





Lower Lakes, Coorong and Murray Mouth

Environmental Water Management Plan



May 2014



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Published by Murray–Darling Basin Authority.

MDBA Publication No 10/14

ISBN 978-1-922177-81-0 (print) ISBN 978-1-922177-82-7 (online)

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Acknowledgement of the Traditional Owners of the Murray–Darling Basin

The Murray–Darling Basin Authority (MDBA) acknowledges and pays its respect to the Traditional Owners and their Nations of the Murray–Darling Basin. The contributions of earlier generations, including the Elders, who have fought for their rights in natural resource management are also valued and respected.

MDBA recognises and acknowledges that the Traditional Owners and their Nations in the Murray–Darling Basin have a deep cultural, social, environmental, spiritual and economic connection to their lands and waters. MDBA understands the need for recognition of Traditional Owner knowledge and cultural values in natural resource management associated with the Basin. Further research is required to assist in understanding and providing for cultural flows. MDBA supports the belief of the Northern Murray–Darling Basin Aboriginal Nations and the Murray Lower Darling Rivers Indigenous Nations that cultural flows will provide beneficial outcomes for Traditional Owners.

The approach of Traditional Owners to caring for the natural landscape, including water, can be expressed in the words of Ngarrindjeri elder Tom Trevorrow: 'our traditional management plan was don't be greedy, don't take any more than you need and respect everything around you. That's the management plan—it's such a simple management plan, but so hard for people to carry out.¹ This traditional philosophy is widely held by Traditional Owners and respected and supported by MDBA.

¹ Tom Trevorrow (2010). Murrundi Ruwe Pangari Ringbalin 'River Country Spirit Ceremony: Aboriginal Perspectives on River Country'.



Summary

The Living Murray initiative is one of Australia's most significant river restoration programs, with the long-term objective to achieve a healthy, working River Murray system. Six icon sites along the River Murray have been identified that have significant ecological, cultural, recreational, heritage and economic values. Ecological objectives (First Step Decisions), were derived from the Outcome Evaluation Framework and have been determined for each icon site to guide the improvement in icon site environmental health.

Lakes Alexandrina and Albert (the 'Lower Lakes'), the Coorong and Murray Mouth (LLCMM) have been identified as an icon site. The LLCMM icon site covers approximately 140,000 ha, is a Ramsar-listed wetland of international importance and is also one of eighteen key indicator sites of the Murray–Darling Basin. The site has a unique mosaic of 23 Ramsar wetland types and provides habitat for nationally significant species. The icon site, which contains the Meeting of the Waters registered heritage site, is central to the life and culture of the Ngarrindjeri people, who continue to live on their traditional country.

The ecological health of the icon site has been severely degraded by river regulation, overextraction, and to a lesser extent a reduction in the diversion of drainage water from the South East into the Coorong South Lagoon. These impacts have been exacerbated in recent times by a prolonged period of drought. Through The Living Murray initiative First Step Decision, the Murray–Darling Basin Ministerial Council (MDBMC) established three broad ecological objectives to improve the condition of the LLCMM icon site:

- an open Murray Mouth
- more frequent estuarine fish spawning and recruitment
- enhanced migratory waterbird habitat in the Lower Lakes and Coorong.

In order to achieve these objectives, 16 LLCMM-specific ecological and physical targets have been developed to quantify changes in the condition of the site.

The purpose of this Environmental Water Management Plan (EWMP) is to define the environmental water needs for the LLCMM, based on the volumes and flow regimes required to achieve the ecological objectives and targets of the icon site. Delivery of flows to the Lower Lakes through the River Murray system to maintain water level, water quality and to prevent exposure of acid sulphate soils, has been identified as the key requirement to achieve the icon site ecological objectives and targets. Sufficient inflows to the Lower Lakes will also allow barrage releases to ensure connectivity between all parts of the icon site (Lake Alexandrina/estuary, and estuary/ocean), maintain an open Murray Mouth, estuarine habitats and water level and quality throughout the Coorong ecosystem. Water quality thresholds have been determined for Lake Alexandrina (electrical conductivity below 1,000 μ S/cm 95% of the time, and below 1,500 EC 100% of the time) and the Coorong (salinity below 100 ppt in the South Lagoon) in response to the physiological tolerance of the icon site's fauna and flora.



The proposed environmental water requirements to achieve the LLCMM icon site First Step Decisions, in order of priority, are:

- Water is provided to maintain lake levels above 0.0 m Australian Height Datum (AHD) to prevent exposure of acid sulfate soils and to maintain connectivity between Lakes Alexandrina and Albert.
- Water is provided to maintain lake levels within the seasonal operating envelope (0.35-0.75 m AHD, and every three years 0.5-0.83 m AHD).
- 3. Fishways are operated year-round (55 GL/yr).
- 4. Attractant flows are provided adjacent to fishways, and a limited estuary achieved in Boundary Creek (up to 230 GL/yr, with spring-summer priority timing).
- Minimum annual flow from the barrages required to achieve salinity target of <1,000 μS/cm in Lake Alexandrina 95% of the time (650 GL/yr minimum in any year incorporating a three-year average of 2,000 GL/yr).
- 6. Minimum annual flow required to keep the Murray Mouth open (730-1,090 GL/yr).
- 7. Flows of at least 2,500 GL over two years to prevent the Coorong existing in a degraded ecosystem state.
- 8. Flows of 6,000 and 10,000 GL per year every three and seven years respectively to achieve a healthy Coorong ecosystem state.

These environmental water requirements were developed to provide information on how much water the site requires to function in a 'healthy' ecosystem state, regardless of what is available in environmental water portfolios. It is not expected that The Living Murray portfolio will be able to meet the full water requirements for the LLCMM icon site.

Requirements 1-3 are likely to be met by South Australian Entitlement Flow (1,850 GL/year). Achieving requirements 3-8 will require periods of above entitlement flow supplemented by significant volumes of environmental water from both The Living Murray and from the Commonwealth Environmental Water Holder. Requirement 8 will also require significant volumes of unregulated flow. The ecological and physical outcomes supported by actions proposed in this EWMP will be assessed by monitoring programs and ecological modelling with ongoing significant input from the scientific community. The LLCMM Icon Site EWMP has been developed, and will be implemented, in consultation with the community and the Ngarrindjeri Regional Authority (NRA). Close collaboration with the NRA will continue regarding their aspirations for the management, protection and enhancement of the Lower Lakes, Coorong and Murray Mouth as a site of enormous cultural significance.



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About this plan

This environmental water management plan consists of:

- A long-term strategic plan, (per Clause 117 of the TLM Business Plan), which outlines the icon site's environmental water requirements and how to broadly achieve them with a combination of environmental water and works and measures.
- Schedules detailing operational information about the icon site such as Condition Monitoring, Risk Management and Communication Plans. These Schedules will be added to the environmental water management plan as they become available and updated to reflect learnings from the operation of works, the results of environmental waterings and the latest science.

The environmental water management plans provide context for an icon site's water planning, delivery, monitoring and consultation processes. While the environmental water management plans include proposed operating strategies, annual water planning and implementation will be responsive to changing water resource conditions, opportunities and environmental priorities throughout the season and from year to year.

This environmental water management plan and associated schedules have been prepared by TLM partner governments in consultation with the relevant stakeholders. The MDBA and the Department of Environment, Water and Natural Resources would like to acknowledge the significant contribution of all those involved in the development of this environmental water management plan.

The Ngarrindjeri Nation is acknowledged as the traditional owner of the country that includes the Lakes, Kurangk (Coorong) and Murray Mouth.

This document is to be read in conjunction with the Ngarrindjeri Nation Yarluwar-Ruwe (SEA Country) Plan, the Ramsar Management Plan and the Ecological Character Description Report.



1. Introduction

1.1 The Living Murray

The Living Murray (TLM) is one of Australia's most significant river restoration programs. Established in 2002, TLM is a partnership of the New South Wales, Victorian, South Australian, Australian Capital Territory and the Commonwealth governments, coordinated by the Murray– Darling Basin Authority (MDBA). The long-term goal of this program is to achieve a healthy working River Murray system for the benefit of all Australians.

The Living Murray aims to improve the environmental health of six icon sites (Figure 1: Location of The Living Murray icon sites) that were chosen for their significant ecological, cultural, recreational, heritage and economic values:

- Barmah–Millewa Forest
- Gunbower-Koondrook-Perricoota Forest
- Hattah Lakes
- Chowilla Floodplain and Lindsay–Wallpolla Islands (including Mulcra Island)
- River Murray Channel
- Lower Lakes, Coorong and Murray Mouth.

Through its First Step water recovery initiative, TLM has acquired a water portfolio consisting of environmental water entitlements. As of November 2013, there was 486.1 GL long-term Cap Equivalent (LTCE), with a further 2 GL LTCE to be recovered by projects still being implemented². The actual volume of water available against these entitlements is dependent on the allocations.

This portfolio will be used to achieve environmental objectives at the icon sites. Regulating structures, water delivery channels and fishways, known as works and measures, will deliver and manage the environmental water at the icon sites.

The Living Murray aims to align itself to the requirements of the Basin Plan Environmental Watering Plan in the future.

Further information on The Living Murray is available on the MDBA website at <u>www.mdba.gov.au</u>.

² The long-term Cap equivalent is a type of average and takes into account different characteristics of water entitlements in New South Wales, Victoria and South Australia and their reliability. The measure of water recovery creates a common unit on measure, thus allowing equitable comparison of a broad range of water recovery measures.





Figure 1: Location of The Living Murray icon sites

1.2 The Living Murray Icon Site Environmental Water Management Plans

This Lower Lakes, Coorong and Murray Mouth Environmental Water Management Plan establishes priorities for the use of TLM water within the icon site, identifies environmental objectives and targets (where appropriate), water delivery options and regimes that can utilise The Living Murray water portfolio for the site.

The development of the Lower Lakes, Coorong and Murray Mouth Environmental Water Management plan has been coordinated by the MDBA in consultation with the Environmental Watering Group to ensure a consistent approach to planning and management across the icon sites.

The revised plan builds on previous iterations of the Lower Lakes, Coorong and Murray Mouth Environmental Water Mangement Plan (previously known as 'environmental management plans') and incorporates consultation, research into icon site key species, learnings from water behaviour modelling and outcomes from previous environmental waterings.

The Lower Lakes, Coorong and Murray Mouth Environmental Water Management Plan reflects the larger volume now held in The Living Murray water portfolio, uses TLM works and measures (i.e. barrage fishways, where construction is completed) and the monitoring information gathered at the icon site to make informed decisions about environmental watering.



1.3 Planning context and legislation framework

There are a range of legislation, agreements and policies that provide direction for the Lower Lakes, Coorong and Murray Mouth icon site. The following is a summary of those agreements and legislation that is directly relevant to the management of the icon site.

1.4 Agreements

Ramsar Convention on Wetlands of International Importance

The Ramsar Convention on Wetlands of International Importance (the Ramsar Convention) is an international treaty with the broad aim of halting the worldwide loss of wetlands and to conserve, through wise use and management, those that remain. For wetlands to be listed as Ramsar wetlands, they need to be representative, rare or unique in terms of their ecological, botanical, zoological, limnological or hydrological importance. Ramsar-listed wetlands can be natural, artificial, permanent or temporary swamps, marshes, billabongs, lakes, salt marshes or mudflats classified as wetlands.

Signatories to the Ramsar Convention, including Australia, are required to formulate and implement their planning so as to promote the conservation of wetlands included in the Ramsar list, and as far as possible the wise use of all wetlands in their territory. This includes recognition of, and support for, Indigenous cultural values associated with wetlands. This planning is completed in the form of an Ecological Character Description which is then used by site managers to manage the sites values. The Ecological Character Description is currently under revision by Department of Environment, Water and Natural Resources (DEWNR). Managing the ecological character of the site is a requirement under the *Environment Protection and Biodiversity Conservation Act 1999* as a matter of national environmental significance (DSEWPC 2009) and is an obligation for State and Commonwealth governments to manage.

Bilateral Migratory Bird Agreements

Over the past 30 years Australia has signed three bilateral migratory bird agreements in an effort to conserve migratory birds in the east Asian and Australian regions: China–Australia Migratory Bird Agreement (signed in 1986); Japan–Australia Migratory Bird Agreement (signed in 1974); and the Republic of Korea – Australia Migratory Bird Agreement (came into effect in 2007).

These agreements protect terrestrial, water and shorebird species that migrate from Australia to Japan or China. The Japan–Australia Migratory Bird Agreement also provides for cooperation on the conservation of threatened birds, while the Republic of Korea–Australia Migratory Bird Agreement ensures conservation of migratory birds and collaboration on the protection of migratory shorebirds and their habitat (D SEW PC 2009).

United Nations Declaration on the Rights of Indigenous Peoples

The *Declaration on the Rights of Indigenous Peoples* was adopted by the United Nations in September 2007 and ratified by the Australian Government in April 2009. The Declaration sets out the individual and collective rights of Indigenous peoples, as well as their rights to culture, identity, language, employment, health, education, lands, waters and other issues. It also "emphasizes the rights of Indigenous peoples to maintain and strengthen their own institutions, cultures and traditions, and to pursue their development in keeping with their own needs and aspirations". In accordance with Articles 19, 25 & 32 Indigenous people must have a central



role in the development, implementation and evaluation of policy and legislative or administrative measures that concern water.

Murray-Darling Basin Agreements

The Murray–Darling Basin Ministerial Council established TLM in 2002. In 2004, the Australian Government and the governments of New South Wales, Victoria, South Australia and the Australian Capital Territory signed the Intergovernmental Agreement on Addressing Water Over-allocation and Achieving Environmental Objectives in the Murray–Darling Basin, which gave effect to a funding commitment (made in 2003) of \$500 million over five years for TLM. The Living Murray program's First Step aimed to recover 500 GL of water for the River Murray and focused on improving the environment at the six icon sites. A supplementary Intergovernmental Agreement was signed in 2006 which provided increased funding of \$200m to The Living Murray.

The Intergovernmental Agreement on Murray–Darling Basin Reform, signed by the Council of Australian Governments, aims to:

promote and co-ordinate effective planning and management for the equitable, efficient and sustainable use of the water and other natural resources of the Murray–Darling Basin (COAG 2008).

This Agreement was the foundation for the *Water Act 2007*, which established the MDBA whose role is to manage the Basin's water resources through the development of a Basin plan.

Kungun Ngarrindjeri Yunnan Agreement 2009 (Ngarrindjeri/SA Government)

The Kungun Ngarrindjeri Yunnan Agreement (Listen to Ngarrindjeri people talking) between Ngarrindjeri and the South Australian Government was set in place to frame the Ngarrindjeri strategy for negotiating Ngarrindjeri interests in natural resource management and, in particular, the South Australian Government's long-term plan for the Coorong, Lower Lakes and Murray Mouth. This is a legal, binding agreement entered into between Ngarrindjeri and various Ministers of the Crown in South Australia to articulate the rights and obligations flowing between them in relation to the subject matter of the agreement. Recital D (KNY 2009) provides an indication of the intentions of the agreement:

D. The Ministers have expressed a desire for a new relationship between the State of South Australia and Ngarrindjeri based upon mutual respect and trust acknowledging that Ngarrindjeri consider protection and maintenance of culture and cultural sites upon its land and water central in every respect to Ngarrindjeri community wellbeing and existence.

This agreement provides for the establishment and funding of a joint taskforce, thereby creating a formal context for the Ngarrindjeri Regional Authority to negotiate regarding South Australian Government programs on Ngarrindjeri *Ruwe/Ruwar*. The agreement also includes recognition of Ngarrindjeri traditional ownership, recognition of the NRA as the Ngarrindjeri peak body, and an agreement to negotiate on key, long-held Ngarrindjeri objectives such as the hand-back of the Coorong National Park.



Ngarrindjeri Regional Partnership Agreement with the Federal and South Australian Governments

A Regional Partnership Agreement between the Ngarrindjeri Regional Authority, the Australian Government and the State Government of South Australia was signed in July 2008. It was resigned and extended in 2011. Its aim is to support the development of Ngarrindjeri caring for country programs in combination with sustainable economic development. It specifically addresses the need to increase Ngarrindjeri participation in all aspects of environmental government and the region. In signing the agreement the State and Federal government and the Ngarrindjeri have agreed to work together in partnership to share responsibility for building the environmental, social and economic assets in the Ngarrindjeri region.

1.5 National Legislation

Water Act 2007 (Commonwealth)

The Water Act 2007 (the Act) established the Murray–Darling Basin Authority with functions and powers to ensure the Basin water resources are managed in an integrated, consistent and sustainable manner. The Act requires the Murray–Darling Basin Authority to prepare and oversee a Basin Plan. The Basin Plan, finalised in November 2012, is a legally enforceable document that provides for the integrated and sustainable management of water resources in the Basin.

The Basin Plan's Environmental Watering Plan provides a strategic framework for coordinated environmental water planning and environmental watering across the Murray–Darling Basin. In the future, TLM will align with the Environmental Watering Plan with respect to the development of Basin states' long term environmental watering plans and annual priorities, through the annual environmental water prioritisation processes.

Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth) The *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places (including natural, historic or Indigenous Australian places) — defined in the EPBC Act as matters of national environmental significance. There are eight matters of national environmental significance to which the EPBC Act applies.

The EPBC Act aims to balance the protection of these crucial environmental and cultural values with our society's economic and social needs by creating a legal framework and decision-making process based on the guiding principles of ecologically sustainable development.

1.6 State Legislation

Aboriginal Heritage Act 1988

This Act provides a legislative basis for recognising and protecting Aboriginal heritage, specifically in relation to culturally significant sites, objects or remains on all land and waters. The Act must be considered prior to on-ground works occuring in the icon site or management decisions that may impact on the Ngarrindjeri cultural landscape that is the icon site.

Environment Protection Act 1993

This Act is the primary legislation for the control and prevention of pollution in South Australia. This Act must be considered prior to dredging and earthworks being carried out in the icon site.



Fisheries Management Act 2007

Some freshwater fish not listed under the federal *EPBC Act 1999* are protected under the state *Fisheries Management Act 2007.* These include freshwater catfish (*Tandanus tandanus*), Murray cod (*Maccullochella peelii*), southern pygmy perch (*Nannoperca australis*), river blackfish (*Gadopsis marmoratus*) and southern purple spotted gudgeon (*Mogurnda adspersa*), all of which are found in the Lower River Murray and associated tributaries.

National Parks and Wildlife Act 1972

An Act to provide for the establishment and management of reserves for public benefit and enjoyment; to provide for the conservation of wildlife in a natural environment. The majority of the Coorong is part of the Coorong National Park.

Native Title (South Australia) Act 1994

This Act sets out processes for determining native title rights where Aboriginal or Torres Strait islander people have maintained a continuous connection to their traditional lands or waters. The Act must be considered prior to on-ground works occuring in the icon site.

Native Vegetation Act 1991

The object of this Act is to protect and enhance native vegetation, in particular remnant native vegetation. The Act must be considered prior to on-ground works occuring in the icon site.

Natural Resources Management Act 2004

The Act aims to assist in the achievement of ecologically sustainable development in South Australia by establishing an integrated scheme to promote the use and management of natural resources.

River Murray Act 2003

The Act aims to ensure that the River Murray is protected from activities that could impact on the health of the River. The *River Murray Act* recognises that the Coorong and Lakes Alexandrina and Albert Ramsar Site, as part of the Murray–Darling Basin, is an area of great environmental and economic significance to South Australia.

1.7 Legislative requirements – respecting Indigenous interests and values

Native Title and Aboriginal heritage requirements under the *Native Title Act 1993* (Cth) ('the NTA"), the *Aboriginal Heritage Act 1988* (SA) and the *Aboriginal and Torres Strait Islander Heritage Protection Act 1984* (Cth) need to be addressed in all programs being considered upon Ngarrindjeri lands and waters. The Ngarrindjeri's governance structure enables the addressing of legislative requirements, policy directions at State and Australian levels and international obligations.

Indigenous interests regarding water are a key objective of the *Water Act 2007* and an important consideration when Basin plans are developed (Section 21). The significance of Indigenous or 'cultural' flows for the Ngarrindjeri makes Indigenous considerations a priority when making restrictions on extractions. The 2004 Intergovernmental Agreement on a National Water Initiative refers to the inclusion of Indigenous 'social spiritual and customary objectives' and the recognition of Native Title Rights in planning of water issues.



The *Environment Protection and Biodiversity Conservation Act 1999* (Cth) promotes the use of Indigenous people's knowledge when taking a cooperative approach to maintenance and Indigenous issues as a key objective. Consultation with the Indigenous owners of the land is a requirement of section 7 of the *River Murray Act 2003* and further includes the participation in the process of management. In addition, the *Natural Resources Management Act 2004* has the serious consideration of Indigenous issues as a key objective.

1.8 Governance and planning arrangements

The Living Murray is a joint initiative and is managed collaboratively by partner governments. The Murray–Darling Basin Intergovernmental Agreement (National Water Commission 2004) outlines the governance arrangement for the implementation of The Living Murray. The IGA 2004 is complemented by The Living Murray Business Plan which provides operational policies to guide the implementation of TLM.

The groups with a direct role in TLM governance are the Murray–Darling Basin Ministerial Council, the Authority, the Basin Officials Committee (BOC), The Living Murray Committee (TLMC) and the Environmental Watering Group (EWG), see Figure 2: The Living Murray governance structure.

While the MDBA plays a key coordination role at a TLM-wide level, management and delivery of TLM activities at the icon sites is primarily undertaken by relevant government agencies in the jurisdictions where the icon sites are located. The ultimate responsibility to ensure the icon sites are successfully governed lies with the Icon Site Manager.





Figure 2: The Living Murray governance structure

1.8.1 Icon site committees

There are numerous government agencies and community groups with responsibilities and interests in management of the Lower Lakes, Coorong and Murray Mouth. Consequently, the previous icon site governance structure has been adapted to complement other structures to ensure an integrated planning and policy approach, avoid duplication of effort and maximise opportunities to achieve multiple benefits and positive outcomes.

The icon site governance arrangements include the provision of community and scientifc advice, through the Community Advisory Panel, the Scientific Advisory Group and the Barrage Operations Group . Ngarrindjeri input into governance, policy and planning is framed by the 2009 whole-of-government Kungun Ngarrindjeri Yunnan Agreement which recognises the Ngarrindjeri Regional Authority as the Ngarrindjeri peak body. Interactions between government and Ngarrindjeri take place through the Kungun Ngarrindjeri Yunnan Agreement Task Force and Leader-to-Leader meetings. The Community Advisory Panel and Scientific Advisory Group advise on environmental works and measures, and monitoring and research at the LLCMM site. The Community Advisory Panel and Scientific Advisory Group also advise on the development of TLM environmental water bids to ensure water bids are informed, scientifically defendable and logistically feasible.



High-Level Coordinating Committee

As of 2013, the Murray-Darling Basin Coordinating Committee provides high-level direction and support to all DEWNR-based River Murray projects, including the implementation of The Living Murray program and The Murray Futures Long Term Plan for the Coorong, Lower Lakes and Murray Mouth (CLLMM), *Securing the Future* (a complementary plan that provides direction for the future management of the CLLMM region as a healthy, productive and resilient wetland of international importance). Previous high-level committees have included a cross agency Coorong, Lower Lakes and Murray Mouth Steering Committee, and a South Australian Icon Site High Level Steering Committee.

LLCMM Community Advisory Panel

In March 2012, the icon site's old Community Reference Group was merged with the then Department of Environment and Natural Resources Community Advisory Group. This new Community Advisory Panel provides advice to both The Living Murray icon site and Murray Futures programs. Advice is provided to the Icon Site Manager on proposed icon site strategies, policies, management actions and proposed works and measures and provides a direct link, through cross membership, to other community groups. The Community Advisory Panel is chaired by a regional community member and comprises representatives from a broad cross-section of the community with local expertise and knowledge.

LLCMM Scientific Advisory Group

The Scientific Advisory Group is chaired by DEWNR as the Icon Site Manager and provides a forum for the scientific community to provide input and advice in relation to icon site planning, water management, research, monitoring, infrastructure initiatives and strategic directions. The Scientific Advisory Group also provides scientific input to environmental watering bids.

LLCMM Barrage Operations Group

The Barrage Operations Group, chaired by the MDBA, advises on real-time barrage water release strategies and provides a direct link to general river operations and management. The Icon Site Manager is a member of the group.

Ngarrindjeri Regional Authority, Yarluwar-Ruwe Program

The Ngarrindjeri Regional Authority was incorporated in 2008 and members include the Ngarrindjeri Nation communities and organisations as well as the Ngarrindjeri native title claimants and the Ngarrindjeri Heritage Committee. The Ngarrindjeri Regional Authority is signatory to the Ngarrindjeri Regional Partnership Agreement with the Australian and South Australian governments. Through its Yarluwar-Ruwe Program (Caring for Country) the Ngarrindjeri Regional Authority is working with government and local communities to develop new forms of natural resource management governance that recongise Ngarrindjeri values and incorporate Ngarrindjeri expertise and capacity. Further research is required to understand the effects of declining water availability and quality on Ngarrindjeri culture in the region. The Ngarrindjeri Regional Authority has established a Research, Policy and Planning Unit to lead the development of its research and policy program.

1.8.2 Management roles and responsibilities

A number of South Australian government agencies and organisations have specific responsibilities in relation to management of the Lakes Alexandrina and Albert, Coorong and Murray Mouth region.



The South Australian Department of Environment, Water and Natural Resources (DEWNR) has the lead role in the management of South Australia's water resources and advises the Government on the quantity, quality, use and availability of the State's water resources. DEWNR also has the lead responsibility for River Murray management including environmental water policy, planning and management; and has the key role in relation to The Living Murray Initiative and icon site management, and is the primary point of contact with the Murray–Darling Basin Authority.

DEWNR provides oversight of the Coorong and Lakes Alexandrina and Albert Ramsar Management Plan, the JAMBA, CAMBA and ROKAMBA agreements, and manages the Coorong National Park and Crown Lands within the region. DEWNR also has the lead responsibility in relation to the Murray Futures Coorong, Lower Lakes and Murray Mouth (CLLMM) Project.

South Australia Water manages MDBA River Murray assets in South Australia and physically operates and maintains the locks, weirs and barrages under direction from the MDBA, with input from DEWNR.

The Department of Primary Industries and Regions South Australia (PIRSA) acts as the caretaker of fish resources in South Australia, through the Fisheries Division. The role of the division includes management and planning of the Coorong and Lakes fisheries.



2. ICON SITE DESCRIPTION

The Lower Lakes, Coorong and Murray Mouth icon site is an important ecological transitional area between the River Murray and the Southern Ocean as it passes through Lake Alexandrina, the Murray Estuary, the Coorong and, finally the Murray Mouth. These are the traditional lands and waters of the Ngarrindjeri people and their cultural significance is, in part, recognised through State Aboriginal Heritage listing. This diverse landscape accounts for much of its unique ecological qualities and the challenges in managing the area (DWLBC 2002). The complex ecology of the area has been changed by a system of barrages which isolate the Lower Lakes from the Murray Mouth and Coorong.

Surface water flow into the icon site is predominantly from the River Murray. Other surface water inputs include inflows via tributaries of the Eastern Mount Lofty Ranges into Lake Alexandrina and the Murray channel near Goolwa. Water of varying salinities, often brackish to saline also flows into the Coorong South Lagoon from the Upper South East Drainage Scheme via Salt Creek. Direct rainfall on the large surface area of Lakes Alexandrina and Albert is also an important source of freshwater input to the system. A series of barrages located between the islands in southern Lake Alexandrina separate the freshwater environments of the River Murray and Lower Lakes from the saline waters of the Murray Mouth estuary and Coorong (Figure 3: Map of the Lower Lakes, Coorong and Murray Mouth icon site. As a consequence, freshwater input to the Murray Mouth estuary and the Coorong during low flow periods are reliant on strategic barrage releases. Barrage and fishway releases help to establish a salinity gradient within the estuary and also facilitate ecological connectivity between the water bodies.

The icon site shares the same boundaries as the designated Ramsar site, and incorporates four diverse sub-regions:

- Lake Alexandrina (including islands) and Lake Albert
- the lower reaches of the tributaries of the Eastern Mount Lofty Ranges
- Murray Mouth estuary
- Coorong (North and South Lagoons).

Physical conditions (e.g. salinity, occurrence and frequency of freshwater inputs) contribute to the complexity of the icon site and its ecological values. Parts of Lake Alexandrina and the Coorong (Kurrangk), and the Murray Mouth estuary, are registered as an Aboriginal site known as the Meeting of the Waters. The whole of the icon site is a Ngarrindjeri cultural landscape.

Lakes Alexandrina and Albert

Lakes Alexandrina and Albert are two large (c. 65,000 and c. 23,000 ha respectively) shallow lakes (depth typically <3 m) at the terminus of the Murray–Darling River system. The River Murray drains into Lake Alexandrina near Wellington. Lake Alexandrina is isolated from the Murray Mouth and Coorong by five barrages constructed between 1935 and 1940 which were constructed to provide freshwater for irrigation, stock and domestic use. Several islands lie within Lake Alexandrina, principally Hindmarsh and Mundoo which are adjacent to the Murray Mouth. Lake Albert is a terminal lake connected to Lake Alexandrina via a narrow channel known as the Narrung Narrows. Lake Alexandrina is the primary source of freshwater flow into Lake Albert.



Prior to European settlement, the Lower Lakes were predominantly fresh (Fluin *et al.* 2007; Fluin *et al.* 2011), with river water discharging to the sea keeping the Murray Mouth open. Saltwater intrusion to the Lower Lakes was not common until after 1900 when significant water resource development had occurred in the River Murray system (Sim & Muller 2004). Only small areas of the Lower Lakes, around the mouth and channels, would be impacted by saltwater intrusion during periods of low river flow or significant storm surges. Historically, the Lake Alexandrina / Murray Mouth interface would have been a spatially and temporally dynamic mosaic of wetlands with variable salinities.

Eastern Mount Lofty Ranges tributaries

The Eastern Mount Lofty Ranges tributaries of particular significance to the icon site include the Tookayerta and Currency creeks, and Finniss, Angas and Bremer rivers. The lower reaches of the Finniss River, and Tookayerta and Currency creeks lie within the boundary of the icon site. Although the Angas and Bremer rivers are outside the icon site boundary, their areas of confluence with Lake Alexandrina are ecologically important. The lower reaches of the Eastern Mount Lofty Ranges tributaries contain important wetland and aquatic habitats for bird, frog and fish communities. Generally, the tributaries are fed by unconfined aquifers and from annual rainfall that varies regionally from 350 mm to 850 mm. These freshwater inputs play an important role in maintaining the ecological complexity of wetland and aquatic habitats located within the lower reaches of these tributaries.

Murray Mouth

The Murray Mouth estuary includes the area from the Goolwa Barrage to Pelican Point. In average years, the area is naturally estuarine but salinity levels fluctuate depending on outflows and which barrage structures are used for releases. The estuary is 'protected' from the highenergy marine environment of the Southern Ocean by the Sir Richard and Younghusband peninsulas. The key factors determining the morphological condition of the Mouth and its adjacent estuarine channels are freshwater flow through the barrages and ambient coastal conditions and processes. Under (barrage) zero and low-flow conditions, water flow through the Murray Mouth is dominated by tidal flows. From October 2002 until December 2010, dredging was required to maintain an open Murray Mouth, maintaining tidal exchange between the ocean and the estuary.

The Coorong

The Coorong is a 140 km long, 2-3 km wide, shallow lagoon with a variable salinity regime. The salinity regime in the Coorong is typical of a 'reverse estuary' where salinity increases further from the estuary mouth. The Coorong comprises two lagoons which are divided by a headland (Parnka Point) which restricts the Coorong to a narrow (c. 100 m) channel. The North Lagoon of the Coorong extends from Pelican Point to Parnka Point and is characterised by similar conditions as the Murray Mouth estuary with barrage releases influencing salinity. The salinity gradient of the North Lagoon increases southwards towards Parnka Point. The hypersaline South Lagoon extends from Parnka Point to Salt Creek where it then becomes a series of hypersaline ephemeral lagoons. Freshwater inputs which historically entered through the southern end of the South Lagoon in winter/spring have decreased enormously since the end of World War II due to extensive drainage networks in the south east which now direct surface water runoff directly to sea.



Ngarrindjeri cultural landscape

The Lower Lakes, Kurrangk (Coorong) and Murray Mouth are central to Ngarrindjeri culture and spiritual beliefs. This association is expressed through creation stories (cultural and spiritual histories) about Yarluwar-Ruwe (Sea Country) which reveal the significance of the relationship between the country and the people, both practically and spiritually:

The land and waters is a living body. We the Ngarrindjeri people are a part of its existence. The land and waters must be healthy for the Ngarrindjeri people to be healthy.

Freshwater flows down the Murray–Darling system are seen by the Ngarrindjeri as the life blood of the living body of the River Murray, Lower Lakes and Coorong. Maintaining connectivity between parts of the living body is a Ngarrindjeri cultural priority.

2.1 Location

The Lower Lakes, Coorong and Murray Mouth icon site is located at the terminus of the River Murray system in South Australia. The icon site is bounded by the Mount Lofty Ranges to the west, the Murraylands to the north, the Upper South-east to the East and the Southern Ocean to the South. The principal towns are Goolwa at the western end of the icon site, Meningie on the shore of Lake Albert and Milang on the shore of Lake Alexandrina.

Boundaries of the Lower Lakes, Coorong and Murray Mouth icon site follow those of the Ramsar-listed Coorong and Lakes Alexandrina and Albert Wetland of International Significance. The icon site covers land and water areas totalling approximately 140,500 hectares incorporating the lagoons of the Coorong, Lakes Alexandrina and Albert, and the lower reaches of the Finniss River and Currency Creek (Figure 3: Map of the Lower Lakes, Coorong and Murray Mouth icon site), and includes:

- all unallotted Crown Land and Crown Land occupied under licence that is connected to the lakes
- wetlands on freehold and perpetual lease land, where the wetland is seasonally connected to the lake
- all land and wetlands on Hindmarsh, Mundoo, Mud, Reedy, Ewe and Long islands and the many other small islands in the lakes
- Tolderol, Mud Islands and Currency Creek Game Reserves
- Salt Lagoon Islands Conservation Park
- all land and water within the Coorong National Park.

2.2 Land tenure

The Lower Lakes, Coorong and Murray Mouth icon site consists of a range of different land tenures (Figure 4: Map of the Lower Lakes, Coorong and Murray Mouth icon site boundary and land tenure details. These include Conservation Park (i.e. Salt Lagoon Islands; 76 ha), Game Reserves (i.e. Currency Creek, Mud Islands and Tolderol; 428 ha), a heritage agreement (4 ha), the Coorong National Park (48,975 ha), other government land (including crown land) (4,034 ha) and private land (9,066 ha). The area is part of the traditional lands and waters of the Ngarrindjeri nation, the Ngarrindjeri & Ors (SAD 6027/98) native title claim and includes registered Aboriginal sites such as the 'Meeting of the Waters'.





Figure 3: Map of the Lower Lakes, Coorong and Murray Mouth icon site





Figure 4: Map of the Lower Lakes, Coorong and Murray Mouth icon site boundary and land tenure details



2.3 Description of key ecological assets of the icon site

The Lower Lakes, Coorong and Murray Mouth icon site is comprised of four key environmental sub-regions, namely:

- Lakes Alexandrina and Albert (Lower Lakes)
- Eastern Mount Lofty Ranges tributaries
- Murray Mouth estuary
- the Coorong (North and South Lagoons).

Lakes Alexandrina and Albert (Lower Lakes)

The Lower Lakes are broad and shallow systems with unique and extensive fringing emergent vegetation. Much of the fringing vegetation is dominated by *Phragmites australis* with the most complex wetland flora found near the confluences of inflowing water bodies (e.g. creeks, drains) and islands. Fringing emergent vegetation has been simplified since the installation and operation of the barrages. Emergent macrophyte communities have thrived whilst communities dependent on variable water regimes have become restricted in their distribution (Phillips & Muller 2006).

Freshwater submerged aquatic plant communities were once extensive in the lakes system (Sim & Muller 2004) but are now restricted to near-shore habitats with good light penetration and low turbidity. Aquatic plant communities included species such as ribbon weed (*Vallisneria australis*), water ribbons (*Triglochin procerum*), pondweeds (*Potamogeton* spp.) and milfoils (*Myriophyllum* spp.). Submerged aquatic plants are now dominated by *Potamogeton* spp., *Ruppia* spp. and various types of charophytes; however, there has been an increase in abundance of *Myriophyllum* salsugineum, *Vallisneria australis* and *Triglochin procerum* since water levels were reinstated (Gehrig *et al.* 2011).

Many fringing wetlands around the Lower Lakes also support lignum (*Muehlenbeckia florulenta*) and samphire (e.g. *Sarcocornia* spp.) above the high water level. There are also remnant areas of swamp paperbark (*Melaleuca halmaturorum*) patchily distributed around Lakes Alexandrina and Albert (Marsland & Nicol 2009).

The EPBC-listed southern bell frog (*Litoria raniformis*) inhabits fringing wetlands of Lake Alexandrina, with known populations in Pelican Lagoon, Clayton Bay and Hindmarsh Island channels (Mason 2010; Mason & Hillyard 2011).

Hindmarsh, Mundoo, Ewe and Tauwitchere islands lie within a transitional zone between Lake Alexandrina and the Coorong. These island areas comprise unique vegetation communities. The freshwater habitats on, and immediately surrounding the islands are critical habitats for fish, particularly EPBC-listed small-bodied native fish such as Murray hardyhead (*Craterocephalus fluviatilis*) and Yarra pygmy perch (*Nannoperca obscura*). These transitional zones provide important ecological connectivity for migration of diadromous fish species such as congolli (*Pseudaphritis urvillii*) and common galaxias (*Galaxias maculatus*).

The area around Hindmarsh, Mundoo, Ewe and Tauwitchere islands are also where mudflats would have occurred before river regulation stabilised water levels. Mudflats in this area are now exposed over short time scales by wind seiching events and act as habitat for wading birds.



Eastern Mount Lofty Ranges tributaries

The lower reaches of the Finniss River, and Tookayerta and Currency Creeks are structurally diverse and support dense and diverse wetland habitats ranging from woodlands (e.g. river red gum (*Eucalyptus camaldulensis*)) to peat bogs. These areas also form part of the EPBC-listed 'Swamps of the Fleurieu Peninsula' ecological community and provide habitat for endangered species such as the Mount Lofty Ranges southern emu-wren (*Stipiturus malachurus intermedius*) (Phillips & Muller 2006).

In drought years, these tributaries act as critical refugia for many fishes and other species dependent on freshwater including the State-listed river blackfish (*Gadopsis marmoratus*) and the nationally-listed Yarra pygmy perch and southern bell frog (DEH 2010a; Mason 2010).

Murray Mouth

The lagoon environment of the estuary (from the Goolwa Barrage to Pelican Point) includes habitats such as exposed mudflats and shallow waters, which provide important foraging grounds for many wader bird species. In the past the vegetation community was dominated by *Ruppia megacarpa*, though this has not been present since 1986 (Hera-Singh, pers. comm. 2011), nor has it been recorded in the entire Coorong for a number of years (Nicol 2005).

An open Murray Mouth is critical for maintaining water quality in the estuary (through tidal exchange) and Coorong under zero and low flow conditions (Hemming *et al.* 2002). Tidal variations also facilitate daily inundation and exposure of mudflats, thereby maintaining invertebrate productivity and biomass in these areas (Dittmann *et al.* 2010). The Murray Mouth is considered open when the Diurnal Tidal Ratio (DTR) at Goolwa exceeds 0.3, with minimum DTR values of 0.05 and 0.2 at Tauwitchere and Goolwa respectively (DWLBC 2008). During high flows (around 35,000 ML/day) the DTR values at Goolwa and Tauwitchere are around 0.7-0.9 and 0.3-0.4 respectively.

The Murray Mouth estuary is an important transitional area for many species of fish that rely on estuarine conditions to complete their lifecycles.

The Coorong

The Coorong is highly regarded for its diversity and abundance of waterbirds (Wainwright & Christie 2008; Paton *et al.* 2009). Historically, the North Lagoon was mainly estuarine and provided rich, sheltered waters for fish and provided the necessary lifecycle cues required for aquatic seed germination, fish passage, breeding and foraging. *Ruppia megacarpa* was the dominant plant. Evidence suggests the South Lagoon was historically fresher than its current hypersaline state (Krull *et al.* 2009) and was freshened by winter/spring flows predominately from the South-east of South Australia. Increased salinity and unfavourable water levels in the South Lagoon over recent years, brought about by low freshwater inflows, have led to the severe decline of keystone species such as *Ruppia tuberosa*, chironomids and small-mouthed hardyheads (*Atherinosoma microstoma*).



2.4 Values of the icon site

2.4.1 Key values

The Ramsar Convention recognises internationally significant wetlands that are rare or unique, or that are important for conserving biological diversity including habitat, which support high numbers of waterbirds. The Lower Lakes, Coorong and Murray Mouth icon site is considered to be an important biodiversity hotspot and meets eight of the Ramsar Convention nominating criteria (see Section 3.1). It was designated as a Wetland of International Importance under the Ramsar Convention on Wetlands in 1985 (Phillips & Muller 2006), although at this stage it was already in a degraded state due to decreased River Murray outflows and the first ever recorded closure of the Murray Mouth in 1981. The site is renowned for providing habitat for many waterbird species and is one of the 10 major havens for large concentrations of wading birds in Australia. The icon site contains a unique mosaic of 23 wetland-types (Phillips & Muller 2006) ranging from the freshwater Lower Lakes, to the Coorong's hypersaline South Lagoon. The icon site provides habitat for nationally threatened species such as the orange-bellied parrot (*Neophema chrysogaster*), the Southern Mount Lofty Ranges emu-wren, the southern bell frog and the Murray hardyhead. All living things in the region are Ngarrindjeri ngartjis (totem – or closest friend).

Birds

The Lower Lakes, Coorong and Murray Mouth supports over 80 species of threatened or migratory birds and is ranked in the six most significant waterbird sites in Australia. As listed in Appendix A, the site includes:

- three species that are nationally-listed as endangered or critically endangered
- five species that are classified as vulnerable in South Australia
- sixteen migratory species that occur at the site at 1% of their global population (estimated)
- thirty-three bird species that are listed under international treaties
- forty-six species that are listed under Australia's migratory bird agreements
- forty-nine species that rely on the wetland at critical life stages (e.g. migration stop-over, breeding habitat, refuge).

Ruppia spp., samphire and mudflat habitats are important foraging sites for water birds and waders in the icon site. Fish (e.g. hardyheads: Family Atherinidae) and invertebrates such as the mottled shore crab (*Paragrapsus gaimardii*) (G. Hera-Singh pers. comm. 2011), polychaete worms, amphipods and chironomid larvae are key food resources for resident and migratory birds of the icon site. Hence, mudflat health and suitable water quality are paramount to sustainable populations of invertebrates and the long-term viability of bird communities in the Lower Lakes, Coorong and Murray Mouth icon site. The abundance of almost all species of waders and waterbirds using the wetlands of the Coorong and Lower Lakes have declined, particularly over the past 30 years (Paton *et al.* 2009).

Fish

The Lower Lakes, Coorong and Murray Mouth icon site provides critical fish habitats including important nursery and feeding areas for commercial and non-commercial fish species (Bice &



Ye 2009; Zampatti *et al.* 2010). The icon site is utilised by a number of fish groups including obligate freshwater, diadromous, euryhaline, estuarine and marine species. Over 75 species of fish have been recorded within the icon site, although 34 of these are of marine origin and are only irregular visitors to the Coorong (Higham *et al.* 2002). Declines in formerly common estuary species (e.g. estuary perch (*Macquaria colonorum*) and jumping mullet (*Liza argentea*)) have been observed by local fishers (G Hera-Singh pers. comm. 2011).

Amongst the native species known from the icon site are three species that are EPBC listed as nationally vulnerable: Murray cod, Murray hardyhead and Yarra pygmy perch. Fourteen species are protected or provisionally listed in South Australia (Appendix A), although numerous others use the site during their life cycle. Little is known about how Lakes Alexandrina and Albert are used by large-bodied native fish (e.g. Murray cod, golden perch (*Macquaria ambigua ambigua*) and silver perch (*Bidyanis bidyanis*)). Consequently, there is no current icon site ecological target associated with large-bodied lakes fish species. Addressing this knowledge gap and implementing an ecological target concerning these species is a future priority.

Freshwater outflows from the Lower Lakes and an open Murray Mouth promotes connectivity, improves estuarine habitats and promotes the flux of nutrients in the Coorong. This is highly favourable for productivity and enhances the survival (e.g. increased turbidity associated with inflows may lessen predation on juvenile fish) and growth prospects of larval and juvenile fish and thus recruitment, and sustains populations of a range of species including the Goolwa cockle (pipi) (*Plebidonax deltoides*) (Ferguson *et al.* 2010; Zampatti *et al.* 2010; Ye *et al.* 2011).

Vegetation

The Lower Lakes and Coorong include a number of ecologically-important terrestrial plant communities, as well as a number of submerged and emergent aquatic plant populations. These plants provide several ecosystem services including habitat structure, and direct and indirect food resources for aquatic fauna and birds. Plant diversity in the icon site is greatest near areas of confluence such as the lower reaches of the Eastern Mount Lofty Ranges tributaries. Sections of the near shore environment around the Lower Lakes have extensive stands of *Phragmites australis* and *Typha domingensis*. These macrophytes provide excellent shelter and habitat for a range of fish and other vertebrate species. Key plant assemblages include those that contain macrophytes (e.g. *Phragmites australis* and *Typha domingensis*), *Ruppia* spp., *Gahnia filum*, *Myriophyllum* spp., *Melaleuca halmaturorum* and samphire (*Sarcocornia* spp. and *Suaeda australis*). The site also contains a section of the critically endangered 'Swamps of the Fleurieu Peninsula', as well as the threatened *Gahnia filum* sedgeland ecosystems and a number of nationally listed plant species.

2.4.2 Cultural values and Ngarrindjeri Yarluwar-Ruwe (Sea Country – all Ngarrindjeri lands and waters)

Note: The information on Ngarrindjeri cultural values and aspirations expressed in this section (2.4.2) are those directly provided by the Ngarrindjeri Regional Authority for inclusion in this plan.

The Ngarrindjeri people as descendants of the original Indigenous inhabitants of the lands and waters of the River Murray, Lower Lakes and Coorong and adjacent areas assert control over the lands and waters by the continuation of their culture upon their traditional lands to pursue their economic, social, and cultural development of the land and waters within the Ngarrindjeri Native Title Claim area. The Ngarrindjeri people are the Traditional Owners of the land and



according to their traditions, customs and spiritual beliefs its lands and waters remain their traditional country.

The Ngarrindjeri approach the issue of water not based upon the notion of use but from a cultural perspective, which means that there is a need to discuss the translation of the notion of use and the cultural perspective in order to achieve outcomes which have integrity and demonstrate respect within Indigenous and non-Indigenous communities. The Ngarrindjeri want a future for the Coorong, Lower Lakes and Murray Mouth that maintains the continuation of their culture upon country, the national and international importance of the site, and that it continues to give life to the 4,000 Ngarrindjeri people who live and work in the region and to all Ngarrindjeri people. The Ngarrindjeri Vision for Country is outlined below:

Our Lands, Our Waters, Our People, All Living Things are connected. We implore people to respect our Ruwe (Country) as it was created in the Kaldowinyeri (the creation). We long for sparkling, clean waters, healthy land and people and all living things. We long for the Yarluwar-Ruwe (Sea Country) of our ancestors. Our vision is all people Caring, Sharing, Knowing and Respecting the lands, the waters and all living things.

Our goals are:

- For our people, children and descendants to be healthy and to enjoy our healthy lands and waters;
- To see our lands and waters healthy and spiritually alive;
- For all our people to benefit from our equity in our lands and waters;
- To see our closest friends our Ngartjis (special animals) healthy and spiritually alive;
- For our people to continue to occupy and benefit from our lands and waters; and
- To see all people respecting our laws and living in harmony with our lands and waters.

(Ngarrindjeri Nation Yarluwar-Ruwe Plan, 2006)

The culture and economy of the Ngarrindjeri have always depended on Yarluwar-Ruwe and its resources. The land and waters are a living body and the Ngarrindjeri are part of its existence. For the Ngarrindjeri to be healthy, the land and waters of the Coorong, Lower Lakes and Murray Mouth region must also be healthy.

Human induced changes at the site and upstream along the River Murray post European settlement, combined with a drying of the land and waters, are causing the health of the region to change. Without action, the site could experience irreversible ecological and environmental changes and degradation. Yarluwar-Ruwe (Sea Country) cannot be lost to the Ngarrindjeri people and their Ngartjis.

The Ngarrindjeri support a range of actions in the Coorong, Lower Lakes and Murray Mouth to prevent, remediate and build resilience at the site. These actions should strive to improve the health of the site and to increase freshwater flows. The Ngarrindjeri desire a new relationship, a strong partnership with governments and other stakeholders so that the land and waters can be



healthy again. Kungun Ngarrindjeri Yunnan agreements are the preferred Ngarrindjeri process for establishing these partnerships.

The Lower Lakes, Murray Mouth and Coorong region is central to Ngarrindjeri culture and spiritual beliefs. This association is expressed through creation stories (cultural and spiritual histories) about Yarluwar-Ruwe which reveals the significance of the relationship between the country and the people, both practically and spiritually.

Freshwater flows down the Murray–Darling system into the lands and water of the Ngarrindjeri are seen by the Ngarrindjeri as the life blood of the living body of the River Murray, Lower Lakes and Coorong. The Ngarrindjeri *Yarluwar-Ruwe Plan*, prepared by the Ngarrindjeri People in 2006, articulates a vision for caring for this country, emphasising that 'the river, lakes, wetlands/nurseries, Coorong estuary and sea have sustained us culturally and economically for tens of thousands of years'.

The Yarluwar-Ruwe Plan refers to Ngarrindjeri creation stories which record dramatic changes in coastal sea levels in the icon site area. These creation stories explain the richness of 'natural resources' – especially a wealth of fresh and salt water marine life such as fish, shellfish, eels, waterbirds and water plants. They also provide Ngarrindjeri with the laws and lessons for sustainable use, care and management of these species. In fact, Ngarrindjeri Yarluwar-Ruwe supported amongst the highest density of Aboriginal People anywhere in Australia prior to European arrival.

Since the arrival of Europeans the Ngarrindjeri witnessed the draining of their wetlands along the rivers, and in the south east, and the disconnection of the living body of the River Murray, Lower Lakes and Coorong through the installation of locks, levee banks and barrages. They have watched their ngartjis (totems) diminish, their lands cleared and the degradation of Yarluwar-Ruwe.

Ngarrindjeri economy has always been based on the sustainable use and trade of the natural resources. Since European settlement, many of the natural resources have deteriorated. The Ngarrindjeri understand that industries that have led to the unsustainable use of resources (e.g. irrigation) are here to stay, however, the Ngarrindjeri seek a "just and rightful share in the economic benefits from our Country across all industries" (Ngarrindjeri Nation Yaruwar-Ruwe Plan 2006). A proper relationship and role in the management of the land is a fundamental platform in building and maintaining Ngarrindjeri culture and self-respect. Ngarrindjeri believe that their future involvement in the management of the land and waters would be positive and beneficial to all members of the community, both Indigenous and non-Indigenous, and would represent a significant step in the process of reconciliation (NRWG 1998, Ngarrindjeri Nation 2006; KNY 2009). The strengthening of Ngarrindjeri people and their culture requires a serious involvement in the management of their traditional lands and waters.

Kungun Ngarrindjeri Yunnan (listen to what Ngarrindjeri have to say): A new way forward

In 2009 the South Australian Government and the Ngarrindjeri people entered into the Kungun Ngarrindjeri Yunnan Agreement whereby the relevant Ministers on behalf of the Crown expressed a desire for a new relationship between the State of South Australia and Ngarrindjeri based on mutual respect and trust, acknowledging that Ngarrindjeri consider protection and maintenance of culture and cultural sites upon its land and waters central in every respect to Ngarrindjeri community wellbeing and existence. Through the Kungun Ngarrindjeri Yunnan



Agreement, the Government provides support and resources to the Ngarrindjeri Regional Authority and enters into negotiations and consultations with the Ngarrindjeri about the maintenance and protection of Ngarrindjeri culture and cultural sites and the natural resources of the land. The Kungun Ngarrindjeri Yunnan Agreement Taskforce meets monthly and provides an important opportunity for engagement between Ngarrindjeri and South Australian Government agencies regarding a range of programs and projects including TLM and icon site management.

The Ngarrindjeri Regional Authority aspire to enter into a Kungun Ngarrindjeri Yunnan Agreement agreement with the MDBA, which would relate to the existing Regional Partnerships Agreement and would complement the 2009 SA Kungun Ngarrindjeri Yunnan Agreement that established the Kungun Ngarrindjeri Yunnan agreement Taskforce, by which engagement in LLCMM icon site management occurs. The Ngarrindjeri Regional Authority believe this would help facilitate the proper management and protection of the Meeting of the Waters and the broader Ngarrindjeri cultural landscape. The Ngarrindjeri see as a priority the development of a management plan for the 'Meeting of the Waters' site.

Ngarrindjeri Ruwe/Ruwar – the Ngarrindjeri connection between lands and waters, body, spirit and all living things

Ngarrindjeri cultural and community wellbeing has suffered through the rapid loss of ecological character of the Coorong, Lower Lakes and Murray Mouth. In recent years Ngarrindjeri leaders have worked with the South Australian Government and researchers to explain the link between Ngarrindjeri culture, people, lands, waters and all living things (Hemming *et al.* 2002; Ngarrindjeri Nation 2006; Bell 2008; Hemming *et al.* 2008; Birckhead *et al.* 2011). This fundamental philosophical and spiritual connection (Ruwe/Ruwar) is reliant on healthy lands and waters, and the maintenance of connectivity between the Coorong, Lower Lakes and Murray Mouth as created by Ngurunderi (Hemming *et al.* 1989; Bell 1998).

Ngarrindjeri have conducted research into the relationship between loss of ecological character and loss of cultural, economic and social wellbeing. Opportunities to manage Yarluwar-Ruwe according to Ngarrindjeri traditions and laws have been affected by successive government's policies and Ngarrindjeri believe this has also contributed significantly to decreased community wellbeing. It is a key Ngarrindjeri aim to re-invigorate the icon site cultural landscape, ensuring that interconnectedness continues to be maintained.

The ecological character of the region needs to be improved through management that incorporates Ngarrindjeri knowledge and expertise. Ngarrindjeri support ensuring a diversity of healthy wetland habitats and restoring and maintaining connectivity between habitats. Ngarrindjeri cultural flows need to be understood and to inform water flows. The fundamental connection between the health of this system and Ngarrindjeri culture will inform management responses. This would incorporate a major role for the Ngarrindjeri Yarluwar-Ruwe Program in governance and management. The Ngarrindjeri Yarluwar-Ruwe Program is a regional initiative that privileges the fundamental connection between healthy people, culture, economy and ecosystems.

The following Ngarrindjeri creation story is reproduced from the Yarluwar-Ruwe Plan (2006). It provides an account of the cultural connections (Ruwe/Ruwar) between Ngarrindjeri and Yarlwuar-Ruwe (all Ngarrindjeri lands and waters):



Ngurunderi the Creator

A long, long time ago Ngurunderi our Spiritual Ancestor chased Pondi, the giant Murray Cod, from the junction where the Darling and Murrundi (River Murray) meet. Back then, the River Murray was just a small stream and Pondi had nowhere to go. As Ngurunderi chased him in his bark canoe he went ploughing and crashing through the land and his huge body and tail created the mighty River Murray. When Ngurunderi and his brother-in-law Nepele caught Pondi at the place where the fresh and salt water meet they cut him up into many pieces, which became the fresh and salt water fish for the Ngarrindjeri people. To the last piece Ngurunderi said, "you keep being a Pondi (Murray Cod)". As Ngurunderi travelled throughout our Country, he created landforms, waterways and life. He gave to his people the stories, meanings and laws associated with our lands and waters of his creation. He gave each Lakalinyeri (clan) our identity to our Ruwe (country) and our Ngarjtis (animals, birds, fish and plants) - who are our friends. Ngurunderi taught us how to hunt and gather our foods from the lands and waters. He taught us, don't be greedy, don't take any more than what you need, and share with one another. Ngurunderi also warned us that if we don't share we will be punished.

Ngarrindjeri respect the gifts of Creation that Ngurunderi passed down to our Spiritual Ancestors, our Elders and to us. Ngarrindjeri must follow the Traditional Laws; we must respect and honour the lands, waters and all living things. Ngurunderi taught us our Miwi, which is our inner spiritual connection to our lands, waters, each other and all living things, and which is passed down through our mothers since Creation. Our Great Grandmothers, Grandmothers and mothers fought to protect our Spiritual waters from desecration when a bridge to Kumarangk (Hindmarsh Island) was to be built.

Ngurunderi taught us how to sustain our lives and our culture from what were our healthy lands and waters. Our lands and waters must be managed according to our Laws to make them healthy once again. As the Ngarrindjeri Nation we must maintain our inherent sovereign rights to our Yarluwar-Ruwe. Ngarrindjeri people have a sovereign right to make our living from the lands and waters in a respectful and sustainable way.

We are asking non-Indigenous people to respect our traditions, our rights and our responsibilities according to Ngarrindjeri laws.

Meeting of the Waters: registered Aboriginal heritage site

The LLCMM icon site includes a registered Aboriginal heritage site – under the *Aboriginal Heritage Act*, 1988 (SA). The 'Meeting of the Waters' site was registered in 2009 via a Kungun Ngarrindjeri Yunnan agreement negotiation with the South Australian Government. This site includes the waters and the bed of the lakes, river and estuary.

2.4.3 Indigenous perspectives from across the Murray–Darling Basin

Aboriginal people recognise the critical importance of the Basin's river systems to social, cultural and economic life and the need for balance in meeting the aspirations of all stakeholders. The desire for restorations of environmental systems and the relationships Aboriginal people have maintained with their countries is a key motivation behind ongoing



engagement with water management issues; indeed it is a compelling obligation in Aboriginal value systems and law (Guide to the proposed Basin Plan Volume 2, p. 226).

The Murray Lower Darling Rivers Indigenous Nations (MLDRIN) and the Northern Murray– Darling Basin Aboriginal Nations have developed their definition of cultural flows as:

Water entitlements that are legally and beneficially owned by the Aboriginal nations and are of a sufficient and adequate quality and quantity to improve the spiritual, cultural, environmental, social and economic conditions of those Aboriginal nations; this is our inherent right.

The Basin Plan provides opportunities to contribute toward cultural values and uses for Aboriginal people in the Basin. However, Aboriginal people believe that the determination of environmental flow requirements must include Aboriginal values in the assessment process. Aboriginal people also believe that environmental water management must recognise Aboriginal resource governance systems and allow for co-management if their values are to be truly incorporated into management structures and decisions.

There may be potential for structural change resulting from the Basin Plan to open up new opportunities for Aboriginal people in emerging cultural and natural resource management based industries, such as payment for environmental services, stewardship arrangements, small-scale bush foods and tourism (Guide to the proposed Basin Plan Volume 2, p. 228).

2.4.4 Social and recreational values

The Lower Lakes, Coorong and Murray Mouth are popular areas for recreational activities such as sightseeing, bird watching, camping, walking, fishing, swimming, canoeing, sailing, water-skiing, picnicking and four-wheel driving. The South Australian Tourism Commission estimated the number of visitors to the Coorong National Park in 2008 at about 138,000 (DEH 2010b).

The Coorong and Lower Lakes are important for recreational boating and fishers due to the quality of the natural environment and the presence of species such as mulloway (*Argyrosomus japonicus*) (MDBC 2006a).

There are also less tangible values important to both residents and visitors which are associated with the area's natural beauty with people holding a strong affinity with the site's aesthetics. Similarly there is also a perceived value in the area being listed as an icon site (MDBC 2006a).

2.4.5 Economic values

The Lower Lakes, Coorong and Murray Mouth support a range of economic industries including irrigated and dryland agriculture; commercial fishing; boat building and maintenance; tourism and recreation activity; and manufacturing industries centred on wine, machinery and equipment. All rely on the ecological health of the icon site for their wealth. A healthy Lower Lakes, Coorong and Murray Mouth ecosystem ensures the existence of large and viable fish populations for commercial and recreational fishing, good quality water for irrigation, healthy bird numbers for ornithologists, and aesthetically attractive and pleasing environment for people to enjoy.



The major towns associated with the LLCMM icon site region include: Clayton Bay, Goolwa, Langhorne Creek, Meningie, Milang, Narrung, Raukkan, Salt Creek and Wellington (Figure 3: Map of the Lower Lakes, Coorong and Murray Mouth icon site.

The gross regional product of the Lower Murray (downstream of Lock 1 at Blanchetown), Lower Lakes and Coorong has been estimated at around \$700 million in 2007-06 (DEH 2010b). Primary industries directly contributed around \$145 million and directly employed about 2,000 people. Irrigated agriculture employed 1,000 people, contributing more than \$70 million to the gross regional product (DEH 2010b). Anecdotal evidence suggests that drought conditions over the period from 2005–10 have substantially reduced these numbers.

The recent drought conditions have seen restructuring of regional industries with changes impacting on all industries in the region. There has been a reduction in the number of dairying farms and a reduction in livestock numbers. Wine production and irrigation industries have been affected by drought, water quality issues and water availability. Water security for irrigation and wine industries has been improved following construction of the Lower Lakes irrigation pipeline in 2009. Pipelines have also been completed to communities in the Lower Lakes and Coorong region for stock and domestic purposes to reduce dependence on the Lower Lakes as a water supply (DEH 2010b). Impacts have also been detected in other agricultural industries as well as the fishing, tourism and boating industries. The easing of recent drought conditions has seen an improvement in the outlook for Lower Lakes and Coorong communities.


3. ECOLOGICAL OBJECTIVES AND WATER REQUIREMENTS

The six The Living Murray icon sites were selected because of their high conservation, recreation, cultural, heritage and economic value. Based on an understanding of the icon site's characteristics and ecological requirements, specific First Step Decision interim ecological objectives were developed and approved by the Murray–Darling Basin Ministerial Council in 2003. The aim of the First Step Decision objectives is to maintain the healthy aspects of the icon sites and to begin to address the apparent declines in health of other aspects, as part of a larger contribution to establishing a healthy working river.

3.1 The Living Murray First Step Decision icon site objectives

Since the objectives were approved by Ministerial Council in 2003, jurisdictional agencies have continued to review and refine the First Step interim objectives to develop refined ecological objectives for icon sites. These refined ecological objectives reflect eight years of learnings from the delivery of environmental water, monitoring, modelling and consultation activities and scientific research, and enable a clearer, more effective, evaluation of environmental responses to environmental water delivery. The Lower Lakes, Coorong and Murray Mouth Environmental Water Management Plan includes both the First Step Decision objectives and refined ecological objectives and targets.

The overarching vision of The Living Murray actions in the Lower Lakes, Coorong and Murray Mouth icon site is to facilitate:

A healthier Lower Lakes and Coorong estuarine environment.

The expected outcomes resulting from the successful delivery of the First Step Decision should provide a number of biological and physical benefits, including:

- an open Murray Mouth (M)
- more frequent estuarine fish recruitment (F)
- enhanced migratory wader bird habitat in the Lower Lakes and Coorong (B).

These expected outcomes are recognised as the icon site's ecological objectives.

3.1.1 Icon Site Ecological Target Review

In order to achieve the objectives of the First Step Decision, ecological and physical targets were developed to specifically quantify changes in the condition of the Lower Lakes, Coorong and Murray Mouth icon site. These targets are based on the site's requirements to function in a 'healthy' ecosystem state, regardless of what is available in environmental water portfolios. Targets are icon site-specific and enable assessment of management actions implemented by The Living Murray program or other environmental water holders.

Ecological targets for the Lower Lakes, Coorong and Murray Mouth icon site have been developed and subsequently revised by a panel of scientific experts, in conjunction with natural resource managers and other key stakeholders e.g. MDBA, CLLMM Scientific Advisory Group (DWLBC 2006; SA MDB NRM Board 2009). Revision has seen targets clarified and has



incorporated knowledge gained throughout the ongoing condition monitoring process and consideration of the changing environmental conditions in the icon site.

Each of the revised ecological targets for the Lower Lakes, Coorong and Murray Mouth icon site contributes to at least one environmental objective of the icon site (Table 1: Summary of revised ecological targets and their contribution to icon site objectives). The relationships between ecological targets and icon site objectives can be either direct and/or indirect.

The purpose of these targets is to enable ongoing assessments of specific bird, fish, vegetation and invertebrate communities of the Lower Lakes, Coorong and Murray Mouth icon site, and the water quality and connectivity conditions which affect the biotic condition, all of which informs the level of achievement of the icon site objectives. Measurable changes to some of the targets can be specifically attributable to management actions of The Living Murray and other environmental water holders, while others may only be inferred.

3.1.2 Other objectives and targets developed for the icon site

The South Australian Department of Environment, Water and Natural Resources long term plan for the Coorong, Lower Lakes and Murray Mouth, "*Securing the Future*" identifies targets which complement The Living Murray Lower Lakes, Coorong and Murray Mouth Icon Site Environmental Water Management Plan First Step Decision objectives, and provides clear objectives for the future management of the region as a healthy, productive and resilient Wetland of International Importance (DEH 2010b) (Table 2). The first six objectives in DEWNR's long-term plan support Ngarrindjeri cultural life. The open mouth, fish recruitment and bird habitat objectives of TLM also help support Ngarrindjeri cultural life.

The Murray–Darling Basin Plan also complements The Living Murray Lower Lakes, Coorong and Murray Mouth icon site objectives by providing for the integrated management of the Basin water resources in a way that promotes the objectives of the *Water Act 2007* (Cth), in particular by providing for:

- giving effect to relevant international agreements, including the Biodiversity Convention and the Ramsar Convention, to the extent they relate to the use and management of Basin water resources
- establishment and enforcement of environmentally sustainable limits on the quantities of surface water and groundwater that may be taken from Basin water resources
- Basin-wide environmental objectives for water-dependent ecosystems, and water quality and salinity objectives
- use and management of Basin water resources in a way that optimises social, economic and environmental outcomes
- water to meet its most productive use through the development of an efficient water trading regime across the Murray–Darling Basin
- requirements that must be met by water resource plans
- improved water security for all uses of Basin water resources.



The ecological objectives and environmental water requirements of The Living Murray Lower Lakes, Coorong and Murray Mouth Icon Site EWMP were developed in a separate process to those of the Basin Plan, and for different purposes and time scales. As a result, there are some minor differences between some indicators in these Plans; however they are broadly consistent.

The LLCMM Icon Site EWMP indicators aim to identify the flow targets and other water requirements to ensure the site functions in a 'healthy' ecosystem state. They are aspirational in nature. They are also focussed on water required for real-time management of the site. Basin Plan indicators were developed as long term statistics for modelling purposes.



Table 1: Summary of revised ecological targets and their contribution to icon site objectives

Target	Na.	lc	Icon site objective			
ID#	Ecological target	Open mouth	Fish recruitment	Bird habitat		
B1	Maintain or improve bird populations in the Lower Lakes, Coorong and Murray Mouth	Yes	No	Yes		
F1	Maintain or improve recruitment success of diadromous fish in the Lower Lakes and Coorong	Yes	Yes	No		
F2	Maintain or improve recruitment success of endangered fish species in the Lower Lakes	No	Yes	No		
F3	Provide optimum conditions to improve recruitment success of small-mouthed hardyhead in the South Lagoon	No	Yes	No		
F4	Maintain or improve populations of black bream, greenback flounder and mulloway in the Coorong	Yes	Yes	No		
l1	Maintain or improve invertebrate populations in mudflats (both exposed and submerged)	Yes	Yes	Yes		
12	Provide freshwater flows that provide food sources for Goolwa cockles	Yes	No	No		
M1	Facilitate frequent changes in exposure and submergence of mudflats	Yes	No	Yes		
M2	Maintain habitable sediment conditions in mudflats	Yes	No	Yes		
V1	Maintain or improve <i>Ruppia megacarpa</i> colonisation and reproduction	No	Yes	Yes		
V2	Maintain or improve <i>Ruppia tuberosa</i> colonisation and reproduction	No	Yes	Yes		
V3	Maintain or improve aquatic and littoral vegetation in the Lower Lakes	No	Yes	Yes		
W1	Establish and maintain variable salinity regime with >30% of area below sea water salinity concentrations in estuary and North Lagoon	No	Yes	Yes		
W2	Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity	Yes	Yes	Yes		
W3	Maximise fish passage connectivity between the Lower Lakes and Coorong	No	Yes	No		
W4	Maximise fish passage connectivity between the Coorong and the sea	Yes	Yes	No		
Icon site obj	ectives – Open mouth: an open Murray Mouth; Fish recruitment: more frequer	nt estuarine	fish recruitment; Bi	rd habitat:		

Icon site objectives – Open mouth: an open Murray Mouth; Fish recruitment: more frequent estuarine fish recruitment; Bird habitat: enhanced migratory wader bird habitat in the Lower Lakes. Target ID – B: bird-related target; F: fish-related targets; I: invertebrate-related targets; M: mudflat-related targets; V: vegetation-related targets; W: water-related targets.



 Table 2: Summary of how the South Australian Department of Environment, Water and Natural Resources

 long term plan for the CLLMM targets compliment The Living Murray LLCMM EWMP icon site objectives

CLLMM long term plan target	LLCMM EWMP icon site objective		
N/A.	Open mouth	Fish recruitment	Bird habitat
Lake Alexandrina and Lake Albert remain predominantly freshwater and operate at variable water levels	Yes	No	Νο
The Murray Mouth is predominantly kept open by end-of- system river flows	Yes	Yes	Yes
There is a return of salinity gradients along the Coorong that are close to historic trends with a corresponding response in species abundance	Yes	Yes	Yes
There is a dynamic estuarine zone	Yes	Yes	Yes
The biological and ecological features that give the CLLMM wetlands their international significance, albeit a changed and changing wetland, are protected	Yes	Yes	Yes
There is a return of amenity for local residents and their communities	Yes	Νο	Yes
There are adequate flows of suitable quality water to maintain Ngarrindjeri cultural life	Yes	Yes	Yes
Tourism and recreation businesses can utilise the lakes and Coorong; and productive and profitable primary industries continue	Νο	Yes	Yes

Icon site objectives – Open mouth: an open Murray Mouth; Fish recruitment: more frequent estuarine fish recruitment; Bird habitat: enhanced migratory wader bird habitat in the Lower Lakes.



3.2 Water requirements

Water level is a key environmental attribute that determines the availability of physical habitat for fish, birds, plants and other aquatic life. Salinity levels, their degree of variation and rate of change, affect the aquatic species present and their "health". Barrage outflows control the water level and influence salinity of Lakes Alexandrina and Albert and provide connectivity to the Coorong. Barrage outflows are the major "driver" of Murray Mouth openness and these, in combination, affect estuarine habitats, water levels and water quality of the entire Coorong.

The River Murray system is the major source of water for barrage outflows, although the Eastern Mount Lofty Ranges tributaries (i.e. Finniss, Currency, Angas and Bremer) also contribute. Additional flows from the South East drainage system, through Morella Basin/Salt Creek into the South Lagoon of the Coorong, are complementary to barrage outflows in controlling water level and salinity (though are much smaller volumes, are of varying salinity and have only a localised effect).

3.2.1 Lakes Alexandrina and Albert

In order to meet the icon site ecological targets, the Lower Lakes require environmental flows to achieve the following (Lester *et al.* 2011b; Muller 2010; Heneker 2010; Pollino 2011):

- sufficient volumes to maintain lake levels above 0.0 m AHD to prevent exposure of sulfidic sediments (refer to Pollino 2011; MDBC 2008a)
- sufficient volumes to vary lake levels seasonally between 0.35 m AHD and 0.75 m AHD annually (Figure 5), with higher lake levels of between 0.5 m AHD and 0.83 m AHD every third year (Figure 6)
- barrage outflows sufficient to maintain electrical conductivity in Lake Alexandrina below 1,000 μ S/cm 95% of the time and below 1,500 μ S/cm 100% of the time
- a total average annual barrage outflow of 2,000 GL per three year rolling period (i.e. not less than 6,000 GL over three years) and not less than 650 GL in any one of the three years will ensure the above target salinities are met in the Lower Lakes
- the river flows to the sea annually higher security to low flow regime.

Fluctuating lake levels across the suggested range (Muller 2010) will maintain habitats for threatened fish (refer Target F2), and maintain and enhance aquatic vegetation (refer Target V3). Under a varied lake operating regime, shoreline mudflats are exposed and re-inundated (Target M1), providing suitable conditions for benthic invertebrates (Target I1), an important food source for migratory waders (Target B1). This range of lake levels also ensures operation of most fishways is achievable year-round, as well as providing greater connectivity between the Lakes and the Coorong via barrage releases (W3). If inflow conditions only allow fishways to operate for part of the year, timing should be prioritised for mid-winter and mid-summer, to optimise diadromous fish movement (Target F1). Barrage releases will promote an export of salt from the Lakes and the River Murray system as a whole, freshening in the Coorong (Target W1), and allowing the maintenance of an open Murray Mouth (Targets W2 and W4) (Table 3).





Figure 5: Proposed ideal operating envelope for Lakes Alexandrina and Albert at an Annual Return Interval of 1 (every year), showing upper and lower limits

The operating ranges described in Figure 5 and Figure 6 are primarily for the benefit of fringing vegetation and the prevention of lakeshore erosion. However, at the lower lake levels (e.g. 0.35 m AHD) consideration must be made of the impact of reduced access to water on the operation of barrage fishways, reverse barrage flows, saltwater intrusion and irrigator offtakes. Lowering the lakes to the minimum recommended level should only be implemented if higher flows are forecast and can reinstate lake levels. Therefore consideration of these factors must be made before intentionally reducing lake levels to the minimum proposed operating level. It is important to consider this an operating *range*, hence lake levels may only rarely achieve the extremes of the range.





Figure 6: Proposed ideal operating envelope for the Lower Lakes at an Annual Return Interval of 3 (once every three years), showing upper and lower limits.

3.2.2 Coorong and Murray Mouth

In order to meet the icon site ecological targets, the Coorong and Murray Mouth require environmental flows to achieve the following (as per Lester *et al.* 2011b):

- There should be no years in which no flow passes over the barrages. The absolute minimum annual barrage flow should be between 50 and 120 GL.
- Over any two-year period, at least 600 GL should be released to the Coorong to prevent certainty that South Lagoon salinity thresholds (maximum of 117 g L⁻¹ (ppt) as described in Lester *et al.* 2011b) being exceeded.
- At least 2,500 GL over two years as a minimum target (95% of the time) to prevent the Coorong from existing in a degraded state across the entire region.

Preferred flow requirements (Lester et al. 2011b):

• Flows of at least 6,000 GL/y are recommended at least every 5 years (preferably every three years) and flows of at least 10,000 GL/y recommended every 17 years (preferably every 7 years).

Achieving these levels, flow and salinity targets are required to maximise the likelihood of achievement of icon site objectives. Greater description of these flow targets is provided in Appendix B.

Delivery of adequate freshwater through barrages releases will ensure an open Murray Mouth (Targets W2, W4) which in turn will maintain variable salinities in the Coorong North Lagoon and Murray Mouth Estuary (W1), improving condition for *Ruppia tuberosa* (Target V2), and



deliver food sources to the Goolwa Cockle (Target I2). Maintaining estuarine habitats and improving the estuarine nature of the North Lagoon will support small-mouthed hardyhead (Target F3), important commercial fish species (Target F4), *Ruppia megacarpa* (Target V1) which will maintain or improve bird populations (Target B1).

A target salinity of 117 g L⁻¹ (ppt) for the Coorong is described above, and optimum salinities for many species of 60-100 ppt are described below in Table 4: Environmental water requirements for the Murray Mouth and Coorong to achieve icon site ecological targets. These values reflect what modelling (Webster 2007, Lester et al. 2011a) suggests is likely to be achieved by returning flows. It is acknowledged that the optimum salinity for many species (e.g. smallmouthed hardyhead) lies at the lower end of the 60-100 ppt salinity range described in Table 4: Environmental water requirements for the Murray Mouth and Coorong to achieve icon site ecological targets. It is highly desirable that salinity in the Coorong, particularly the South Lagoon is reduced to support the regions key fauna and flora. However, it needs to be recognised that the salinity in the Southern Lagoon cannot be reduced to pre-European conditions (Krull et al. 2009) over a short (i.e. 5 year) timescale, taking into account current water diversion rates and the relatively small volume of environmental water available. These limitations highlight the importance of investigating the 'South Lagoon Pumping' and 'Upper South East Flows Restoration to the Coorong' projects, however, Lester et al. (2011b) stress that the River Murray must continue to be the primary source of fresh water to the Coorong to maintain ecological condition. Refer to section 4.3.2 for further detail on these proposed environmental water delivery works.



Table 3: Environmental water requirements for Lakes Alexandrina and Albert to achieve icon site ecological targets

TLM Objective (M/F/B)	Target	Biota	Optimum salinity*	Level (m AHD)	Frequency (yrs)	Annual Volume (GL)	Duration and Timing
	Maintain or improve	Waders	fresh - brackish	0.35 - 0.7 0.5 - 0.85	1 in 1 1 in 3	min 650 GL/yr barrage outflow#	As per hydrographs (Figs 5 &6)
В	bird populations in the Lower Lakes	Fish-eating birds, Water fowl (herbivorous)	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650 GL/yr barrage outflow#	As per hydrographs (Figs 5 &6)
M & F	Maintain or improve recruitment success of diadromous fish in the Lower Lakes <i>(and Coorong)</i>	Fish requiring both marine & freshwater habitats	fresh - brackish	>0.5 m AHD for fishway releases	1 in 1	minimum outflow of 52 GL/y fishway operation +attractant flows	Fishways run for 12 months
_	Maintain or improve recruitment success	Murray hardyhead	brackish	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650 GL/yr barrage outflow#	As per hydrographs (Figs 5 &6)
F of endangered fish species in the Lower Lakes	Southern pygmy perch, Yarra pygmy perch	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650 GL/yr barrage outflow#	As per hydrographs (Figs 5 &6)	
O, F & B Maintain or improve invertebrate populations in mudflats (Lakes)	Maintain or improve invertebrate	Mudflat invertebrates	fresh - brackish	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650 GL/yr barrage outflow#	As per hydrographs (Figs 5 &6)
	Aquatic invertebrates	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650 GL/yr barrage outflow#	As per hydrographs (Figs 5 &6)	
В	Facilitate frequent changes in exposure and submergence of mudflats (Lakes)	Mudflat invertebrates	N/A	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	N/A	As per hydrographs (Figs 5 &6)
В	Maintain habitable sediment conditions	Mudflat invertebrates	N/A	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650 GL/yr barrage outflow#	As per hydrographs (Figs 5 &6)
F & B	Maintain or improve aquatic and littoral vegetation in the Lower Lakes	Freshwater aquatic vegetation	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650 GL/yr barrage outflow#	As per hydrographs (Figs 5 &6)
F	Maximise fish passage connectivity between the Lower Lakes and Coorong	Fish requiring both marine & freshwater habitats	N/A	>0.5 m AHD for fishway releases	1 in 1	minimum outflow of 52 GL/y fishway operation + attractant flows	Fishways run for 12 months

TLM objectives: M refers to open Murray Mouth, B refers to enhanced migratory bird habitat and F refers to more frequent estuarine fish recruitment.

*Salinity ranges: Fresh 0 – 800 μ S/cm, Brackish (Oligohaline) 800 – 8000 μ S/cm. (USGS 2011).

#A minimum barrage outflow of 650 GL is dependent on larger outflows in subsequent years (averaging 2,000GL over 3 years), as described above.



Table 4: Environmental water requirements for the Murray Mouth and Coorong to achieve icon site ecological targets

TLM Objective (M/F/B)	Target	Biota	Optimum salinity (ppt)*	Preferred Annual Volume (GL)	Frequency	Duration & Timing
В	Maintain or improve bird populations in the Coorong	Waders, Fish-eating birds, Water fowl (herbivorous)	60 - 100 ppt South Lagoon	6,000 10,000	1 in 3 1 in 7	As per hydrographs (Fig 7)
M, F	Maintain or improve recruitment success of diadromous fish in the Coorong	Fish requiring both marine and freshwater habitats	fresh - marine	52 GL fishway operation (min) + attractant flows	1 in 1	Year-round fishway operation
F	Provide optimum conditions to improve recruitment success of small-mouthed hardyhead in the South Lagoon	Small-mouthed hardyhead	60 - 100 ppt South Lagoon	6,000 10,000	1 in 3 1 in 7	As per hydrographs (Fig 7)
F	Maintain or improve populations of black bream, greenback flounder and mulloway in the Coorong	Black bream, greenback flounder, mulloway	fresh – marine: maintenance of a salinity gradient is the key requirement	6,000 10,000	1 in 3 1 in 7	As per hydrographs (Fig 7)
М, F, В	Maintain or improve invertebrate populations in mudflats in the Coorong	Mudflat and subtidal invertebrates, waders	brackish - marine	6,000 10,000	1 in 3 1 in 7	As per hydrographs (Fig 7)
M, B	Facilitate frequent changes in exposure and submergence of mudflats in the Coorong	Mudflat invertebrates, waders	brackish - marine	Murray Mouth open (730-1,090 GL)	1 in 1	Diurnal tide ratios met
В	Maintain habitable sediment conditions	Mudflat invertebrates, waders	N/A	N/A	N/A	N/A
F	Maximise fish passage connectivity between the Lower Lakes and Coorong	Fish requiring both marine and freshwater habitats, e.g. congolli	N/A	52 GL fishway operation (min) + attractant flows	1 in 1	Year-round fishway operation
F, M	Maximise fish passage connectivity between the Coorong and the sea	Fish that move between the Coorong & ocean, e.g. diadromous fish, mulloway, yelloweye mullet, black bream & greenback flounder.	N/A	Murray Mouth open (730-1,090 GL)	1 in 1	Diurnal tide ratios met
Μ	Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity	Fish that move between the Coorong & ocean, e.g. diadromous fish, mulloway, yelloweye mullet, black bream & greenback flounder.	N/A	Murray Mouth open (730- 1,090GL)	1 in 1	Diurnal tide ratios met
F, B, M	Maintain or improve <i>Ruppia megacarpa</i> colonisation and reproduction	Ruppia megacarpa	0 - 19 ppt North Lagoon for recruitment. Further investigation of optimum recruitment conditions and transplantation options also to be investigated	6,000 10,000	1 in 3 1 in 7	As per hydrographs (Fig 7)



TLM Objective (M/F/B)	Target	Biota	Optimum salinity (ppt)*	Preferred Annual Volume (GL)	Frequency	Duration & Timing
F, B, M	Maintain or improve <i>Ruppia tuberosa</i> colonisation and reproduction	Ruppia tuberosa	60 - 100 ppt South Lagoon	6,000 10,000	1 in 3 1 in 7	As per hydrographs (Fig 7)
F, B, M	Establish and maintain a variable salinity regime with >30% of area below sea water salinity concentrations in estuary and North Lagoon	Ruppia megacarpa, diadromous fish, black bream, mulloway, yelloweye mullet and greenback flounder, benthic invertebrates.	< 35 ppt in 30% of area of estuary and North Lagoon	modelling required	modelling required	modelling required

TLM objectives: M refers to open Murray Mouth, B refers to enhanced migratory bird habitat and F refers to more frequent estuarine fish recruitment.

3.2.3 Barrage flow delivery patterns and operations

While the annual volume delivered through the barrages is paramount to achieving the icon site's objectives and targets, the pattern or seasonality of water delivery is even more critical for keystone species of the Coorong. Modelling has indicated that longer, sustained barrage outflows have greater benefits to Coorong salinity than short, pulsed releases (Lester et al. 2011a). Barrage flows should increase from early spring to peak over the early summer months to alleviate evaporative losses in the Coorong. This will maintain water levels in the Coorong during this period, inundating mudflats for enough time to allow Ruppia tuberosa to reproduce (Paton & Bailey 2010b). This 'spring pulse' of outflows will also provide recruitment cues for a number of other species in the estuary and Coorong. Following this, a gradual reduction in barrage flows from mid-summer will then provide more exposure of mudflats, and provide feeding habitat for migratory waders. This seasonal barrage release pattern, developed by J Higham (DEWNR) also provides for water exchange and salinity reduction in the Coorong South Lagoon. This pattern of delivery can be achieved over various annual water availability scenarios (Figure 7). It should be noted that none of the volumes associated with Figure 7 can be achieved from entitlement flow alone; considerable inflows in the form of environmental water (TLM and/or Commonwealth Environmental Water Holder (CEWH)) and/or unregulated flow is needed.





Figure 7: Hypothetical optimal timing of barrage releases for various annual flow scenarios

The difficulties in maintaining lake levels and barrage releases within a certain operating envelope per month must be highlighted. SA Water, in collaboration with the MDBA and South Australian government (DEWNR) engage in weekly barrage operating teleconferences to determine barrage opening and closing strategies to achieve the required lake level and flow targets. Water availability and tidal conditions (refer Appendix C) play a major role in the ability to operate the system, and day-to-day management decisions are often required to optimally manage barrage operations. Factors determining short-term (daily-weekly) barrage operations typically include salinity, weather, tides, fishway operations and knowledge of flow. SA Water, who manage day-to-day barrage operations will continue to liaise and consult on best operation practice for the barrages and strive to be proactive in their operation of the barrages to achieve maximal ecological outcomes and minimise inconvenience for the local community. This collaborative cross-agency management approach must continue if the proposed operations are to be achieved.

Barrage releases will occur in a strategic fashion depending on management objectives. For example, the bulk of flow would be directed through Goolwa Barrage to maintain an open Murray Mouth, whereas opening Tauwitchere Barrage, particularly at the southern end, would be primarily used for managing salinity in the Coorong.

3.3 Climate and rainfall in the Murray–Darling Basin

Historically the climate of the Murray–Darling Basin varies year to year. Climate change science has demonstrated there is likely to be an increased variability in the future, resulting in more frequent and extreme floods and droughts than in the past (MDBA 2010). Consequently the river storages and use of environmental water are managed to mitigate these varying river flows.

Between 1996 and 2010 the Murray–Darling Basin was in a drought characterised by below average rainfall in autumn and winter and very few wet periods. This drought has been significantly drier than the Federation (mid 1890s to early 1900s) and the World War II drought (1940s).



In spring 2010 widespread, above-average rainfall across the Murray–Darling Basin alleviated the short-term dry conditions. This rainfall has been associated with the breakdown of the 2009–10 El Niño and the development of a moderate to strong La Niña event in 2010–12.

3.3.1 Local climatic conditions

The Lower Lakes, Coorong and Murray Mouth icon site has a Mediterranean climate with warm dry summers and cool wet winters. The mean annual rainfall is 467.6 mm. The mean monthly maximum rainfall is in June (61.7 mm). The expected mean maximum daily temperature is highest in February at 26.4°C, lowest in July 14.9°C, and has an annual mean of 20.8°C (Figure 8: Monthly climate summary statistics for the Meningie area within the LLCMM Icon Site. Bureau of Meteorology 2010 Meningie (number 024518). The minimum daily temperature is at its maximum in January and February at 13.9°C, minimum in July at 6.7°C, and has an annual daily mean of 10.2°C Figure 8.



Figure 8: Monthly climate summary statistics for the Meningie area within the LLCMM Icon Site. Bureau of Meteorology 2010 Meningie (number 024518)

3.4 Baseline condition

3.4.1 Antecedent hydrological conditions

River regulation, water extraction and the recent extreme drought have reduced the total volume of water available to the river and Coorong Estuary, and have significantly altered the natural pattern of remaining flows. These changes have resulted in a substantial decline in the health of the river.

The operation of the barrages has significantly changed the hydrological regime of the Lower Lakes and the Coorong. Lake levels are now more elevated and static than under natural conditions. Historically, the target lake level was 0.75 m AHD but this varied slightly between 0.6 m and 0.85 m AHD annually. The lake level was surcharged to 0.85 m AHD in early spring to allow for evaporation losses during summer. When the lake level exceeds 0.83 m AHD, freshwater spillage may occur near the barrages. Prior to the drought, the lake level had to be maintained above 0.6 m AHD to enable flood irrigation in the Lower Murray Reclaimed Irrigation Areas below Lock 1 (Mannum–Wellington) (MDBC 2007).



Maintaining elevated lake levels has affected the geomorphology of the lakes, including:

- prograded shorelines in sheltered areas
- accelerated shoreline erosion in exposed localities
- accelerated rates of sedimentation in the lakes
- changed the character of the sediments deposited.

This has implications for littoral plants and wildlife communities, infrastructure damage, turbidity and nutrient levels in the lakes (MDBC 2007).

Since river regulation, barrage releases have been insufficient to counteract the incoming tidal flow and have resulted in congestion of the channels inside the estuary, altering the hydrological conditions in the icon site. Congestion of the mouth has allowed coarse marine sands to smother productive mudflats and reduce the area of suitable habitat for aquatic plants in the estuary and the North Coorong Lagoon. These cumulative impacts have reduced habitat and adversely affected the food chain (Paton 1997).

Sand build-up reached a critical level in mid-2002 following the longest ever period of barrage closure (630) days. This led the South Australian Government to undertake a sand dredging program at the Murray Mouth from 2002 until 2010. While sand dredging is an effective tool to maintain an open Murray Mouth during low flow periods, environmental flows are essential for this to occur naturally and achieve the icon site plan's key target to maintain an 'open Murray Mouth', with adequate tidal variations to meet the needs of the Coorong ecosystem (DWLBC 2007).

3.4.2. Past management actions/activities

Since the development of the previous LLCMM Icon Site Environmental Water Management Plan in 2006 (MDBC 2006a), a number of environmental water delivery projects and the development of water delivery infrastructure have been completed within the icon site. Table 5: Summary of past management actions and activities in the Lower Lakes, Coorong and Murray Mouth icon site provides a summary of some of these key achievements (greater detail can be found in Appendix D).

Table 5: Summary of past mana	gement actions and activities in the	Lower Lakes, Cooron	g and Murray Mouth icon site
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Action	Summary				
Environmental	Environmental watering				
Threatened fish refuge protection	9 ML of TLM water was delivered over summer 2009–10 to Boggy Creek on Hindmarsh Island, a refuge site for an isolated population of Murray hardyhead, an IUCN, EPBC and state listed species. Delivery of this water allowed this population to be sustained through the drought, which allowed the re-colonisation to Lake Alexandrina when drought conditions eased.				
Submerged aquatic vegetation seedbank protection	250 ML of TLM water was delivered in spring 2009 to Narrung wetland, a fringing wetland on the shore of Lake Alexandrina, to protect the seedbank of <i>Ruppia tuberosa</i> . The seedbank increased by 64% as a result of this watering.				
Enhanced barrage releases	In 2010–11 a total of 392 GL of environmental water from TLM, CEWH, Victorian Environmental Water Return Flows and the South Australian Drought Allocation Framework was added to the large unregulated flow event. Barrage releases were enhanced and Coorong salinities were reduced.				
The Living Murray Environmental Works and Measures Program					
Barrage fishways	Several fishways have been installed on the barrages separating Lake Alexandrina from the Murray Mouth Estuary. These have been designed to pass a wide range of species. This program is funded by the Murray–Darling Basin Authority(MDBC 2006b).				

Summary
A variety of investigations on fish movement, reproduction and recruitment, specifically concerned with the barriers posed by the barrages, have been undertaken by SARDI Aquatic Sciences. These studies have documented the reproductive behaviour, movement and recruitment ecology of the fishes of the icon site, as well as the challenges posed to these species by the loss in connectivity imposed by the barrages and other regulating structures which have disconnected the aquatic environments in the icon site. The findings of these studies are helping to inform biologically sensitive operation of the barrages in the icon site.
This project extended the range of the telemetered surface water monitoring systems present in the Lower Lakes into 11 sites in the estuarine reaches of the North Lagoon of the Coorong. The extension of the system into the Coorong allows for the hydrological and physical effects of barrage operations to be
viewed as they happen in the estuarine environment, better informing barrage operations.
The current extent of the surface water monitoring system can be viewed on-line :-
http://data.rivermurray.sa.gov.au/
This project involved a prioritisation process where 15 wetland sites identified within the LLCMM were ranked based on predicted improvements in ecological condition for 12 ecological values. A number of sites were also identified for which the proposed works would contribute significantly to ecological values of the entire LLCMM region. The sites which ranked highly included Hindmarsh Island, Dunn's Lagoon, Tolderol and Milang, leading to the development of management and operational plans, including recommendations for on-ground works to support key biological assets.

Action	Summary
DEWNR droug	nt emergency actions
Acid sulphate soil remediation	The primary threat during the drought condition within the Lower Lakes was the presence and potential for exposure of acid sulfate soils as a result of declining water levels. A series of emergency measures were put in place to prevent, mitigate, and control soil acidification. These measures included construction of regulators (bunds) at Clayton and the Narrung Narrows; pumping to water to maintain lake levels above acid sulfate soil trigger thresholds; and the application of limestone in Currency Creek, Finniss River and the Goolwa Channel;
Bioremediation and revegetation	Several thousand hectares of exposed lakebed sediments were aerial, machine and hand seeded in order to add carbon into lake beds to facilitate the consumption of acidity through sulfate reduction. This program also stabilized soils preventing soil erosion. This program has now moved into the ecological restoration phase where over 1.1 million plants have been planted during 2009–10 and over 500,000 plants planted during 2011.
Fish conservation	The threat of local extinction of threatened fish species from the Lower Lakes due to drought lead to a variety of conservation measures being employed. DENR project managed threatened fish breeding programs through the drought in order to ensure species in the future can be returned to the Lakes. Environmental water was deliver to refuge sites of threatened species as well as a captive breeding program being undertaken to ensure the survival of Murray hardyhead, Yarra pygmy perch and southern pygmy perch.
Facilitating passage for diadromous fish	The Goolwa boat lock was used to allow movement of the diadromous Congolli between Lake Alexandrina and the Coorong in August 2010. This intervention was undertaken to overcome the inoperability of the barrage fishways caused by low lake levels. Recent fish monitoring has recorded abundant juvenile congolli, indicating successful reproduction as a result of utilising existing infrastructure.



4. WATER DELIVERY

4.1 Prioritisation of water requirements

The Living Murray Annual Watering Plan, developed by the EWG includes a flexible decision framework to guide prioritisation of environmental watering actions, icon site environmental watering proposals developed by the icon site managers with jurisdictional agencies, water availability forecasts and management objectives for water resource scenarios (see Table 6). Further detail on these scenarios is provided in Appendix E).

Throughout the year the EWG recommends environmental watering actions, based on The Living Murray Annual Environmental Watering Plan and the volume available in The Living Murray environmental water portfolio, to the MDBA office for approval. Annual water planning and implementation is responsive to changing water resource conditions, opportunities and environmental priorities throughout the season and from year to year. Consequently the water requirements identified for the LLCMM icon site will be prioritised along with the requirements for all other TLM icon sites. The Living Murray portfolio alone is not expected to be sufficient to meet the full LLCMM icon site environmental water requirements and there will be opportunities for other environmental water holders to contribute water to the site as well.

'Catastrophic extreme dry'

The Murray–Darling Basin recently experienced the worst drought in recorded history (2002– 10) and combined with the over allocation and extraction of water from the system, resulted in reduced freshwater inflows to the Lakes and Coorong. With limited end-of-system flows, lake levels receded to below -1.0 m AHD, exposing large areas of previously saturated sulfidic sediments that formed acid sulfate soils upon drying.

The situation that the Lower Lakes and Coorong faced during this drought was unprecedented and is not considered in the icon site plan to be 'extreme dry' rather 'catastrophic extreme dry'. If conditions are to return to what was experienced during this period then large volumes of water for direct delivery to the Lower Lakes will be sought from environmental water holders to maintain lake levels above 0.0 m AHD, noting that other icon sites will also require water and that a prioritisation process will occur. Lake levels need to be maintained to prevent the formation of acid sulfate soils and subsequent environmental collapse. Exact volumes required will depend on modelling, condition forecasting and water availability, but could be several hundred gigalitres. Refer to Appendix B (Table 17: Required volume (GL) to raise water levels in the weir pool from Lock 1 to the barrages by 10 cm from the corresponding starting water levelfor a description of volumes required to raise the weir pool from Lock 1 to the barrages (including the Lower Lakes) in 10 cm increments).

If this situation is repeated, programs to prevent large-scale acidification, potentially including the (re)construction of blocking banks at Narrung and Clayton; bioremediation programs and large-scale limestone dosing, may be necessary as an alternative to flows. These actions cost millions of dollars, and are less effective at mitigating acid sulphate soils compared to reinundation through fresh water delivery. The Drought Emergency Framework for Lakes



Alexandrina and Albert (MDBA unpublished³) outlines acidification-related hazards and triggerlevels associated with receding lake levels as well as potential management actions.

However, recent modelling to inform the Basin Plan (MDBA 2012) indicates that the initial volume to be recovered (2,750 GL) would be sufficient to keep lake levels above the 0.0 m AHD threshold if the same drought conditions were repeated, subject to water delivery as per the modelling assumptions. Once the Basin Plan is fully implemented, the likelihood of a return to a 'catastrophic extreme dry' event is limited.

Refer to Appendix E for a description of required management activities in the LLCMM icon site under each water availability scenario.

Table 6: Ecologica	l objectives	under different	t water availability	/ scenarios
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	Extreme dry	Dry	Median	Wet
Ecological watering objectives	Avoid irretrievable loss of key environmental assets	Ensure priority river reaches and wetlands have maintained their basic functions	Ecological health of priority river reaches and wetlands have been protected or improved	Improve the health and resilience of aquatic ecosystems
Management objectives	 Avoid critical loss of species, communities and ecosystems Maintain key refuges Avoid irretrievable damage or catastrophic events Avoid exposure of acid sulfate soils 	 Maintain river-Lower Lakes-Murray Mouth-Coorong functioning though likely with reduced reproductive capacity Maintain key functions of high priority wetlands Manage within dry - spell tolerances Support connectivity between sites 	 Enable growth, reproduction and small- scale recruitment for a diverse range of flora and fauna Promote low-lying floodplain-river- Lower Lakes-Murray Mouth- Coorong connectivity Support medium flow Lower Lakes, Murray Mouth, Coorong river and floodplain functional processes 	 Enable growth, reproduction and large- scale recruitment for a diverse range of flora and fauna Promote higher floodplain-river Lower Lakes-Murray Mouth- Coorong connectivity Support high flow Lower Lakes, Murray Mouth, Coorong river and floodplain functional processes
Volumes	 Up to 9 GL through barrage fishways (over 2 months) <0.5 GL for threatened fish sites 1-2 GL for fringing wetlands Water to maintain levels above 0 m AHD 	 ~1,800 ML/day through barrages and fishways (~650 GL/yr) 	 >1,800ML/day through barrages and fishways (>650GL/yr) 	 >2,800 ML/day through barrages and fishways (>1,000 GL/yr)
Example priority actions for LLCMM icon site	 Pumping to threatened fish refugia Pumping to fringing lakes wetlands Barrage fishways operational for minimum 2 months per year, alternatively use Goolwa boat lock if lake levels too low Divert water from SE drainage system into Coorong 	 Barrage fishways operational for minimum 6 months Small attractant flows from Goolwa and Tauwitchere barrages next to fishways Small release from Boundary Creek for estuarine conditions Larger volumes to the Lakes to operate 	 Barrage fishways operational year-round Medium attractant flows from Goolwa and Tauwitchere barrages Release from Boundary Creek for estuarine conditions Each barrage has some bays open Larger volumes to the Lakes allow for fluctuating levels 	 Barrage fishways operational year-round Large flows through all barrages Each barrage has most bays open Flows directed to keep Murray Mouth open, to restore large extent of estuarine habitats in the Coorong and to reduce salinities in the South Lagoon

³ Will be published in 2014.



Extreme dry	Dry	Median	Wet
 Murray Mouth dredging Maintain lake levels >0.0 mAHD via delivery of environmental water 	 water levels > 0.35 m AHD and to prime the site for recovery Murray Mouth dredging if required 	 Maintain water levels and salinity in Coorong to promote <i>Ruppia</i> Maintain estuarine habitats to facilitate fish recruitment 	 Managed fringing lakes wetlands fitted with flow control structures operated to create mudflat habitat

4.2 The Living Murray works and water modelling

Modelling completed in 2008 (MDBC 2008) found that the environmental water requirements of the floodplain icon sites (with the exception of Barmah–Millewa and the Lower Lakes, Coorong and Murray Mouth icon sites) could largely be met by a combination of the proposed TLM works, the 500 GL of recovered TLM water and 70 GL long-term Cap equivalent (LTCE) of River Murray Increased Flows.

This modelling was based on a number of assumptions including the use of unregulated flow events for environmental watering actions. It was also agreed as a modelling principle that return flows could be used to water at multiple environmental sites. There are a number of constraints to the implementation of this principle which TLM are currently working to resolve and trialling solutions.

Further modelling is also planned to allow greater optimisation of works and measures to achieve icon site ecological objectives as a greater understanding of operating scenarios is gained.

4.3 Operating regimes for environmental watering actions

This section of the Environmental Water Management Plan provides a broad description of the proposed operating regimes to maximise ecological outcomes from the use of The Living Murray water portfolio and works. To meet the proposed operating regimes, a combination of unregulated and regulated environmental water may be used.

While this environmental water management plan focuses on the use of environmental water from The Living Murray water portfolio, there will also be other sources of environmental water available to meet the proposed regimes, including the Commonwealth Environmental Water Holder, state allocations and private donations. The contribution of varying operating regimes to the achievement of the ecological objectives is detailed further in Table 7.

Table 7: Operating regimes contribution to the ecological objectives

Ecological watering objective	Icon site First Step Decision objective	Vegetation community *	Works or other mechanisms to assist meeting objectives	Preferred level (Lakes Alexandrina and Albert, m AHD)	Long term average frequency	Durati on (days)	Water availability scenario	Estimated volume of water required (GL)
Preferred operation	ng scenario							
Improve the health and resilience of aquatic ecosystems	 An open Murray Mouth More 	Fringing wetlandsCoorong and Lakes	 Barrage operation/manipulation to lower and raise Lake levels Barrage fishways operational year-round Large flows through all barrages Each barrage has most bays open Flows directed to keep Murray Mouth open, restore large extent of estuarine habitats in the Coorong and reduce salinities in the South Lagoon 	Lake levels vary seasonally between 0.35 - 0.75m AHD	Annually	365	Dry - Median	SA Entitlement (1,850 GL/yr) + ADF presumed >1,800 ML/day out barrages (>650 GL/yr)
	frequent estuarine fish recruitment • Enhanced migratory wader bird habitat	riparian habitat • Coorong north and south lagoon • Murray Mouth		Lake levels vary seasonally between 0.5 - 0.83m AHD	Every third year	365	Median - Wet	SA Entitlement + ADF + large unregulated flows presumed >2,800 ML/day through barrages (>1,000 GL/yr)
Ecological health of priority habitats and wetlands have been protected or	ealth of ats Murray Iakes s have Mouth wetlands ed or More Coorong and	 Barrage operation/manipulation to lower and raise Lake levels Barrage fishways operational 	Lake levels vary seasonally between 0.35 - 0.7m AHD	Annually	365	Median	SA Entitlement + ADF + unregulated flows >1,800 ML/day out barrages (>650 GL/yr)	
Impioved	frequent estuarine fish recruitment • Enhanced migratory wader bird habitat	Lakes riparian habitat • Coorong north and south lagoon • Murray Mouth	 year-round Medium attractant flows from Goolwa and Tauwitchere barrages Release from Boundary Creek for estuarine conditions Each barrage has some bays open Larger volumes to the Lakes allow for fluctuating levels Maintain water levels and salinity in Coorong to promote <i>Ruppia</i> Maintain estuarine habitats to facilitate fish recruitment 	Lake levels vary seasonally between 0.5 - 0.83m AHD	Every third year	365	Median	SA Entitlement + ADF + unregulated flows >1,800 ML/day out barrages (>650 GL/yr)

Ecological watering objective	Icon site First Step Decision objective	Vegetation community *	Works or other mechanisms to assist meeting objectives	Preferred level (Lakes Alexandrina and Albert, m AHD)	Long term average frequency	Durati on (days)	Water availability scenario	Estimated volume of water required (GL)
Minimum operating	scenario							
Ensure priority habitats and wetlands have maintained their basic functions	y • An open Murray • Coorong and Lakes riparian eir • More • habitat	Coorong and Lakes riparian habitat	 Barrage operation / manipulation to lower and raise Lake levels Allow larger volumes to Lakes 	Lake levels vary seasonally between 0.35 - 0.7m AHD	Annually	365	Dry	SA Entitlement (1850 GL/yr) ~1,800 ML/day out barrages (~650 GL)
	 requent estuarine fish recruitment Enhanced migratory wader bird habitat 	 Fringing lakes wetlands Coorong North lagoon 	 to maintain water levels and prime site for recovery Barrage fishways operational for minimum 6 months Small attractant flows from Goolwa and Tauwitchere barrages next to fishways in Spring Small release from Boundary Creek for estuarine conditions Murray Mouth dredging 	Lake levels vary seasonally between 0.5 - 0.83m AHD	Every third year	365	Dry	SA Entitlement (1850 GL/yr) ~ 1,800 ML/day out barrages (~650 GL)
Avoid irretrievable loss of key environmental assets	 An open Murray Mouth More frequent estuarine fish recruitment Enhanced migratory wader bird habitat 	 Critical habitats Priority fringing wetlands 	 Operate Lock 1 and barrages to maintain lakes >0 m AHD (acidification threshold) Pumping to threatened fish refuges Pumping to fringing lakes wetlands Barrage fishways operational for minimum 2 months per year, alternatively use Goolwa boat lock if negative head Divert water from SE drainage system into Coorong Murray Mouth dredging 	Maintain lake levels above 0 m AHD	Emergency actions implemented for duration of extreme dry period	365	Extreme dry	9 GL of water through the fishways over 2 months (or use boat lock if water levels too low); Required volume to maintain lakes >0 m AHD depends on starting level (refer Table 16 for corresponding volumes for 10cm increments)



4.3.1 Water delivery and existing water delivery infrastructure

The LLCMM icon site receives most of its water through gravity-fed flows from the River Murray through Lock 1, 275 km from the Murray Mouth. Under previous operating conditions, the Lower Lakes were maintained at an average pool level of around 0.75 m AHD to Lock 1 at Blanchetown, to ensure sufficient water for irrigation activities. Pool level fluctuated over the season around this level, and was highest in early summer and lowest in winter. This pool level is achievable when South Australia receives Entitlement (1,850 GL/year) or above-Entitlement Flow. Entitlement or above-Entitlement Flow would typically be achieved annually, outside of extreme drought conditions. During Entitlement Flow conditions, approximately 100 GL is available to release through the barrages.

Barrages

Barrage releases are a key management tool for keeping the Murray Mouth open and to control the water level in the Lower Lakes. Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere barrages Table 8 were built between 1935 and 1940, in order to separate the fresh water of the Lower Lakes from the estuarine-marine conditions of the Murray Mouth. They are operated by SA Water on behalf of the MDBA.

Table 8: Barrage details

Description	Length	Bays	Combined bay length	Gates
Goolwa	632 m	128	632 m	123 stop log bays
Mundoo	792 m	26	117 m	26 stop log bays
Boundary Creek	244 m	6	26 m	6 stop log bays
Ewe Island	2,270 m	111	470 m	50 stop log bays, 61 radial gates
Tauwitchere	3,658 m	322	1,368 m	130 stop log bays, 192 radial gates

Fishways

Associated with the operation of the barrages are a series of fishways (Table 9). These structures are located at Goolwa and Tauwitchere barrages, and allow fish to travel bidirectionally between Lake Alexandrina and the Murray Mouth estuary. Reduced flow velocities and turbulence allow fish of various sizes to successfully navigate through these structures.



Table 9: Barrage fishway details

Description	Volume/day (ML)*	Year installed	Funded by
Goolwa large vertical slot fishway	57	2004	MDBA
Hunters Creek vertical slot fishway	7	2008	MDBA
Tauwitchere large vertical slot fishway	35	2004	MDBA
Tauwitchere small vertical slot fishway	4	2009	MDBA
Tauwitchere rock ramp	50	2004	MDBA

*Note: approximate volumes are estimated as at Full Lakes Supply Level (0.75-0.8 m AHD), with releases likely to change dramatically in response to high tides or strong wind events.

Managed fringing wetlands

Within the Lower River Murray, many wetlands which were previously ephemeral are now permanently inundated, due to river regulation (Pressey 1986). Flow control structures to recreate a more natural wetting and drying regime, or to hold water on the floodplain have been installed at several sites which have had an ecological baseline survey monitoring program undertaken and a wetland management plan developed (DWLBC 2003). While management of the Lower Lakes water level is key to wetting and drying the fringing wetlands, several wetlands can be hydrologically managed using existing flow-control structures (Table 10). These wetlands are important during times of high lake and Coorong water levels, as water levels can be lowered to provide mudflat habitat for waders.

Table 10: Description of managed fringing wetlands of Lakes Alexandrina and Albert

Description	Туре	Year Installed	Funded By
Narrung wetland	Stop logs and rotating carp screens at ferry road and inlet channel connections	2007 & 2009	SA MDB NRM Board / CTLAP
Waltowa wetland	Sluice gate at inlet under Princes Highway on lake side	1999	NHT
Tolderol wetland	Sluice gates and pump from inlet channel	2001	NHT
Hunters Creek	Vertical slot fishway with stop logs and attractant flow at Hunters Creek estuary	2008	EWMP (MDBA)

Lower Lakes pipeline

Reduced freshwater flows to the Lower Lakes during the recent drought resulted in salinity levels within the lakes rising well above (as much as five times) that which was once suitable for stock, domestic supplies and irrigation. In order to provide reliable, quality drinking water to the communities reliant on the lakes, as well as reduce the pressure of water extraction on the lakes, 170 km of pipeline was installed to deliver quality drinking water to households and



properties at Langhorne Creek, the Raukkan Aboriginal Community and the Narrung and Poltalloch Peninsulas. A separate irrigation pipeline delivering irrigation water to the Langhorne Creek and Currency Creek communities was also installed in 2010, in time for the 2009–10 irrigation season. Another pipeline to supply Point Sturt with drinking water was connected to the existing Milang–Clayton system, with an additional pipeline to supply Hindmarsh Island with drinking water connected to an existing system which receives water via the Myponga Reservoir. While not directly related to the delivery of environmental water to the icon site, the pipeline does allow for a more variable lake operating regime to be implemented in the future, pending suitable consultation with all water users. This project was implemented by the South Australian Murray Futures CLLMM program, funded by the Australian Government's Water for the Future program.

Telemetered surface water monitoring stations

Eleven locations for new surface water quality logging equipment were determined in 2006–07 through the LLCMM icon site program. Sites were chosen to coincide with existing ecological monitoring sites used by the CSIRO Water for a Healthy Country: CLLMM Ecology project, and in areas where no other logging was available, in order to assist with research and consistent data collection. The extension of the system into the Coorong allows for the hydrological and physical effects of barrage operation decisions to be viewed as they happen in the estuarine environment. The enhanced Surface Water Monitoring System therefore demonstrates to the operators of the barrages with greater accuracy how the hydrology, physical conditions and ultimately the estuarine ecosystem response to management actions. This allows for management decisions to be more accurately made around barrage operations and environmental water delivery. This project was implemented by the then South Australian Department for Water, funded by the MDBA. A number of telemetered surface water monitoring stations in the LLCMM were decommissioned during 2011 due to reduced funding.

The surface water monitoring system can be viewed on-line:

http://data.rivermurray.sa.gov.au/

4.3.2 Proposed environmental water delivery works

South East flows to the Coorong South Lagoon - implementation As well as barrage releases, water and salinity levels within the Coorong are influenced by redirected groundwater and surplus surface water from the upper south east, which is released into the South Lagoon of the Coorong at Salt Creek. The Coorong South Lagoon Flows Restoration project was developed through The Living Murray EWMP program, and progressed through modelling and investigations to determine potential water delivery and salinity benefits to the Coorong South Lagoon through the further redirection of drainage water. At the time of developing this environmental water management plan, a funding proposal was with the Department of Sustainability, Environment, Water, Population and Communities for approval under the South Australian Murray Futures program funded through the Australian Government's Water for the Future program.

South Lagoon pumping

A proposal to pump hyper-saline water out of the South Lagoon of the Coorong for ecological benefit is being considered. Initial assessments have shown that this project is feasible. If implemented, the project would involve minor highway upgrades, a pumping station - on the western side of the lagoon to reduce visual impacts, a pipeline from the South Lagoon to the



Southern Ocean, monitoring of salinity levels in the Coorong and the sea and regular meetings with local stakeholders. At the time of developing this environmental water management plan, a funding proposal was with the Department of Sustainability, Environment, Water, Population and Communities for approval under the South Australian Murray Futures program funded through the Water for the Future program. The future of this project is dependent on future South Lagoon salinities and the ability to export salt from the Coorong under current flow conditions using existing barrage infrastructure.

Additional barrage fishways

By building on the existing knowledge gained through the Murray Fishways Program and the MDBA funded Barrage Fishway Monitoring program, additional fishways may be installed at priority locations on the barrages. This will improve connectivity between the estuarine and freshwater environments, and provide passage for a greater range and number of fish and in a greater number of locations. At the time of developing this environmental water management plan, a funding proposal was with the Department of Sustainability, Environment, Water, Population and Communities for approval under the South Australian Murray Futures program funded through the Water for the Future program.

Automated barrage gates

Automated barrage gates provide the opportunity for barrage operators to remotely operate the opening and closing of barrage bays. This may allow for some releases into the estuary to be made under low lake level conditions, but still prevent salt-water ingress into Lake Alexandrina. While already installed at Mundoo, Ewe Island and Tauwitchere, further modifications are required. Boundary Creek may also benefit from the installation of automated gates.

Channel maintenance for Lower Lakes fringing wetlands

Many freshwater channels associated with the Lower Lakes are 'choking' from sand drifts or sediment accumulation which may lead to dense build-up of Typha spp. and/or Phragmites spp., which further exacerbates the problem. Removal of channel blockages is required to maintain connectivity and may be best achieved using an excavator. Sand build up across channel mouths may be prevented by planting 'buffer zones' of native reeds, sedges or rushes (e.g. river club rush, (*Schoenoplectus validus*)) to buffer wave action which may lead to sand build-up.

Fringing lakes wetland hydrological management

While some fringing lakes wetlands have flow control structures that allow for hydrological manipulation (see Section 4.3.1 Water delivery and existing water delivery infrastructure, additional wetlands where a baseline survey has been undertaken (SKM 2004; SKM 2006) could also be managed in a similar fashion for enhanced ecological outcomes following completion of a management plan. This is especially critical during 'wet' water years, when mudflat habitat is flooded in both the lakes and Coorong due to high water levels. Managed lakes wetlands are then the only areas in the icon site where water levels can be lowered to create suitable mudflat habitat for waders. Upgrades to existing flow control infrastructure at existing managed wetlands could also improve hydrologic management. A number of new culvert designs have already been developed (Tolderol, Hindmarsh Island and Loveday Bay) through The Living Murray Environmental Works and Measures Program.



4.4 Water accounting and measurement

Water accounting methodology will be developed and agreed in advance by TLMC and the Basin Officials Committee (BOC). Consistency of water accounting methodology will be sought wherever possible. Where relevant, water accounting will be consistent with the Water Accounting Conceptual Framework and Australian Water Accounting Standards. The best available, most appropriate and cost-effective measurement technique will be used to determine environmental water use. The appropriateness of the measurement technique is likely to differ from icon site and event. For example, under dry conditions environmental water pumped into Hattah is likely to be measured via a meter and return flows measured via a gauging station. Under wet conditions, environmental water returning from Barmah–Millewa Forest and other upstream sites will need to be modelled. It should be noted that current calculations for barrage releases are estimates only, and a better calculation of discharge volumes is needed in the near future taking into account lake and estuary water level and bay openings.

4.5 Evaluation and management of potential risks

A number of risks have been identified associated with the Lower Lakes, Coorong and Murray Mouth Icon Site EWMP (Table 11), adapted from DSEWPAC (2011). Monitoring and mitigation will be carried out where possible. The results will be taken into consideration when implementing adaptive management principles. These risks and mitigating measures are further detailed in a Risk Monitoring Plan. The risks identified have been linked to LLCMM icon site First Step Decision objectives where relevant.

Risks associated specifically with climate change including sea level rise and reduced inflows have been further explored in Matthews (2005) and Lester *et al.* (2009b).

Threat	Raw risk strategy			Mitigation strategy	Mitigated	FSD impacted		
	Likelihood	Consequences	Risk ranking		Likelihood	Consequences	Risk ranking	
Acid sulphate soils	Possible	High	Severe	Implement Real Time Management Strategy (RTMS)	Possible	Critical	Severe	FΒ
Areas of unstable bank around Lake Alexandrina and Albert 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 fluctuation. Adjust rates of rise and fall as necessary	Unlikely	Insignificant	Low	FΒ
Benefits to alien species	Possible	Moderate	Medium	Monitor and apply an adaptive management approach to pest animal and plant control	Possible	Minor	Low	FΒ
Adverse community reaction to releases of water	Likely	Moderate	Medium	Liaise with SAMDBNRMB and LLCMM community advisory panel. Make pre- emptive media releases	Possible	Minor	Low	-
Blackwater	Possible	Moderate	Medium	Pre-emptive media releases, implement large barrage releases (water permitting) to flush out blackwater	Unlikely	Minor	Low	F

Table 11: Potential risks and mitigation strategies in relation to Lower Lakes, Coorong and Murray Mouth icon site objectives

Threat	Raw risk strategy			Mitigation strategy	Mitigated	FSD impacted		
	Likelihood	Consequences	Risk ranking		Likelihood	Consequences	Risk ranking	
Water loss – water exits Murray Mouth without mixing with waters of the North Lagoon	Possible	Moderate	Medium	Monitor and apply an adaptive management approach. Adjust flow releases between barrages to enhance mixing	Unlikely	Minor	low	FΒ
Harmful increase in sediment transport causing unwanted movement in the Murray Mouth	Unlikely	Minor	Low	Considered unlikely at flow rates proposed. Adjust flow releases between barrages to avoid the extent of unwanted results	Unlikely	Insignificant	Low	F B M
Not achieving the proposed ecological objectives of the EWMP'	Possible	Critical	Severe	Maintain existing regime of lobbying and sourcing water to achieve outcomes. Continue monitoring and research programs to determine the achievement of outcomes.	Possible	Critical	Severe	F B M
Climate change- rising sea level, reduced rainfall in the Basin	Almost certain	Critical	Severe	Continue to assess risk to ecological assets. Assess engineering solutions to maintain site's ecological character	Almost certain	Major	Severe	F B M

Threat	Raw risk strategy			Mitigation strategy	Mitigated	FSD impacted		
	Likelihood	Consequences	Risk ranking		Likelihood	Consequences	Risk ranking	
Water required for icon site is not available (e.g. extreme drought) leading to loss of key environmental assets, site desiccation, possible species loss, closure of Murray Mouth	Possible	Critical	Severe	Develop and implement water bids for small volumes for protection of refugia and maintenance of lakes water levels , dredge Murray Mouth, 'rescue' threatened species, implement RTMS	Possible	Moderate	Medium	FΒM

FSD Objectives: M refers to open Murray Mouth, B refers to enhanced migratory bird habitat and F refers to more frequent estuarine fish recruitment.



5. MONITORING

Different monitoring methods are used to assess progress toward TLM icon site ecological objectives. These include River Murray system-scale, icon site condition, intervention and compliance monitoring. The Living Murray Outcomes Evaluation Framework (MDBC 2007) outlines the rationale for these monitoring methods and are summarised below.

Icon site condition monitoring plans must be written for each icon site and are the responsibility of the Icon Site Manager. A condition monitoring plan for the Lower Lakes, Coorong and Murray Mouth icon site was completed in February 2009 (see SA MDB NRM Board 2009 and the Condition Monitoring Plan).

River Murray system-scale, intervention and compliance monitoring projects are implemented across icon site programs and are coordinated by the MDBA TLM monitoring program. Specific monitoring plans for each icon site are known as Icon Site Condition Monitoring Plans.

5.1 River Murray system-scale monitoring

River Murray system-scale monitoring and evaluation measures improvements across the River Murray system ecological health in relation to fish, waterbirds and vegetation. Conducted annually, this monitoring focuses on the system's ecological health.

5.2 Icon site condition monitoring

Condition monitoring assesses the icon site condition in relation to the ecological objectives at each site. It is typically conducted on a medium frequency basis (months to years) depending on the rate of change. Condition monitoring includes standard methodologies for monitoring fish, birds and vegetation, as well as icon site specific methods for monitoring other ecological objectives (see Condition Monitoring Plan). These monitoring activities have been classified into three categories A, B and O:

'A' category monitoring activities are undertaken at all icon sites using agreed standardised methodologies. These are:

- fish condition monitoring using the MDBA Sustainable Rivers Audit methodology
- waterbird condition monitoring using a standard on-ground method to link with the annual aerial waterbird survey
- tree condition monitoring for river red gum and black box using on-ground assessments linked to remote-sensing data.

'B' category contains icon site-specific monitoring using locally appropriate methods. This monitoring responds to unique icon site characteristics and is less easily standardised.

'O' category uses icon site monitoring related to objectives and is less easily linked to First Step Decision ecological objectives.

5.2.1 Implementation of Icon Site Condition Monitoring Program

Progress towards the achievement of the identified LLCMM ecological objectives and targets will be monitored on an annual basis by a range of contractors who are the experts in their field.



These service providers include SARDI Aquatic Sciences, The University of Adelaide, Flinders University and Coorong Nature Tours. The Icon Site Manager is then responsible for compiling all information into an annual Condition Monitoring Report for the MDBA, which details progress against each objective and target.

Ngarrindjeri Regional Authority and State government agency staff meet regularly to coordinate research and monitoring activities at the icon site. The LLCMM Icon Site Indigenous Facilitator sits on this group, known as the CLLMM Research and Monitoring Working Group, along with staff of the Ngarrindjeri Regional Authority's Yarulwar-Ruwe program, and DEWNR.

The respective components of the current LLCMM condition monitoring program, delivered by the above-listed contractors, and their relationship to the three condition monitoring categories is presented in Table 12.

 Table 12: Individual Lower Lakes, Coorong and Murray Mouth condition monitoring programs, and their relationship to A, B and O categories of monitoring

LLCMM Condition Monitoring Program	Target*	А	В	0
Birds				
Waterbirds- aerial survey	B1	Yes	No	No
Waterbirds- monthly ground surveys	B1	Yes	No	No
Waterbirds- Coorong and Lower Lakes summer census	B1	No	Yes	No
Vegetation				
Lower Lakes aquatic vegetation	V3	No	Yes	No
Ruppia monitoring	V1, V2	No	Yes	No
Fish				
Lower Lakes small bodied threatened fish (Murray hardyhead, Southern pygmy perch, Yarra pygmy perch)	F2	No	Yes	No
Coorong fish (black bream, greenback flounder, small- mouthed hardyhead)	F3, F4	No	Yes	No
Barrage fish recruitment (diadromous species)	F1	No	Yes	No
Invertebrates & Mudflats				
Benthic invertebrates and mudflats	I1, M1, M2	No	No	Yes
Diatom communities in relation to Goolwa cockles	12	No	No	Yes

*'Target' refers to the 16 ecological targets developed for the LLCMM Icon Site (refer Table 1)

5.3 Icon site intervention monitoring

The complexity of ecological system processes make the results of any management intervention difficult to predict. Therefore intervention monitoring is a key component of The Living Murray Environmental Monitoring Program. The aim of intervention monitoring is to improve understanding about the causal links between TLM environmental watering and other management actions, and ecological responses at icon sites. This knowledge enables TLM to



continually adapt and improve management of icon sites and watering into the future to optimise ecological outcomes.

As TLM works are completed, measuring the volume of water used at icon sites (including timing, volume and quality of any return flows) is essential to account for and report on how TLM environmental water is used and managed. This area of monitoring was previously included in the compliance monitoring category in the Outcomes and Evaluation Framework, but is now encompassed within intervention monitoring. This change was made to ensure clear linkages between the various information requirements for managing successful watering events and informing the operation of works at icon sites. This includes systems for water measurement and accounting and monitoring risks (previously defined in compliance monitoring) and assessing ecological outcomes resulting from specific watering events or other management actions.

A number of intervention monitoring projects have been funded in the LLCMM icon site by the MDBA from 2007–11. These have focused on weir pool manipulation (specifically weir-pool lowering, i.e. the impact of drought), pumping to key refuge sites and flow enhancement (i.e. flow through barrage fishways). Appendix F provides an example of one such intervention monitoring and details of the background hypotheses underpinning current and future intervention monitoring projects.

5.4 Other ecological monitoring undertaken in the icon site

In addition to the monitoring undertaken through The Living Murray program, a number of key programs that fall outside the fish/vegetation/birds convention are currently undertaken in the LLCMM, predominantly through the SA Murray–Darling Basin Natural Resource Management Board and DEWNR (Table 13 and Appendix G). The Living Murray icon site staff work collaboratively with staff from DEWNR and the SA MDB NRM Board to ensure all monitoring programs are complementary, there is no doubling-up of information collected, and all data is shared and utilised appropriately.

Many of these extra monitoring programs provide additional feedback on the work undertaken through TLM, in that they have helped to inform which sites should be a priority for future watering, or have assisted with the on-going gathering of information at watered sites.

Table 13: Details of additional ecological monitoring undertaken in the Lower Lakes, Coorong and Murray Mouth icon site

Project	Body	Details
Southern Bell Frogs (<i>Litoria</i> <i>raniformis</i>) monitoring	SA MDB NRM Board / DEWNR	This projects seeks to determine the location of Southern Bell Frog populations around Lakes Alexandrina, Lake Albert and the EMLR tributaries to assess the species status in the region and determine sites for environmental water delivery to support this EPBC listed species
Community Wetland Monitoring	SA MDB NRM Board / DEWNR / GWLAP / CTLAP	This project involves working with community groups to monitor photo points, ground water, surface water quality and level, fish, frogs, birds and vegetation at several wetlands adjacent to the Lower Lakes
Drought Action Plan threatened fish monitoring	DEWNR / Aquasave Consultants / SARDI	This project monitors populations of threatened fish in, and nearby, the Lower Lakes. Additionally, this project has also undertaken captive breeding of threatened species and established populations in non-drought affected sites outside the LLCMM Icon Site
Ramsar habitat mapping	DEWNR	This project has compared the 2010 condition of the Lower Lakes wetlands with a baseline condition assessment made in 2003 and has also assessed the relative benefit of intervention management strategies by comparing managed versus non-managed wetlands
Acid Sulphate Soil and Water Quality Monitoring	SA MDB NRM Board / DEWNR / GWLAP / CSIRO / EPA	Acid sulfate soil and water quality monitoring is conducted around the Lower Lakes and EMLR tributaries by the EPA, CSIRO and GWLAP on behalf of the SA MDB NRM Board and DEWNR to assess the impacts of acid sulphate soils exposed during the low lake levels between 2006-2010

Project	Body	Details
Goolwa Channel Water Level Management Project	DEWNR	To assess the impacts of the Goolwa Channel Water Level Management Project, the response of water quality, phytoplankton, zooplankton, macroinvertebrates, vegetation, fish, frogs and birds have been monitored
Barrage release monitoring	DEWNR	Monitoring was conducted during spring/summer 2010/2011 to assess the response of water quality, nutrients, phytoplankton, zooplankton, fish, birds, macroinvertebrates, recruitment and connectivity to the first barrages releases in four years.
CLLMM Long- term plan monitoring	DEWNR	In establishing their CLLMM long-term plan, DEWNR are undertaking i.condition/baseline, ii. investigative, iii. emergency response, and iv. intervention monitoring in the LLCMM Icon Site. DEWNR and NRA have developed a Statement of Commitment regarding research and monitoring in the CLLMM region.

Greater detail on these monitoring projects is provided in Appendix G.


6. COMMUNITY CONSULTATION AND COMMUNICATION

The SA Department of Environment, Water and Natural Resources (DEWNR) has responsibility for community consultation and communication activities in relation to the icon site.

The Lower Lakes, Coorong and Murray Mouth Icon Site Community Reference Committee was formed in 2006 and since that time has met four to six times per year to provide informed input to the planning and management of the Lower Lakes, Coorong and Murray Mouth icon site. As of March 2012, the former Community Reference Committee has been replaced by the Community Advisory Panel.

The Community Advisory Panel comprises representation from the Ngarrindjeri Regional Authority and from a range of key stakeholder groups including the SA Murray–Darling Basin Natural Resource Management Board, the Mallee and Coorong NRM Group, Coorong–Tatiara and Goolwa to Wellington Local Action Planning associations, irrigation and fishing industries, recreational boating and marina industries, regional development, conservation interests, and local government.

The Community Advisory Panel receives detailed briefings regarding every aspect of icon site management including planning, environmental watering, monitoring and investigations and implementation of a range of projects occurring through The Living Murray.

The Community Advisory Panel also provides advice and valuable input to other programs and projects associated with drought response actions and the Murray Futures Coorong, Lower Lakes and Murray Mouth (CLLMM) Program. Staff from DEWNR support a joint approach as it facilitates cost savings, promotes collaboration across projects and limits 'burn-out' in key community members.

Feedback and advice is sought from the Community Advisory Panel about all key components of The Living Murray and other associated projects occurring within the icon site.

The recent long period of drought and the associated emergency responses along with the development of the CLLMM long-term plan has put a lot of pressure on the communities of the region requiring their involvement in a number of demanding and ongoing consultation processes. The need to ensure integration of consultation activities to maximise the effectiveness of engagement processes and minimise the impost on community members has been highlighted.

Briefings have been provided to the former Community Reference Committee regarding the update of the Icon Site Environmental Water Management Plan, its purpose and content and how it is being developed. A workshop session was held at which the details of the draft document were presented to the Community Reference Committee with a particular focus on:

- ecological objectives and the associated water requirements and water delivery
- monitoring and adaptive management and reporting.

Community Reference Committee members reviewed this Icon Site EWMP and were encouraged to share information to and provide feedback from their own community networks.



The new Community Advisory Panel have also received a presentation on the new LLCMM Icon Site EWMP.

The LLCMM Icon Site Scientific Advisory Group was also provided with the draft Icon Site EWMP to provide comment and feedback. This group has provided important input into the development of the environmental water requirements for the site, particularly in relation to achieving the 16 icon site ecological targets.

The LLCMM icon site project team continue to undertake a range of communication and community engagement activities including:

- provision of program updates for community and other groups via presentations at meetings or input to newsletters
- input to local print media.

The development of the LLCMM Icon Site Environmental Water Management Plan and its ongoing implementation will be communicated via these networks to the wider community.

The Lower Lakes, Coorong and Murray Mouth Community Engagement and Communications Strategy (see Community Engagement and Communications Strategy) guides the ongoing engagement and communication for the icon site.

Key components of the strategy include ongoing support for the role undertaken by the Community Advisory Panel which includes:

- providing a forum for discussion, input and advice on the ongoing development and implementation of Lower Lakes, Coorong and Murray Mouth icon site planning
- acting as a sounding board regarding decisions relating to environmental flows, environmental watering actions and other icon site management actions; in the icon site
- providing a conduit for information and feedback regarding icon site management between icon site managers and Community Advisory Panel member networks
- reporting on community attitudes, issues and expectations and providing advice on actions and responses to address these
- providing specific advice and input into the review of the ongoing engagement and communications strategy and regarding how to effectively communicate and engage with the wider community.

Other icon site engagement and communication activities will include:

- regular email updates
- articles in regional newsletters and media
- inclusion of icon site information on relevant websites
- development and update of factsheets regarding icon site management
- convening technical and community based forums and workshops.



7. INDIGENOUS ENGAGEMENT

Aboriginal people have many social, cultural, customary and economic interests in the water resources of the River Murray.

The Living Murray aims to maximise ecological outcomes through the delivery of environmental water. However, TLM is committed to taking into account Indigenous values and objectives in its environmental water planning and management. As Indigenous communities identify objectives and strategies for achieving these Indigenous objectives they will be incorporated into EWMPs in the future. Indigenous consultation will be reported on in the Annual TLM Environmental Watering Report and Annual TLM Implementation Report.

A Memorandum of Understanding (MOU) between Murray Lower Darling River Indigenous Nations (MLDRIN) and the Murray–Darling Basin Commission was signed in March 2006. The MOU provides for engagement with Traditional Owners at a strategic level along the length of the River Murray and across state boundaries, while being inclusive of formal jurisdictional arrangements.

In addition to the MOU input is also sought from Indigenous communities through the establishment of local Indigenous reference groups. Consultation takes an inclusive approach to ensure community knowledge, values and perspectives are considered.

The Aboriginal community, particularly Traditional Owners, have an important role to play in natural resource management.

The Lower Lakes, Coorong and Murray Mouth icon site lies within Ngarrindjeri country. The Ngarrindjeri have negotiated a Kungun Ngarrindjeri Yunnan agreement with the South Australian Government. It provides a framework for engagement between non-Indigenous (krinkari) and Ngarrindjeri programs – recognising the Ngarrindjeri Regional Authority as the peak Ngarrindjeri regional body. The Department for Water and the MDBA work with the Ngarrindjeri Regional Authority through the Kungun Ngarrindjeri Yunnun agreement and the associated Kungun Ngarrindjeri Yunnun Taskforce meeting process. The Ngarrindjeri Regional Authority has established a Ngarrindjeri Yarluwar-Ruwe Program to manage all projects and issues concerning Ngarrindjeri lands and waters. This program supports the Ngarrindjeri heritage program and includes representation from the Ngarrindjeri Native Title Management Committee, the Ngarrindjeri Tendi, the Ngarrindjeri Regional Authority's Research, Policy and Planning Unit and the regional Working on Country programs. The Ngarrindjeri LLCMM Icon Site Indigenous Facilitator is a member of this program committee and derives support from its coordinated approach to Ngarrindjeri Caring for Country.

Ngarrindjeri Regional Authority input into the LLCMM Icon Site Environmental Water Management Plan has been facilitated through the Kungun Ngarrindjeri Yunnun Taskforce, the Ngarrindjeri Regional Authority Yarulwar- Ruwe Program and the Indigenous Faciliator. The Ngarrindjeri also provided input to the initial icon site plan, in particular with regard to ecological targets, management options and the provision of cultural knowledge on a range of issues.

The Living Murray Indigenous Facilitator services for the LLCMM icon site provide advice on, and support the implementation of, the responsibilities and actions outlined in The Living Murray Business Plan, The Living Murray Indigenous Partnerships Project Plan and the Icon Site Environmental Water Management Plan. This includes the ongoing implementation of



protocols and processes that build effective partnerships between the Indigenous Nations people, responsible agencies and other interest groups. The MDBA has contracted DEWNR to manage and support the Indigenous Facilitator. The Indigenous Facilitator is part of a network of Indigenous Facilitators working on The Living Murray program.

The Ngarrindjeri Regional Authority is the peak indigenous body in the region, and the Ngarrindjeri Regional Authority Yarluwar-Ruwe Program acts as a reference group for the Indigenous Partnerships Program in the LLCMM. The Ngarrindjeri Regional Authority hosts the position of The Living Murray LLCMM Indigenous Facilitator.

Some of the key LLCMM Indigenous Facilitator services provided through the Ngarrindjeri Regional Authority include:

- · representation and input at icon site Community Advisory Panel meetings
- provision of advice and assistance with heritage assessments required for on-ground works under the direction and control of the Ngarrindjeri Heritage Committee Inc, and with research or monitoring associated with The Living Murray Program
- support for provision of input and content around Indigenous perspectives and cultural outcomes in wetland management planning
- · organisation of site visits with Aboriginal leadership, community and agency staff
- ensuring Aboriginal participation and assistance with TLM monitoring activities and establishment of monitoring at environmental watering sites
- representing the Lower Lakes, Coorong and Murray Mouth icon site at MLDRIN meetings and MDBA Indigenous forums including provision of presentations and reporting back to the Ngarrindjeri Regional Authority and the DEWNR regarding Indigenous projects occurring in other icon sites
- provision of advice on agreements/heritage process/ other Indigenous issues and input to the development of LLCMM icon site communications and engagement products and events.

The involvement of the Indigenous community is sought in icon site management and planning to ensure the aspirations, interests and contributions of Indigenous people are recognised during the development and implementation of icon site plans. The delivery of icon site Indigenous facilitation services through the Ngarrindjeri Regional Authority ensures and supports this involvement.

The LLCMM Icon Site EWMP will be implemented with ongoing input and advice from the Ngarrindjeri Regional Authority via its Kungun Ngarrindjeri Yunnan Taskforce and Yarluwar-Ruwe Program (Caring for Country).

Specific actions to provide information to the Ngarrindjeri Regional Authority regarding the development of the Icon Site Environmental Water Plan and its ongoing implementation include:

- presentations and discussion at Kungun Ngarrindjeri Yunnan Authority meetings
- site inspections with Aboriginal Elders and community members
- presentations at Ngarrindjeri Community meetings.



8. ADAPTIVE MANAGEMENT AND REPORTING

An adaptive approach is critical in managing water dependent ecosystems so both land managers and policy makers can learn and change strategies based on the outcomes of research and watering actions. It is also known as 'learning by doing' through designing, implementing, monitoring, reporting and evaluating our work. Adaptive management informs the on-going refinement and implementation of the EWMP by incorporating outcomes from environmental delivery, ecological monitoring, operation of works at each site, modelling and community consultation.

The Annual TLM Environmental Watering Plan is developed at the beginning of the watering season and complements the Icon Site EWMP. As the season progresses, the annual water planning process is responsive to changing water resource conditions, opportunities and environmental priorities. A flexible decision making framework is included in the annual plan so that as water resource conditions change the EWG is able to adaptively assess watering priorities during the year.

To highlight and analyse the past year's activities and outcomes the MDBA coordinates with the Icon Site Managers to produce an annual TLM Implementation Report (also a requirement under Clause 199 of TLM Business Plan) which is presented to the Murray–Darling Basin Ministerial Council.

To capture key learnings and changing icon site management practices, schedules appended to the EWMP will be updated as required.

For the LLCMM icon site, the condition and intervention monitoring programs and environmental water requirements modelling provide the core information for water bids, and are integral to the adaptive management process. Past monitoring programs have informed the need to protect key refugia in the Lower Lakes, enhance connectivity between the Lakes and Coorong and develop optimal barrage release patterns for Coorong health, leading to the development of water bids which aimed to deliver these objectives. Monitoring programs have also been used to determine whether the aims and objectives of particular watering events have been successfully met. Long-term monitoring results have helped to shape the current environmental water requirements for the icon site, and it is envisaged that these will be further refined in the future as more up-to-date information becomes available.



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10. SCHEDULES

This section provides the details of the schedules to this Environmental Water Management Plan.

Condition Monitoring Plan

Refer to SA Water connect publications.

Community Engagement and Communications Strategy

Refer to Media & Publications | Murray-Darling Basin Authority.

Future schedules

A future Lower Lakes Barrage Operating Strategy is to be developed – details of which will be made available in the future. Other schedules to this plan may be developed as required.



GLOSSARY OF TERMS

Attractant flow — flow designed to provide a physical or chemical stimulus for fish to utilise a fishway.

Aquatic ecosystem – any water environment from small to large, from pond to ocean, in which plants and animals interact with the chemical and physical features of the environment.

Basin Officials Committee (BOC) — a jurisdictional committee to coordinate the management of Basin water resources between the Commonwealth, the Authority and the Basin States.

Coorong — general title used for the 140 km long expanse of water, separated from the Southern Ocean by a narrow dune barrier encompassing both the North and South lagoons.

Diadromous species — a species which moves between fresh and salt water.

Diurnal Tidal Ratio (DTR) — a measure of the tidal energy fluctuations in the Coorong estuary relative to that in the ocean. Used as a measure of Murray Mouth openness. A value of one (1) indicates tides in the Coorong are equal in range to those in the ocean.

Ecological Objectives — an objective is a statement of the desired condition. It is not necessary to quantify an objective.

Ecological Targets — a target is generated from the ecological objective and will ideally be quantitative.

Electrical Conductivity (EC) — the ability of water or soil to conduct an electric current; commonly used as a measure of salinity or total dissolved salts. One EC unit is equal to one micro Siemens per centimetre at 25°C (μ S/cm-1).

Environmental Water — water that is available for the environment.

Environmental Watering Group (EWG) — a jurisdictional committee that develops and implements the annual TLM Environmental Watering Plan. The EWG recommends annual TLM watering priorities and proposals to ensure consistency between icon sites

Estuarine species — a species which either resides in, relies upon for the completion of a life stage, or opportunistically utilises the estuarine environment.

Euryhaline species — are those which are capable of tolerating a wide salinity range, i.e. freshwater to marine.

Flow regime — a flow regime is a specific combination of the timing, volume, frequency and duration of flow events in river systems.

Icon Site Environmental Watering Plan — A plan that details the aims, objectives and management actions at an icon site that are in accord with The Living Murray program. The plan is complementary to state based plans and processes.

Krinkari — Ngarrindjeri term for 'non-Indigenous' people.

Kurrangk — Ngarrindjeri term for the area referred to by Krinkaris as the Coorong.

Kungun Ngarrindjeri Yunnan agreements — a negotiation and contract (agreement) making methodology known as Kungun Ngarrindjeri Yunnan (KNY) (listen to what Ngarrinderi people have to say). Ngarrindjeri use this methodology in significant interactions with government and other non-Indigenous interests impacting on Ngarrindjeri Ruwe/Ruwar (see Hemming & Trevorrow 2005; Hemming, Rigney & Berg 2011). This approach has been adopted by the new Ngarrindjeri nation's peak body, the Ngarrindjeri Regional Authority (NRA).



Littoral — the edge or shallow area of a water body.

Lower Lakes — Lake Alexandrina and Lake Albert.

Marine straggler — marine fish species which enter an estuary infrequently and in low numbers.

Murray–Darling Basin Authority — previously the Murray–Darling Basin Commission.

Murray–Darling Basin Commission — now the Murray–Darling Basin Authority.

Murray–Darling Basin Ministerial Council (Ministerial Council) — Ministerial Council who develops and agrees to the Intergovernmental Agreements, approve The Living Murray Business Plan and make key decisions.

Murray Mouth estuary — usually defined as the region between Goolwa Barrage and Pelican Point.

Ngarrindjeri Regional Authority (NRA) — Ngarrindjeri contemporary governing organisation recognised by State and Federal governments as the peak governing body for the Ngarrindjeri nation. The NRA Board includes representation from the Ngarrindjeri Native Title Management Committee, the Ngarrindjeri Heritage Committee and the Ngarrindjeri Tendi.

Ngartji — for Ngarrindjeri people birds, animals, plants and all living things are spiritually connected – they are considered Ngartjis. A Ngartji is Ngarrindjeri totem – often referred to as a close friend and relative.

Ngurunderi — Ngarrindjeri creator ancestor: Ngurunderi creation 'story' is a primary Ngarrindjeri account of the creation in the Lower Lakes, Coorong and Murray Mouth region.

Objective — refer 'ecological objectives'.

Obligate — by necessity, e.g. an obligate diadromous fish requires access to both fresh and salt water to complete its lifecycle.

Parameter — a measurable or quantifiable characteristic or feature.

Prograded — built out; a term that refers to areas of lake edge where elevated water levels have caused erosion of the sediment underneath the topsoil, resulting in a 'shelf'.

Ramsar — a global treaty adopted in the Iranian city of Ramsar in 1971 that focuses on the conservation of internationally important wetlands.

Ruwe/Ruwar — Ngarrinderi ontology: represents the interconnectedness between lands, waters, body, spirit and all living things.

Target — refer ecological target.

Tendi — The traditional Ngarrindjeri governing body.

The Living Murray Committee (TLMC) — A jurisdictional committee who is responsible for the implementation of The Living Murray Business Plan.

Water Requirements — includes the flow, volume, timing, duration, velocity, depth, quality or any other attribute that is required to meet the ecological target.

Yarluwar-Ruwe — Ngarrindjeri 'Sea Country': represents the interconnectedness between what western traditions understand as sea and land, fresh water and salt.

ACRONYMS

AHD	Australian Height Datum
BOC	Basin Officials Committee
CAMBA	China-Australia Migratory Bird Agreement
CLLMM	Coorong, Lower Lakes and Murray Mouth
DENR	the former Department for Environment and Natural Resources
DEWNR	Department of Environment, Water and Natural Resources – amalgamation of DENR and DFW in 2012
DSEWPC	Department of Sustainability, Environment, Water, Population and Communities
DWLBC	the former Department of Water, Land and Biodiversity Conservation
EC	Electrical conductivity (1 µs/cm-1)
EPBC	Environment Protection and Biodiversity Conservation Act 1999
EWG	Environmental Watering Group
EWMP	Environmental Works and Measures Program
EWP	Environmental Watering Plan
GL	Gigalitre (1GL = 1 billion litres)
IUCN	International Union for Conservation of Nature
JAMBA	Japan-Australia Migratory Bird Agreement
LLCMM	Lower Lakes, Coorong and Murray Mouth
LTCE	Long-term Cap Equivalent
MDBA	Murray–Darling Basin Authority- absorbed the functions of the former Murray–Darling Basin Commission
MDBC	Murray–Darling Basin Commission
MDBMC	Murray–Darling Basin Ministerial Council
MDFRC	Murray–Darling Freshwater Research Centre
ML	Megalitre (1ML = 1 million litres)
MLDRIN	Murray Lower Darling Rivers Indigenous Nations
PPT	Parts per Thousand (g.L-1)
ROKAMBA	Republic of Korea-Australia Migratory Bird Agreement
SA MDB NRM	South Australian Murray-Darling Basin Natural Resources Management Board
SARDI	South Australian Research and Development Institute
TLM	The Living Murray
TLMC	The Living Murray Committee



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11. APPENDIX A: SIGNIFICANT AMPHIBIAN, BIRD, FRESHWATER FISH AND REPTILE SPECIES OF THE LLCMM ICON SITE

Table 14: Significant amphibian, bird, freshwater fish and reptile species of the LLCMM icon site

Fauna type	Common name	Scientific name	EPBC conservation listing	SA conservation listing	Migratory listing
Amphibian	Bibron's toadlet	Pseudophryne bibroni		R	
	Southern bell frog	Litoria raniformis	Vu	Vu	
Bird	Australasian bittern	Botaurus poiciloptilus	En	Vu	
	Australasian darter	Anhinga novaehollandiae		R	
	Australasian shoveler	Anas rhynchotis		R	
	Australian painted snipe	Rostratula australis	Vu	Vu	С
	Australian pied Oystercatcher	Haematopus longirostris		R	
	Australian reed-warbler	Acrocephalus australis			В
	Banded stilt	Cladorhynchus leucocephalus		Vu	
	Bar-tailed godwit	Limosa lapponica		R	BCJR
	Black-tailed godwit	Limosa limosa		R	BCJR
	Blue-billed duck	Oxyura australis		R	
	Cape barren goose	Cereopsis novaehollandiae		R	
	Caspian tern	Hydroprogne caspia			CJ
	Cattle egret	Ardea ibis		R	CJ
	Common greenshank	Tringa nebularia			BCJR
	Common sandpiper	Actitis hypoleucos		R	BCJR
	Common tern	Sterna hirundo		R	CJR
	Curlew sandpiper	Calidris ferruginea			BCJR
	Double-banded plover	Charadrius bicinctus			В
	Eastern curlew	Numenius madagascariensis		Vu	BCJR
	Eastern great egret	Ardea modesta			CJ
	Eastern osprey	Pandion cristatus		En	В
	Fairy tern	Sternula nereis	Vu	En	
	Flesh-footed shearwater	Ardenna carneipes		R	JR
	Freckled duck	Stictonetta naevosa		Vu	
	Glossy ibis	Plegadis falcinellus		R	ВC
	Great crested grebe	Podiceps cristatus		R	
	Great knot	Calidris tenuirostris		R	BCJR
	Greater sand plover	Charadrius leschenaultii		R	BCJR
	Grey falcon	Falco hypoleucos		R	
	Grey plover	Pluvialis squatarola			BCJR
	Grey-tailed tattler	Tringa brevipes		R	BCJR
	Hooded plover	Thinornis rubricollis		Vu	
	Intermediate egret	Ardea intermedia		R	
	Latham's snipe	Gallinago hardwickii		R	BCJR
	Lesser sand plover	Charadrius mongolus		R	BCJR



Fauna type	Common name	Scientific name	EPBC conservation listing	SA conservation listing	Migratory listing		
	Lewin's rail	Lewinia pectoralis		Vu			
	Little egret	Egretta garzetta		R			
	Little tern	Sternula albifrons		En	BCJR		
	Long-toed stint	Calidris subminuta		R	BCJR		
Fauna type	Common name	Scientific name	EPBC conservation listing	SA conservation listing	Migratory listing		
Bird	Marsh sandpiper	Tringa stagnatilis			BCJR		
	Musk duck	Biziura lobata		R			
	Orange-bellied parrot	Neophema chrysogaster	Cr	En	J		
	Pacific golden plover	Pluvialis fulva		R	BCJR		
	Pectoral sandpiper	Calidris melanotos		R	BJR		
	Peregrine falcon	Falco peregrinus		R			
	Red knot	Calidris canutus			BCJR		
	Red-necked phalarope	Phalaropus lobatus			BCJR		
	Red-necked stint	Calidris ruficollis			BCJR		
	Ruddy turnstone	Arenaria interpres		R	BCJR		
	Ruff	Philomachus pugnax		R	BCJR		
	Sanderling	Calidris alba		R	BCJR		
	Sharp-tailed sandpiper	Calidris acuminata			BCJR		
	Spotless crake	Porzana tabuensis		R			
	Terek sandpiper	Xenus cinereus		R	BCJR		
	Wandering tattler	Tringa incana			BCJR		
	Whimbrel	Numenius phaeopus		R	BCJR		
	White-bellied sea-eagle	Haliaeetus leucogaster		En	С		
Fish	Chanda perch	Ambassis agassizii		Cr, P			
	Climbing galaxias	Galaxias brevipinnis		R			
	Congolli	Pseudaphritis urvillii		Vu			
	Estuary perch	Macquaria colonorum		En			
	Freshwater catfish	Tandanus tandanus		En, P			
	Mountain galaxias	Galaxias olidus		Vu			
	Murray cod	Maccullochella peelii	Vu	En, (P*)			
	Murray hardyhead	Craterocephalus fluviatilis	Vu	Cr			
	River black fish	Gadopsis marmoratus		En, P			
	Short-finned eel	Anguilla australis		Ra			
	Short-headed lamprey	Mordacia mordax		En			
	Silver perch	Bidyanus bidyanus		En, P			
	Southern pygmy perch	Nannoperca australis		En, P			
	Yarra pygmy perch	Nannoperca obscura	Vu	Cr , P			
Reptile	Broad shelled turtle	Chelodina expansa		Vu			
	Murray turtle	Emydura macquarii		Vu			
Conservation listing: Cr- Critically endangered, En- endangered, Vu- vulnerable, R- rare, P- protected under South							

Australian *Fisheries Management Act 2007*. Migratory listing: B- Bonn convention, C- CAMBA, J- JAMBA, R- ROKAMBA. *- Murray cod is subject to a partial closed season.



12. APPENDIX B: DETAIL ON LOGIC TO SUPPORT WATER REQUIREMENTS (SECTION 3.2.)

Lakes Alexandrina and Albert overview

The Lower Lakes annually require sufficient environmental flows to achieve the following (Muller 2010; Lester *et al.* 2011b):

- sufficient volumes to maintain lake levels above 0.0 metres AHD to prevent exposure of sulfidic sediments
- sufficient volumes to vary lake levels seasonally between 0.35 m and 0.75 m above sea level annually, with higher lake levels of between 0.5 m and 0.83 m above sea level every third year (Muller 2010)
- barrage outflows sufficient to maintain salinity in Lake Alexandrina below 1,000 EC 95% of the time and below 1,500 EC 100% of the time
- a total average annual barrage outflow of 2,000 GL per three year rolling period and not less than 650 GL in any one of the three years will ensure the above target salinities are met in the Lower Lakes
- the river flows to the sea annually higher security to low flow regime.

Lower Lakes water level

In order to achieve icon site ecological targets and to protect the key species of Lakes Alexandrina and Albert, lake level variation is required over the course of a year. In the past, the lakes required surcharging in early September to ensure irrigation supplies, evaporative losses and other uses could be met over summer. However, drought conditions between 2006 and 2010 have resulted in the installation of the Lower Lakes pipeline, which allows irrigation to be achieved in some (e.g. Langhorne Creek), but not all (e.g. Lake Albert fringes), areas adjacent to the Lakes regardless of lake level. SA Water off-takes on the river channel below Lock 1 have also been lowered, allowing water extraction to occur over the entire proposed operating range. It is therefore now possible to manage lake levels for ecological purposes, not solely for supply demands, although consultation will be required with consumptive users without access to the Lower Lakes pipeline. For optimal ecological outcomes, Muller (2010) suggests both an annual lake level envelope, with a return interval of one (every year), in conjunction with an occasional flooding envelope, with a return interval of three (once every three years).

Annual lake operating envelope (ARI = 1)

Muller (2010) proposes an annual variable lake level, fluctuating between 0.35m AHD – 0.70m AHD (Figure 9).

A minimum lake operating level of 0.35 m AHD allows for key fringing wetlands, channels and aquatic habitats, particularly around Hindmarsh and Mundoo islands, to remain inundated. These wetland environments are inhabited by key threatened fish species such as Murray hardyhead, Yarra pygmy perch and southern pygmy perch (refer Target F2), and diverse submerged aquatic vegetation (refer Target V3). This range of lake levels also ensures operation of most fishways is achievable year-round, especially for the smaller vertical slots,



and in particular, Hunters Creek fishway (refer Target F1). A lowering of levels is needed to establish fringing lakeshore vegetation (Target V3), which prevents lakeshore erosion. Under a varied lake operating regime, shoreline mudflats near the barrages are exposed and reinundated (Target M1), providing suitable conditions for benthic invertebrates (Target I1), an important food source for migratory waders (Target B1).

An upper lake operating level of 0.70 m AHD in spring allows for ephemeral fringing wetlands of Lake Alexandrina and Lake Albert to be inundated briefly, creating a wetting and drying cycle. The wetting period promotes the growth of aquatic vegetation (Target V3) and stimulates a release of aquatic invertebrates from the egg-bank of the sediments, providing food for waterbirds (Target B1) and fish. Higher lake levels allow for larger barrage releases to be made during this period, providing greater connectivity between the Lakes and the Coorong (Target W3) for diadromous fish (Target F1). Refer to Table 15 for a description of monthly ecological outputs corresponding to an upper and lower lake level.



Figure 9: Proposed ideal operating envelope for Lakes Alexandrina and Albert at an Annual Return Interval of 1 (every year), showing upper and lower limits



Table 15: Rationale around ideal operating envelope for the lakes at an Annual Return Interval of 1 (every year).

	Upper	Lower					
Month	(m /	AHD)	Rationale				
January	0.60	0.45	Gradual drawdown over late summer to expose mudflats and promote diverse vegetation, whilst supporting completion of life cycles for vegetation and dependent fauna.				
February	0.55	0.40	February drawdown not to drop below +0.4 m AHD to ensure upstream migration of congolli (and common galaxias) juveniles from estuarine to fresh waters.				
March	0.50	0.40	Summer/autumnal drawdown to expose mudflats and promote diverse vegetation but still support biotic movement between fresh and estuarine waters.				
April	0.50	0.35	Autumnal drawdown to promote diverse vegetation can drop to +0.35 m AHD assuming that functional connectivity between the lakes and the island anabranches remains at this level.				
Мау	0.50	0.35	Autumnal drawdown to promote diverse vegetation but maintain connectivity to islands and fringing wetlands.				
June	0.50	0.35	Winter low point prior to inflows commencing, supports overwintering reeds which die- off and need their new shoots to grow at a rate that matches rising water levels in spring.				
July	0.50	0.40	Fill typically begins in mid- to late winter. It may naturally have occurred very quickly but this proposed rate of fill would allow growth of new shoots of reeds and other vegetation to match rising water levels (highly turbid water) and thus promote diversity.				
August	0.60	0.45	Highest rate of fill in late winter and early spring. Native fish, frogs and other fauna need access to vegetation from now onwards into spring/summer to obtain food and shelter for recruitment and protection from predation.				
September	0.65	0.50	High water in spring for native fish, frogs and other fauna to access habitats and successfully recruit.				
October	0.70	0.50	High water in spring for native fish, frogs and other fauna to access habitats and successfully recruit.				
November	0.70	0.50	High water in spring for native fish, frogs and other fauna to access habitats and successfully recruit.				
December	0.65	0.45	Commencement of summer drawdown to expose mudflats and promote diverse vegetation.				

Occasional lake flooding envelope (ARI = 3)

Muller (2010) also proposes a one-in-three year higher lake level event, at which lake levels can fluctuate within a higher envelope of 0.50 m AHD - 0.95 m AHD (Figure 10). This follows a more natural pre-regulation regime, and was also informed by native species' flow requirements.

Occasional flooding, at levels >0.70 m AHD in spring and summer, allows extensive floodplain inundation in the key breeding season for threatened fish (Target F2), waterbirds (Target B1) and frogs. Long-lived vegetation such as the swamp paperbark (*Melaleuca halmaturorum*), often situated high on the floodplain, is also benefited by occasional inundation (Target V3). It ensures year-round operation of all fishways is achievable (supporting targets W3 and F1), with larger releases likely during high water levels in spring and summer. This may also coincide with an export of salt from the Lakes and the River Murray system as a whole, freshening in the



Coorong (Target W1), and the maintenance of an open Murray Mouth (Targets W2 and W4). Refer to Table 16 for a description of monthly ecological outputs corresponding to an upper and lower lake level for the one in three year scenario.



Figure 10: Proposed ideal operating envelope for Lakes Alexandrina and Albert at an Annual Return Interval of 3 (once every three years), showing upper and lower limits.



Table 16: Rationale for ideal envelope for lake levels that would occur at an Annual Return Interval of 3, showing upper and lower limits

	Upper Lower		
Month	(m /	AHD)	Rationale ARI = 3
January	0.85	0.60	Gradual drawdown over late summer to expose mudflats and promote diverse vegetation, whilst supporting completion of life cycles for floodplain vegetation and dependent fauna. Optimal outcomes for small-bodied native fish if water levels are \geq +0.8 m AHD from August to February (Bice pers. comm.).
February	0.80	0.60	Summer drawdown to expose part of the mudflats and promote diverse vegetation but stay above +0.6 m AHD so as to support faunal access to littoral vegetation and upstream migration of congolli (and common galaxias) juveniles from estuarine to fresh waters.
March	0.75	0.55	Summer/autumnal drawdown to expose mudflats and promote diverse vegetation, whilst still supporting high levels of connectivity between lakes, island anabranches and the Coorong.
April	0.70	0.55	Autumnal drawdown to promote diverse vegetation but maintain connectivity to islands and fringing wetlands.
Мау	0.70	0.50	Autumnal drawdown can drop to +0.50 m AHD to promote diverse vegetation but maintain connectivity to islands and fringing wetlands
June	0.70	0.50	Winter low point prior to inflows commencing, supports overwintering reeds which die- off and need their new shoots to grow at a rate that matches rising water levels in spring.
July	0.75	0.55	Fill typically begins in mid- to late winter. It may naturally have occurred very quickly but this proposed rate of fill would allow growth of new shoots of reeds and other vegetation to match rising water levels in highly turbid waters.
August	0.80	0.60	Highest rate of fill in late winter and early spring. Native fish, frogs and other fauna need access to vegetation from now onwards into spring/summer to obtain food and shelter for recruitment and from predation.
September	0.85	0.65	Some species require occasional inundation of whole floodplain (e.g. long-lived vegetation), which is assumed to occur at average water levels of +0.83 m AHD given that is when flow commences over the islands and into the Coorong. NB: water levels can exceed +1.0 m AHD in some areas.
October	0.95	0.70	Some species require occasional inundation of whole floodplain (e.g. long-lived vegetation) at lake levels of ≥+0.85 m AHD.
November	0.95	0.70	Some species require occasional inundation of whole floodplain (e.g. long-lived vegetation) at lake levels of \geq +0.85 m AHD. Extended floodplain inundation compared to ARI = 1 to allow fish and plants to complete life cycles.
December	0.90	0.65	Commencement of summer drawdown to expose mudflats and promote diverse vegetation.

Lakes Alexandrina and Albert salinity

An average annual salinity threshold of 1,000 EC for Lake Alexandrina is recommended by Muller (2010), based on salinity tolerances of key ecological indicators, many of which are consistent with icon site targets. This is considered to be the maximum threshold and has been selected due to the salinity relationship between Lake Alexandrina and Lake Albert. A maximum average salinity of 1,000 EC in Lake Alexandrina traditionally coincides with a salinity of around 1,700 EC in Lake Albert (Heneker 2010). As 1,700 EC is the upper end of salinity tolerance for many key freshwater species, including species of fish and aquatic vegetation,



these figures have been selected as average annual upper salinity thresholds for both Lake Alexandrina and Lake Albert (Lester *et al.* 2011b).

Lakes Alexandrina and Albert volumes

Volumes required to achieve target lake levels

It is very difficult to determine the volume of water required for the Lower Lakes (and the entire weir pool below Lock 1) to achieve a certain water level, as this is dependent on inflows and starting lake levels. As a guide, the following table describes fill volumes required to raise Lower Lakes levels in 10 cm increments (Table 17). This table may be used to estimate water requirements to lift lake levels to within the above-described operating ranges, particularly when levels fall below 0.35 m AHD.

Volumes required to achieve Lower Lakes salinity targets

In order to achieve an average annual salinity of 1,000 EC in Lake Alexandrina, rules for required cumulative annual barrage discharges have been determined through extensive modelling (Henneker 2010, cited in Lester *et al.* 2011b).

B1 is the minimum barrage outflow volume in any given year

B2 is the minimum cumulative barrage outflow volume over two years

B3 is the minimum cumulative barrage outflow volume over three years.

- 1. B1
- 2. B2 Fx-1
- 3. B3 Fx-1 Fx-2

The rules associated with maintaining a salinity threshold in Lake Alexandrina of 1,000 EC equates to a minimum barrage outflow volume that is required in a given year (Fx) is equal to the greater of:

- 1. 650 GL
- 2. 4,000 GL Fx-1
- 3. 6,000 GL Fx-1 Fx-2 (where Fx-2 is equal to the lesser of the actual outflow 2 years prior to the current year and 2,000 GL).

The above rules for lake operation and barrage releases, which are required to achieve optimal lake levels and salinities, can be related back to the LLCMM icon site ecological targets which are specific to the Lower Lakes. This is documented in Table 18.



Table 17: Required volume (GL) to raise water levels in the weir pool from Lock 1 to the barrages by 10 cm from the corresponding starting water level

Starting Level (m AHD)	Increase in Surface Area (ha)	Volume (GL)
0.6	243	87
0.5	266	86
0.4	403	86
0.3	641	85
0.2	1,122	85
0.1	1,407	83
0	1,333	82
-0.1	1,613	80
-0.2	1,762	79
-0.3	1,789	77
-0.4	1,873	75
-0.5	2,881	73
-0.6	2,351	70
-0.7	1,654	68
-0.8	1,691	66
-0.9	1,783	65
-1	2,107	63
-1.1	3,086	60
-1.2	2,680	57
-1.3	2,881	55
-1.4	4,071	51
-1.5	3,351	47
-1.6	2,082	45
-1.7	1,792	43

For example, to increase water level from 0.0 m AHD to 0.1 m AHD 83.35 GL are required, this input would increase the surface area by 1,407.18 ha.



Table 18: Environmental water requirements of the Lower Lakes to achieve icon site ecological targets

TLM Objective (M/F/B)	Target	Biota	Optimum salinity*	Level (m AHD)	Frequency (yrs)	Annual Volume (GL)	Duration and Timing
В	Maintain or improve bird populations in the Lower	Waders	fresh - brackish	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
	Lakes	Fish-eating birds	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
		Water fowl (herbivorous)	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
M & F	Maintain or improve recruitment success of diadromous fish in the Lower Lakes (and Coorong)	Fish requiring both marine & freshwater habitats	fresh - brackish	>0.5 m AHD for fishway releases	1 in 1	minimum outflow of 52 GL/y fishway operation +attr flows	Fishways run for 12 months
F	Maintain or improve recruitment success of endangered fish species in the Lower Lakes	Murray hardyhead	brackish	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
		Southern pygmy perch	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
		Yarra pygmy perch	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
O, F & B	Maintain or improve invertebrate populations in	Mudflat invertebrates	fresh - brackish	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
	mudflats (Lakes)	Aquatic invertebrates	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
В	Facilitate frequent changes in exposure and submergence of mudflats (Lakes)	Mudflat invertebrates	N/A	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	N/A	As per hydrographs (Figs 5 & 6)
В	Maintain habitable sediment conditions (Lakes)	benthic invertebrates	N/A	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)



TLM Objective (M/F/B)	Target	Biota	Optimum salinity*	Level (m AHD)	Frequency (yrs)	Annual Volume (GL)	Duration and Timing
F&B	Maintain or improve aquatic and littoral vegetation in the Lower Lakes	Freshwater aquatic vegetation	< 1,000 EC	0.35 - 0.7 0.5 - 0.8	1 in 1 1 in 3	min 650GL/yr barrage outflow#	As per hydrographs (Figs 5 & 6)
F	Maximise fish passage connectivity between the Lower Lakes and Coorong	Fish requiring both marine & freshwater habitats	N/A	>0.5 m AHD for fishway releases	1 in 1	minimum outflow of 52 GL/y fishway operation + attr flows	Fishways run for 12 months

TLM Objectives: M refers to open Murray Mouth, B refers to enhanced migratory bird habitat and F refers to more frequent estuarine fish recruitment.

*Salinity ranges: Fresh 0 – 800 EC, Brackish (Oligohaline) 800 – 8000 EC. (USGS 2011).

#A minimum barrage outflow of 650GL is dependent on larger outflows in subsequent years (averaging 2,000GL over 3 years), as described above.

Murray Mouth and Coorong overview

The Coorong requires the following minimum environmental flows (Lester et al. 2011b)

- There should be no years in which no flow passes over the barrages. The absolute minimum annual barrage flow should be between 50 and 120 GL.
- Over any two-year period, at least 600 GL should be released to the Coorong to prevent certainty of South lagoon salinity thresholds (of 117 g L-1) being exceeded.
- At least 2,500 GL over two years as a minimum target (95% of the time) to prevent the Coorong from existing in degraded states across the entire region.

Preferred flow requirements (Lester et al. 2011b)

• Flows of at least 6,000 GL/y are recommended at least every 5 years (preferably every three years) and flows of at least 10,000 GL recommended every 17 years (preferably every 7 years).

Ecosystem states modelling

The best available model for determining barrage outflow needs of the Coorong in relation to ecosystem response is 'Ecosystem states of the Coorong: An ecosystem response model' (see Lester & Fairweather 2009a for a detailed overview). This model was developed as an end-point to the CLLAMMecology Water for a Healthy Country National Research Flagship program and was integral to determining the Environmental Water Requirements for the Coorong as per Lester *et al.* (2011b). The main model assumptions are that sufficient water delivered over the barrages will prevent degraded ecosystem states in the Coorong and that a healthy ecosystem state associated with high flows should occur at least as often as it had historically. It uses modelled Coorong salinity and water levels to predict corresponding ecosystem states. The above flow requirements have been developed through the use of this model.



Murray Mouth estuary

During drought conditions, congestion at the Murray Mouth reduces the tidal signature, preventing an exchange of water between the sea and the Coorong (refer target W4). This congestion also keeps water levels unnaturally high in the lagoons: water is unable to flow back out through the mouth during the period when mudflat exposure is critical, reducing the area available for foraging waders (target B1), and retaining salty water in the Coorong (Phillips & Muller 2006). It is important to maintain a channel from the Coorong to the Murray Mouth to ensure suitable water level variability in both lagoons through tidal exchange (target M1), with the preferable method being sufficient outflows from the River Murray through the Murray Mouth (refer target W2) rather than a dredging program. An average daily outflow of 2,000 ML is required to maintain an open Murray Mouth. Mouth openness will be impacted by multi-annual (e.g. El Niño/Southern Oscillation) and seasonal climatic conditions which impact sand movements. Ongoing monitoring of the Murray Mouth will occur, and other management options (e.g. dredging) may be required if barrage flows are not sufficiently maintaining the Murray Mouth open.

Barrage outflows also allow for connectivity between Lake Alexandrina and the Murray Mouth estuary (target W3), enhancing the opportunity for recruitment in diadromous fish (target F1). In order to continuously run all barrage fishways, a total volume of 55 GL/year is required. Commercial fish species such as black bream and greenback flounder (target F4) have spawning and recruitment cues directly related to freshwater outflows through the barrages (Ye *et al.* 2010). The Goolwa cockle population (target I2), situated along the beaches of Goolwa, Sir Richard and Younghusband Peninsulas, also benefits from freshwater flows through the barrages, in the form of freshwater diatoms- a food source for Goolwa cockles (Seuront & Leterme 2009).

The North Lagoon

In the North Lagoon of the Coorong, variation in water levels is required with high levels in spring and early summer to maintain habitable sediment conditions (target M2) to support invertebrate populations (target I1) and lower water levels in mid to late summer to expose mudflats providing foraging habitat for waders (target B1). Ruppia megacarpa has not been recorded in the Coorong since the mid-1990s (Nicol 2005) and the sediment seed bank is extremely depauperate (Nicol 2007). Therefore, a transplant program is needed if this target (target V1) is to be achieved in the future. Ruppia megacarpa requires salinity below 46 parts per thousand (ppt) for adult plant survival (Brock 1982) and less than 30 ppt for seed germination (Kim et al. 2013). Hence, larger-volume barrage releases will be required for lower salinities in the North Lagoon (target W1) to ensure a self-sustaining population of Ruppia megacarpa establishes.

The South Lagoon

Water level variations are required over spring and early summer for *Ruppia tuberosa* (target V2) to reproduce successfully (Paton & Bailey 2010b) and to maintain habitable sediment conditions (M2). This water level variation provides suitable conditions for benthic invertebrates if a suitable salinity levels are also optimum (target I1) (Dittmann *et al.* 2010). Chironomid larvae are one of the main food sources for migratory waders (target B1) (Paton & Bailey 2010c) and are also dependent on suitable salinity.



In order to maintain healthy ecosystem states in the Coorong, target salinity ranges for *Ruppia tuberosa*, small-mouthed hardyhead (target F3) and chironomid larvae must be achieved. Modelling has determined that barrage outflows of 6,000 GL and 10,000 GL every three and seven years respectively are required to maintain optimum conditions (Lester *et al.* 2011b). Over any two year period, at least 600 GL should be released.

The above rules for barrage releases and Murray Mouth openness, which are required to achieve optimal Coorong water levels and salinities, can be related back to the LLCMM icon site ecological targets which are specific to the Coorong and Murray Mouth estuary. This is documented in Table 19 (below).

Combining all water requirements for the Lower Lakes, Coorong and Murray Mouth

The future aim of LLCMM icon site managers will be to achieve as many of the above-listed flow targets as possible for the Lower Lakes and Coorong, in any given year. As more environmental water is incrementally available to the icon site, more targets can be met, and a greater ecological outcome achieved.

The following is based on the above discussion, and is a summary of targets to be achieved in priority order on an annual basis, as more water becomes available to the icon site:

- Lake levels are maintained above 0 m AHD to prevent exposure of acid sulfate soils.
- Lake levels are maintained within the seasonal operating levels.
- Fishways are operated year-round.
- Attractant flows are provided adjacent to fishways, and a limited estuary achieved in Boundary Creek.
- Minimum annual flow from the barrages required to achieve salinity target of <1,000 EC in Lake Alexandrina (650 GL+).
- Minimum annual flow required to keep the Murray Mouth open (730 1,090 GL).
- Flows of at least 2,500 GL over two years to prevent the Coorong existing in a degraded ecosystem state.
- Flows of 6,000 10,000 GL in a year to achieve a healthy Coorong ecosystem state.

Note that more specific information about barrage operation is provided in Chapter 4 - Water Delivery.



Table 19: Environmental water requirements of the Murray Mouth and Coorong to achieve icon site ecological targets

TLM Objective (M/F/B)	Target	Biota	Optimum salinity (ppt)*	Preferred Annual Volume (GL)	Frequency	Duration & Timing
В	Maintain or improve bird populations in the Coorong	Waders	60 - 100 ppt South Lagoon	6,000 10,000	1 in 3 1 in 7	Refer hydrograph (Table 5)
		Fish-eating birds	60 - 100 ppt South Lagoon	6,000 10,000	1 in 3 1 in 7	Refer hydrograph (Table 5)
		Water fowl (herbivorous)	60 - 100 ppt South Lagoon	6,000 10,000	1 in 3 1 in 7	Refer hydrograph (Table 5)
M, F	Maintain or improve recruitment success of diadromous fish in the Coorong	Fish requiring both marine and freshwater habitats	fresh - marine	52 GL fishway operation (min) + attr flows	1 in 1	Year- round fishway operation
F	Provide optimum conditions to improve recruitment success of small-mouthed hardyhead in the South Lagoon	Small-mouthed hardyhead	60 - 100 ppt South Lagoon	6,000 10,000	1 in 3 1 in 7	Refer hydrograph (Table 5)
F	Maintain or improve populations of black bream, greenback flounder and mulloway in the Coorong	Black bream, greenback flounder, mulloway	fresh – marine: maintenance of a salinity gradient is the key requirement	6,000 10,000	1 in 3 1 in 7	Refer hydrograph (Table 5)
M, F, B	Maintain or improve invertebrate populations in mudflats in the Coorong	Mudflat invertebrates, waders	brackish - marine	6,000 10,000	1 in 3 1 in 7	Refer hydrograph (Table 5)
М, В	Facilitate frequent changes in exposure and submergence of mudflats in the Coorong	Mudflat invertebrates, waders	N/A	Murray Mouth open (730- 1,090 GL)	1 in 1	Diurnal tide ratios met
В	Maintain habitable sediment conditions in the Coorong	Mudflat invertebrates, waders	N/A	N/A	N/A	N/A
F	Maximise fish passage connectivity between the Lower Lakes and Coorong	Fish requiring both marine and freshwater habitats	N/A	52 GL fishway operation (min) + attr flows	1 in 1	Year- round fishway operation
F, M	Maximise fish passage connectivity between the Coorong and the sea	Fish that move between the Coorong & ocean, e.g. diadromous fish, mulloway, yelloweye mullet & greenback flounder.	N/A	Murray Mouth open (730- 1,090 GL)	1 in 1	Diurnal tide ratios met
F, B, M	Maintain or improve <i>Ruppia</i> <i>megacarpa</i> colonisation and reproduction	Ruppia megacarpa	0 - 19 ppt North Lagoon for recruitment	6,000 10,000	1 in 3 1 in 7	Refer hydrograph (Table 5)
F, B, M	Maintain or improve <i>Ruppia</i> <i>tuberosa</i> colonisation and reproduction	Ruppia tuberosa	60 - 100 ppt South Lagoon	6,000 10,000	1 in 3 1 in 7	Refer hydrograph (Table 5)
F, B, M	Establish and maintain a variable salinity regime with >30% of area below sea water salinity concentrations in estuary and North Lagoon	Ruppia megacarpa, diadromous fish, mulloway, yelloweye mullet and greenback flounder, benthic invertebrates.	< 35 ppt in 30% of area of estuary and North Lagoon	Modelling required - annual volume will vary depending on starting conditions'	Modelling required - annual volume will vary depending on starting conditions'	Modelling required - annual volume will vary depending on starting conditions'



13. APPENDIX C: MONTHLY AVERAGE, MINIMUM AND MAXIMUM VICTOR HARBOUR TIDE HEIGHTS (M AHD) USING DATA FROM 1964–2009.



Figure 11: Monthly average, minimum and maximum Victor Harbour tide heights (m AHD) using data from 1964-2009



14. APPENDIX D: DETAILS OF PAST MANAGEMENT ACTIVITIES AND ACTION IN THE LOWER LAKES, COORONG AND MURRAY MOUTH ICON SITE.

Past The Living Murray watering activities (2008–10)

Case study 1: Threatened fish refuge protection—Boggy Creek

A population of the nationally 'vulnerable' (EPBC Act 1999) and internationally 'Endangered' (IUCN Redlist: Wager 1996) native freshwater fish; Murray hardyhead (*Craterocephalus fluviatilis*), was saved from drought through the delivery of environmental water from The Living Murray. The SA Murray–Darling Basin Natural Resources Management Board and DENR successfully delivered this collaborative project.

In 2008, the Lower Lakes threatened fish condition monitoring program, carried out by the University of Adelaide, located a population of more than 500 adult Murray hardyhead in Boggy Creek on Hindmarsh Island (Figure 12), Lake Alexandrina (Wedderburn & Barnes 2009). The population was stranded as a result of drought conditions ('extreme dry' status), with receding water levels concentrating the fish in a small section of the creek. Due to the extended disconnection from Lake Alexandrina, ongoing drought and high evaporation rates, the site was in danger of completely drying out in early 2009. As part of DENR's Drought Action Plan (DEH 2010a), approximately 200 Murray hardyhead were removed and maintained in a specialised captive breeding program undertaken by the Murray–Darling Freshwater Research Centre (MDFRC) before the site dried completely in February 2009.

After successful breeding of Murray hardyhead at MDFRC during early 2009 approximately half of the fish were released back to Boggy Creek after the site received environmental water from Waterfind's Healthy Rivers Australia program.

The remaining captive-bred fish were released into a surrogate refuge site in the Eastern Mount Lofty Ranges. The site now holds a 'back-up' population from which stock can be reintroduced back into the Lower Lakes when conditions improve.

Environmental water from The Living Murray has been delivered to the site since April 2009, with associated funding for pumping costs and management. Monitoring in November 2009 detected young-of-year Murray hardyheads, and then an abundant adult cohort was sampled in March 2010. Therefore, a successful recruitment event was confirmed for the 2009–10 breeding season as a result of the watering. This signalled the success of the watering intervention, which prevented the habitat from drying, enabling the population of threatened fish to be maintained.

The watering of Boggy Creek most likely triggered a food-web response that provided zooplankton for Murray hardyhead as all fish captured in March 2010 were, visually, in very healthy condition. With the aim of informing future management options at Boggy Creek and other sites in the Murray–Darling Basin, a study comparing zooplankton emergence and fish diet at Boggy Creek with un-watered 'control' sites on nearby Mundoo Island has been undertaken to identify some of the specific factors that resulted in the successful recruitment. The study was managed by the SA Murray–Darling Basin Natural Resources Management



Board and funded through The Living Murray 'Intervention Monitoring' program and undertaken by researchers from the University of Adelaide.

A report has been produced outlining the impacts of watering on the zooplankton community and Murray hardyhead recruitment as well as a dietary analysis of Murray hardyhead compared with the introduced fish species Gambusia (*Gambusia holbrooki*) (Wedderburn *et al.* 2010).

Due to the drought, the number of wild populations of Murray hardyhead in Lake Alexandrina and Albert has dropped dramatically since spring 2008 when 14 healthy populations were recorded by The University of Adelaide and SARDI Aquatic Sciences (Wedderburn & Barnes 2009).

Since April 2010 water levels in Lake Alexandrina have continued to rise. In September 2010 the site was reconnected with the rest of the lake and the Murray hardyheads now have the chance to recolonise to other parts of Lake Alexandrina. Continued monitoring by the University of Adelaide will identify any newly established populations.



Figure 12: Murray hardyhead at Boggy Creek

Case study 2: Submerged aquatic plant seedbank protection–Narrung Wetland Narrung Wetland is a naturally ephemeral and saline fringing wetland of Lake Alexandrina. In the past, the wetland would fill over spring and summer when water levels in the lakes were surcharged for irrigation purposes. This would induce a wetting and drying cycle. As a result, the wetland was a hot-spot for native aquatic vegetation and invertebrates and also hosted a high diversity and abundance of waterbirds (SKM 2004). However, since 2007 when water levels below Lock 1 dropped significantly ('extreme dry' status), the wetland has not received water from the lake and has been completely disconnected.



Results of the Lower Lakes aquatic vegetation condition monitoring program by SARDI Aquatic Sciences in spring 2008 indicated that rainfall over spring would pool in Narrung Wetland for one-two weeks, and create a 'false start' for submerged aquatic plants (Marsland & Nicol 2009) in particular *Ruppia tuberosa*, a highly salt-tolerant species more commonly found in the Coorong. This means that aquatic plant seeds in the sediment would be cued to germinate by the presence of water. However, as the water from the rainfall would only last for a maximum of two weeks, this didn't give the germinants enough time to complete their lifecycles; to flower and set-seed and thus replenish the seedbank. Therefore, if drought conditions continued and the seedbank of the wetland continued to be reduced from sequential 'false starts', there was a danger that the wetland would completely lose its seedbank and not respond to re-filling in the future when conditions improved.

In order to protect and replenish the seedbank, 250 ML of environmental water was pumped into the wetland in spring 2009, as a result of a successful water bid to The Living Murray (Figure 13). Five to six weeks after watering, the wetland burst back into life, with fringing aquatic plants germinating and flourishing, waterfowl feeding and roosting in the wetland and migratory waders feeding on the mudflats. Many species of submerged aquatic plants, including *Ruppia tuberosa* and various charophytes, were also recorded at the wetland.

In order to determine if the watering had in fact improved the density of seeds in the seedbank, a targeted monitoring project was undertaken before, during and after the watering event. The study was managed by the SA Murray–Darling Basin Natural Resources Management Board and funded through The Living Murray 'Intervention Monitoring' program and undertaken by researchers from the University of Adelaide. Results showed that the seed density of *R. tuberosa* in Narrung Wetland was around 700 seeds/m2 in October 2009 (prior to watering), yet in March 2010 (post-watering), seed density had significantly increased to 1150 seeds/m2 (Paton & Bailey 2010a). The delivery of environmental water had therefore successfully achieved the original objectives of the project.

Monitoring at the wetland through the 2010 spring Lower Lakes aquatic vegetation condition monitoring program will assess the plant response to re-connection with Lake Alexandrina and Lake Albert. It is expected that this wetland will have a healthier aquatic plant community in comparison to other fringing lake wetlands, as a direct result of the environmental watering the previous year.





Figure 13: Environmental water being pumped into Narrung wetland

Environmental Works and Measures Program

The Environmental Enhancement of the Lower Lakes, Coorong and Murray Mouth Project commenced in 2005 and comprises a conglomeration of various smaller projects in the region such as fishways, water quality monitoring stations and various on-ground works.

Fishways for barrages

As part of the Murray–Darling Basin Authority's 'Native Fish Strategy' (MDBC 2006b), a program was undertaken to install fishways on the main channel weirs and barrages of the River Murray in order to re-instate connectivity from Lake Hume to the sea (Barrett & Mallen-Cooper 2006).

Tauwitchere Barrage is one of five barrages which separates the Lower Lakes from the Coorong and Murray Mouth and as part of the program was fitted with both a large vertical slot fishway in the centre of the barrage and a rock ramp (Figure 14) and small vertical slot fishway at the Pelican Point end of the barrage. A regulator and fishway was also installed in Hunters Creek on Hindmarsh Island to enable water efficient operation to deliver low volumes of water to the Coorong during periods of minimum flow for the best ecological outcomes, while preventing the stranding of resident freshwater fish in the Coorong or impeding the migration of diadromous fish species. The fishways were fitted between 2004 and 2009.




Figure 14: Vertical slot fishway at Tauwitchere Barrage

Fish investigations

In August 2006 a project was initiated by SARDI Aquatic Sciences to investigate the movement and recruitment ecology of freshwater and estuarine fishes in the Coorong and Lower Lakes utilising three existing barrage fishways (Goolwa vertical-slot, Tauwitchere vertical-slot and rock-ramp) as a way to assess the effectiveness of the current infrastructure for native fish passage (Figure 15) and to provide supporting information for the design and construction of new fishways.

Before these particular fish investigations there was very little information to describe the requirements of fish communities in the Coorong and Lower Lakes and in particular fish species that move between the two environments. Furthermore there was little data on the link between freshwater inflows and the spawning and recruitment of fish species in the Coorong.

The first stage of the monitoring (September 2006 – March 2007) produced substantial preliminary data on fish movement and response to freshwater flows into the Coorong. Based on this data, the report recommended that in times of limited water availability, fishway operation between August and January (as a minimum) should be viewed as a management priority.

Fishways were closed in March 2007 as drought continued within the Murray–Darling Basin and water levels in the Lower Lakes decreased. Sites below Tauwitchere Barrage sampled in 2006–07 were again sampled in 2007–08. However, with the fishways shutdown and zero flows



into the Coorong, objectives in 2007–08 were broadened to document the response of fish to unprecedented (since river regulation) drought conditions.



Figure 15: Barrage fishway monitoring being undertaken by SARDI Aquatic Sciences

The cessation of freshwater discharge and fishway operations in 2007–08 significantly reduced the abundance and diversity of freshwater and estuarine dependant species in the Coorong downstream of Tauwitchere Barrage. Of note was the decline in abundance of diadromous fishes, and increases in the abundance of marine opportunists. Elevated salinities exposed an estuarine adapted ecosystem to predominantly marine conditions and an increasingly hypersaline environment.

In 2008–09 the barrages again remained closed in response to the negative headloss across the barrages and concerns of declining water quality in the Lower Lakes. Despite these closures, Tauwitchere and Goolwa barrages were sampled to describe the fish assemblages below each barrier. Sites remained consistent (between 07–08 and 08–09) at Tauwitchere Barrage, whilst additional sites were selected for sampling at Goolwa Barrage to allow comparative analysis of the species assemblages between barrages.

Abundances of freshwater and diadromous species at Tauwitchere and Goolwa barrages were very low compared to the previous two sampling seasons. At the same time, the proportion of marine species increased and in the continued absence of freshwater inflows the estuary resembled a marine dominated tidal system. The significant decline in the abundance of diadromous fishes and most importantly continued evidence of poor recruitment of these



species was cause for concern for the long-term viability of these populations in the Lower Lakes and Coorong.

This project has generated extensive data on the ecology of fish assemblages at the freshwater/estuarine (and now marine) interface of the Coorong and Lower Lakes. A paper was produced discussing the changes in fish assemblages and recruitment of diadromous fish over the three year sampling period (Zampatti *et al.* 2009). Data has also been used to continuously inform not only barrage operation and drought response but also the location and design of future fishways, condition monitoring of the icon site and the development of future monitoring methodologies. Data collected as part of this project also contributed to the assessment of several interim ecological targets within the Lower Lakes, Coorong and Murray Mouth Environmental Management Plan (MDBC 2006a).

Data collected as part of this project has contributed to the development of the Goolwa Barrage Fishway environmental water bid.

Telemetered surface water monitoring stations

This project extended the range of the telemetered surface water monitoring systems into the estuarine reaches of the North Lagoon of the Coorong.

Eleven locations for the logging equipment were determined as part of the adaptive management program of DWLBC, from Goolwa Barrage to the South Lagoon. In addition, sites were chosen to coincide with existing ecological monitoring sites used by the CSIRO Water for a Healthy Country: CLLAMMEcology project, in order to assist with research and consistent data collection.

The extension of the system into the Coorong allows for the hydrological and physical effects of barrage decisions to be viewed as they happen in the estuarine environment. For example, following the opening of structures at Boundary Creek the system will allow the monitoring of the water levels and relative salinity as they change in the channel downstream into the Coorong.

Localised conditions have a direct effect on biota. If the system is not brackish, containing a mix of fresher water, marine species will begin to dominate; if the system is freshened too much species stimulated into reproduction can be adversely affected.

The enhanced Surface Water Monitoring System therefore demonstrates to the operators of the barrages with some precision how the hydrology, physical conditions and ultimately the estuarine ecosystem respond to management actions.

The current extent of the surface water monitoring system can be viewed on-line:-

http://data.rivermurray.sa.gov.au/

This website illustrates live lake levels, salinity readings and wind direction at various sampling points around the Lower Lakes and Coorong. Currently it is routinely used to assist with decisions on barrage operations. It readily displays the hydrological effects of wind upon Lake levels and remote awareness of seiche has many advantages for barrage decision-making.



Additional on-ground works

This project involved a prioritisation process where 15 sites identified within the LLCMM were ranked based on predicted improvements in ecological condition for 12 ecological values. A number of sites were also identified for which the proposed works would contribute significantly to ecological values of the entire CLLMM region.

Hindmarsh Island, Dunn's Lagoon, Tolderol and Milang ranked very highly and this lead to the development of management and operational plans. Within each plan recommendations were made for on-ground works which would contribute to improving the overall health of the wetland. The following recommendations have been implemented with these high priority wetlands:

- A stormwater capture and release system was installed in Milang Wetland in order to increase the amount of stormwater run-off the wetland receives. This will promote habitat for the threatened migratory species Latham's Snipe (*Gallinago hardwickii*). As well as providing a source of water to the wetland while it is disconnected from Lake Alexandrina, the storm water run-off which is serviced by a gross pollutant trap will increase the area of wetland which receives water.
 - The Dunn's Lagoon management plan identified the need to preserve the seed bank of aquatic vegetation communities during the drought. In order to achieve this, blocking banks would need to be constructed across the lagoon inlets. Before carrying out large-scale works seed bank trails were set up to determine if there would be a positive response from the soil seed bank if artificial inundation through pumping were to be implemented.

The trials were conducted by SARDI Aquatic Sciences (Figure 16). Soil samples were collected and submerged in fresh (control), 6,400 (Lake Alexandrina) and 11,000 (Goolwa Channel) EC water. Conductivity and depth measurements were undertaken at least twice a week and germination counts every fortnight.

Based on the results of the seed bank trials, the recommendation of installing blocking banks across the inlet of Dunn's Lagoon in order to artificially inundate the wetland via pumping was withdrawn. Current lake levels have risen and the wetland has reconnected with Lake Alexandrina, resulting in natural inundation of the wetland.





Figure 16: Seed bank trials comparing sediment from Dunn's Lagoon and Shadows Lagoon

- Works on Hindmarsh Island were recommended in order to provide estuarine conditions and fish connectivity. This was achieved though the upgrade of a structure to facilitate greater connectivity. Once complete the structure will incorporate stop logs and a fish grate.
- Priority on-ground works identified in the Tolderol management plan include the upgrade of pipe culverts, the dredging of the main water access channel, an upgrade of regulating structures (i.e. stop logs and sluice gates). Designs have been developed for a structure and the channel has been cleared to allow for reconnection with Lake Alexandrina.
- Designs have also been developed for a culvert which will allow Loveday Bay Wetland to be reconnected with Lake Alexandrina. A causeway, built across the inlet channel prevents water flowing through from the lake and the pipes currently under the causeway are too high to allow a connection at pool level. The structure designs propose a seven opening box culvert with stop logs on the lake side to allow management of the wetland.

Department for Environment and Natural Resources— emergency actions (2008–10)

As part of the DENR's Murray Futures Long-term Plan, several remediation measures were carried out within the icon site during the drought. These measures were designed to reduce



the impacts of continued low or non-existent flows and to prevent continued ecological degradation.

Acid sulfate soil remediation

The primary threat during the drought condition within the Lower Lakes was the presence and potential for exposure of acid sulfate soils as a result of declining water levels. A series of emergency measures were put in place to prevent, mitigate and control soil acidification including:

- the Goolwa Channel Water Level Management Project which included the installation of temporary flow regulators at Clayton Bay, and Currency Creek in order to retain fresh water, maintain soil saturation and prevent further soil and water acidification
- limestone application in Boggy Lake, Currency Creek, Finniss River and the Goolwa Channel to mitigate acidity released from acidification
- construction of a bund at the Narrung Narrows between Lake Alexandrina and Lake Albert to allow the Lakes to be managed independently of each other. Pumping was undertaken to maintain water levels in Lake Albert above the predicted acidification trigger point

Bioremediation and revegetation

Several thousand hectares of exposed lakebed sediments were aerial, machine and hand seeded in order to stabilize soils and prevent soil erosion. In addition to addressing soil erosion, the seeding was part of a trial to understand how plants grow in acid sulfate soils and to assess whether the techniques used mitigates acid sulfate soils by promoting bioremediation.

Fish conservation

The threat of local extinction of threatened fish species from the Lower Lakes has led to specific conservation measures. Yarra pygmy perch (*Nannoperca obscura*) are also being bred in captivity at Cleland Wildlife Park. Environmental water was delivered to Boggy Creek on Hindmarsh Island to conserve a population of Murray hardyhead (*Craterocephalus fluviatilis*), while a captive breeding population was also established. Environmental water has also been delivered to Turvey's Drain near Milang, to conserve southern pygmy perch (*Nannoperca australis*) and Murray hardyhead. Extensive ex-situ conservation measures have also been undertaken by releasing and breeding native fish within spring fed dams within the catchments near the CLLMM region. These populations will then be translocated back to the CLLMM when suitable conditions have re-established.

Goolwa Barrage boat lock intervention for congolli conservation

Monitoring of diadromous fish populations (including congolli), common Galaxias (*Galaxias maculatus*), lampreys (*Geotria australis* & *Mordacia mordax*) and short-finned eels (*Anguilla australis*)) in the Lower Lakes and Coorong estuary through The Living Murray program over the last four years by SARDI Aquatic Sciences has detected catastrophic declines in populations and recruitment due to a lack of flows over the barrages and a loss of connectivity between Lake Alexandrina and the Murray Mouth/Coorong region (Jennings *et al.* 2009).

Prior to the drought, the last barrage fishway releases occurred in 2006–07. As congolli only live for only 4-5 years, there was a real concern that this species would be lost from the



Murray–Darling Basin, as the lack of connectivity between freshwater and marine environments prevented recruitment of the species. Acoustic tagging of adult females in Lake Alexandrina and specifically the Goolwa weir-pool detected fish travelling large distances over winter between barrages trying to find a passage out of the lake and into the Coorong and ocean environments to breed.

As a result of the alarming data collected through the barrage fish assemblage monitoring program and congolli tagging and tracking, a water bid to operate the Goolwa barrage vertical slot fishway was submitted to TLM for 5.5 GL to be split between winter and summer 2010–11 by Department for Water. While the bid was ultimately approved, water levels on the freshwater side of Goolwa barrage in winter 2010 (critical migration time for adult females) were still too low to operate the fishway, therefore fresh and estuarine environments were still separated.

In a joint State government agency initiative led by DENR, the boat-lock at Goolwa Barrage was then utilised in a successful trial to provide passage for fish. The trial took place in August 2010; when the upstream gate was partially opened, nearly 800 adult congolli and various other species of fish swam into the lock. After the water equalised, the downstream gate was partially opened, allowing the adult female congolli to exit into the estuarine environment. SARDI Aquatic Sciences trapped and released around 1,700 adult females utilising the lock during the trial, indicating the boat lock was an effective method of providing fish passage during periods of low lake levels (Figure 17).

Conditions in spring 2010 allowed for all fishways to be operational since the 14 September 2010. Monitoring by SARDI Aquatic Sciences has determined juvenile congolli and common galaxias utilising fishways (in particular Hunters Creek) to gain access into Lake Alexandrina. This indicates that spawning and recruitment has occurred in the estuary, and that this is likely due to the Goolwa lock intervention (B. Zampatti, personal communication, 31 January 2011).



Figure 17: Adult female congolli monitored by SARDI Aquatic Sciences in the Goolwa boat lock intervention



15. Appendix E: Details of management activities in the Lower Lakes, Coorong and Murray Mouth icon site under different water availability scenarios.

Scenario 'extreme dry': assumes Lower Lakes water levels maintained at ≥ 0.0 m AHD with infrequent barrage outflows.

During 'extreme dry' conditions, when lake levels are low, key habitat for threatened freshwater fish in fringing wetlands and channels becomes disconnected. A loss of connectivity at these sites leads to water quality impacts, declining habitat, the threat of total desiccation and isolation of genetic units. As such, remnant refuge sites for key threatened species will be prioritised for the delivery of environmental water. A prioritisation matrix such as that outlined in Department of Environment and Heritage (2010a) will be used. This matrix will compare data collected through The Living Murray small bodied threatened fish condition monitoring and the DENR Drought Action Plan monitoring programs in the Lower Lakes to assess where threatened fish populations remain and which are most critical for protection through interventions such as the delivery of environmental water.

Criteria for prioritisation of refuge sites (DEH 2010a) includes:

- current and predicted water levels and quality
- current and predicted habitat condition
- ability to mitigate threatening processes
- fish species present and their conservation status
- genetic uniqueness of threatened fish population within particular region
- costs required / volume required / community support for the project.

Small annual volumes are likely to be needed (i.e. <100 ML per site per year), but costs associated with water delivery are likely to be high, due to the long distances needed to be pumped to access water. Water needs to be delivered in small volumes on several occasions over the year, to maintain levels during the periods of highest evaporative losses.

Associated actions to do with water delivery to priority refuge during the 'extreme dry' scenario may include:

- site set-up at new refuge areas, including the installation of blocking banks, piping infrastructure and gauge boards
- more frequent monitoring (i.e. weekly) of water quality parameters at watered refuge sites
- targeted ecological intervention monitoring to assess if project objectives are being achieved
- organised rescue of threatened fish species at sites where intervention is not possible, as per Hammer *et al.* (2009)
- captive breeding programs for threatened fish protection for future re-stocking, as per Hammer *et al.* (2009).

During 'extreme dry' conditions, many fringing Lower Lakes wetlands will be disconnected and key wetland habitats will dry out. Along with protecting fish refuge sites, priorities for the delivery of environmental water will also include key fringing wetlands that support diverse aquatic vegetation and water bird communities. By delivering environmental water to key



fringing wetlands and maintaining water levels for a period of 3–4 months over spring/summer, the seed/egg bank of the wetland will be stimulated to germinate/hatch, and provide aquatic plants and invertebrates for the use of aquatic species such as waterbirds and frogs. In order to prioritise which fringing Lower Lakes wetlands will receive environmental water, a number of criteria will be used to create a short-list. These include:

- the ability of the site to retain water
- whether the wetland has previously been a known hot-spot for submerged aquatic plants or waterbirds (i.e. from River Murray Wetlands Baseline Survey Project (SKM 2004; 2006) or past condition monitoring programs)
- community/landholder support for the project
- whether the wetland is within 1 km of lake water of depth ≥0.5 m (i.e. water is able to be pumped into the site).

Note that this prioritisation exercise has already been completed for the Lower Lakes fringing wetlands during the 2010–11 water bid.

Small volumes are likely to be needed for these activities, i.e. in the range of 200 – 500 ML/year per site. Water delivery will involve an initial fill-volume, and then a subsequent 'top-up' volume to compensate for evaporation and seepage; therefore at least two pumping events are required.

Associated actions with water delivery to key wetland habitats during the 'extreme dry' scenario may include:

- · minor earthworks such as bank construction to ensure wetlands retain water
- installation of a gauge board to monitor water depth
- targeted protection of submerged aquatic plants from waterbird grazing (if necessary)
- more frequent monitoring (i.e. weekly) of surface water level and quality
- targeted ecological intervention monitoring to assess if project objectives are being met.

In addition to small volumes for priority drought refuges and protecting key wetland habitats, small volumes should also be released through the barrage fishways for up to two months to enable a connection with the Lakes and Coorong. This can only be achieved if Lake Alexandrina is ≥0.5 m AHD, above Coorong water levels. Operating the fishways during the periods key to life stages of diadromous fish such as congolli and common galaxias will enable connectivity and the movement between the Lower Lakes and Coorong, and vice versa for recruitment, habitat selection and feeding. By opening the fishway in July/August, adult female congolli will migrate downstream to spawn. Opening the fishway again in December/January will allow recruits from the winter spawning cycle to move into the lakes to complete their lifecycle. Limited operation of fishways not only provides benefits to fish, but also creates localised estuarine conditions which are critical for sustaining a range of biota in the Coorong.

If the barrage fishways are unable to be used due to lake levels remaining <0.5 m AHD during the year, the Goolwa boat lock may be used as an alternative to allow fish passage between Lake Alexandrina and the estuary.

Environmental water may also be requested to maintain lake levels at >0.0 m AHD (if required), a critical threshold for maintaining connectivity between Lakes Alexandrina and Albert, and for preventing acidification.



Scenario 'Dry': assumes Lower Lakes water levels >0.35 m AHD with minor barrage outflows.

During dry conditions, there will be re-connection of fringing Lower Lakes wetlands (if the preceding year was in the 'extreme dry' category). Any earthworks installed through pumping and water delivery projects during the 'extreme dry' scenario that are preventing wetlands from natural re-connection will need to be removed.

The fishways at Tauwitchere Barrage (small vertical slot, large vertical slot, rock-ramp), Goolwa Barrage (vertical slot) and Hunters Creek (vertical slot) will be opened to allow releases through the fishways for a minimum of 6 months between August— February. This corresponds to a volume of around 30,000 ML/year for fishways alone. Attractant flows (i.e. prioritised at Tauwitchere and Goolwa barrages adjacent to a fishway) will be instated to direct fish to the fishways at Tauwitchere and Goolwa barrages.

Additionally, small releases through the Boundary Creek Barrage will be opened as a last priority if water is available to create additional estuarine conditions within the creek for invertebrate and aquatic plant responses. Releases through the Goolwa, Tauwitchere and Boundary Creek barrages should be calculated to maintain water and salinity levels within the Coorong to promote the growth and reproduction of *Ruppia tuberosa*. Larger volumes for direct delivery to the Lower Lakes and Coorong will be sought from Environmental Water Holders to maintain lake levels above 0.35 m AHD and to maintain salinity levels in the Lakes and Coorong. A target minimum annual barrage release of 650 GL is the preferred volume for this scenario, a minimum requirement to maintain target Lake Alexandrina salinity levels.

If water levels below Lock 1 remain low during this scenario, it may be necessary to continue pumping to maintain refuge habitats, as described in the 'extreme dry' scenario. Larger volumes of environmental water delivered to the site however should negate this need.

Scenario 'median': assumes entitlement flows + Additional Dilution Flow, with lake levels > 0.35 m AHD.

The 'median' water availability scenario assumes South Australia is receiving at least entitlement flows across the border (i.e. 1,850 GL/year), Additional Dilution Flow and potentially unregulated flow. This corresponds to a lake level of >0.35 m AHD, with all fringing wetlands inundated, and barrage outflows of more than 650 GL/year. All previously-managed threatened fish and fringing wetland sites have reconnected and pumping is no-longer required, and the threatened species that they hosted are now free to recolonise to other parts of the lower lakes.

Fishways should be operated year round to provide connection with the lakes and Coorong. Additionally, median flows through Boundary Creek barrage will be maintained to create estuarine conditions within the creek for invertebrate and aquatic plant outcomes.

Large volumes of environmental water will be requested from Commonwealth water-holders to enhance the small releases already possible under entitlement, Additional Dilution Flows (and potentially unregulated flow) conditions, especially during spring and summer. Larger volumes will enhance and prolong estuarine conditions in the Murray Mouth and North Lagoon regions. Larger volumes will also help to maintain an open Murray Mouth. The following table describes the priority order of operation as available outflows increase (DFW 2010) (Table 20).

	Barrage/ fishways	No. of bays	Timing													
Action													Daily Outflow (ML/day)	Total Outflow (ML)		
															N/A	N/A
			Sep	Oct	Νον	Dec	Jan	Feb	Mar	Apr	May	ηυ	٦n	Aug		
1	Goolwa vertical slot fishway	1 x fishway	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	50	18,250
2	Tauwitchere vertical slot fishways	2 x fishways	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	32	11,680
3	Hunter's Creek fishway	1 x fishway	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10	3,650
4	Tauwitchere rock ramp fishway	1 x fishway	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	50	18,250
									_		_	٦	fotal Vo	lume (M	L) of Actions 1-4:	51,830
5	Goolwa	1 x bay (adjacent to fishway)	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	300	45,300
6	Tauwitchere	2 x bays (adjacent to fish ways)	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	600	90,600
7	Boundary Creek	1 x bay	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	300	45,300
Т									Total Volume (ML) Actions 5-7:					181,200		
								Total Volume (ML) Actions 1-7:						233,030		

Table 20: Priority barrage releases under increasing water availability



Scenario 'wet': assumes South Australia entitlement flow + Additional Dilution Flow with lake levels >0.5 m AHD.

The 'wet' water availability scenario assumes South Australia is receiving entitlement flows across the border (i.e. 1,850 GL/yr), plus Additional Dilution Flow and unregulated flows. This corresponds to a lake level of >0.5 m AHD, and a '1 in 3 year lake level operating regime' (refer to Figure 10) with all fringing Lower Lakes wetlands inundated. The major difference to the 'median' scenario is the addition of considerable unregulated flows on top of entitlement flows, which allows for sustained lake levels over summer and large volumes of water released through the barrages (>1,000 GL/yr). While also having the ability to provide extra 'attractant flows' to guide fish to the barrage fishways, large release volumes also provide the opportunity to export salt from the Lower Lakes, and can provide extended estuarine conditions into the Coorong and Murray Mouth region.

Targeted releases should be underpinned by the following principles (DFW 2010):

- a flexible, adaptive and consultative response to actual impacts of specific decisions
- as per the 'Median' water availability scenario, all fishways to be opened year-round
- releases to be informed by both real-time monitoring and observation and previous monitoring outputs, with direction from the barrage operations committee
- slower releases initially to ensure the ecological system adjacent to the barrages is not 'shocked'
- release of 'trickle flows' for longer periods, which are likely to be more beneficial ecologically that larger flows for shorter periods
- the release hydrograph should ideally mimic the natural hydrograph to the best extent possible
- potential impacts on mouth openness should be considered keeping in mind the 'rule of thumb' that releases should be split in a ratio of around one to two (1:2) between Tauwitchere and Goolwa barrages
- when operating the barrages to draw salt out of the Coorong South Lagoon, large outflows should be directed through Tauwitchere Barrage to push freshwater into the Coorong, followed by a recession of outflows with a corresponding drop in Coorong levels. Barrage outflows during flow recession should be targeted through Goolwa barrage, to assist receding water from the Coorong to be drawn into the estuary, and to maintain an open Murray Mouth.

After it has been ascertained that fishways can remain open for a year, and additional flows are available for release, the following staged approach described in Table 21 should be followed. This process allows for a gradual ramping up and down of barrage release volumes consistent with the shape of the hydrograph, and will need to be further developed as confidence increases regarding timing of inflows and release volumes. Additional barrage bays should be opened adjacent to fishways, so that fish can follow the plume of water and be attracted towards the fishway entrance. However, under relatively high volumes of outflow, the Murray Mouth estuary region is often 'saturated' with fresh water, i.e. there is very little head difference



between the fresh and estuarine sides of the barrages. Under these conditions it is assumed that most species of fish can pass through barrage bays with relative ease, and hence aren't reliant on using the barrage fishways (B. Zampatti, pers. comm., 31 January 2011). The fishways are most effective under lower release conditions.

Large volumes of environmental water sourced from Commonwealth water-holders during 'wet' water scenarios are still extremely beneficial to the ecology of the system. Additional flows are critical to maintaining salinities in the Coorong South Lagoon below 100 ppt, the threshold for the small-mouthed hardyhead, a current keystone species (Aldridge *et al.* 2008). Recent modelling (Lester *et al.* 2011a) has determined that large volumes in any one year not only have an immediate benefit to salinities during that year, but also in future years. The optimal flow scenarios of 6,000 GL once in every three years and 10,000 GL once in every seven years will be typified by a 'wet' scenario.

The high flows experienced in 2010–11 have resulted in a rapid change of conditions coming out of the drought, and a sudden change to very high water levels in both the Lower Lakes and Coorong. A significant drop in wader numbers, even in the context of the declines in the last five years, has been recorded in the summer of 2010–11 (D. Paton, pers. comm., 28 March 2011), likely due to the saturation of the Coorong and inundation of mudflat habitat. Under a wet scenario, mudflat habitat may be created in managed fringing wetlands of the Lower Lakes (i.e. those wetlands with flow regulators) to drop water levels and temporarily expose mudflats for waders. However, very few fringing lakes wetlands are fitted with flow regulators (see Table 10: Description of managed fringing wetlands of Lakes Alexandrina and Albert) and many require upgrades and maintenance.

Priority	Structure	Fish	First Step Ecological Objective
1	Adjacent bays (2) next to Goolwa vertical slot fishway	Extra flow adjacent to fishway will attract a greater number of fish from downstream	FR, OM, BH
2	Adjacent bays (2) next to Tauwitchere Rock Ramp and Large Vertical Slot	Extra flow will attract a greater number of fish from downstream	FR, OM, BH
3	Boundary Creek flows 1 bay	Open barrage gates may provide passage for larger fish species	FR, OM, BH
4	Mundoo Barrage flows 1 bay	Large bodied fish may be able to find passage through barrage bay.	FR, OM, BH
5	Ewe Island Barrage flows 1 bay	Large bodied fish may be able to find passage through barrage bay.	FR, OM, BH
6	Goolwa Barrage flows (2-8 bays)	Large bodied fish may be able to find passage through barrage bay. Attractant flow towards fishway.	FR, OM, BH
7	Tauwitchere Barrage flows (2-6 bays)	Large bodied fish may be able to find passage through barrage bay. Attractant flow towards fishway.	FR, OM, BH

Table 21: Priority list of larger barrage releases, likely impacts for fish and all ecological benefits, following all fishways being opened

Priority	Structure	Fish	First Step Ecological Objective
8	Boundary Creek (all gates open)	Large bodied fish may be able to find passage through barrage bay. Attractant flow towards fishway.	FR, OM
9	Progressively open Goolwa, Tauwitchere and Ewe Island Barrages – split flow releases depending on management objective	Large bodied fish may be able to find passage through barrage bay. Attractant flow toward fishway.	FR, OM
10	Mundoo Barrage (all gates open)	Large bodied fish may be able to find passage through barrage bay.	FR, OM



16. APPENDIX F: EXAMPLE OF ONE INTERVENTION MONITORING PROJECT UNDERTAKEN IN THE LOWER LAKES, COORONG AND MURRAY MOUTH ICON SITE

The following is a short case study detailing the results of one such intervention monitoring project; 'Food web study of zooplankton and fish, in relation to environmental watering in wetlands of the Lower Lakes', undertaken by the University of Adelaide in 2009–10 (Wedderburn *et al.* 2010). This project was one of the first intervention monitoring studies which was shaped by the development of the 'bundled hypotheses' project. Specific hypotheses relating to food-webs which were developed by this process, and are answered through the study, include:

Hypothesis 1

Flood-induced increases in diversity and abundance of zooplankton (emergence, immigration, reproduction) promotes recruitment in some fish species on the floodplain.

Hypothesis 2

Shifts in zooplankton composition from small (rotifer-dominant) to large (microcrustaceandominant) species are positively correlated with ontogenetic dietary shifts in fishes.

Hypothesis 3

Floodplain recruitment in native fish species is impacted by alien fish species due to competition for prey items during developmental life stages.

Case study: assessing ecological benefits of environmental watering for threatened fish at the Lower Lakes

The MDBA provided funding to the South Australian Murray–Darling Basin Natural Resources Management Board towards research into the effects of using an environmental water allocation in the few remaining wetland habitats at the Lower Lakes. Dr Scotte Wedderburn, Dr Russell Shiel, A/ Professor Justin Brooks and Karl Hillyard from The University of Adelaide's Water Research Centre sampled water quality, zooplankton and fish at Boggy Creek (watered site) and Mundoo Island (control sites) from November 2009 to March 2010.

Boggy Creek was sampled before and after environmental water allocations of several megalitres in early December 2009 and early February 2010. Murray hardyhead had begun breeding prior to the first watering, but zooplankton abundance was low and hence food supply was thought to limit growth and survivorship of the young fish over summer. Beneficially, the first watering event triggered a bloom in zooplankton (mostly the rotifer (*Brachionus plicatilis*) and its eggs (Figure 18)) that provided an abundance of food for young Murray hardyhead. Subsequently, the young developed strongly over summer, and by March 2010 the species had successfully recruited and the new adult population was secure.

The allocation of scarce environmental water should include targeting unique habitats in the Murray–Darling Basin and the threatened species they often hold. The maintenance of threatened fish populations in the few remaining wetland habitats at the Lower Lakes during the



2006-10 drought is paramount, so that these species re-establish in off-channel habitats when they re-fill. In understanding the ecological dynamics, successful management techniques for environmental watering can be applied.



Figure 18: Brachionus plicatilis with eggs (Left), Zooplankton sampling (Right).



17. APPENDIX G: DETAILS OF OTHER ECOLOGICAL MONITORING BEING UNDERTAKEN IN THE LLCMM ICON SITE.

Southern bell frog monitoring

As of 2011, The South Australia Murray–Darling Basin Natural Resources Management Board have undertaken two annual Southern bell frog censuses of Lakes Alexandrina and Albert. Previously managed by The Living Murray icon site team and funded through the State Drought Fund, the project is now managed and funded by DENR as a part of the Long Term Plan monitoring program. Refer to Figure 19 for maps of known locations in 2009–10 and 2010–11. The location of southern bell frog hot-spots may be important in the future when prioritising key refuge sites for the delivery of environmental water.

Community wetland monitoring

The SA Murray–Darling Basin Natural Resources Management Board, in conjunction with the Goolwa to Wellington Local Action Planning group and Coorong–Tatiara Local Action Planning Association, have implemented a long-term (since 2003) community wetland monitoring program at several priority Lower Lakes wetlands. Photopoints, groundwater, surface water quality and level, fish, frogs and assistance with the lakes aquatic vegetation condition monitoring program are all undertaken. Priority wetlands include Narrung, Teringie, Waltowa, Loveday Bay, Dunns Lagoon, Hunters Creek/Boggy Creek system, Milang and Tolderol. The Living Murray program, through EWMP, has assisted with the management process for some of these priority wetlands by funding the development of several wetland management plans, and the design and installation of key flow control structures. In turn, the SA Murray–Darling Basin Natural Resources Management Board provide support to The Living Murray team by collecting valuable and frequent data on water quality and level, photopoints and frogs, at environmental watering sites in the Lower Lakes. As such, both programs are complimentary to the other, and have lead to more effective management of key Lower Lakes wetland sites.

Drought Action Plan threatened fish monitoring

The Protecting Critical Environmental Assets Program – Critical Fish Habitat and Refuge project is a recurring activity now in its fourth year of operation. Five species were identified as having undergone significant declines and thus a high priority for protection; Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), Yarra pygmy perch (*Nannoperca obscura*), river blackfish (*Gadopsis marmoratus*) and southern purple-spotted gudgeon (*Mogurnda adspersa*). This project covers 26 sites across the SA Murray–Darling Basin including 17 within the CLLMM Ramsar Boundary.

In response to extreme reductions in abundances and distribution of all of the five listed fish species, urgent action was undertaken in South Australia lead by the Department for Environment and Natural Resources (DENR) and included the support of a consortium of both Government and non-Government organisations collaborating to ensure the survival of these five targeted critically endangered freshwater native fish.







Figure 19: Southern Bell Frog distribution in the Lower Lakes in summer (a) 2009 and (b) 2010, based on call recognition, call playback and spotlighting



During 2007 a 'Rescue to Recovery' plan was implemented which targeted the conservation of these fish species and their habitats. Emergency intervention included; intensive monitoring, critical environmental watering, and as a last resort, rescue. Rescued fish were placed into a specialised captive breeding program as a back-up measure for wild stocks. The Drought Action Plan worked in alignment with The Living Murray Condition Monitoring program and intervention monitoring programs relating to threatened fish in the Lower Lakes, to assess the ecological response to types of interventions or environmental management actions at the CLLMM icon site. The Living Murray program also provided the foundation information for adopting an adaptive-management approach.

Recovery of these populations has been made possible by the success of specialised breeding programs and intensive monitoring coupled with an adaptive management approach. Juvenile river blackfish, Yarra pygmy perch, Murray hardyhead and southern purple-spotted gudgeon have been effectively reared in captivity with numerous juveniles being released into surrogate refuge sites which provide a stepping stone between captive breeding and wild reintroductions.

The surrogate site method was adopted when juvenile fish were successfully being produced through various captive breeding programs yet their wild habitats were still in critically poor condition.

Restoration of this species and other endangered native fish species is the long-term vision for the South Australian Murray–Darling Basin Natural Resources Management and Coorong Lower Lakes and Murray Mouth Long-term Plans and an adaptive management framework is being adopted to reach the best possible outcomes for reintroducing these important components of South Australia's freshwater ecosystem.

Ramsar habitat mapping

Given the international importance of the Lower Lakes wetland system, a habitat condition study was commissioned in February 2010 to document the impact of the drought. A stratified repeated measures study design was used to compare the 2010 condition of the Lower Lakes wetlands to a baseline condition assessment of the same wetlands that was undertaken in 2003 (Seaman 2003).

The objective of this study was to assess the impact of drought on wetland condition within the Lower Lakes area. The project also assessed the relative benefit of intervention management strategies by comparing managed versus non-managed wetlands.

The study found that intervention management techniques that were applied preserved wetlands but those sites that were not managed suffered a decline in condition and in some cases a change in vegetation community. A clear example of a management intervention that contributed to habitat condition being maintained is Turvey's Drain, located near Milang at Lake Alexandrina. Turvey's Drain has a reed bed (Typha sp.) vegetation association which was managed as a fish refuge during the drought and due to the artificial watering that this drain received throughout the drought the condition of the wetland habitat was preserved, whereas a similar wetland habitat in Tolderol Reserve that had the same Ramsar classification received no artificial watering and consequently the wetland dried out and the vegetation community changed from a reed bed (Typha sp.) to a terrestrial habitat dominated by introduced grasses and samphire. This example illustrates changes that occur in condition and communities when water levels are reduced in the Lower Lakes.



Similarly, Narrung Wetland received artificial watering via pumping from Lake Alexandrina whilst under the management of the Narrung Wetland Management Plan (Bjornsson 2006). The Coorong–Tatiara Local Action Plan and the SA Murray–Darling Basin Natural Resources Management Board managing Narrung Wetland were concerned about the potential loss of the seed bank through rainfall germination and prolonged drought conditions. Seed banks play an essential role in the persistence of wetland plant species during adverse conditions such as drought, therefore ensuring the seed bank remained viable was an immediate management action necessary to maintain a resilient wetland. Hence, given that the duration of the drought period was unknown, the Coorong–Tatiara Local Action Plan and the SA Murray–Darling Basin Natural Resources Management board chose to proactively manage Narrung Wetland to ensure the seed bank was not lost. The strategy they applied included fencing the wetland, obtaining an environmental water allocation to deliver environmental water to the main wetland basin via pumping water from Lake Alexandrina and implementing a revegetation program. When assessing the site, revegetation and environmental water added diversity and structure and a viable seed bank, thus the site was assessed to be in good condition compared to its 2003 degraded condition. Hence, this case study exemplifies the benefits of management interventions in protecting wetland systems.

Acid sulfate soil and water quality monitoring

Soil monitoring

Acid sulfate soil monitoring was carried out by CSIRO on behalf of the SA Murray–Darling Basin Natural Resources Management Board in 2009–10 to investigate representative environments in Lakes Alexandrina and Albert and assess the implications of lowering and rising water levels in the Lower Lakes in relation to the development of acid sulfate soils.

Following on from this 2009/10 monitoring, CSIRO has continued acid sulfate soil monitoring of the Lower Lakes as part of DENR's Murray Futures Program. This will be effective for understanding how soils change over time and the hazard they pose to ecosystems and human health. The surveys can assist in highlighting high-risk or hotspot areas, and will inform the need for, and effectiveness of, management actions (e.g. limestoning) necessary to mitigate acidification risks.

Monitoring locations include Currency Creek, Finniss River, Narrung, Waltowa, Loveday Bay, Dunns Lagoon, Boggy Creek system and Tolderol.

Community acid sulfate soil monitoring

In 2009–10 a community acid sulfate soils monitoring program occurred due to community concern about the ecological, economic and recreational impacts of the degradation of the Lower Lakes. The program coordinated by the Lakes' Remediation Project Officer is the recruitment of community volunteers to monitor acid sulfate soil changes along the lakes' shoreline. The volunteers are using an Acid Sulfate Soil Field Guide specifically adapted by CSIRO Land and Water for easy use. The field guide outlines a systematic protocol for sampling site selection, sampling methodology, soil description and field testing (pH and electrical conductivity (EC)).



Water quality monitoring

The Lower Lakes region monitoring program includes continuation of ambient water quality monitoring within the Lower Lakes region and event-based monitoring covering:

- a. response monitoring associated with known hotspot areas including:
 - the Goolwa Channel Water Level Management Project
 - the Lake Albert Water Level Management Project
 - lake margins around in Lake Alexandrina such as Boggy Lake, Loveday Bay, Salt Lagoon, Dunns Lagoon and creeks on Hindmarsh Island
- b. groundwater (sediment porewater) monitoring using piezometers within Lakes Albert and Alexandrina and the tributaries to help assess the risks of acidic groundwater reaching the lakes
- c. benthic ecological monitoring in relation to acid sulfate soils to assess impacts and recovery.

The overall objectives are to use the monitoring data to make informed management decisions by:

- providing early warning of changes to water quality and ecology in the Lower Lakes that indicate imminent acidification
- validating hydrodynamic and alkalinity trigger prediction models and more accurately predict changes that occur as the result of low flows, low lake levels and acid sulfate soil re-wetting (via rainfall or inflows)
- assessing the impacts of low inflows, changes in lake levels and acid sulfate soils on the ecological communities in the region
- examining the effectiveness, or any adverse impacts, of implemented management actions over time.

Bioremediation study

This study is led by Southern Cross University as part of the Murray Futures Program. The aim is to measure the impact of carbon additions through the lake stabilisation program in facilitating sulfate reduction.

Goolwa Channel Water Level Management Project

An extended period of low inflows from the River Murray negatively impacted the ecological condition of the Coorong and Lower Lakes (CLLMM) region. As part of the CLLMM region, the Goolwa Channel and its associated tributaries (Finniss River and Currency Creek) experienced significant declines in water levels, exposing vast areas of sulfidic sediments. When exposed to air, sulfidic sediments can produce acid sulfate soils which can release acidity in the form of sulfuric acid as well as toxic quantities of iron, aluminium and other metals into the water column.



In order to mitigate the risk of acidification, the Australian Government through a Ministerial Council decision constructed a temporary earthen regulator in the Goolwa Channel as a part of the Goolwa Channel Water Level Management Project. This regulator allowed the inundation of acid sulphate sediments in Currency Creek, Finniss River and the Goolwa Channel west of Clayton. Inundation of the sediments with freshwater prevents exposure and prevents acidification of the aquatic environments.

Year 1 of the Goolwa Channel Water Level Management Project monitored the response of water quality, phytoplankton, zooplankton, macroinvertebrates, vegetation, fish and birds to the construction of the Clayton regulator in August and September 2009, the subsequent rise in water levels and the changing environmental conditions within the Goolwa Channel. A final synthesis report on this first year of monitoring is now available.

A Goolwa Channel Water Level Management Project ecological monitoring review workshop was held in July 2010 and its recommendations were used to design the ecological monitoring activities for year 2. As the Clayton regulator was breached in September 2010 as a result of greater than expected inflows, the objectives of year 2 ecological monitoring are different to that of year 1, instead monitoring the response of biota to the breach and subsequent reconnection to Lake Alexandria and the change in environmental conditions within the Goolwa Channel. Southern bell frogs were added to the biota being monitored.

Barrage release monitoring

As a result of greater than expected rainfall and inflows into the CLLMM region in winter and spring 2010, the first barrage flows since 2006/2007 began on 4 September 2010. A joint monitoring process between DENR and Department for water has led to the biotic response to these flows being monitored in the Murray Mouth and Coorong regions from November 2010. Biota, parameters and processes being monitored include water quality, nutrients, phytoplankton, zooplankton, fish, birds, macroinvertebrates, recruitment and connectivity.

Department of Environment and Natural Resources Long-term Plan adaptive management and monitoring

Adaptive management

Coorong, Lower Lakes and Murray Mouth Projects are developing a structured adaptive management process through which the proposed goals, objectives and management actions of the CLLMM Long-term Plan can be implemented through all future scenarios.

Adaptive management uses both existing and developing knowledge and understanding to assist with identifying what can be done to address issues or threats affecting the site, how proposed management action(s) might achieve this, and why. This is then documented and forms a management plan or roadmap. By utilising the learnings from an effective and well-planned monitoring framework, input from community and scientific reference groups and targeted research to fill key knowledge gaps, future decisions for the site will be improved as the information upon which decisions are based is improved, resulting in the best possible outcomes for the site.



Adaptive monitoring

A whole-of-site Ecological Monitoring Framework and Plan will be expanded on and developed in order to: quantitatively assess changes in ecological character; assess the impact of management actions on biota and processes; and assess whether management actions are achieving their targets and objectives. The vision of this work is to develop a whole-of-site ecological monitoring framework and plan for the Coorong, Lower Lakes and Murray Mouth region for 2010–15 that integrates existing agency and community monitoring, in particular The Living Murray Condition Monitoring program, to document any ecological changes to inform the management of the site.

The framework aims to develop an adaptive ecological monitoring process through reviewing existing monitoring programmes in the region. This review has identified priority ecological monitoring requirements for 2010–11 that have the capacity to undergo review and adaptation for extension beyond 2011.

Gap analysis on current ecological monitoring activities in parallel with discussions with stakeholders identified several common themes including: increasing contractor stability through funding availability and commitment; the necessity of objective-driven ecological monitoring programmes; the importance of monitoring processes as well as biota. The importance of developing a synthesis of monitoring components for an overall understanding of biotic and process response to management actions and changing environmental conditions.

Key biota and process monitoring gaps not included in The Living Murray program but required for whole-of-site management identified include: mammals; reptiles; zooplankton; recruitment; and connectivity; as well as specific gaps for biota presently monitored (such as samphire communities as part of vegetation monitoring in the region).

In order to ensure that such monitoring gaps are filled and that monitoring informs management decisions and actions, four monitoring themes have been identified:

- Condition/baseline monitoring will determine the current ecological condition of the biota of the CLLMM region and provide baseline data for biota and processes to inform on the ecological character of the site and limits of acceptable change that will feed into the adaptive management framework for the site. Most condition/baseline monitoring for 2010–11 will align with current TLM icon site condition monitoring.
- 2. **Investigative monitoring** will identify reasons for localised changes in ecological condition or departures from the established baseline and also identify potential methods for re-establishing the desired ecological condition. Investigative monitoring is a short-term and localised action.
- 3. **Emergency response monitoring** will be initiated in response to trigger levels identified through condition/baseline monitoring in order to assess the environmental response to the emergency (such as an acidification event) and any mitigation actions. Like investigative monitoring, emergency response monitoring is a short-term and localised action.
- 4. **Intervention monitoring** identifies that any intervention action should have its own specific monitoring programme designed to assess whether the intervention action is achieving its stated ecological objectives.



In following the Wilkinson framework, the monitoring framework and plan highlight the necessity of an overall monitoring synthesis component, as well as regular reporting requirements for each monitoring aspect, in order to create an integrated, holistic whole-of-system understanding of the monitoring programme. The regular reporting, as well as the overall synthesis, will feedback into both the adaptive monitoring and the adaptive management processes.

The adaptive monitoring framework identified in the plan ensures that the outcomes and deliverables produced by monitoring programmes are used to inform both further monitoring in the region and the adaptive management process. Priority monitoring activities identified under each of the four monitoring themes in the framework and plan will be commissioned for a maximum of one year, with an ongoing review component compulsory during the year. This will allow the adaptation of the monitoring programme for further years, if required, in order to inform all management decisions and actions and to assess that the programmes' objectives are being met.

Information provided through regular reporting and the monitoring synthesis is fed into the adaptive management process through the governance structure of the CLLMM Project identified in the framework. Therefore the adaptive monitoring framework feeds into every stage of the adaptive management framework and underpins the critical processes of planning management actions and developing the research priorities for the region for the period of 2010–15. The proposed monitoring initiatives described will require approval from the Australian Government before implementation.