2009). *Spatial and temporal changes in water quality in Lake Alexandrina and Lake Albert during a period of rapid water level drawdown*. CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

Aldridge, K, Payne A, & Brookes J (2010). *Literature Review: nutrient cycling and phytoplankton communities of the Lower River Murray, Lower Lakes and Coorong*. Department of Environment and Heritage, Adelaide.

ANZECC (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Paper No. 4, Volume 1. The Guidelines (Chapters 1-7). Australian and New Zealand Environment and Conservation Council, Canberra.

AWE (2009). *Coorong South Lagoon Restoration Project Hydrological Investigation*. Prepared for DWLBC (AWE Report 09053), Adelaide.

Bice, CM (2010). *Literature review of the ecology of fishes of the Lower Murray, Lower Lakes and Coorong*. Report to the South Australian Department for Environment and Heritage. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication No. F2010/000031-1, Adelaide.

Bice, CM, & Ye, Q (2009). *Risk assessment of proposed management scenarios for Lake Alexandrina on the resident fish community*. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication Number F2009/000375-1, Adelaide.

Boon, PI (2000). *Biological impacts of changes to water level and salinity in the Coorong*. Upper South East Dryland Salinity and Flood Management Scheme, DFW, Adelaide.

Bourman, RP (2000). 'Geomorphology of the lower Murray Lakes and Coorong' in *River Murray Barrages Environmental Flows: An evaluation of environmental flow needs in the Lower Lakes and Coorong*. Report for the Murray-Darling Basin Commission, Canberra.

Brandis, K, Nairn, L, Porter, J, & Kingsford RT (2009). *Preliminary assessment for the environmental water requirements of waterbird species in the Murray Darling Basin*. University of New South Wales, Sydney.

Brookes, JD, Lamontagne, S, Aldridge, KT, Benger, S, Bissett, A, Bucater, L, Cheshire, AC, Cook, PLM, Deegan, BM, Dittman, S, Fairweather, PG, Fernandes, MB, Ford, PW, Geddes, MC, Gillanders, BM, Grigg, NJ, Haese, RR, Krull, E, Langley, RA, Lester, RE, Loo, M, Munro, AR, Noell, CJ, Nayar, S, Paton, DC, Revill, AT, Rogers, DJ, Rolston, A, Sharma, SK, Short, DA, Tanner, JE, Webster, IT, Wellman, NR, & Ye, Q (2009). *An ecological assessment framework to guide management of the Coorong*. Final report of the CLLAMMecology Research Cluster. CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

Close, AF (2002). *Options for reducing the risk of closure of the River Murray mouth*. MDBC Technical Report 2002/2, Options, Version 3, 24 April. Murray-Darling Basin Commission, Canberra.

Cooling, MP, Lloyd, LN & Walker, KF (2010). *SA River Murray Weir Operating Strategy*. Lloyd Environmental report to SA Murray-Darling Basin NRM Board, Syndal.

Coulter, C (1992). *Investigating options for improving the management of Lakes Alexandrina and Albert*. Murray Darling Association Inc., Canberra.

CSIRO (2007). *Water availability in the Eastern Mount Lofty Ranges*. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Canberra.

CSIRO (2008). *Water availability in the Murray Darling Basin*. A report to the Australian Government from the CSIRO Sustainable Yields Project. CSIRO, Canberra.

De Deckker, P. (2002). `Ostracod palaeoecology', In: Applications of the Ostracoda in Quaternary Research. *American Geophysical Monograph*, 131: 121-134.

DEH (2010). *Securing the Future, Long Term Plan for the Coorong, Lower Lakes and Murray Mouth*. Department for Environment and Heritage, Adelaide.

Department of Environment and Planning (1990). *The Coorong National Park Management Plan*. National Parks and Wildlife Service, a division of the Department of Environment and Planning, Adelaide.

DEWHA (2009). *A Framework for Determining Commonwealth Environmental Watering Actions*. Department of the Environment, Water, Heritage and the Arts, Canberra.

DFW (2010). Unpublished material.

DFW (2011). Department for Water, Adelaide, viewed 29 April 2011, <http://www.waterforgood.sa.gov.au/rivers-reservoirs-aquifers/river-murray/unbundling-water-rights/explaining-water-access-entitlement-classes/>

Dittman, S, Cantin A, Noble W, & Pocklington J (2006). *Macrobenthic survey 2004 in the Murray Mouth, Coorong and Lower Lakes Ramsar site, with an evaluation of food availability for shorebirds and possible indicator functions of benthic species*. Department for Environment and Heritage, Adelaide.

Duffy, JE, Bradley, JC, France, KE, McIntyeare, PB, Thebault, E & Loreau, M. (2007). The functional role of biodiversity in ecosystems: incorporating trophic complexity. *Ecology Letters* 10: 522-538.

DWLBC (2009). Morella release protocol. Version 2. Upper South East Program – Coorong Sub-program. Department of Water, Land and Biodiversity Conservation, Mount Gambier.

DWLBC (2011). Department for Water, Adelaide, viewed 12 November 2011, <http://www.waterforgood.sa.gov.au/rivers-reservoirs-aquifers/river-murray/unbundling-water-rights/>

DWLBC (2011b). Department for Water, Adelaide, viewed 29 April, 2011, <http://www.waterforgood.sa.gov.au/rivers-reservoirs-aquifers/river-murray/unbundling-water-rights/frequently-asked-questions/>

Ecological Associates (2010a). *Estimation of Water Requirements of Wetlands in the South East of South Australia*. Department of Water, Land and Biodiversity Conservation, Adelaide.

Ecological Associates 2010b. *Literature Review of the ecology of birds of the Coorong, Lakes Alexandrina and Albert Ramsar Wetlands*. Ecological Associates Report CC-014-1. Department for Environment and Heritage, Adelaide.

Ehmke, G, Herrod, A, Green, R & Tzaros, C. (2009). Habitat protection and restoration plan for the orange-bellied parrot Neophema chryogaster in the south east of South Australia. Birds Australia (Royal Australasian Ornithologists Union), Carlton Victoria.Fairweather, PG, & Lester, RE (2010). *Predicting future ecological degradation based on modelled thresholds.* Marine Ecology Progress Series 413:291-304.

Ferguson, G (2006a). *Fisheries biology of the greenback flounder Rhombosolea tapirina (Günther 1862) (Teleostei: Pleuronectidae) in South Australia*. RD076/0008-1. August 2006., SARDI, Adelaide.

Ferguson, G (2006b). *Monitoring of Recreational Catch and Effort during/after the 2005 Tauwitchere Fishway Trial*. Report to the Department of Water, Land and Biodiversity Conservation and Primary Industries and Resources, South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Ferguson, G (2006c). *The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries*. RD04/0099-2. pp1-12., South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Ferguson, G (2006d). *The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries*. RD04/0099-3. pp1-12., South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Ferguson, G, Ward T, & Geddes, M (2008). 'Do recent age structures and historical catches of mulloway, Argyearosomus japonicus (Sciaenidae), reflect freshwater inflows in the remnant estuary of the Murray River, South Australia?'. *Aquatic Living Resources* 21:145-152.

Fitzpatrick, RW, Shand, P, Merry, RH, Thomas, B, Marvanek, S, Creeper, N, Thomas, M, Raven, MD, Simpson, SL, McClure, S & Jayalath, N (2008a). *Acid Sulfate Soils in the Coorong, Lake Alexandrina and Lake Albert: properties, distribution, genesis, risks and management of subaqueous, waterlogged and drained soil environments*. CSIRO Land and Water Science Report 52/08. Prepared for the Department of the Environment, Water, Heritage and the Arts, Canberra.

Fitzpatrick, R, Marvanek, S, Shand, P, Merry, R, & Thomas, M (2008b). *Acid Sulfate Soil Maps of the River Murray below Blanchetown (Lock 1) and Lakes Alexandrina and Albert when water levels were at pre-drought and current drought conditions.* CSIRO Land and Water Science Report 12/08. CSIRO, Adelaide.

Fitzpatrick, RW, Grealish, G, Shand, P, Simpson, SL, Merry, RH & Raven, MD (2009). *Acid sulfate assessment in Finniss River, Currency Creek, Black Swamp and Goolwa Channel, South Australia*. CSIRO Land and Water Science Report 26/09. Murray-Darling Basin Authority, Canberra.

Fluin, J, Haynes, D, & Tibby, J (2009). *An environmental history of the Lower Lakes and the Coorong*. A report for the Department of Environment and Heritage, University of Adelaide, Adelaide.

Geddes, MC, & Wedderburn S (2007). *Fish monitoring in Boundary Creek and Mundoo Channel during freshwater inflow to the River Murray estuary in 2005 and 2006*. University of Adelaide, Adelaide.

Gehrig, S, & Nicol, J (2010). *Aquatic and littoral vegetation of the Murray River downstream of Lock 1, the Lower Lakes, Murray Estuary and Coorong: a literature review*. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Gell, P, & Haynes, D (2005). *A Palaeoecological Assessment of Water Quality Change in The Coorong, South Australia*, Diatoma, The University of Adelaide & Department of Water, Land and Biodiversity Conservation, Adelaide.

Haese, RR, Murray EJ & Wallace L (2009). *Nutrient sources, water quality, and biogeochemical processes in the Coorong, South Australia*. Geoscience Australia Record 2009/19. Commonwealth Government, Canberra.

Hammer, M, Wedderburn, S & Van Weenen, J (2009). *Action Plan for South Australian Freshwater Fishes*. Native Fish Australia (SA) Inc., Adelaide.

Harvey, N (1996). Coastal Processes affecting Management of the River Murray Estuary. *Aust. Geog. Stud.*, 34:45–57

Heard, L. & Channon, B (eds) (1997). *Guide to a Native Vegetation Survey (Agricultural Region) Using the Biological Survey of South Australia Methodology.* Department of Housing and Urban Development, and Department of Environment and Natural Resources, Adelaide.

Heneker, TM (2010). *Development of flow regimes to manage water quality in the Lower Lakes in South Australia*. Department for Water, Adelaide.

Herzeg, AL, Smith, AK, & Dighton, JC (2001). 'A 120 year record of changes in nitrogen and carbon cycles in Lake Alexandrina, South Australia: C:N, δ^5 N, δ^3 C in sediments'. *Applied Geochemistry* 16: 73-84.

Jennings, PR, Zampatti, BP, Stuart, IG, & Baumgartner, LJ (2008). 'Fish Passage at the Murray River Barrages', in J Barrett (ed), *The Sea to Hume Dam: Restoring Fish Passage in the Murray River.* Murray-Darling Basin Commission, Canberra.

Jensen, A, Good, M, Harvey, P, Tucker, P & Long, M (2000). *River Murray Barrages Environmental Flows*. Report to Murray-Darling Basin Commission. Wetlands Management Program, Department of Environment and Natural Resources, Adelaide.

Jones, L & Miles, M (2009), *River Murray Wetland Classification Project (DEH) report to the Riverine Recovery Project*, Department of Water, Land & Biodiversity Conservation. Adelaide.

Lamontagne, S, McKewan, K, Webster, I, Ford, P, Leaney, F, & Walker, G (2004). *Coorong, Lower Lakes and Murray Mouth. Knowledge gaps and knowledge needs for delivering better ecological outcomes*. Water for a Healthy Country National research Flagship, CSIRO, Canberra.

Lester, RE, Fairweather, PG, & Higham, JS (2011a). *Determining the Environmental Water Requirements for the Coorong, Lower Lakes and Murray Mouth region—Methods and Findings to date*. Technical Report 2011. A report prepared for the Department of Environment and Natural Resources, Adelaide.

Lester, RE, Fairweather, PG, Heneker, TM, Higham, JS, & Muller, KL (2011b). *Specifying an environmental water requirement for the Coorong and Lakes Alexandrina and Albert: A first iteration*. A report prepared for the Department of Environment and Natural Resources, Adelaide.

Lester, RE, Langley, RA, & Fairweather, PG (2008). *What are the Sensitivities of Key Biota in the Lower Lakes to Changes in Salinity that may be Triggered by the Introduction of Seawater into the Lower Lakes?* A report prepared for the Murray Darling Basin Commission. Flinders University, South Australia.

Littley, T. & Cutten, J (1994). *Draft Recovery Plan for the Mt Lofty Ranges Southern Emu-wren (Stipiturus malachurus intermedius).* Conservation Council of South Australia, Adelaide.

Lothian, JA, & Williams, WD (1988). 'Wetland Conservation in South Australia', in AJ McComb & PS Lake (eds), *The Conservation of Australian Wetlands*. Surrey Beatty & Sons, Chipping Bay, pp. 147-165

Marsland, K.B & Nicol, J.M (2009). *Lower Lakes vegetation condition monitoring- 2008/09*. SARDI Publication number F2009/000370-1. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

MDBA (2009). *The Living Murray Annual Environmental Watering Plan 2010–11*. MDBA Publication No. 106/10. Murray-Darling Basin Authority, Canberra.

MDBA (2010). 'Chapter 11: The Coorong, Lower Lakes and Murray Mouth' in *Assessing environmental water requirements*, Murray Darling Basin Authority, Canberra.

MDBA (2010b). *River Murray System Annual Operating Plan (Public Summary)*. MDBA Publication Number 111/10. Murray-Darling Basin Authority, Canberra.

MDBC & DWLBC (2002). *The Murray Mouth Mouth. Exploring the implications of closure or restricted flow*. Murray-Darling Basin Commission and Department for Water Land and Biodiversity Conservation, Adelaide.

MDBC (2006). The Lower Lakes, Coorong and Murray Mouth Icon Site Environmental Management Plan 2006–2007. Murray-Darling Basin Commission, Canberra.

Muller, KL (2010). *Material prepared to support the development of an Environmental Water Requirement for the Coorong, Lower Lakes and Murray Mouth region*. Prepared for the Department of Environment and Natural Resources, Adelaide.

Napier, GM (2010). *Literature Review: Freshwater Macroinvertebrates of the Lower Lakes and Lower River Murray (below Lock 1)*. A report prepared for the Department for Environment and Heritage. Adelaide.

Noell, CJ, Ye, Q, Short, DA, Bucater, LB, & Wellman, NR (2009). *Fish assemblages of the Murray Mouth and Coorong region, South Australia, during an extended drought period*. SARDI Aquatic Sciences Publication No F2009/000014-1. SARDI Research Report Series No 339. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Paton, DC, Rogers, DJ, Cale, P, Willoughby, N, & Gates, JA (2009). 'Chapter 14: Birds' in JT Jennings (ed), *Natural History of the Riverland and Murraylands*. Royal Society of South Australia Inc, Adelaide.

Paton, DC (2010). *At the End of the River: the Coorong and Lower Lakes*. Hindmarsh: ATF Press. South Australia.

Phillips, W, & Muller, K (2006). *Ecological Character of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance*. Department for Environment and Heritage, Adelaide.

Pickett, M (2004). *Recovery Planning for the Eyeare Peninsula Southern Emu-wren - 2004 Survey*. Unpublished report prepared for the Department for Environment and Heritage, South Australia.

Power, ME, Tilman, D, Estes, JA, Menge, BA, Bond, WJ, Mills, LS, Daily, G, Castilla, JC, Lubchenco, J & Paine, R.T. (1996). Challenges in the quest for keystones. *BioScience* 46: 609-620.

Rogers, DJ. and Paton, DC (2009). *Changes in the distribution and abundance of Ruppia tuberosa in the Coorong*. CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

Rolston, A, Gannon, R, & Dittmann, S (2010). *Macrobenthic invertebrates of the Coorong, Lower Lakes and Murray Mouth Ramsar Site: A Literature Review of Responses to Changing Environmental Conditions*. Report to the Department for Environment and Heritage, Adelaide.

SA MDB NRM Board (2009). *Water Allocation Plan for the River Murray Prescribed Watercourse*. South Australian Murray-Darling Basin Natural Resources Management Board, Murray Bridge.

Seaman, RL (2003). *Coorong and Lower Lakes habitat-mapping program*. Conservation Programs, Department for Environment and Heritage, Adelaide.

SEWPaC (2011). Department of Sustainability, Environment, Water, Population and Communities, viewed October 2011. <http://environment.gov.au/water/publications/action/cewh-qna.html>

Shiel, R. J (1995). *A guide to identification of rotifers, cladocerans and copepods from Australian inland waters*. CRCFE Ident. Guide 3: 1–144.

Shiel, RJ (2010). *Lower Murray, Lower Lakes & Coorong zooplankton: a review*. A report prepared for Department for Environment and Heritage, Adelaide.

Sim, T, & Muller, K (2004). *A fresh history of the Lakes: Wellington to the Murray Mouth, 1800s to 1935*. River Murray Catchment Water Management Board, Strathalbyn.

Sloan, S (2005). *Management Plan for the South Australian Lakes and Coorong Fishery*, 135pp. The South Australian Fisheries Management Series Paper No. 44, Fisheries Division, Primary Industries and Resources South Australia. Adelaide.

Stribley, L & Goode, J (2008). *South Australian River Murray Environmental Watering Framework*. In draft. South Australian Murray-Darling Basin Natural Resources Management Board, Adelaide.

Thompson, R. M & Starzomski, B. M (2007). 'What does biodiversity actually do? A review for managers and policy makers', *Biodiversity and Conservation*, 1:1-20. Springer, Netherlands.

Thoms, M, Suter, P, Roberts, J, Keohn, J, Jones, G , Hillman, T, & Close, A (2000). *Report of the River Murray Scientific Panel on Environmental Flows: River Murray - Dartmouth to Wellington and the Lower Darling River*. River Murray Scientific Panel on Environmental Flows, Canberra.

Souter, NJ (2009). *A conceptual state-and-transition model of Lake Alexandrina*. Report to the Department of Environment and Heritage. Adelaide.

Wainwright P & Christie, M (2008). 'Wader surveys at the Coorong and S.E. Coastal Lakes, South Australia'. *Stilt* 54, 31-47. Australasian Wader Studies Group, Australia.

Walker, DJ (2002). *What is possible: hydrology and morphology. In The Murray Mouth: Exploring the Implications of Closure or Restricted Flow*. Murray-Darling Basin Commission and Department of Water, Land and Biodiversity Conservation, Adelaide.

Webster, IT (2005). *An Overview of the Hydrodynamics of the Coorong and Murray Mouth*. Technical Report No. #/2005. CSIRO Water for a Healthy Country National Research Flagship. CSIRO, Canberra.

Webster, I, Maier, H, Baker, P & Burch, M (1997). 'Influence of wind on water levels and lagoon-river exchanges in the River Murray, Australia'. *Marine and Freshwater Research* 48: 541-50. CSIRO, Canberra.

Webster, IT (2007). *Hydrodynamic modelling of the Coorong*. Water for a Healthy Country Research Flagship. CSIRO, Canberra.

Webster, IT, Lester, RE, & Fairweather, PG (2009). *Preliminary determination of environmental water requirements for the Coorong*. CSIRO Water for a Healthy Country National Research Flagship. CSIRO, Canberra.

Wedderburn, S & Barnes, T (2009). Condition Monitoring of Threatened Fish Species at Lake

Alexandrina and Lake Albert (2008-2009). The University of Adelaide, Adelaide.

Wedderburn, S, & Hammer, M (2003). *The lower lakes fish inventory: distribution and conservation of freshwater fishes of the Ramsar Convention wetlands at the terminus of the Murray Darling Basin, South Australia*. Native Fish Australia (SA) Inc., Adelaide.

Appendix 1

Modelling achievement of ecological targets and water requirements

Source: Christopher Gippel, Fluvial Systems Pty Ltd.

Modelling achievement of ecological targets and water requirements

Background

The ecological objectives, and associated water level, flow and salinity targets to achieve a healthy CLLMM, have been identified. Four bands of annual flow at the barrages have been identified that relate to specific ecological thresholds (Table 10-5).

Table 10-5: Bands of forecast annual flow at the barrages for July to June water year with suggested management responses to meet ecological objectives.

Forecast flow over barrages for water year (July–June)	Management response	Ecological objectives	Frequency of implementation of response
0 to 60 GL/year	• Boost flows to at least 60 GL/year. • Further boost flow as required to achieve salinity target. • Manipulate water level of lakes to achieve target regime.	• Maintain connectivity between the lakes and the estuary. • Achieve a salinity ≤ 1,500 EC. • Achieve water level variability of lakes to maintain health of riparian vegetation.	• Every year
60 to 650 GL/year	• Boost flows to at least 650 GL/year (includes spring fresh of 150 GL in Oct and 80 GL in Nov). • Further boost flow as required to achieve salinity target.	• Achieve the minimum flow required to avoid unrecoverable degradation of ecological health, including stimulating fish recruitment through flows for fishways, attractant flows, spring fresh and maintaining connectivity between the lakes and the estuary. • Achieve a salinity ≤ 1,000 EC. • Maintain functional connectivity at the mouth in the majority of years.	• Meet in at least 95 per cent of years, with non-complying years non-sequential.
650 to 2,000 GL/year	• Boost flows to at least 1,090 GL/year (includes boosting spring fresh to 180 GL in Oct and Nov). • Achieve 2,000 ML/day.	• Additionally, achieve an enhanced degree of openness of the Murray Mouth. • Enhanced spring fresh to increase certainty of stimulating fish recruitment.	• Meet mouth maintenance target in at least 90 per cent of months. • Meet full spring fresh target in 90 per cent of years.
>2,000 GL/year	• Boost flows as required to achieve salinity target.	• Additionally, achieve a salinity ≤ an annual mean of 700 EC to prevent degradation of marine states in the Coorong and achieve a high degree of certainty that the Ramsar-nominated ecological character will be maintained.	• Maintain as the long-term average (meet in at least 50 per cent of years).
	• Periodically boost flows to at least 6,000 GL/year.	• Additionally, achieve a healthy hypersaline state in the South Lagoon.	• Maintain long-term average frequency of every 3.6 years, and maximum interval of 5 years.
	• Periodically boost flows to at least 10,000 GL/year.		• Maintain long-term average frequency of every 10.4 years, and maximum interval of 17 years.

Note: The objectives of each flow band are additional to those of the lesser flow band/s.

Maintaining the water level of the Lower Lakes within the target envelope of seasonal variability has only a minor implication for water allocation. Under the historical water level management regime, for the benchmark scenario (1995 level of development assuming historical climate), the monthly variability in losses from the Lower Lakes was high, with the average ranging from less than 1 gigalitre in June to around 140 gigalitres in December and January. Over the normal water level range of 0.4 to 0.9 mAHD, the surface area of the Lower Lakes varies by approximately 3 per cent, so the seasonal variation in loss was driven by climate (mainly evaporation) seasonality, not variation in lake surface area. Most of the time the water level in the lakes is controlled by barrage operation rather than River Murray inflows, although lake level will fall if inflows are insufficient to offset losses. Lester et al. (2011a) assumed that the average annual losses were 850 gigalitres. The MDBA provided a 114-year MSM-Bigmod modelled daily flow series of benchmark with TLM (The Living Murray) allocations and barrage operation rules to meet an ecologically desirable target range of lake water levels (Table 0-1). Compared with benchmark (assuming historical lake level management regime), this TLM scenario produced overall lower lake levels (Figure 10-1). While this scenario would produce lower losses than under benchmark conditions, the difference would be small as the lake surface area differences in summer would generally be less than 0.5 per cent.

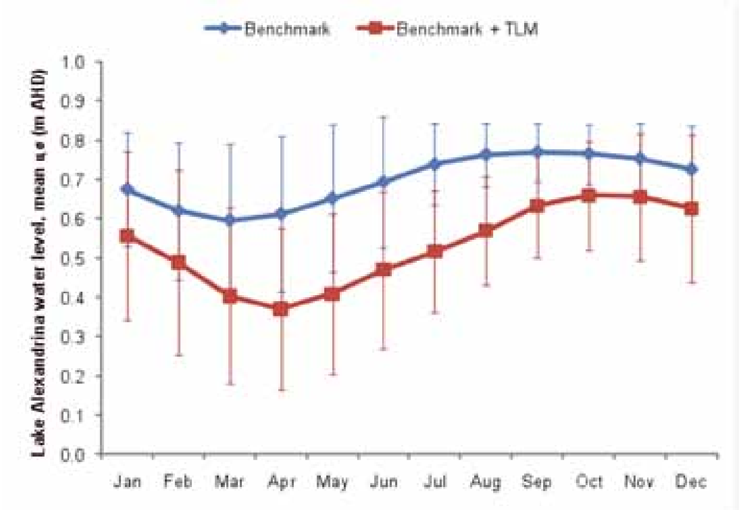

Figure 10-1: Monthly mean (and standard deviation) of water levels for the Lower Lakes for benchmark and benchmark plus TLM with ecologically desirable target lake levels (MSM-Bigmod Run 1009 Benchmark (21967000)).

The steady state annual flow that will sustain less than 1,500 µS cm^{-1} is 1,000 gigalitres, but annual flows less than this (down to 60 gigalitres) are tolerable for individual years, provided the flows in the two previous years are sufficient that salinity remains less than 1,500 µS cm^{-1}. The steady state annual flow that will sustain less than 1,000 µS cm^{-1} is 2,000 gigalitres. When annual flows regularly exceed 2,000 gigalitres, available additional water can be used to reduce salinity towards the target of 700 µS cm^{-1} (annual mean). The long-term average salinity target for the Lower Lakes is 700 µS cm^{-1} (Lester et al. 2011a), which would be approximated by achieving an annual mean salinity of 700 µS cm^{-1} in 50 per cent of years.

By providing sufficient steady baseflow over the barrages each month, the flow in the river would tip the balance in the mouth to a net outward flow that would assist in preventing sediment entering the inlet during a rising tide, and assist in flushing sediment during an ebb tide (Walker 2002). There is an increasing relationship between flow volumes and the relative openness of the mouth (i.e. more flow means that the mouth with be more open). Functional connectivity at the mouth will be maintained in the majority of years by delivering the flows that achieve salinity lower than or equal to 1,000 µS cm^{-1} in the Lower Lakes (Lester et al. 2011a). Close (2002) modelled the impact on risk of mouth closure of maintaining low flows over the barrages of 2,000 ML/day. It was estimated that providing this baseflow would reduce the frequency of risk of mouth closure to about 6 per cent of years, compared to the benchmark scenario with 31.5 per cent of years (Close 2002). Thus, improved connectivity can be achieved with baseflows of 2,000 ML/day. When combined with an enhanced spring fresh, the total annual requirement is 1,090 gigalitres. Target frequencies for these objectives have not been specified in the literature. Logically, the average frequency of year-round low risk of mouth closure occurring jointly with a high certainty of stimulating fish recruitment (through a spring fresh), should fall between that of achieving the 1,000 µS cm^{-1} target (95 per cent of years) and the 700 µS cm^{-1} target (50 per cent of years). Indicative targets for these objectives were set a little lower than their frequency of occurrence in the natural scenario. Compliance with enhanced mouth maintenance flows is best assessed on a monthly basis, rather than annually, which would require achievement of the target flow of 2,000 ML/day in every month of the year to achieve compliance for that year. In the natural scenario, enhanced mouth maintenance flows complied in 96 per cent of months and 74 per cent of years, so the target was set at 90 per cent of months. Compliance with enhanced spring fresh flows was assessed annually. In the natural scenario, enhanced spring fresh flows complied in 96 per cent of years, so the target was set at 90 per cent of years.

Achievement of a healthy hypersaline state in the South Lagoon requires regular flows of 6,000 GL/year and 10,000 GL/year (Lester et al. 2011a). According to Lester et al. (2011a), these flows should continue to be exceeded at the long-term average frequencies characteristic of the benchmark scenario, which they calculated to be every three and seven years respectively. The modelling undertaken for this project utilised a MSM-Bigmod TLM scenario extending from July 1895 to June 2009 and all calculations were based on water year. In this scenario, annual flows exceeding 6,000 gigalitres and 10,000 gigalitres occurred at long-term average frequencies of every 3.6 and 10.4 years respectively, so the long-term targets were set to these frequencies.

The specification of long-term average frequency alone is insufficient information to manage the 6,000 GL/year and 10,000 GL/year flow components, as long-term average is calculated after the event. In order to be able to make decisions in real time about when to augment flows to achieve these thresholds it is necessary to specify for each threshold: (i) a forecast annual discharge that triggers augmentation, (ii) a maximum desirable interval between occurrence of the flow threshold, (iii) a minimum interval (less than the maximum interval) after which the flows can potentially be augmented, (iv) a maximum allocation that can be used to augment the forecast discharge, and (v) a rule that either allows or prevents exceeding the allocation in the event that the maximum desirable interval is exceeded. Lester et al. (2011a) have no advice regarding these requirements, so expert opinion was used to develop the specifications. It was assumed that the maximum tolerable intervals were five years (for 6,000 GL/year target) and 17 years (for 10,000 GL/year target). These correspond to the average frequencies under a median climate change (Lester et al. 2011a). These particular targets were based on expert opinion and should be managed adaptively. Augmentation was allowed after intervals of two years (for 6,000 GL/year target) and eight years (for 10,000 GL/year target). The discharge trigger for using an allocation to augment the flow was set on the basis of the allocation available. These high flow targets would normally be difficult to meet under an allocation cap that would otherwise be adequate to meet the other ecological targets. So, in years when these high flow targets were due to be met, an additional allocation was allowed, under the presumption that these high flow components would be targeted in years of plentiful surplus water. The maximum allocations available to achieve these flows were set to 2,700 gigalitres, with these allocations including any water already held in storage from carryover of the regular allocation. Under these rules the trigger discharges were 3,300 gigalitres (for 6,000 GL/year target) and 7,300 gigalitres (for 10,000 GL/year target). These are large allocations that are likely to be available only in high flow years with large volumes of surplus water. For the scenarios tested here, it was assumed that under normal circumstances these allocations could not be increased in the event that the maximum interval was exceeded (because this usually coincided with a low flow period when large allocations would not be available).

The Framework for Determining Commonwealth Environmental Watering Actions (DEWHA 2009) and the Environmental Working Group (EWG) of the Murray-Darling Basin Authority (MDBA) (MDBA 2009) also utilise a model that outlines management objectives for four different water resource availability scenarios. In contrast to the ecological needs based flow bands identified for the CLLMM (Table 10-5), these are generic flow bands that correspond to prevailing hydrological conditions, specifically:

- extreme dry (lowest annual flow on record)
- dry (30th percentile annual flow)
- median (50th percentile annual flow)
- wet (70th percentile annual flow).

These are arbitrary flow percentiles that do not relate to the appropriate management actions in the CLLMM (for the benchmark MSM-Bigmod flow series, from 1895 to 2009, 60 gigalitres equalled 5th percentile flow, 650 gigalitres equalled 21st percentile flow, and 2,000 gigalitres equalled 43rd percentile flow).

At other Murray-Darling Basin assets, in years of very low flow, when environmental allocations are likely to be highly constrained, high water demand actions such as flooding wetlands can be foregone, and the focus can turn to in-channel ecological processes and pumping relatively small volumes of water to wetlands. In this case the main objective is to avoid irreversible degradation of the assets so that they might recover in a following, wetter, year. At the CLLMM, ecological health is a direct function of total River Murray inflow volume, so as natural flows decrease in dry years, and salinity rises, a higher ecological allocation is required, even to meet bare minimum ecosystem survival requirements. In setting hydrological targets for the CLLMM, this conflict has been taken into consideration. So, for example, in naturally very dry years, the salinity target is higher, and is satisfied by lower flows; in naturally wet years, the target salinity is lower, which takes advantage of the greater likelihood of water availability (Table 10-5). Nevertheless, there is a fundamental reason why, in any particular year, the CLLMM allocation cannot be simply managed on the basis of hydrological conditions forecast to prevail in that year. That is, the salinity balance does not operate on an annual cycle. Fairweather and Higham (2011a) proposed that the minimum flow required in any particular year to meet salinity targets was a function of flow in the previous two years. So, the appropriate management action cannot simply depend on the prevailing hydrological conditions of the current year, but must take into consideration flows over the previous two years. If flows were high in those two years, a completely different response would be appropriate than if the flows were low in those two years.

A Water Delivery Plan would ideally specify the most appropriate way to manage a given allocation in a year having a particular forecast annual flow. If the volume of allocation available for the environment is closely correlated to annual flow in the river, then general management rules can be devised based on predicted annual flow. Water can be allocated to the CLLMM from entitlements held under The Living Murray program, and by the Commonwealth and the South Australian Governments. These might total approximately 1,500 gigalitres per year at most. At this stage there is no information available on which to base predictions about what additional water might become available to the CLLMM under given hydrological conditions. The alternative then is to model the allocation required to meet the ecological targets for a given flow time series, presuming that managers would have been following the water use delivery strategy recommended here (Table 10-5). This approach results in time series' of predicted annual compliance with ecological targets, and allocation used. The flow time series' used in this modelling were derived by MSM-Bigmod.

CLLMM environmental flow model structure

MSM-Bigmod daily time series' modelled for the period July 1895 to June 2009 (inclusive) were obtained from MDBA for the following scenarios:

- natural (assumes no water resources development)
- benchmark run (assumes 1995 level of water resources development)
- benchmark plus TLM contribution (assumes 1995 level of water resources development, and within assumed allocation constraints (i) attempting to meet an ecologically desirable target range of lake water levels (Figure 0-1), and (ii) providing 2,000 ML/day (2,500 ML/day in October to December) over the barrages for maintaining the Murray Mouth in an open state).

Of these three scenarios, the third (benchmark plus TLM) was the most important, as this was used to assess the effectiveness of additional water allocation strategies on achievement of ecological targets. Note that the TLM allocation was used essentially to maintain the Murray Mouth in an open state, and to maintain lake levels within the ecologically desirable range. These are both objectives of the water use delivery strategy recommended by this Water Delivery Plan (Table 10-5).

The natural scenario was used to test whether the ecological targets that form the basis of the water use delivery strategy recommended here (Table 10-5) were met under unregulated flow conditions. It was hypothesised that if these ecological targets were reasonable, they would have a high degree of compliance in the natural scenario. The benchmark series was used to determine the benchmark state of ecological health from which improvements under an augmented flow regime could be compared. In this report, an augmented flow regime is the benchmark regime with new environmental water added, either from The Living Murray (TLM), and/or Commonwealth Environmental Water (CEW).

The natural and benchmark MSM-Bigmod scenarios assume historical climate. This report makes no assumption about the reliability of the historical climate as a guide to the future climate (and therefore future river flows).

The MSM-Bigmod modelled flow series essentially provides 'forecast' flows to the environmental flow model. The model responds to the forecast flows in the most efficient way, because the forecasts are always perfect. The real world situation has inefficiencies, because of incorrect forecasts, and the time lag in responding to unexpected flows. These inefficiencies would result in lower river health compared to the ideal case of perfectly forecast flows.

The environmental flow model estimates the water required to meet CLLMM ecological targets (Table 10-5), calculated at the barrages. The volume of water required to be released from storages (Dartmouth Dam, Hume Dam, Menindee Lakes and Lake Victoria) to meet those needs is higher (due to delivery losses). This report does not attempt to estimate how much water is required to be released from storages to meet ecological targets at the CLLMM. This is a complex optimisation problem that requires consideration of the needs of all of the Basin's ecological assets, other water demands, losses and storages.

In the environmental flow model, the MSM-Bigmod daily flow series is first converted to monthly totals (as flow targets are specified monthly), and dates are redefined as water years (starting 1 July, and ending 30 June). The model then runs through time, comparing the monthly flow with the required monthly total to meet the ecological targets, and the mouth maintenance targets. There is no option to redistribute the forecast annual flow through the months in an effort to meet the ecological targets, because this level of flow control is not available in South Australia. Rather, any monthly shortfalls are met by augmentation, within rules that constrain allocation. Next, the augmented monthly flow series is converted to an annual flow series. To this series the formulas of Lester et al. (2011a) for salinity targets are applied. Any shortfalls are met by augmentation, within rules that constrain allocation. The annual salinity augmentation volumes are then retrospectively distributed by months. This has no effect on the result—it is done only to allow presentation of the augmented time series on a monthly time-step.

The environmental flow model constrains the volume of environmental water available to meet shortfalls. This simply reflects the reality that environmental water allocations are not unlimited. At present, there is no option to carry over environmental water in South Australia. This limitation will not necessarily apply into the future, so the model allowed the option of carry over, up to a specified cap on the volume that could be held in storage. The other parameters were an annual allocation, the unused portion of which could potentially be carried over to the next year. The amount actually carried over was limited by the cap on the volume that could be held in storage, and also by a rule that set the proportion of the unused portion that could be carried over. The latter rule was set to 100 per cent for all model runs reported here. A range of hypothetical values of (i) annual allocation and (ii) cap on allocation held in storage, were run as scenarios. Model output included the volume of allocation actually used, and the volume held in storage, for each year.

As well as reporting flow statistics, the environmental flow model reported compliance with environmental targets. These targets were split into two types, salinity targets, and other needs. "Other needs" lumped fishway flows, attractant flows, flows to maintain connectivity between the lakes and the estuary, spring freshes and mouth maintenance flows. Compliance with 'other needs' was assessed for each month, with the sum of any monthly shortfalls over a water year being the annual shortfall. Compliance with salinity targets of 1,500, 1,000 and 700 µS cm^{-1} were also assessed. According to Lester et al. (2011a), 1,500 µS cm^{-1} is the highest salinity that should occur, 1,000 µS cm^{-1} should not be exceeded in more than 5 per cent of years, and 700 µS cm^{-1} is the ecologically desirable mean salinity (Table 10-5). The targets associated with achievement of 6,000 and 10,000 GL/year were based on the desirable maximum interval between these thresholds (Table 10-5). As the flow augmentation procedure (as defined here) cannot reduce flows, it can be assumed that the target long-term average frequencies of these high flows are met under all management scenarios evaluated here.

The augmented annual flow was regarded as the 'observed' (O) and the annual flow required to meet the ecological targets regarded as the 'expected' (E). In this way, the ratio O/E is a measure of degree of compliance with the target. This is a ratio in the range 0 to 1, with 1 being perfect compliance, and zero only occurring if annual flow is zero. This scale assumes that some ecological benefit is derived from any flow, and that the benefit increases proportionately up to the flow required to meet the target. Flows higher than necessary to meet the target do not score higher than 1. The O/E score was reported on a five-point scale, with 0.2 wide classes. These were: 0 to 0.2 critical, 0.2 to 0.4 very poor, 0.4 to 0.6 poor, 0.6 to 0.8 moderate and 0.8 to 1.0 good. The number of classes, class widths and descriptors are all arbitrary, intended only as a simple device to provide a rapid visual indication of relative health of the CLLMM asset. The other statistic reported for each scenario was the percentage of years in the time series that met the ecological targets.

It is apparent that achieving perfect compliance with the ecological targets would require a large allocation in some years, so the above river health indicators were devised as an aid to the process of balancing river health expectations against water availability constraints.

Ecological compliance of flow scenarios, and allocation used

As expected, the natural flow scenario showed a high level of compliance with the ecological targets, meeting the salinity needs within the desired long-term frequencies (Table 10-6). The other ecological needs were met in 96 per cent of months, but because the non-complying months were scattered throughout the record, only 74 per cent of years had full compliance with other ecological needs (Table 10-6).

The benchmark scenario had low compliance with ecological targets, failing on all required long-term frequencies for salinity targets, and achieving the targets for other needs in only 8 per cent of years (Table 10-6). The Living Murray allocation led to a significant improvement in achievement of other ecological needs, rising to 42 per cent of years targets achieved (Table 10-6). The improvement in achievement of salinity targets was less dramatic. This is explained by the main objective of The Living Murray allocation being to maintain the mouth in an open state.

A scenario was run assuming that there was no constraint on water availability (Table 10-6). For this scenario only, the rules for achieving the 6,000 and 10,000 GL/year targets were adjusted to achieve the desirable long-term average frequency and no better than the maximum frequency (without this adjustment, the frequencies would have been higher than necessary to meet the targets). This scenario revealed the volume of water required in each year to augment the flow with the objective of fully complying with all ecological targets (Figure 10-2 and Figure 10-3). There are some aspects of this scenario that deem it impractical:

- In 22 per cent of years the required allocation exceeds 1,500 gigalitres, and in 9 per cent of years it exceeds 4,000 gigalitres—these volumes can be considered high compared to the volumes that are likely to be available.
- In 19 per cent of years, flow at the barrage has to be more than doubled to achieve the targets.
- In general, higher allocations are required in years of lower flow at the barrages, when in reality, the availability of water for environmental allocations is likely to be lower in such years.

The other scenarios assumed that the allocation was constrained (Table 10-6). These are hypothetical scenarios, intended only to illustrate the trade-off between allocation available and achievement of ecological health targets. Given the unlikelihood of unconstrained allocations being available, it will not be possible to meet all of the ecological targets all of the time, so it is inevitable that some of the time the health of the CLLMM asset will be sub-optimal. Having an effective process for balancing water availability and ecological health will be fundamental to the management of the CLLMM asset.

In the scenarios tested, the hypothetical available allocation of Commonwealth water ranged from 200 to 800 GL/year, and the maximum volume that could be held in storage ranged from 200 to 3,000 gigalitres (Table 10-6). None of the scenarios achieved all of the targets, although an allocation of 800 GL/year with carry over permitted (up to 3,000 gigalitres in storage) failed on only one target (Table 10-6). The requirement of no sequential years with salinity exceeding 1,000 µS cm^{-1} was difficult to meet without a large annual allocation (more than 1,400 GL/year) and large allowable volume in storage (3,300 gigalitres). When the 1,000 µS cm^{-1} salinity target was met in 95 per cent of years, there remained two spells of dry years, in 1943 to 1945 and 2006 to 2008, with sequential non-complying years. The targets for other ecological needs were easier to achieve than the salinity targets. An annual allocation of 500 gigalitres or more, with no carry over, achieved the less than 2,000 GL/year targets in 99 per cent of years. Carryover was of variable importance; it was instrumental in improving compliance with targets for other needs if the annual allocation was low, and it was important in improving compliance with salinity targets if the annual allocation was large (Table 0-6). Success in meeting the 6,000 and 10,000 GL/year targets principally depended on the arbitrary additional volume of allocation provided for this purpose. In reality, the target maximum intervals for these high flows may be difficult to meet, because of the very large allocation that has to be found in some years of only moderate flow.

The water allocation was called on in 67 to 74 per cent of years (Table 10-6). The other years had adequate water to meet all of the targets (Table 10-6).

Illustration of the distribution of Commonwealth water supplied to augment the flow under the constrained allocation scenarios are provided for two scenarios: 300 gigalitres with no carryover (up to 300 gigalitres in storage) (Figure 10-4 and Figure 10-5) and 800 GL/year with carryover permitted (up to 3,000 gigalitres in storage) (Figure 10-6 and Figure 10-7). These scenarios illustrate how allocations are required in years of low to moderate flow, which is the fundamental management problem of the CLLMM asset.

The CLLMM asset health indicator scores were favourable for the entire time series of the natural scenario, except for 2006 to 2008, when the 700 EC salinity target was rated very poor (Figure 10-8). In the benchmark scenario there were periods of high compliance with ecological targets, but overall, the health indicator scores were poor most of the time. The period of worst health was from 2002 to 2008 (Figure 10-8). The TLM contribution led to big improvements in health scores for other needs, such that most years scored good or moderate (Figure 10-8).

Comparing three of the environmental water availability scenarios:

- A scenario with 300 gigalitres' annual allocation and no facility for carryover satisfied the other needs, but the 700 µS cm^{-1} and 1,000 µS cm^{-1} targets were only partially met in most years (Figure 10-9).
- A scenario with 800 gigalitres annual allocation and up to 3,000 gigalitres being held in storage almost satisfied all of the targets; the 700 µS cm^{-1} target was met in approximately half of the years (as desired), and in the non-complying years the health score for this indicator was mostly in the range poor to very poor (O/E score of 0.2 to 0.6) (Figure 10-9).
- A scenario with unlimited allocation available satisfied all of the targets (Figure 10-9). Note that for good ecological health the 700 µS cm^{-1} target does not have to be met in every year, as the requirement is for this to be the long-term average salinity. This is the main difference in health achieved by this scenario compared to that of the natural scenario (Figure 10-8).

Although having unlimited allocation available achieved all of the ecological targets, the performance of this scenario was only marginally better than the scenario with allocation constrained to 800 gigalitres per year and carryover available, but at an average annual cost of 263 gigalitres per year in additional water.

The monthly distributions of the allocations for the above three scenarios are shown in Figure 10-10, Figure 10-11 and Figure 10-12.

Table 10-6: Compliance of flow scenarios with ecological targets and environmental water use.

Scenario	Salinity targets			Other ecological needs						Other ecological needs combined (for Q < 2,000 GL)		CEW allocation used		
	0 – 60 GL	60 – 650 GL	>650 GL	0 – 60 GL	60 – 650 GL	650 – 2,000 GL		> 2,000 GL						
	1,500 EC % of years met	1,000 EC % of years met	700 EC % of years met	% of years met	% of years met	Mouth open % of mths met	Spring fresh % of years met	6,000 GL max. interval (years)	10,000 GL max. interval (years)	% of mths met	% of years met	% of years called on	Mean (±SD) (GL/year)	Max. (GL/ year)
Target	100	95	50	100	95	90	90	5 years	17 years	-	-	-	-	-
Natural	100	98	94	100	100	96	96	3	5	96	74	-	-	-
BM	82	63	31	95	88	51	50	11	22	49	8	-	-	-
BM + TLM	89	71	32	95	92	92	46	11	21	86	42	-	-	-
BM + TLM + CEW 200/200	93	75	38	100	92	93	78	7	14	93	68	74	373 (629)	2,888
BM + TLM + CEW 200/1000	94	76	40	100	95	93	84	7	14	94	76	73	425 (702)	3,664
BM + TLM + CEW 200/2000	94	76	42	100	95	93	85	7	14	94	77	73	428 (702)	3,664
BM + TLM + CEW 300/300	96	77	39	100	96	93	91	7	14	96	83	74	417 (619)	2,888
BM + TLM + CEW 300/1000	96	78	44	100	97	93	94	7	14	97	88	73	502 (745)	3,664
BM + TLM + CEW 300/2000	96	78	45	100	97	93	95	7	14	97	89	73	503 (746)	3,664
BM + TLM + CEW 500/500	97	80	39	100	100	96	100	6	14	100	99	73	505 (659)	3,016
BM + TLM + CEW 500/1000	98	80	46	100	100	96	100	5	14	100	99	71	623 (829)	3,664
BM + TLM + CEW 500/2000	98	81	49	100	100	96	100	5	14	100	99	71	643 (840)	3,664
BM + TLM + CEW 800/800	98	82	43	100	100	96	100	6	14	100	100	72	625 (739)	3,475
BM + TLM + CEW 800/1000	98	85	46	100	100	96	100	5	14	100	100	71	709 (875)	3,664
BM + TLM + CEW 800/2000	98	88	50	100	100	96	100	5	14	100	100	71	775 (951)	3,800
BM + TLM + CEW 800/3000	100	92	51	100	100	96	100	5	14	100	100	71	815 (1,014)	3,930
BM + TLM + CEW unlimited	100	98	65	100	100	96	100	5	17	100	100	67	1,078 (1,713)	8,384

Note: BM = Benchmark, TLM = The Living Murray, CEW = Commonwealth Environmental Water, XXX/YYYY (XXX = annual allocation, YYYY = maximum allocation that can be held in storage. Green shading = target met, red shading = target not met.

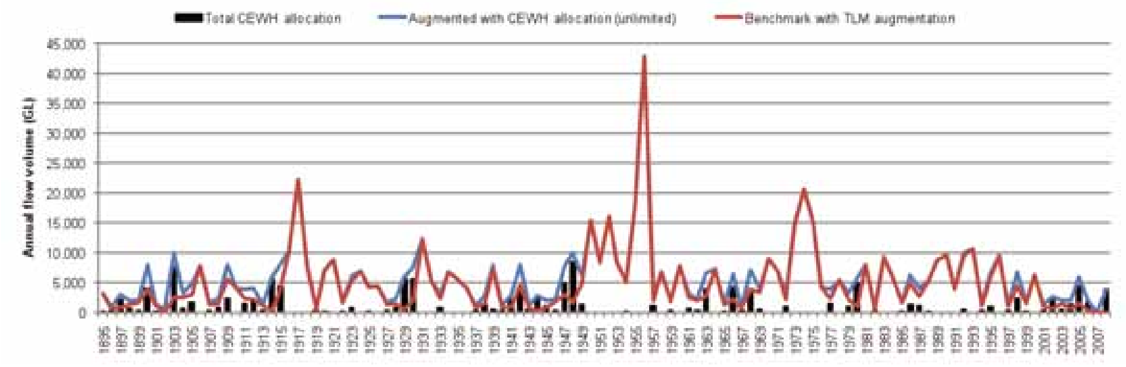

Figure 10-2: Annual flow for the benchmark + TLM scenario and augmented flow scenario, boosted by unlimited Commonwealth allocation to achieve all ecological targets.

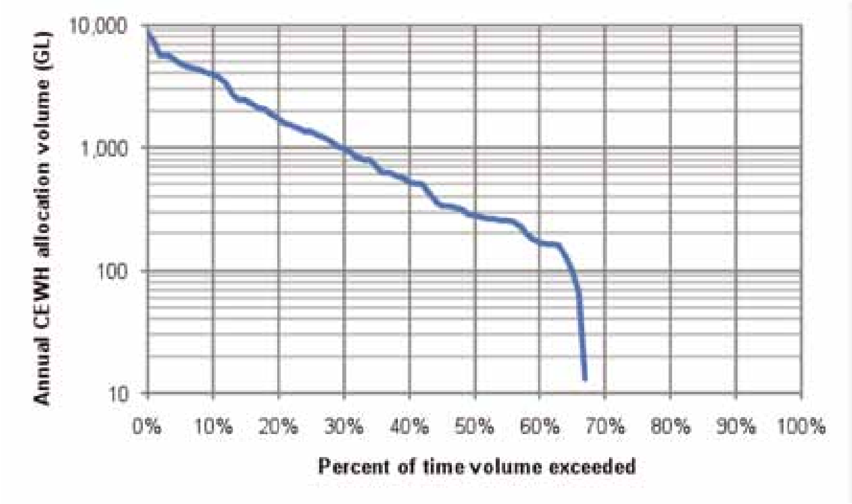

Figure 10-3: Distribution of annual Commonwealth allocation required to achieve all ecological targets, with unlimited allocation availability.

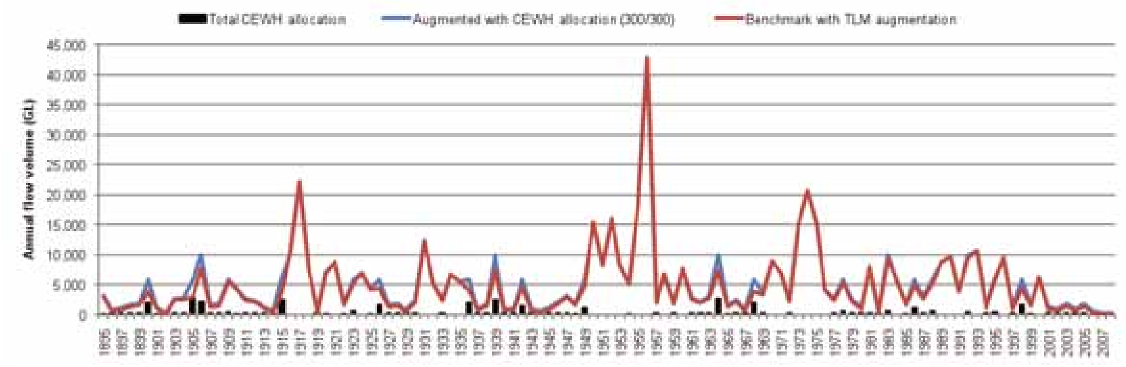

Figure 10-4: Annual flow for the benchmark + TLM scenario and augmented flow scenario, boosted by a constrained Commonwealth allocation of 300 GL/year with no carryover.

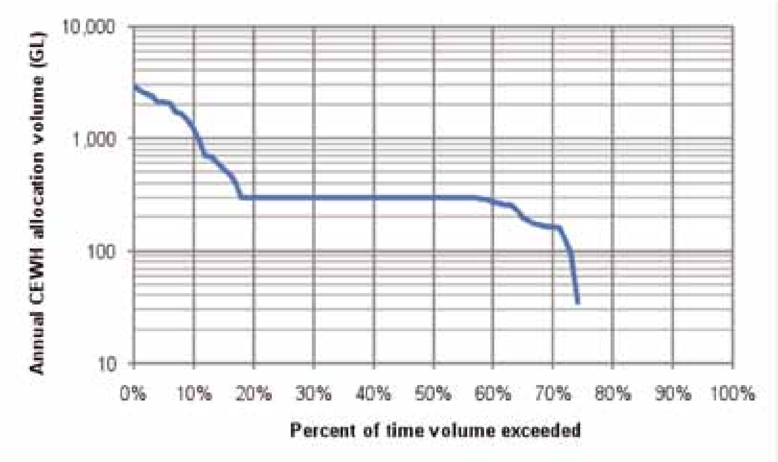

Figure 10-5: Distribution of annual Commonwealth allocation required to achieve all ecological targets, with allocation of 300 GL/year with no carryover.

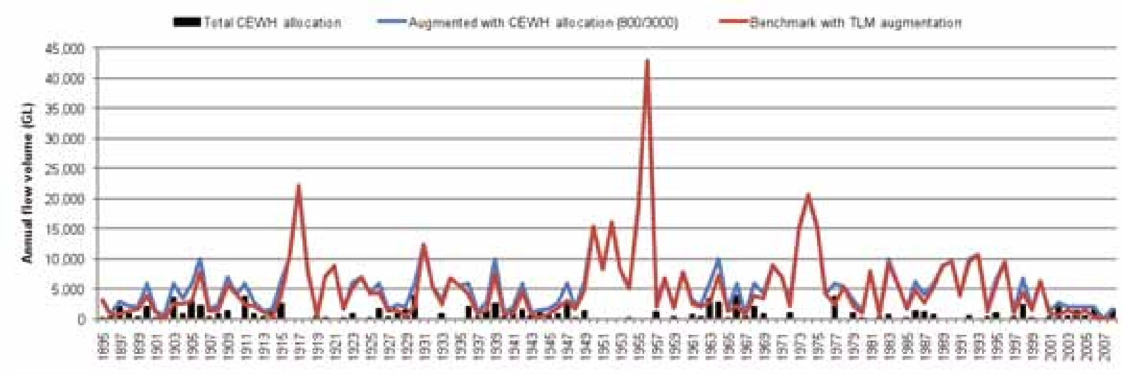

Figure 10-6: Annual flow for the benchmark + TLM scenario and augmented flow scenario, boosted by a constrained Commonwealth allocation of 800 GL/year with carryover that allows up to 3,000 GL to be held in storage.

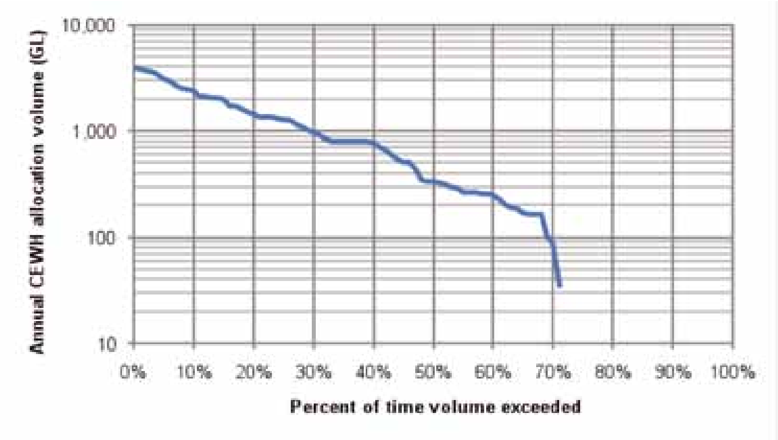

Figure 10-7: Distribution of annual Commonwealth allocation required to achieve all ecological targets, with allocation of 800 GL/year with carryover that allows up to 3,000 GL to be held in storage.

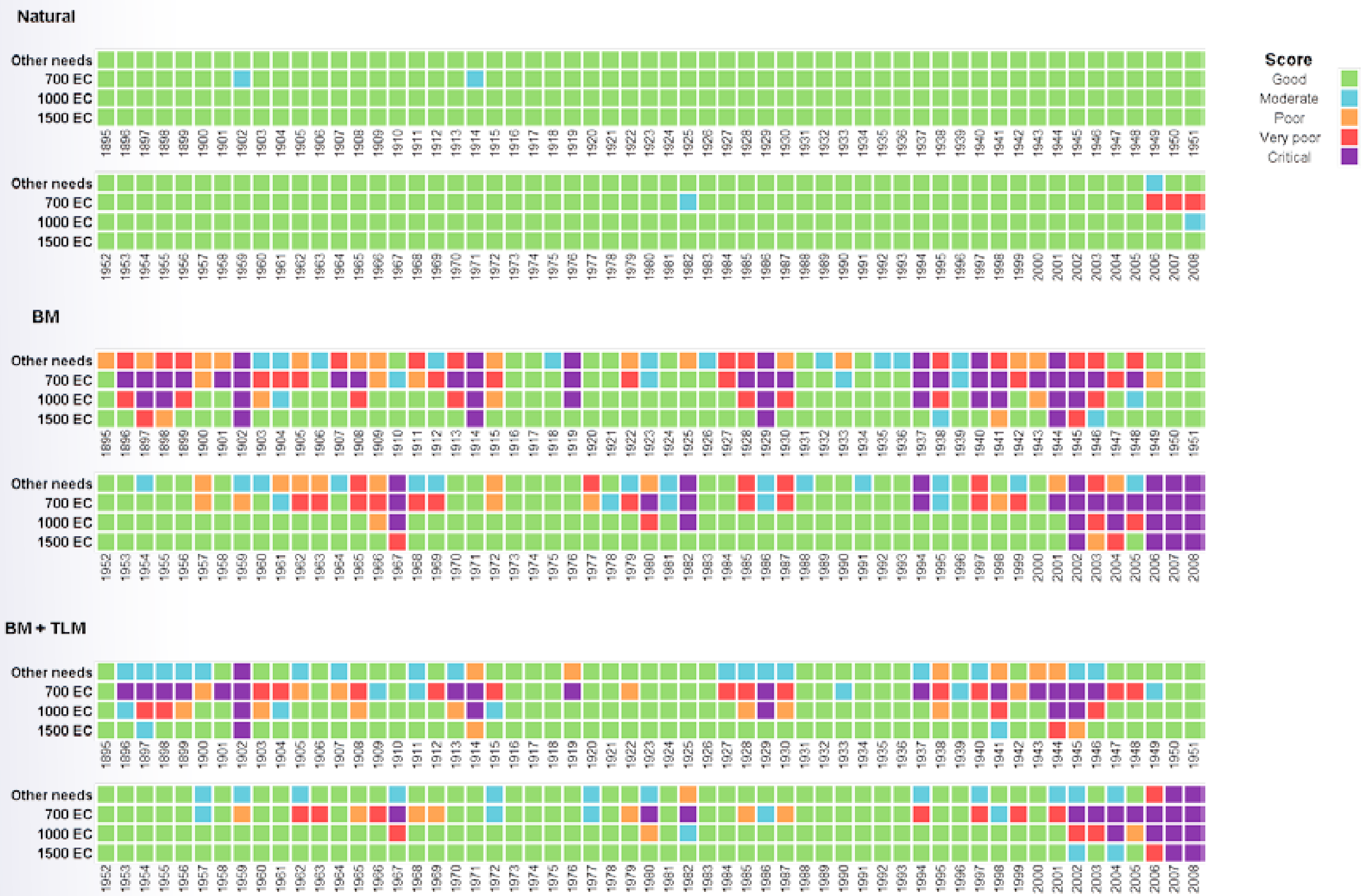

Figure 10-8: Time series of annual CLLMM asset health indicator scores for natural, benchmark and benchmark with TLM augmentation scenarios.

Note: The indicator scores represent O/E ratios, or observed annual flow divided by the annual flow required to fully meet the targets.

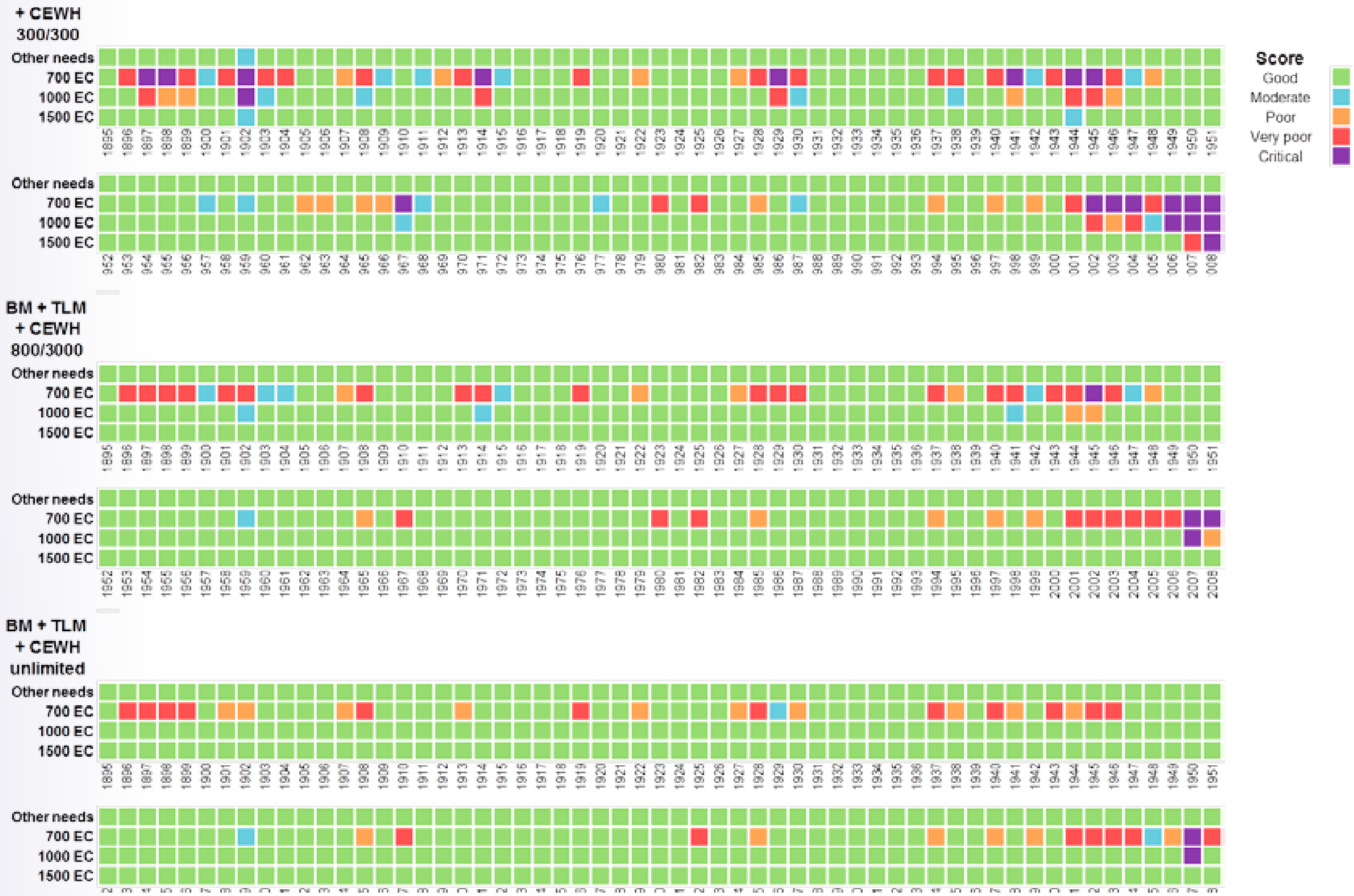

Figure 10-9: Time series of annual CLLMM asset health indicator scores for a range of environmental water availability scenarios.

Note: The indicator scores represent O/E ratios, or observed annual flow divided by the annual flow required to fully meet the targets.

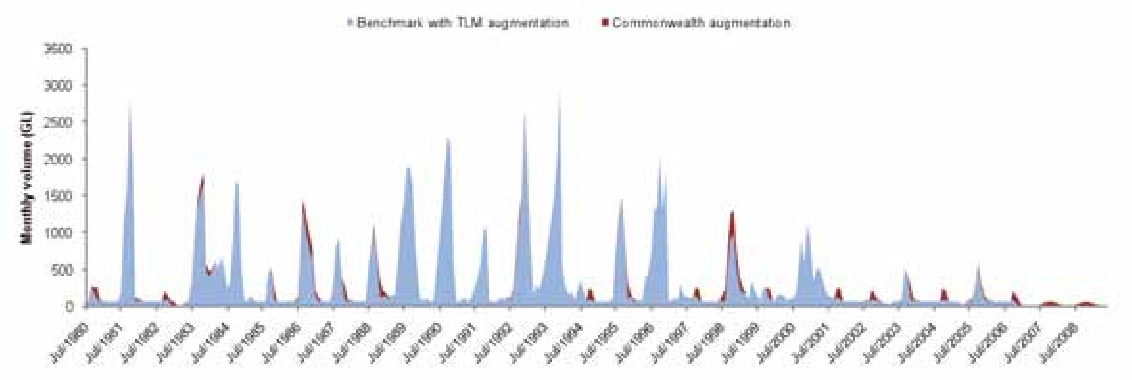

Figure 10-10: Monthly time series of benchmark flows and monthly allocations of Commonwealth water, for a scenario allowing an annual allocation of 300 GL/year and no facility for carryover. The model ran from 1895 to 2008, but only the years from 1980 onwards are shown here.

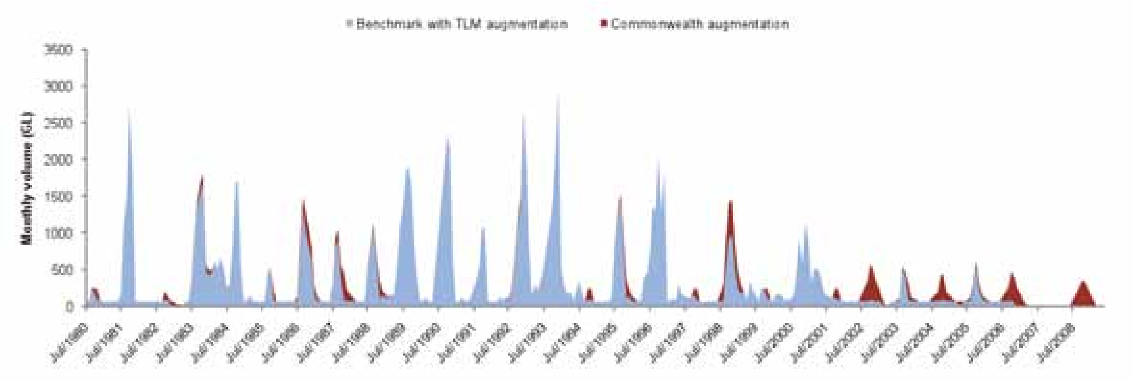

Figure 10-11: Monthly time series of benchmark flows and monthly allocations of Commonwealth water, for a scenario allowing an annual allocation of 800 GL/year and a maximum of 3,000 GL held in storage. The model ran from 1895 to 2008, but only the years from 1980 onwards are shown here.

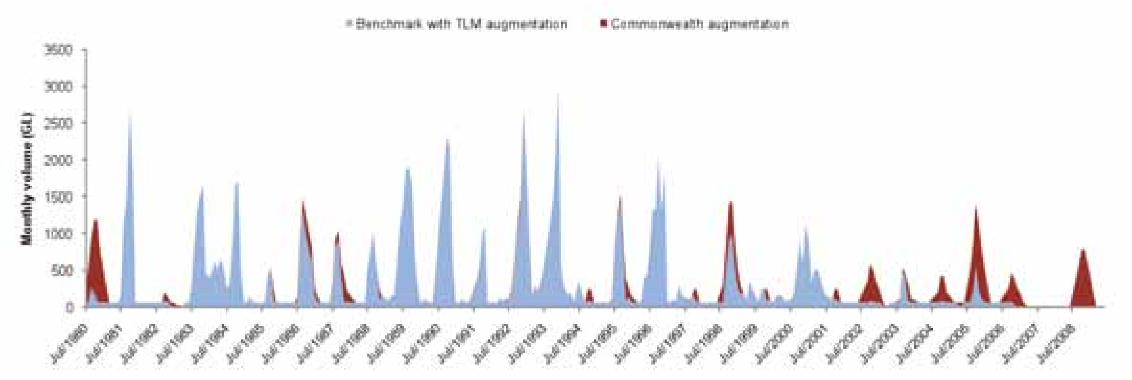

Figure 10-12: Monthly time series of benchmark flows and monthly allocations of Commonwealth water, for a scenario allowing unlimited annual allocation. The model ran from 1895 to 2008, but only the years from 1980 onwards are shown here.

Appendix 2
Case studies of proposed approach for predicting likely water-allocation requirements

Case Study 1: Forecast flow to SA: 2,410 gigalitres, available water allocation is 300 gigalitres.

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
62	62	60	78	75	62	62	15	0	0	21	58

1. The forecast flow to South Australia for the year is 2,410 gigalitres. When run through MSM-Bigmod to account for antecedent conditions the forecast flow over the barrages for the year is 555 gigalitres and is distributed as follows:
2. Flow over the barrages in the previous two years were 1,265 gigalitres and 2,094 gigalitres. This creates a target flow over the barrages for the forecast year of 2,735 gigalitres for the 1,000 µS cm^{-1} target and 8,641 gigalitres for the 700 µS cm^{-1} target.
3. The available environmental water is 300 gigalitres.

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
68	68	78	79	78	79	79	61	67	66	67	66

4. The total forecast flow over the barrages with additional environmental water is (up to) 855 gigalitres. The highest target that can be achieved is the 650 gigalitre target. The idealised flow distribution is as follows (from Table 5-2):
5. The idealised flow regime incorporates all the requirements for the 650 gigalitre target level plus additional water is provided in October and November in line with the flow requirements for the next highest target regime (the 1,090 gigalitre target regime). It does not however allow for the expected actual distribution of flow hence the allocation release must be apportioned across the year to support the achievement of the target by a combination of natural flow and TLM release water.

   The required additional environmental water (ignoring transfer losses) to best approximate the idealised flow distribution is:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
6	6	18	1	3	17	17	46	67	66	46	8

Which would achieve the following barrage flow regime:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
68	68	78	79	78	79	79	61	67	66	67	66

The 650 gigalitre target regime is achieved in all months.

Alternatively:

a. If an extreme dry period is experienced the highest target that can be fully achieved with additional environmental water is 60 gigalitres. The balance would be put towards the next highest target (with allowance for any minimum lake level top up requirements).

b. If a 30th percentile year is experienced (1,030 gigalitres) a target of 1,095 gigalitres could be achieved in full with 60 gigalitres of environmental water being utilised to firstly achieve the target with the remainder (240 gigalitres) to be used to move towards (but not meet) the higher target of 2,000 gigalitres.

c. If a 50th percentile year is experienced (2,235 gigalitres) a target of 2,000 gigalitres could be achieved in full with the 300 gigalitres of environmental water either being carried over or being utilised to move towards (but not meet) the next higher target of 2,735 gigalitres.

d. If a 70th percentile year is experienced (5,285 gigalitres) a target of 2,735 gigalitres (the 1,000 µS cm^{-1} target figure) could be achieved in full with the 300 gigalitres of environmental water either being carried over or being utilised to move towards (but not meet) the next higher target of 8,641 gigalitres (to achieve the 700 µS cm^{-1} target).

6. The original MSM-Bigmod model run (incorporating provision for TLM water but not other environmental water) through the forecast year identifies that lake levels are expected to fall below the minimum target level from February to June and approximately 232 gigalitres is required over this period to maintain levels above the target minimum. The model must be run with the proposed water allocation to test if the addition of all available environmental water over the spring period is sufficient to avoid missing the lake level target. If it fails to do so the monthly flow allocation would need to be redistributed until this criteria is met.

Case Study 2: Forecast flow to SA: 5,728 gigalitres, available water allocation is 500 gigalitres.

1. The forecast flow to South Australia for the year is 5,728 gigalitres. When run through MSM-Bigmod to account for antecedent conditions the forecast flow over the barrages for the year is 4,121 gigalitres as is distributed as follows:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
193	552	531	789	415	172	66	153	300	551	222	177

2. Flow over the barrages in the previous two years were 5,777 gigalitres and 1,605 gigalitres. This creates a target flow over the barrages for the forecast year of 650 gigalitres for the 1,000 µS cm^{-1} target and 4,618 gigalitres for the 700 µS cm^{-1} target.
3. The available environmental water is 500 gigalitres.
4. The total forecast flow over the barrages with environmental water is up to 4,621 gigalitres. All annual targets can be achieved. The idealised flow distribution is as follows (from Table 5-2):

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
402	499	669	745	669	520	445	250	107	104	107	104

The idealised flow regime incorporates all the requirements for the 4,000 gigalitres target level. The flows have been apportioned across the year as per the 4,000 gigalitres flow distribution (by percentages). Comparison between the idealised and the expected actual highlights that the forecast predicts high flows in autumn which exceed the management targets in those months. Conversely the spring flows are lower than desired. All months meet the next lowest target regime (2,000 gigalitres). Hence the environmental water should be used to boost spring flows as all other minimum monthly requirements are met.

The recommended environmental water component (ignoring transfer losses) to best approximate the idealised flow distribution is:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
73	0	48	0	89	122	133	34	0	0	0	0

Which would achieve the following barrage flow regime:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
266	552	579	789	504	294	199	187	300	551	222	177

5. The original MSM-Bigmod model run (incorporating provision for TLM water but no environmental water) through the forecast year identifies that lake levels are not expected to fall below the minimum target level.
6. All targets are met for the ecological responses and the 700 µS cm^{-1} target flow is achieved in this year by the addition of environmental water.

Case Study 3: Forecast for 2011–12: assumed water allocation cap is 300 gigalitres.

1. The adopted forecast flow to South Australia for 2011–12 is as follows and assumes that July and August will be categorised as 'wet' with the balance of the year being median. The forecast flow over the barrages for the year is then 2,980 gigalitres as is distributed as follows:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
491	818	490	524	168	79	62	57	62	60	62	107

2. Flow over the barrages in the previous two years were 9,000 gigalitres (assumed) and zero gigalitres. This creates a target flow over the barrages for the forecast year of 650 gigalitres for the 1,000 µS cm^{-1} target and 3,150 gigalitres for the 700 µS cm^{-1} target.
3. The available environmental water is 300 gigalitres.
4. The total forecast flow over the barrages plus environmental water is (up to) 3,280 gigalitres. All annual targets can be achieved. The idealised flow distribution for 3,150 gigalitres target is as follows (from Table 5-2):

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
274	344	461	512	461	362	312	172	97	94	97	94

Comparison between the idealised and the forecast highlights a surplus of flows in winter and a deficit in spring and summer. Hence the available environmental water should be used to boost spring and summer flows as all other minimum monthly requirements are met by the forecast flow. However there is insufficient environmental water to boost both spring and summer flows. Preference is given to boosting spring flows, with the next lower target summer flows still being met.

The recommended environmental water component (ignoring transfer losses) to best approximate the idealised flow distribution is:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
0	0	0	0	84	81	72	33	10	10	10	0

Which would achieve the following barrage flow regime:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
491	818	490	524	252	160	134	90	72	70	72	107

5. Under this forecast scenario it is expected that the original MSM-Bigmod model run (incorporating provision for TLM water but no other environmental water) through the forecast year would identify that lake levels were not expected to fall below the minimum target level.
6. All targets are met for the ecological responses and the 700 µS cm^{-1} target flow is achieved in this year by the addition of 300 gigalitre of environmental water. Total flow over the barrages is 3,280 gigalitres.

Case Study 4: Forecast for 2011–12: assumed water allocation cap is 300 gigalitres.

1. The adopted forecast flow to South Australia for 2011–12 year assumes a 'dry' year compromising a series of 30th percentile for each month. The forecast flow over the barrages for the year is then 1,030 gigalitres as is distributed as follows:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
62	116	199	155	75	62	62	56	62	60	62	60

2. Flow over the barrages in the previous two years were 9,000 gigalitre (assumed) and 0 gigalitres. This creates a target flow over the barrages for the forecast year of 650 gigalitres for the 1,000 µS cm^{-1} target and 3,150 gigalitres for the 700 µS cm^{-1} target.
3. The available environmental water is 300 gigalitres.

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
113	113	109	113	109	113	113	102	113	109	113	109

4. The total forecast flow over the barrages plus environmental water is (up to) 1,330 gigalitres. The highest target flow that can be potentially be fully achieved is the 1,095 gigalitre target. The idealised flow distribution for the 1,095 gigalitre target is as follows (from Table 5-2):

   Comparison between the idealised and the forecast highlights a surplus of flow in August and September but a deficit in October and November. The late summer and autumn forecast flows match those for the target distribution. Hence the environmental water should be used to boost the spring (October and November) flows as all other minimum monthly requirements are met by the forecast flow

   The recommended environmental water component (ignoring transfer losses) to best approximate the idealised flow distribution is:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
35	0	0	0	24	35	35	32	35	34	35	34

   Which would achieve the following barrage flow regime:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
97	116	199	155	99	97	97	88	97	94	97	94

5. If the original MSM-Bigmod model run (incorporating provision for TLM water but no other environmental water) through the forecast year identifies that lake levels could fall below the minimum target level then consideration may need to be given to hold back some of the environmental water to ensure the water level targets can be met. This would require a forecast run of MSM-Bigmod with the proposed environmental water releases to test if this were a potential outcome.

6. All targets are met for the flow-based ecological responses and the 1,000 µS cm^{-1} target flow is also achieved in this year by the addition of environmental water.

7. In this case only 252 gigalitres of the available 300 gigalitre environmental water is required to meet the targets. The balance could be used elsewhere, held in reserve to boost lake levels in autumn, or provide additional flows surplus the target (most likely in spring). The total predicted flow over the barrages for the year is 1,282 gigalitres.

Appendix 3

Pool-level managed wetlands in South Australia that are approved to receive allocations against Class 9 Water Access Entitlements

Lock reach	Wetland
Below Lock 1	Devon Downs South
	Morgans Lagoon LM
	Narrung
	PaiwallaReedy Creek
	Riverglades
	Sugar Shack
	Sweeney's LagoonTeringe
	Waltowa
Lock 1 to 2	Brenda Park
	Morgan Lagoon CP
	Murbpook Lagoon
	Murbko South
Lock 2 to 3	Nigra Creek/Schillers Lagoon (bypasses Lock 2)
	Hart Lagoon
	Ramco Lagoon
Lock 3 to 4	Banrock (bypasses Lock 3)
	Loveday Lagoons (Mussels)
	Loveday North
	Loveday South
	Spectacle Lakes/Beldora
	Yatco
Lock 4 to 5	Causeway Wetland Complex
	Martin Bend
	Nelwart
	Ngak Indau

Lock reach	Wetland
Lock 5 to 6	Lake Merreti Lake Woolpoolool
Lock 6 to 7	Pilby Wetland Complex Pipeclay Billabong Slaney Billabong

Source: H Hill (DFW) 2011, pers. comm., 29 April.

Note: This list is likely to change over time as more wetlands are managed (plans developed and infrastructure installed); and that some of these wetland complexes may contain features that do not receive water at pool level.

For pool-level managed wetlands to obtain a water allocation a Wetland Management Plan must be endorsed by the Department for Water (DFW). These Wetland Management Plans must conform to the "Guidelines for developing wetland management plans for the River Murray in South Australia 2003" (DWLBC 2003).

Appendix 4

Key water dependent species: Lock 1 to Murray Mouth and Coorong

Key:
State Government listing under the National Parks and Wildlife Act 1972 (South Australia)
v = vulnerable
e = endangered
r = rare

International Union for Conservation of Nature Red List of Threatened Species (IUCN)
LC = least concern
NT = near threatened
VU = vulnerable
EN = endangered
CR = critically endangered
DD = data deficient

State Government listing (under the National Parks and Wildlife Act 1972 (South Australia))
v = vulnerable
e = endangered
r = rare

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Fish	Black bream	*Acanthopagrus butcheri*	MM/estuary	Breed	•								
Fish	Bridled gobi	*Acentrogobius bifrenatus*		Breed		•	•						
Fish	Tamar goby	*Afurcagobius tamarensis*	MM/estuary, N Lagoon	Breed	•								
Fish	Yelloweye mullet	*Aldrichetta forsteri*	MM/estuary, N Lagoon		•								
Fish	Agassiz's glassfish	*Ambassis agassizii*	Historically recorded in Finniss River, not recorded since 2003/present.			•							e

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Fish	Longsnout flounder	*Ammotretis rostratus*	MM/estuary, N Lagoon		•								
Fish	Short-finned eel	*Anguilla australis*	Historically recorded in Lake Alexandrina (Alex). Not recorded since 2003/ present.			•							r
Fish	Bridled goby	*Arenigobius bifrenatus*	MM/estuary	Breed	•								
Fish	Mulloway	*Argyearosomus hololepidotus*	MM/estuary		•							EN	
Fish	Australian herring	*Arripis georgianus*	MM/estuary, N Lagoon		•								
Fish	Western Australian salmon	*Arripis truttaceus*	MM/estuary, N Lagoon		•								
Fish	Smallmouth hardyhead	*Atherinosoma microstoma*	MM/estuary, N Lagoon, S Lagoon/abundant.	Breed	•								
Fish	Silver perch	*Bidyanus bidyanus*	Historically recorded in Lake Alex. Not recorded since prior to 2003/ present.			•						VU	e
Fish	Murray hardyhead	*Craterocephalus fluviatilis*	Recorded at two sites in Lake Alex in Nov 2008, but were not detected in March 2009 (Wedderburn & Barnes 2009). Recorded Lock 1 to Wellington/present.	Breed		•	•	VU				EN	e
Fish	Australian anchovy	*Engraulis australis*	MM/estuary, N Lagoon	Breed	•								

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Fish	River black fish	*Gadopsis marmoratus*	Recorded breeding 2011 in Bremer River.	Breed		•	•						e
Fish	Climbing galaxias	*Galaxias brevipinnis*		Breed		•	•						r
Fish	Barred galaxias	*Galaxias fuscus*	MM/estuary	Breed	•	•		EN				CE	
Fish	Common galaxias	*Galaxias maculatus*	MM/estuary	Breed	•								
Fish	Mountain galaxias	*Galaxias olidus*	Recorded in Finniss River in 2003, not recorded since then/present.	Breed		•							v
Fish	Pouched lamprey	*Geotria australis*	Murray estuary Historically recorded in Lake Alex. Not recorded since 2003/present.	Breed	•	•							e
Fish	Soldier	*Gymnapistes marmoratus*	MM/estuary		•								
Fish	Striped perch	*Helotes sexlineatus*	MM/estuary	Breed	•							LC	
Fish	Ogilby's weedfish	*Heteroclinus heptaeolus*	MM/estuary		•								
Fish	Sandy sprat	*Hyperlophus vittatus*	MM/estuary, N Lagoon		•								
Fish	Western carp gudgeon	*Hypseleotris klunzingeri*			•								
Fish	Midgley's carp gudgeon	*Hypseleotris* sp.				•							
Fish	Hybrid carp gudgeon	*Hypseleotris* spp.				•							

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Fish	Big-bellied seahorse	*Hippocampus abdominalis*	MM/estuary		•							DD	
Fish	Southern garfish	*Hyporhamphus melanochir*	MM/estuary	Breed	•								
Fish	River garfish	*Hyporhamphus regularis*	MM/estuary, N Lagoon	Breed	•								
Fish	Goldspot mullet	*Liza argentea*	MM/estuary	Breed	•								
Fish	Murray cod	*Maccullochella peelii peelii*	Historically recorded in Lake Alex. Not recorded since prior to 2003/ present.			•		VU				CE	v
Fish	Estuary perch	*Macquaria colonorum*	Murray estuary. Historically recorded in Lake Alex. Not recorded since prior to 2003/ present.	Breed	•	•							c
Fish	Murray rainbow fish	*Melanotaenia fluviatilis*		Breed		•	•						
Fish	Purple-spotted gudgeon	*Mogurnda adspersa*	Recorded breeding 2011 in Paiwalla Wetlands.	Breed			•						e
Fish	Short-headed lamprey	*Mordacia mordax*	Murray estuary. Historically recorded in Lake Alex. Not recorded since prior to 2003/ present.	Breed	•	•							e
Fish	Sea mullet	*Mugil cephalus*	MM		•							LC	
Fish	Southern eagle ray	*Myliobatis australis*	MM		•							LC	

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Fish	Southern pygmy perch	*Nannoperca australis*	Recorded in Lake Alex in 2003, not recorded since then. Have undergone a significant reduction in distribution and abundance since early 2007 (Wedderburn & Barnes 2009)/present.	Breed		•							e
Fish	Yarra pygmy perch	*Nannoperca obscura*	Recorded in Lake Alex in 2003. Have undergone a significant reduction in distribution and abundance since early 2007. Despite extensive sampling they were not detected within Lake Alex in Nov 2008 or Mar 2009 surveys, and the species is now likely extinct from the Murray-Darling basin (Wedderburn & Barnes 2009)/present.	Breed		•		VU				VU	e
Fish	Bony bream	*Nematalosa erebi*	MM/estuary	Breed	•								
Fish	Western striped grunter	*Pelates octolineatus*	MM/estuary		•								
Fish	Flat-headed gudgeon	*Philypnodon grandiceps*	Murray estuary. Recorded recently in Coorong but only under conditions of freshwater inflow.	Breed	•								r
Fish	Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Murray estuary. Recorded recently in Coorong but only under conditions of freshwater inflow.	Breed	•								r

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Fish	Tailor	*Pomatomus saltatrix*	MM/estuary		•								
Fish	Congolli	*Pseudaphritis urvillii*	Murray estuary. Diadromous. Has apparently declined over the past few years, to the point that it was not captured in Mar 2009 (Wedderburn & Barnes 2009). Jennings et al. (2008) found a 99% decline in young of that year for congolli, six months after flow cessation over the barrages between 2006–07 and 2007–08. Accumulations of sexually mature female congolli were present from Sept 2008 to winter 2010 upstream of the Goolwa Barrages/ present.	Breed	•	•							r
Fish	Silver trevally	*Pseudocaranx dentex*	MM/estuary		•								
Fish	Bluespot goby	*Pseudogobius olorum*	MM/estuary	Breed	•								
Fish	Australian smelt	*Retropinna semoni*	MM/estuary	Breed	•								
Fish	Greenback flounder	*Rhombosolea tapirina*	MM/estuary, N Lagoon	Breed	•								
Fish	Australian sardine	*Sardinops neopilchardus*	MM/estuary		•								

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Fish	Blue sprat	*Spratelloides robustus*	MM/estuary		•								
Fish	Spotted pipefish	*Stigmatopora argus*	MM/estuary		•								
Fish	Freshwater catfish	*Tandanus tandanus*	Historically recorded in Lake Alex: not recorded since 2003/present.	Breed		•							e
Fish	Scary's tasmangoby	*Tasmanogobius lasti*	MM/estuary, N Lagoon	Breed	•								
Fish	Smooth toadfish	*Tetractenos glaber*	MM/estuary		•								
Bird	Australian reed-warbler	*Acrocephalus australis (orientalis)*	Present	Breeding migrant	•	•		m	X		X	LC	
Bird	Common sandpiper	*Actitis (Tringa) hypoleucos*	Rarely recorded/ present in Coorong. Not recorded 2003–2009 in either lake. Recorded Lock 1 to Wellington/ present.	NB Migrant	•	•	•	m	X		X	LC	r
Bird	Chestnut teal	*Anas castanea*		Breed	•	•	•					LC	
Bird	Grey teal	*Anas gracilis*		Breed	•	•	•					LC	
Bird	Australasian shoveler	*Anas rhynchotis*	Population variable with recent low/present in Coorong. Marked decline 2003–2009 in both lakes. Uncommon in 2009. Recorded Lock 1 to Wellington/ present.	Breed	•	•	•					LC	r

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Pacific black duck	*Anas superciliosa*		Breed	•	•	•					LC	
Bird	Darter	*Anhinga melanogaster (novaehollandiae)*	Rarely recorded in Coorong, variable estuary/present. Marked decline-to-uncommon in Lake Alex, uncommon in Lake Albert. Recorded Lock 1 to Wellington/ present.	Breed	•	•	•					LC	r
Bird	Cattle egret	*Ardea ibis*	Increase then decline in estuary, not recorded in Coorong/present. Uncommon in Lake Alex, rare in Lake Albert. Recorded Lock 1 to Wellington/ present.		•	•	•		X	X		LC	r
Bird	Intermediate egret	*Ardea intermedia*	Coorong: not recorded since 2000/present. Lower Lakes: not recorded 2003–2009. Recorded Lock 1 to Wellington/present.		•	•	•					LC	r
Bird	Eastern great egret	*Ardea modesta*	Coorong: population decline to very low numbers/present. Common but variable in Lake Alex, marked decline-to-rare in Lake Albert 2003–2009/ present.	No	•	•			X	X		LC	
Bird	Flesh-footed shearwater	*Ardenna carneipes*			•					X	X	LC	r
Bird	Ruddy turnstone	*Arenaria interpres*	Coorong: rare/present.	NB Migrant	•			m	X	X	X	LC	r

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Hardhead	*Aythya australis*		Breed	•	•	•					LC	
Bird	Musk duck	*Biziura lobata*	Coorong: variable but at times common/present. Lower Lakes: rare 2003–2009. Recorded Lock 1 to Wellington/present.	Breed	•	•	•					LC	r
Bird	Australasian bittern	*Botaurus poiciloptilus*	Coorong: not recorded recently/present. Lower Lakes: rare 2003–2009/ present.	?	•	•						EN	v
Bird	Sharp-tailed sandpiper	*Calidris acuminata*	Coorong: very common but recent marked decline/present.	NB Migrant	•			m	X	X	X	LC	
Bird	Sanderling	*Calidris alba*	Coorong: variable population from common to absent/ present.	NB Migrant	•			m	X	X	X	LC	r
Bird	red knot	*Calidris canutus*	Coorong: not present in most years/present.	NB Migrant	•			m	X	X	X	LC	
Bird	Curlew sandpiper	*Calidris ferruginea*	Coorong: marked decline/present. Decline 2004–2009 in Lake Alex, increase in Lake Albert in same period/present.	NB Migrant	•	•		m	X	X	X	LC	
Bird	Pectoral sandpiper	*Calidris melanotos*	Coorong: rare not recorded since 2000/ present.	NBMigrant	•	•		m		X	X	LC	r

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Red-necked stint	*Calidris ruficollis*	Coorong: large population but recent large decline/present. Trend variable but common in Lake Alex, marked increase in Lake Albert 2003–2009/ present.	NBMigrant	•	•		m	X	X	X	LC	
Bird	Long-toed stint	*Calidris subminuta*	Rare in estuary/present. Lower Lakes: not recorded 2003–2009/ present.	NBMigrant	•	•		m	X	X	X	LC	r
Bird	Great knot	*Calidris tenuirostris*	Coorong: generally uncommon/present.	NBMigrant	•			m	X	X	X	VU	r
Bird	Cape Barren goose	*Cereopsis novaehollandiae*	Coorong: population variable/present. Marked decline-to-uncommon in Lake Alex, rare in Lake Albert 2003 to 2009. Recorded Lock 1 to Wellington/present.	NBMigrant	•	•	•	m				LC	r
Bird	Double-banded plover	*Charadrius bicinctus*		NBMigrant	•	•	•	m				LC	
Bird	Greater sand plover	*Charadrius leschenaultii*	Coorong: not recorded recently/present. Recorded Lock 1 to Wellington/present.	NBMigrant	•		•	m	X	X	X	LC	r
Bird	Lesser sand plover	*Charadrius mongolus*	Coorong: rare/present.	NBMigrant	•			m	X	X	X	LC	r
Bird	Red-capped plover	*Charadrius ruficapillus*			•	•	•					LC	

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Australian wood duck	*Chenonetta jubata*		Breed	•	•	•					LC	
Bird	Whiskered tern	*Chlidonias hybridus*			•	•	•					LC	
Bird	Banded stilt	*Cladorhynchus leucocephalus*	Coorong: recent large population increases/ present. Marked decline-to-uncommon in Lake Alex, rare in Lake Albert 2003 to 2009. Recorded Lock 1 to Wellington/ present.	Breed	•	•	•					LC	v
Bird	Black swan	*Cygnus atratus*		Breed	•	•	•					LC	
Bird	Little egret	*Egretta garzetta*	Coorong: uncommon/ present. Lower Lakes: rare 2003–2009. Recorded Lock 1 to Wellington/ present.	Breed: Lake Alex	•	•	•					LC	r
Bird	White-faced heron	*Egretta novaehollandiae*		Breed	•	•	•					LC	
Bird	Black-fronted dotterel	*Elseyornis melanops*		Breed	•	•	•					LC	
Bird	Red-kneed dotterel	*Erythrogonys cinctus*		Breed	•	•	•					LC	
Bird	Latham's snipe	*Gallinago hardwickii*	Lower Lakes: not recorded 2003–2009. Recorded Lock 1 to Wellington/present.		•	•	•	m	X	X	X		r

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Brolga	*Grus rubicunda*	Recorded Lock 1 to Wellington/present.				•					LC	r
Bird	Sooty oystercatcher	*Haematopus fuliginosus*	Coorong: uncommon, population established in early 1980s/present.	Breed	•							LC	
Bird	Pied oystercatcher	*Haematopus longirostris*	Coorong: stable/present.	Breed	•							LC	r
Bird	White-bellied sea-eagle	*Haliaeetus leucogaster*		Breed	•	•			X			LC	e
Bird	Black-winged stilt	*Himantopus himantopus*		Breed	•	•	•	m				LC	
Bird	Caspian tern	*Hydroprogne (Sterna) caspia*	Marked decline in estuary, and habitat in Coorong is variable. Marked decline 2003–2009 in both lakes. Rare 2009/present.	Breed	•	•			X			LC	
Bird	Pacific gull	*Larus pacificus*			•	•	•					LC	
Bird	Lewin's rail	*Lewinia pectoralis*	Coorong: rare/present. Lower Lakes: rarely recorded in Lake Alex, not recorded in Lake Albert 2003–2009. Recorded Lock 1 to Wellington/present.	Breed	•	•						LC	v

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Bar-tailed godwit	*Limosa lapponica*	Coorong: recent population increases/ present. Lower Lakes: rarely recorded 2003 to 2009/present.	NB Migrant	•	•		m	X	X	X	LC	r
Bird	Black-tailed godwit	*Limosa limosa*	Coorong: population variable/present. Rarely recorded in Lower Lakes 2003–2009. Recorded Lock 1 to Wellington/ present.	NB Migrant	•	•	•	m	X	X	X	NT	r
Bird	Pink-eared duck	*Malacorhynchus membranaceus*			•	•	•					LC	
Bird	Little pied cormorant	*Microcarbo (Phalacrocorax) melanoleucos*		Breed	•	•	•					LC	
Bird	Orange-bellied parrot	*Neophema chrysogaster*	Coorong: recent marked decline to very low numbers/present. Rarely recorded 2003–2009. Recent marked decline evident (Ehmke et al. 2009)/present.	NB Migrant	•	•		CR		X		CE	e
Bird	Eastern curlew	*Numenius madagascariensis*	Coorong: population variable/present. Lower Lakes: not recorded 2003–2009/present.	NB Migrant	•	•		m	X	X	X	VU	v
Bird	Whimbrel	*Numenius phaeopus*	Coorong: historically common but now rare/ present. Not recorded 2003–2009/present.	NB Migrant	•	•		m	X	X	X	LC	r

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Nankeen night heron	*Nycticorax caledonicus*		Breed	•	•	•					LC	
Bird	Blue-billed duck	*Oxyura australis*	Coorong: rarely recorded/present. Lower Lakes: rare 2003–2009. Recorded Lock 1 to Wellington/present.	NB Migrant	•	•	•					NT	r
Bird	Eastern osprey	*Pandion cristatus*	Lower Lakes: present. Recorded Lock 1 to Wellington/present.			•		m				LC	e
Bird	Australian pelican	*Pelicanus conspicillatus*		Breed	•	•	•						
Bird	Great cormorant	*Phalacrocorax carbo*		Breed	•	•	•					LC	
Bird	Black-faced cormorant	*Phalacrocorax fuscescens*			•							LC	
Bird	Little black cormorant	*Phalacrocorax sulcirostris*		Breed	•	•	•					LC	
Bird	Pied cormorant	*Phalacrocorax varius*		Breed	•	•	•					LC	
Bird	Red-necked phalarope	*Phalaropus lobatus*	Vagrant/present	NB Migrant	•				X	X	X	LC	
Bird	Ruff	*Philomachus pugnax*	Coorong: rare/present. Lower Lakes: not recorded 2003–2009/ present.	NB Migrant	•	•		m	X	X	X	LC	r

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Yellow-billed spoonbill	*Platelea flavipes*		Breed	•	•	•					LC	
Bird	Royal spoonbill	*Platelea regia*		Breed	•	•	•					LC	
Bird	Glossy ibis	*Plegadis falcinellus*	Coorong: not recorded since 2002/present. Lower Lakes: not recorded since 2007, 268 recorded in Lake Alex in 2005. Recorded Lock 1 to Wellington/present.	Breed: Lake Alex	•	•	•	m	X			LC	r
Bird	Pacific golden plover	*Pluvialis fulva*	Coorong: variable in moderate numbers/ present. Lower Lakes: not recorded since 2007, 14 recorded Lake Alex in 2004/present.	NB Migrant	•	•		m			X	LC	r
Bird	Grey plover	*Pluvialis squatarola*	Coorong: uncommon/ present. Lower Lakes: rarely recorded in Lake Alex, not recorded in Lake Albert 2003–2009/ present.	NB Migrant	•	•		m	X	X	X	LC	
Bird	Great crested grebe	*Podiceps cristatus*	Variable in Coorong; marked decline in estuary/present. Lower Lakes: severe decline 2005–2009 to rare in 2009. Recorded Lock 1 to Wellington/present.	Breed	•	•	•					LC	r
Bird	Regent parrot	*Polytelis anthopeplus*	Recorded Lock 1 to Wellington/present.	Breed		•		VU				LC	v

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Hoary-headed grebe	*Popiocephalus poliocephalus*		Breed	•	•	•					LC	
Bird	Purple swamphen	*Porphyeario porphyeario*		Breed	•	•	•					LC	
Bird	Australian spotted crake	*Porzana fluminea*		Breed	•	•	•					LC	
Bird	Spotless crake	*Porzana tabuensis*	Lower Lakes: rare 2003–2009. Recorded Lock 1 to Wellington/present.	Breed	•	•	•					LC	r
Bird	Red-necked avocet	*Recurvirostra novaehollandiae*		Breed	•	•	•					LC	
Bird	Australian painted snipe	*Rostratula australis*	Recorded Lock 1 to Wellington/present.	Breed			•	VU	X			EN	v
Bird	Common tern	*Sterna hirundo*	Coorong: rarely recorded/present. Rarely recorded in Lake Alex, not recorded in Lake Albert 2003–2009/ present.	NB Migrant	•	•		m	X	X	X	LC	r
Bird	Gull-billed tern	*Sterna nilotica*			•	•	•	m				LC	
Bird	Little tern	*Sternula (Sterna) albifrons*	Coorong: not recorded since 2000/present. Lower Lakes: not recorded 2003–2009/ present.	Breed: Coorong Islands	•	•		m	X	X	X	LC	e
Bird	Fairy tern	*Sternula (Sterna) nereis*	Coorong: population decline/present. Rarely recorded in Lake Albert, not recorded in Lake Alex 2003–2009/present.	Breed	•	•						VU	e

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Freckled duck	*Stictonetta naevosa*	Coorong: uncommon and irregular/present. Lower Lakes: marked decline 2003–2009 in both lakes. Not recorded 2007–2009. Recorded Lock 1 to Wellington/ present.	NB Migrant	•	•	•					LC	v
Bird	Crested tern	*Thalasseus (Sterna) bergii*		Breed	•	•	•	m				LC	
Bird	Hooded plover	*Thinornis rubricollis*	Coorong: uncommon but stable population/ present. Rarely recorded in Lake Alex, not recorded Lake Albert 2003–2009/present.	Breed	•	•						NT	v
Bird	Australian white ibis	*Threskiornis molucca*		Breed	•	•	•					LC	
Bird	Straw-necked ibis	*Threskiornis spinicollis*		Breed	•	•	•					LC	
Bird	Black-tailed native-hen	*Tribonyx (Gallinula) ventralis*		Breed	•	•	•					LC	
Bird	Grey-tailed tattler	*Tringa brevipes*	Vagrant/present	NB Migrant	•			m	X	X	X	LC	r
Bird	Wood sandpiper	*Tringa glareola*	Uncommon in Lake Alex then recent decline to zero, not recorded in Lake Albert 2003–2009/ present.	NB Migrant		•						LC	
Bird	Wandering tattler	*Tringa incana*		NB Migrant	•			m	X	X	X	LC	

Fauna type	Common name	Scientific name	Species habitat/ presence of species	Breeding status	Coorong	Lower Lakes	Lock 1 to Wellington	EPBC Act	CAMBA	JAMBA	RoKAMBA	IUCN Red list	State gov. listing
Bird	Common greenshank	*Tringa nebularia*	Stable in Coorong, increase in estuary/ present. Lower Lakes: decline 2004–2009 in Lake Alex, uncommon Lake Albert in same period/present.	NB Migrant	•	•		m	X	X	X	LC	
Bird	Marsh sandpiper	*Tringa stagnatilis*	Coorong: variable but at times common/present. Lower Lakes: uncommon, but variable in numbers recorded in Lakes Alex and Albert.	NB Migrant	•	•		m	X	X	X	LC	
Bird	Masked lapwing	*Vanellus miles*		Breed	•	•						LC	
Bird	Terek sandpiper	*Xenus cinereus*	Coorong: rare/present.	NB Migrant	•			m	X	X	X	LC	r
Amphibian	Brown toadlet	*Pseudophryne bibronii*		Breed	•	•						NT	v
Amphibian	Golden bell frog	*Litoria raniformis*		Breed	•	•		VU				EN	v
Amphibian	Marbled toadlet	*Pseudophryne semimarmorata*		Breed	•	•						LC	v
Reptile	Long-necked tortoise	*Chelodina longicollis*		Breed		•	•					LC	
Reptile	Macquarie tortoise	*Emydura macquarii*	Recorded Lower Lakes and Lock 1 to Wellington/ present.	Breed		•	•					LC	v
Mammal	Southern myotis	*Myotis macropus*	Recorded Lock 1 to Wellington/present.	Breed			•					LC	e
Flora	Leafy twig-rush	*Cladium procerum*			•	•							r

Note: NB Migrant = winter non-breeder migrant.

Appendix 5
Lake Alexandrina and Lake Albert volumetric data

Lake Alexandrina (including Goolwa Channel)

Water level m (AHD)	Surface area (ha)	Estimated volume[1] (GL)	Increment volume (GL)
0.8	64,912.00	1,651.16	32.44
0.75	64,845.60	1,618.72	32.40
0.7	64,778.67	1,586.32	64.71
0.6	64,652.97	1,521.62	64.57
0.5	64,496.32	1,457.05	64.39
0.4	64,293.79	1,392.66	64.11
0.3	63,906.69	1,328.55	63.54
0.2	63,110.55	1,265.01	62.65
0.1	62,213.89	1,202.36	61.76
0	61,281.82	1,140.60	60.74
-0.1	60,171.80	1,079.86	59.56
-0.2	58,938.03	1,020.31	58.29
-0.3	57,622.92	962.02	56.95
-0.4	56,243.17	905.06	55.40
-0.5	54,304.02	849.67	53.82
-0.6	53,411.39	795.84	52.98
-0.7	52,533.18	742.86	52.05
-0.8	51,609.86	690.81	51.18
-0.9	50,752.39	639.63	50.28
-1	49,804.71	589.35	49.23
-1.1	48,607.59	540.12	47.95
-1.2	47,307.43	492.17	46.66

Water level m (AHD)	Surface area (ha)	Estimated volume[1] (GL)	Increment volume (GL)
-1.3	45,973.43	445.51	45.11
-1.4	44,151.87	400.41	43.13
-1.5	42,180.94	357.27	41.20
-1.6	40,205.64	316.08	39.35
-1.7	38,486.18	276.73	37.72
-1.8	36,872.28	239.01	35.78
-2	32,549.79	169.58	31.17
-2.2	26,081.50	110.51	24.16
-2.4	19,296.92	65.44	17.89
-2.6	12,907.22	32.74	11.52
-2.8	7,136.35	12.75	5.95
-3	2,892.82	3.08	2.55
-3.5	84.06	0.53	0.26
-4	26.19	0.27	0.08
-4.5	11.26	0.19	0.05
-5	8.25	0.14	

1. These volumes are calculated using bathymetry based on Lidar and Sonar spatial data. The vertical accuracy of the LiDAR raw data is +/- 0.15 m. The vertical accuracy of the Sonar raw data collected by the echo sounder is +/-0.1 m. Bathymetry was based on resampled 10 m resolution from source 2 m data. Sonar data points in less than 1 m of water are synthetic due to access restrictions for boat-based sonar and have a stated accuracy of +/- 0.5 mAHD. Sonar was obtained at a time when the lake levels where at 0.75 mAHD, giving a accuracy level of +/- 0.1 m to level of –0.25 mAHD. The LiDAR was flown at a time when water levels were less than –0.4 mAHD, hence the LiDAR more than covers the extent of less accurate Sonar data. As such, the combined bathymetry accuracy can be taken as +/- 0.15 m. Extract by mask using management unit boundary Surface Volume_3D Analyst tool in ArcGIS 9.1. Data source: CLLMM Project, Department of Environment and Natural Resources (2009).

Lake Albert

Water level m (AHD)	Surface area (ha)	Estimated volume[1] (GL)	Increment volume (GL)
0.8	17,187.41	287.56	8.59
0.75	17,175.69	278.97	8.58
0.7	17,163.06	270.39	17.15
0.6	17,133.89	253.24	17.11
0.5	17,096.98	236.13	17.07
0.4	17,042.35	219.07	17.00
0.3	16,960.01	202.07	16.89
0.2	16,821.03	185.18	16.70
0.1	16,590.34	168.47	16.45
0	16,288.82	152.03	16.09
-0.1	15,856.09	135.94	15.60
-0.2	15,369.69	120.34	7.63
-0.25	15,143.34	112.71	7.52
-0.3	14,929.42	105.19	14.70
-0.4	14,473.59	90.49	14.16
-0.5	13,578.86	76.33	12.71
-0.6	12,105.29	63.61	11.75
-0.7	11,341.48	51.87	5.57
-0.75	10,960.28	46.30	5.38
-0.8	10,586.22	40.91	10.13
-0.9	9,673.84	30.78	9.17
-1	8,528.09	21.61	7.58
-1.1	6,653.46	14.03	5.93
-1.2	5,289.60	8.10	4.56
-1.3	3,759.13	3.55	2.68
-1.4	1,525.73	0.87	0.56
-1.5	164.99	0.31	0.12

Water level m (AHD)	Surface area (ha)	Estimated volume[1] (GL)	Increment volume (GL)
-1.6	77.95	0.19	0.03
-1.7	27.67	0.16	0.03
-1.8	25.07	0.13	0.02
-1.9	22.57	0.11	0.02
-2	20.26	0.09	0.02
-2.2	14.79	0.05	0.01
-2.5	7.24	0.02	0.01
-3	1.38	0.00	0.00
-3.4	0.00	0.00	0.00

1. These volumes are calculated using bathymetry based on Lidar and Sonar spatial data. The vertical accuracy of the LiDAR raw data is +/- 0.15 m. The vertical accuracy of the Sonar raw data collected by the echo sounder is +/-0.1 m. Bathymetry was based on resampled 10 m resolution from source 2 m data. Sonar data points in less than 1 m of water are synthetic due to access restrictions for boat based sonar and have a stated accuracy of +/- 0.5 mAHD. Sonar was obtained at a time when the lake levels where at 0.75 mAHD, giving a accuracy level of +/- 0.1 m to level of –0.25 mAHD. The LiDAR was flown at a time when water levels were less than –0.4 mAHD, hence the LiDAR more than covers the extent of less accurate Sonar data. As such, the combined bathymetry accuracy can be taken as +/- 0.15 m. Extract by mask using management unit boundary Surface Volume_3D Analyst tool in ArcGIS 9.1. Data source: CLLMM Project, Department of Environment and Natural Resources (2009).

Appendix 6
Risk assessment framework

Risk likelihood rating

Almost certain	Is expected to occur in most circumstances
Likely	Will probably occur in most circumstances
Possible	Could occur at some time
Unlikely	Not expected to occur
Rare	May occur in exceptional circumstances only

Risk consequence rating

Critical	Major widespread loss of environmental amenity and progressive irrecoverable environmental damage
Major	Severe loss of environmental amenity and danger of continuing environmental damage
Moderate	Isolated but significant instances of environmental damage that might be reversed with intensive efforts
Minor	Minor instances of environmental damage that could be reversed
Insignificant	No environmental damage

Risk analysis matrix

LIKELIHOOD	CONSEQUENCE				
	Insignificant	Minor	Moderate	Major	Critical
Almost certain	Low	Medium	High	Severe	Severe
Likely	Low	Medium	Medium	High	Severe
Possible	Low	Low	Medium	High	Severe
Unlikely	Low	Low	Low	Medium	High
Rare	Low	Low	Low	Medium	High

Appendix 7
Operational monitoring report template

Commonwealth Environmental Watering Program

Operational Monitoring Report

Please provide the completed form to <insert name and email address>, within two weeks of completion of water delivery or, if water delivery lasts longer than 2 months, also supply intermediate reports at monthly intervals.

Final Operational Report Intermediate Operational Report Reporting Period: From To

Site name	**<EWDS to prefill>**	**Date**
Location	GPS Coordinates or Map Reference for site (if not previously provided)	
Contact Name	*Contact details for first point of contact for this watering event*	
Event details	*Watering Objective(s) <EWDS to prefill>*	
	Total volume of water allocated for the watering event *CEW:* *Other(please specify) :*	
	Total volume of water delivered in watering event *CEW:* *Other (please specify):*	*Delivery measurement* *Delivery mechanism:* *Method of measurement:* *Measurement location:*
	Delivery start date (and end date if final report) of watering event	
	Please provide details of any complementary works	
	If a deviation has occurred between agreed and actual delivery volumes or delivery arrangements, please provide detail	
	Maximum area inundated (ha) (if final report)	
	Estimated duration of inundation (if known)[1]	
Risk management	*Please describe the measure(s) that were undertaken to mitigate identified risks for the watering event (eg. water quality, alien species); please attach any relevant monitoring data.* *Have any risks eventuated? Did any risk issue(s) arise that had not been identified prior to delivery? Have any additional management steps been taken?*	
Other Issues	*Have any other significant issues been encountered during delivery?*	
Initial Observations	*Please describe and provide details of any species of conservation significance (state or Commonwealth listed threatened species, or listed migratory species) observed at the site during the watering event?*	
	Please describe and provide details of any breeding of frogs, birds or other prominent species observed at the site during the watering event?	
	Please describe and provide details of any observable responses in vegetation, such as improved vigour or significant new growth, following the watering event?	
	Any other observations?	
Photographs	*Please attach photographs of the site prior, during and after delivery*[2]	

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[1] Please provide the actual duration (or a more accurate estimation) at a later date (e.g. when intervention monitoring reports are supplied).

[2] For internal use. Permission will be sought before any public use.