Ecological objectives, targets, and environmental water requirements for the Lower Lakes, Coorong and Murray Mouth

DEWNR Technical report 2015/45

Government of South Australia
Department of Environment, Water and Natural Resources

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Department of Environment, Water and Natural Resources

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
CHIEF EXECUTIVE
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GLOSSARY

ARI	Average return interval - the long-term average number of years between the occurrence of a flow event equal to or great than the selected event.
CPS	Components, Processes and Services are identified through the Ecological Character Description. Ecosystem components are physical, chemical and biological parts of a wetland, from large-scale to very small-scale (e.g. habitat, species and genes). Ecosystem processes include all processes that occur between organisms and within and between populations and communities, including interactions with the nonliving environment that result in existing ecosystems and bring about changes in ecosystems over time. Ecosystem services are 'the benefits that people receive from ecosystems'
e-water	Environmental water (see below)
ECD	An Ecological Character Description, a requirement of the Ramsar Agreement, provides the baseline description of the wetland at a given point in time, which can be used to assess change in the ecological character of these sites.
Environmental asset	Identified in accordance with *The Basin Plan* (Chapter 8.49)
Environmental water	Environmental water is 'held' or 'planned' environmental water, defined in the Water Act 2007. *Held* environmental water is available under a water access right for the purposes of achieving environmental outcomes; *planned* environmental water is committed to environmental outcomes and cannot be used for any other purpose
EWR	Environmental Water Requirements are the water regime needed to sustain the ecological values of aquatic ecosystems and biological diversity at a low level of risk.
LAC	Limits of Acceptable Change are quantitative thresholds to indicate whether there has been a significant change in ecological character
CLLMM	Coorong, Lower Lakes and Murray Mouth
LTWP	Long Term Watering Plan, to be developed for priority environmental assets identified under the *Basin Plan*
MDBA	Murray-Darling Basin Authority
Priority environmental asset	That part of the environmental asset that can be managed with environmental water, identified in accordance with *The Basin Plan* (Chapter 8.49). *For the purposes of this document, the floodplain priority environmental asset is equivalent to the managed floodplain.*
SARM	South Australian River Murray
SARM channel	The South Australian River Murray main channel, defined for the purposes of the LTWP to be the area inundated at flows to South Australia of ≤40,000 $ML.day^{-1}$; and longitudinally from the SA border to Wellington.
SARM floodplain	The South Australian River Murray floodplain, defined for the purposes of the LTWP to be the area inundated from QSA 40,000 $ML.day^{-1}$ to the peak 1956 flood level, and longitudinally from the New South Wales–Victorian–South Australian border to Wellington.
TLM	The Living Murray *Icon Site* initiative

Summary

The Coorong, Lower Lakes and Murray Mouth (CLLMM) form a terminal wetland system between the River Murray and the coast of South Australia. This wetland has been identified as a *priority environmental asset* of the South Australian River Murray. River Murray flows are the main driver of ecological condition in the CLLMM and the achievement of environmental outcomes of the Murray-Darling *Basin Plan*. This paper describes the ecological objectives, targets and environmental water requirements of the CLLMM asset, which will inform both the SA River Murray Long Term Watering Plan and the evaluation of environmental outcomes of the *Basin Plan*.

Ecological objectives, targets, and Environmental Water Requirements (EWRs) for the CLLMM were developed by collating and consolidating planning material from *The Living Murray* and *Coorong, Lower Lakes and Murray Mouth* programmes. Nine ecological objectives and 31 targets were defined for a number of biotic groups and processes (functions and vegetation, macroinvertebrates, fishes and waterbirds). Four EWRs were also described:

- CLLMM 1: annual barrage flows of >2000 GL.y^{-1} (average over a 3-year period with no less than 650 GL in any one year) and Coorong South Lagoon water levels of 0.0 to 0.2 m AHD for ≥90 days in spring.
- CLLMM 2: annual barrage flow of >4000 GL.y^{-1} (average over a 3-year period with no less than 3150 GL every two years) and Coorong South Lagoon water levels of 0.35-0.45 m AHD for ≥120 days over spring and summer.
- CLLMM 3: barrage flows of >6000 GL.y^{-1} every three to five years, and Coorong South Lagoon water levels of 0.35-0.45 m AHD for ≥150 days over spring and summer.
- CLLMM 4: barrage flows of >10,000 GL.y^{-1} every seven to 17 years and Coorong South Lagoon water levels of 0.35-0.45 m AHD for ≥180 days over spring and summer.

To align environmental water requirements with targets, the expected contribution of each EWR towards achieving ecological targets was assessed in an expert workshop. The contributions were scored using a ranking system, with three categories: 1) large positive contribution, 2) moderate positive contribution and 3) contribution unlikely to be detectable.

The EWRs collectively represent the water regime required to achieve the overarching objectives of the CLLMM. Progress towards achieving the desired outcomes can be assessed through an evaluation of the associated objectives and targets

1 The Coorong, Lower Lakes and Murray Mouth priority environmental asset

The site is formally recognised as the 'Coorong, Lake Alexandrina and Lake Albert wetland' under the Ramsar Convention. The Murray Mouth is included within the Ramsar boundary, but is not explicitly stated in the Ramsar site name, however the 'Murray Mouth' has been included within this asset's name in the LTWP as it is considered to be an important part of the system. As a result, the site is hereafter referred to as the Coorong, Lower Lakes and Murray Mouth (CLLMM). Lake Alexandrina and Lake Albert are collectively described as the 'Lower Lakes', as presented in the *Basin-wide environmental watering strategy* (MDBA 2014a).

1.1 Identification as a priority environmental asset

The CLLMM is a '*priority environmental asset*' within the SA River Murray Water Resource Planning Area, meeting all assessment criteria in Schedule 8 of the Murray-Darling *Basin Plan*, namely that it:

1. Is formally recognised in international agreements or is capable of supporting species listed in those agreements,
2. Is natural, near-natural, rare or unique,
3. Provides vital habitat,
4. Supports Commonwealth, State or Territory listed threatened species or ecological communities, and
5. Supports, or is capable of supporting, significant biodiversity.

Information meeting these five criteria can be found in Table B16.1 in the *Guide to the Proposed Basin Plan*.

The *Basin Plan* further defines priority environmental assets as those that can be managed with environmental water (Section 8.49). This is true for the CLLMM.

According to Section 8.19 of the *Basin Plan*, Long Term Watering Plans (LTWPs) for priority environmental assets must include the following information:

1. Ecological objectives,
2. Ecological targets, and
3. Environmental watering requirements (EWRs) needed to meet the targets, hence objectives.

This document describes ecological objectives, targets and environmental water requirements for the CLLMM. As there has been extensive planning around the optimal water delivery to achieve ecological outcomes for the region, through The Murray Futures *Coorong, Lower Lakes and Murray Mouth* (CLLMM) programme and The Living Murray (TLM) *Icon Site* initiative, the report draws on previous publications rather than developing new content.

1.2 Description of the asset

The Coorong, Lower Lakes and Murray Mouth wetland is a freshwater lake and coastal lagoon system covering an area of approximately 142,530 hectares (DEWNR 2013) in south-eastern South Australia. The site encompasses Lake Alexandrina, Lake Albert, the lower reaches of Currency Creek and the Finniss River, the Murray Mouth estuary, the Coorong and a number of ephemeral lakes (DEWNR 2013). Flows from the River Murray pass into Lake Alexandrina (approximately 5 km south of Wellington) and out to the Southern Ocean via the Murray Mouth Estuary. Lake Alexandrina also connects to the terminal Lake Albert through a small channel on its eastern shore. The freshwater Lower Lakes (Alexandrina and Albert) are physically separated from the Murray Mouth and Coorong via a complex of islands and channels and five barrages. The construction of the barrages was completed in 1940 to prevent ingress of saline water to the Lower Lakes and to regulate lake water levels (Phillips and Muller 2006). Since 2002, five fishways have been incorporated into three of the barrages, allowing fish movements between freshwater and saline environments, and another seven are under construction (A. Rumbelow (DEWNR) 2015, pers. comm. 29 April).

The Coorong is a shallow coastal lagoon complex that stretches over 140 km from the Murray Mouth. It receives inflows from Lake Alexandrina, the Southern Ocean and Salt Creek, and is separated from the sea by a narrow sand dune. The Coorong has a strong salinity gradient, from fresh to brackish in parts of the Murray Mouth estuary to hypersaline in areas of its southern lagoon. This gradient varies temporally, depending on the respective inflows.

The diverse freshwater and saline wetland habitats within the CLLMM support a wide range of wetland-dependent biota. The site regularly supports >200,000 waterbirds during summer (Paton 2010), significant numbers of colonial-nesting and beach-nesting waterbirds (O'Connor et al. 2013) and a number of threatened waterbird species (DEWNR 2013). The wetlands play an important role for 49 native fish species, including diadromous, endangered and commercial species (Phillips and Muller 2006; Ye et al. 2014a). It is also characterised by a range of ecologically significant submerged, emergent and fringing plant species and communities including *Gahnia* sedgelands, beds of *Ruppia tuberosa* and the Fleurieu Swamps (Phillips and Muller 2006).

The CLLMM is recognised as a site of high conservation significance. It is included as an *Icon Site* through The Living Murray initiative, and as such has access to a share of up to 500 gigalitres of environmental water that has been recovered for use at Icon Sites (MDBA 2014b). It is also listed as a Ramsar *Wetland of International Importance*. For detailed descriptions of ecological character and hydrology, see Phillips and Muller (2006), Paton (2010), Lester et al. (2011) and MDBA (2012b).

1.3 Consistency with the Basin Plan and international agreements

The CLLMM site is recognised under the following international agreements:

- Japan-Australia Migratory Bird Agreement (JAMBA)
- Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA)
- China-Australia Migratory Bird Agreement (CAMBA)
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention)
- Ramsar Convention on Wetlands

The significance of these agreements for the ecological management of the CLLMM is discussed elsewhere (Phillips and Muller 2006; DEWNR in prep.). The ecological objectives, targets and EWRs presented here were developed to be consistent with the objectives of the above-mentioned agreements, acknowledging the need to provide habitat for migratory waders and to maintain the ecological character of the site.

As a contracting partner to the Ramsar Convention, Australia has made a commitment to plan for sustainable use of this wetland and maintain its ecological character. Understanding and documenting the ecological character of the CLLMM are therefore important for future management. An Ecological Character Description (ECD) includes critical Components, Processes and Services (CPS) that determine the nature of the wetland. In addition, an ECD documents procedures to detect whether the ecological character has changed, or is likely to change, as a result of threatening processes. Limits of Acceptable Change (LAC) include quantitative thresholds to indicate whether there has been a significant change in ecological character. The ECD for the CLLMM is currently under revision and will provide further descriptions of CPS, LAC and the maintenance of ecological character (DEWNR in prep.).

The Murray-Darling *Basin Plan* contains overarching environmental objectives for water-dependent ecosystems, including (s8.05 (1)(a)): 'an objective is to protect and restore a subset of all water-dependent ecosystems of the Murray-Darling Basin, including by ensuring that declared Ramsar wetlands that depend on Basin water resources maintain their ecological character'. The *Basin Plan* also requires that a LTWP must be consistent with relevant international agreements (s8.20 (5)). The methods for identifying environmental assets and their environmental watering requirements (s8.49) state that the ecological objectives of an environmental asset should be consistent with the criteria used to identify the asset, and specifies that, if the asset is a declared Ramsar wetland, the objectives must be directed towards maintaining the ecological character of that wetland.

2 Identifying ecological objectives and targets for the CLLMM asset

The objectives and targets for the CLLMM were identified through the collation of information presented within a number of existing documents, including:

1. The development of ecological objectives and targets for the Long Term Water Plan resulted largely from the synthesis of TLM and CLLMM programme content. Existing ecological objectives, targets and ECD content were developed within these programmes and have been continually improved since the establishment of the TLM programme in 2002 and the CLLMM programme in 2009. This information was also informed by CLLAMMecology (Brookes et al. 2009). TLM monitoring targets and CLLMM ECD content are currently being refined and/or revised, and the LTWP considers the most recently updated content (in some cases, unpublished).

2. Outputs of the Murray-Darling Basin Authority's (MDBA) 2014 Quantitative Environmental Outcomes workshops for *Ruppia*, shorebirds, waterbirds and Coorong fish, which were used to develop the *Basin-Wide Environmental Watering Strategy* (BWEWS). Consistency with environmental outcomes for waterbirds, native fish and river flows and connectivity was also considered, following the BWEWS in November 2014 (MDBA 2014c).

For the purpose of developing ecological objectives and targets for the LTWP, the following definitions have been adopted:

- **Ecological objectives:** provide a clear articulation for managers, scientists, stakeholders and the wider community of what planned deliveries of environmental water are intended to achieve. For example: *"Maintain or improve bird populations in the Coorong and Lower Lakes"*.

- Clearly defined, specific and measurable **ecological targets** are tools for measuring progress towards the ecological objectives. Targets may encapsulate site-specific differences – acknowledging the ecological role of different habitats, and differences in achievable condition for different habitats. They are based on an understanding of critical ecological processes/life stages/characteristics of the ecological attribute. For example: *"Abundances and area of occupation of TLM target waterbird species to be above defined median reference values (median of data from the 15 years between 2000 and 2014)*".

Ecological targets should streamline monitoring and reporting needs for both short-term (event-specific) and longer-term outcomes, and allow for (i) assessing and reporting condition over time, (ii) indicating the need for management action and assessing the outcomes of management actions, and (iii) plain-language reporting on progress towards the relevant ecological objectives (Wallace et al. 2014).

2.1 Ecological content relevant to development of objectives and targets

2.1.1 The Living Murray ecological objectives and targets

The Living Murray (TLM) Initiative developed ecological objectives and targets to guide the improvement in environmental health of the CLLMM, and to guide the delivery of environmental water (MDBA 2013; Appendix A). TLM targets refer to the maintenance or improvement of ecological conditions that can be achieved through e-water delivery.

The TLM monitoring programme reports on the 'condition' of CLLMM fish, bird, macroinvertebrate and vegetation groups according to 17 TLM targets (Appendix A). At the time of developing this report, refinement of the CLLMM TLM targets was being undertaken (Robinson 2014). These refinements have been utilised where possible.

2.1.2 Murray Futures CLLMM programme ecological objectives and Ecological Character Description content

DEWNR's CLLMM programme also has developed objectives to guide ecological monitoring and management of the site. These include:

1. Three high-level monitoring objectives, outlined in the CLLMM monitoring framework (DENR 2011) (Appendix B), and
2. Eight ecological objectives that, if met, would maintain the health and resilience of the CLLMM and allow the ecosystem to adapt to changes in climate and flow (Lester et al. 2011).

In addition, CPS developed as part of the ECD describe the attributes that are important for the maintenance of Ecological Character, and the corresponding LAC give thresholds for reporting on changes in ecological character. LAC are set at thresholds at which critical changes in CPS are expected to have occurred.

Other non-DEWNR funded ecological monitoring programmes are conducted in the CLLMM; these may have ecological objectives that are not explicitly considered here.

2.1.3 Basin Plan

The *Basin Plan* includes several objectives and targets specific to the CLLMM, including:

- *Objectives relating to the protection and restoration of the ecosystem functions of water-dependent ecosystems by protecting and restoring connectivity within and between water-dependent ecosystems (s8.06 (3)) by ensuring that:*

  (c) the Murray Mouth remains open at frequencies, for durations, and with passing flows, sufficient to enable the conveyance of salt, nutrients and sediment from the Murray-Darling Basin to the ocean; and

  (d) the Murray Mouth remains open at frequencies, and for durations, sufficient to ensure that the tidal exchanges maintain the Coorong's water quality (in particular salinity levels) within the tolerance of the Coorong ecosystem's resilience; and

  Note: This is to ensure that water quality is maintained at a level that does not compromise the ecosystem and that hydrologic connectivity is restored and maintained.

  (e) the levels of the Lower Lakes are managed to ensure sufficient discharge to the Coorong and Murray Mouth and help prevent river bank collapse and acidification of wetlands below Lock 1, and to avoid acidification and allow connection between Lakes Alexandrina and Albert, by:

  (i) maintaining levels above 0.4 metres Australian Height Datum for 95% of the time, as far as practicable; and

  (ii) maintaining levels above 0.0 metres Australian Height Datum all of the time

- *Water quality targets for managing flow (s9.14): the levels of salinity at Milang should not exceed 1000 EC, 95% of the time*.

As required under the Basin Plan (s8.13), the MDBA published the BWEWS in November 2014 (MDBA 2014a). The LTWP content proposed in this report is consistent with assets/functions and requirements identified in the BWEWS.

2.2 Identification of ecological objectives

In order to identify a consolidated suite of ecological objectives for the CLLMM, content from the ECD and TLM condition monitoring plan was reviewed, collated and aligned in order to ensure information presented within the LTWP captures the content of information presented for both programmes. The list of TLM objectives and targets and CLLMM CPS that were considered are in Appendix C.

A gap analysis was applied to align the following:

1. Existing TLM objectives and targets (Maunsell 2009), and
2. CPS from the ECD (DEWNR in prep.).

This review identified considerable overlap between TLM objectives and targets and CPS (Appendix C). The content and wording of TLM targets are consistent with the definition of ecological objectives used here (see Section 2). Consequently, TLM targets were considered to be *objectives* for the purposes of the LTWP.

Overall, a condensed list of nine ecological objectives for the Long Term Watering Plan was developed by:

- Listing all TLM targets (adopted as ecological objectives for the LTWP),

- Identifying any gaps where CPS were not covered by TLM targets,
- Developing new objectives based on CPS, when corresponding TLM targets were not present, and
- Identifying content that should be excluded from the LTWP (discussed in Section 2.3.1).

Seven of the nine ecological objectives listed in Table 1 are exact representations of TLM 'targets'. Two additional objectives (EO2 and EO8) were developed as a result of the gap analysis. These objectives correspond with CPS related to fish diversity and salinity, described in the ECD report for the site (DEWNR in prep.). All CPS have been represented by an ecological objective for the LTWP (Table 2).

A higher-level objective for the CLLMM was also developed in accordance with the overall Basin Plan environmental objectives and outcomes for water-dependent systems (s 8.05, s 5.02). Specifically, to support outcome 5.02 c: *'healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean',* the following higher-level objective was adopted:

- *'Maintain the ecological character of the Coorong, Lower Lakes, and Murray Mouth wetland by restoring a healthy and resilient ecosystem'*

This is considered to be consistent with the overall Basin Plan objective for declared Ramsar wetlands, namely that '*declared Ramsar wetlands that depend on Basin water resources maintain their ecological character*' (s 8.05 2a), as the ecological character refers to maintaining conditions prevailing at the time of Ramsar listing (1985), when the CLLMM was considered to be a healthy and resilient ecosystem (DEWNR in prep.).

2.3 Identification of ecological targets

The ecological targets for the LTWP are described in Table 1. These were largely developed via a synthesis of existing monitoring data, thresholds and expert opinion from recent technical reports and MDBA workshops. In particular, they draw on outputs from a recent TLM condition monitoring refinement project (summarised in Robinson 2014), including indices that allow for quantitative assessments of CLLMM condition and changes in condition over time. The remainder of LTWP target content has been derived from the MDBA's 'Quantitative Environmental Outcome' workshops for shorebirds, general waterbirds, Coorong fish and *R. tuberosa*.

All objectives and targets link to material in TLM Condition Monitoring Programme and the CLLMM ECD. Corresponding CPS are identified for each ecological objective and target in Table 2. Each CPS has associated LAC. LAC are not equivalent to ecological targets; rather, they represent thresholds that indicate a change in ecological character.

Ecological targets for mudflat sediment conditions (E04: targets 19&20) are not expected to respond as strongly to different flow volumes as other targets, especially areas of lower flow velocity such as the Coorong lagoons. These targets are included in order to measure sediment habitability for macroinvertebrate communities.

2.4 Exclusions

Objectives and targets for *Ruppia megacarpa* are not included, as this species is considered 'functionally extinct' (although present in small numbers) in the Coorong North Lagoon (MDBA 2014c). Re-establishment of *R. megacarpa* would require management interventions beyond flow provisions, and is not considered appropriate for the LTWP (MDBA 2014c).

The TLM target: 'Provide freshwater flows that provide food sources for Goolwa cockles' is considered to be an appropriate ecological objective for the CLLMM LTWP, as it can provide an assessment of the ecological benefits provided by Murray Mouth outflows. It is not included in Table 2 because an appropriate ecological target still needs to be developed via a pending review of monitoring data and reports.

The TLM target: 'Facilitate frequent changes in exposure and submergence of mudflats' was not adopted as an ecological objective because the expected outcomes were similar to those of ecological objective 5: 'Maintain habitable sediment conditions in mudflats' and ecological target 3: 'Provide functional mudflat habitat to sustain active shorebird foraging behaviour during November–March with a foraging effort of <50%'.

Table 1. Ecological objectives and associated ecological targets for the Lower Lakes, Coorong and Murray Mouth for the LTWP (TL = Total Length; YOY = Young of Year)

Ecological objective	Ecological targets	Target details and supplementary information
EO1 **Maintain or improve waterbird populations in the Coorong and Lower Lakes**	1. Abundances, area of occupation and extent of occurrence of TLM target waterbird species (Appendix D) to be above defined median reference values (median of data from the 15 years between 2000 and 2014)[1]	Area of occupation is a presence absence score to assess the number of cells containing a certain species. Extent of occurrence is a measure of the distance between the northernmost and southernmost cells where a species was observed in one count. The 'extent of occurrence' reference has not yet been determined. In the interim, reference values could follow the same 15 year median example (e.g. 92 km of shoreline for Fairy Terns, 102 km for Red-necked Stints)[18] In the Coorong, cells are defined as 1 km sections of the lagoons and Murray estuary area that are divided into three components: the land-side shoreline, sea-side shoreline and lagoon centre. In the Lakes, cells represent 1kmx1km grid cells that cover the entire shoreline.
	2. Detect annual breeding activity in waterbird species that are expected to breed annually at the site (Appendix E) and at least two breeding events in any four consecutive years in species that breed regularly at the site (Appendix F)[2,4]	Using the 'median of data from the 15 years between 2000 and 2014' was proposed as a reference value for assessing changes in abundance and area of occupation (i.e. EO1, Target 1), and has also been used as a surrogate for targets related to waterbird breeding events in the absence of more specific metrics. Lack of or reduced size of breeding events must be attributable to on-site conditions. Current TLM monitoring activities have limited capacity to detect breeding activity outside of the regular January site census.
	3. Provide functional mudflat habitat to sustain active shorebird foraging behaviour during November–March with a foraging effort of <50%[3].	Functional mudflat is defined as mudflat that has the following characteristics: 1) contains adequate prey resources (i.e. macroinvertebrates and/or *Ruppia* spp.), 2) experiences sufficient changes in submergence and exposure to maintain adequate prey resources, and 3) can be accessed by shorebirds (i.e. water depth does not exceed shorebird beak or leg length, and sediment penetrability is suitable). See also: EO4 for mudflat habitat suitability measures. Shorebirds spending less than 50% of the daylight hours foraging will indicate that the habitat is of good quality (lower foraging limits yet identified). Foraging effort should be measured in summer or two months after the delivery of water (when shorebirds foraging activity is at its peak)[3]

Ecological objective	Ecological targets	Target details and supplementary information
	4. Maintain abundances of 12 waterbird species (Appendix G) at or above 1% of the total flyway population size[4]	12 waterbird species are regularly (3 out of 5 years on average) observed in abundances >1% of total flyway populations thresholds (O'Connor, in prep). 12 species were identified as regularly meeting 1% flyway thresholds using 2012 Wetland Population Estimates (Wetlands International, 2015) and total census data (Coorong 2000-2014, entire CLLMM 2009-2014). Most up to date flyway estimates can be sourced from the Wetlands International online database
EO2 **Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the lower lakes and Coorong**	5. A spatio-temporally diverse fish community is present including all 27 fish families stated in the Ramsar site draft Ecological Character Description (Appendix H)[3,4]	List of 27 fish families was developed via expert opinion for Limits of Acceptable Change in the CLLMM ECD[4]. Included are fish that are characteristic of the site and would be expected to be present on a regular basis[4]. This target is reliant on 'adequate' sampling to detect different species within a 12-month period[3]
	6. Annual detection of juvenile catadromous fish at abundances ≥ that of defined 'Recruitment Index' values (44.5 for Congolli; 6.1 for Common galaxias)[5]	Congolli and Common galaxias are categorised as 'Young of the Year' (juvenile) when TL is less than 60 mm[5]. See Bice and Zampatti 2014 for index calculation.
	7. Annual detection of migration for anadromous species (Short-Headed and Pouched Lamprey) at index values of >0.6[5]	This index requires further development with an increased data set[5]. See Bice and Zampatti (2014) for index calculation.
	8. Maximise fish passage connectivity between the Lower Lakes and Coorong, and between the Coorong and the sea, by allowing fishways to operate year-round[6]	Connectivity is required by species that require both marine and freshwater habitats. For connectivity, minimum barrage outflows of 52 $GL.y^{-1}$ are required for fishway operation and attractant flows[6].
	9. Maintain or improve abundances of Murray Hardyhead and Pygmy perch so that 'Relative Abundance Index' values of ≥1 are achieved on an annual basis[7]	Baseline data for these assessments was collected in 2003 when 'healthy' populations of threatened fish species inhabited waterbodies fringing the Lower Lakes[7]. See Wedderburn (2014) for index calculation.
	10. Detect recruitment success of Murray hardyhead and Pygmy perch at least every second year[7]	Recruitment success is defined as the number of Young of Year (YOY) fish. Target YOYI >0.5 for each site where Murray hardyhead is detected; Target YOYI >0.3 for each site where the pygmy perch species is detected In autumn. YOY Murray hardyhead are defined as <50 mm TL (or <48 mm fork length) and YOY Pygmy perch as <40 mm TL.

Ecological objective	Ecological targets	Target details and supplementary information
	11. Maintain or improve abundances, distribution and recruitment of Black bream and Greenback flounder with population condition score ≥3[8]	See Ye et al. 2014b for details on calculation of population condition scores
	12. Facilitate regular recruitment and a broader distribution of juvenile Mulloway[8]	This index requires further development[8]. Regular recruitment is defined as: 5 out of 10 years e.g. with relative abundance of 1-year-olds ≥ 1.7 fish per net.day[8]. See Ye et al. (2014b) for index calculation.
	13. Maintain an average Catch-Per-Unit-Effort (CPUE) of Small-mouthed hardyhead sampled in spring/early summer of >120 CPUE for adults, and >790 CPUE for juveniles[9]	Adult reference (2014) was set at 158 ± 40. 120 is the lower confidence interval (rounded up to the nearest 10). Juvenile reference (2014) was set at 1052 ± 263. 790 is the lower confidence interval (rounded up to the nearest 10). Young fish are defined as fish that measure < 40 mm TL. References can be updated as more data are collected.
	14. Maintain the proportional abundance of Small-mouthed hardyhead juveniles at >60% in 75% of defined monitoring sites within the CLLMM[9].	Proportional abundance is calculated for each of the 8 sites. See Ye et al. (2014c) for index calculation.
EO3 **Maintain or improve invertebrate communities in estuarine and lagoon sediments**	15. Macroinvertebrate taxonomic distinctness falls within the expected ranges of a regional reference[10]	See Dittmann (2014) for index calculation. Funnel plots can be used to assess whether diversity falls within or outside of an expected range (derived from all species records so far from various studies per site or region).
	16. The distribution of macroinvertebrate species remains within or above the species-specific reference level for their index of occurrence[10]	See Dittmann (2014) for index calculation. Reference index of occurrence for key macroinvertebrates (Dittmann 2014): *Simplisetia aequisetis*: 0.82, Amphipoda: 1, *Capitella capitata*: 1, Chironomidae: N/A, *Arthritica helmsi*: 0.73, *Nephtys australiensis*: 0.55
	17. The area of occupancy where abundance and biomass are at or above the reference level should be >20% of the monitoring sites[10]	See Dittmann (2014) for index calculation.
	18. The macroinvertebrate community has a higher multivariate similarity to the community present in years with flow than without flow[10]	See Dittmann (2014) for index calculation.
EO4 **Maintain habitable sediment conditions in mudflats**	19. Median grain size of sediments in the Coorong and Murray Mouth will remain between 125–500 µm[10]	Grain size should be within the current reference dynamic based on a decade of flow and drought years (Dittmann 2014).
	20. Sediment organic matter content between 1 and 3.5 % dry weight in the Coorong and Murray Mouth[10]	Sediment organic matter content should be within the current reference dynamic based on a decade of flow and drought years (Dittmann 2014).
EO5	21. A continuous distribution of *R. tuberosa* beds along a 50 km section of the southern Coorong (excluding outliers)[11]	*R. tuberosa* bed width varies with bathymetry (assuming water levels are adequate: *R. tuberosa* beds can grow to a wider extent in shallower

Ecological objective	Ecological targets	Target details and supplementary information
Restore *Ruppia tuberosa* colonisation and reproduction in the Coorong at a regional and local scale		environments, and a lesser extent in steeply sloped environments). The interim *R. tuberosa* bed width reference should be average of 100 m wide, although this estimate is only provided as an interim measure pending further examination of *R. tuberosa* transect data (D. Paton, University of Adelaide) 2015, pers. comm. 8 February).
	22. Within the abovementioned distribution, 80% of the monitored sites should have *R. tuberosa* plants present in winter and summer[11]	Area of occupation is a presence/absence score (at the regional scale). Only a small number of sites are currently surveyed (~20). The occupation index responds to change in occupation, and ranges between 0 (poorest condition) and 1 (best condition) (Paton 2014b).
	23. 50% of sites with *R. tuberosa* to exceed the local site indicators for a healthy *R. tuberosa* population[11]	'To be defined as a healthy population, all five local site indicators need to be considered healthy'[11]. Local site indicators include: 1) % sites with >30% cover (cores) with shoots, 2) % sites with >10 shoots/core for one depth, 3) % sites with 50 flower-heads per m^2, 4) % sites with >50% cores with seeds, 5) % sites with >~8 seeds/core[11]
	24. Support a resilient *R. tuberosa* population with seed densities of 2000 seeds/m^2 by 2019 and 50% of sites having 60% cover in winter and a seed bank of 10,000 seeds.m^{-2} by 2029 in the Coorong South Lagoon[11]	Resilience is considered to be secured via the accumulation of a significant seed bank. Current density of *R. tuberosa* seeds is around 200 seeds/m^2 (Paton 2014b).
EO6 **Maintain or improve aquatic and littoral vegetation in the Lower Lakes**	25. Maintain or improve diversity of aquatic and littoral vegetation in the Lower Lakes as quantified using the CLLMM vegetation indices[12]	Five habitats are proposed: Lake Alexandrina, Lake Albert, Goolwa Channel (including the lower Finniss River and lower Currency Creek), permanent wetlands and temporary wetlands. See Nicol and Gehrig (2015) for details on individual indices.
EO7 **Establish and maintain stable salinities in the lakes and a variable salinity regime in the Murray estuary and Coorong**	1. Barrage outflows sufficient to maintain electrical conductivity in Lake Alexandrina at a long term average of 700 µS.cm^{-1}, below 1000 µS.cm^{-1} in 95% of years and below 1500 µS.cm^{-1} 100% of the time[14,15,16,17]	Volumes and underlying assumptions required to achieve salinity targets are described in Heneker (2010). Assessment against all targets uses the observed daily average salinity, calculated as a five day rolling average of five Lake Alexandrina monitoring locations. In most cases, these will be the sites at Milang, Tauwitchere, Mulgundawa, Pomanda Point and Poltalloch. For the 700 µS.cm^{-1} target, the 'long term average' refers to a rolling five year average of the daily average salinity. For the 1000 µS.cm^{-1} target to be met in a given year, the daily average salinity must be less than 1000 µS.cm^{-1} on all days. For the 1500 µS.cm^{-1} target to be met, the daily average salinity must be less than 1500 µS.cm^{-1} at all times.

Ecological objective	Ecological targets	Target details and supplementary information
	2. To support aquatic habitat: maintain a salinity gradient from 0.5 ppt to 35ppt between the Barrages and Murray Estuary area[3], <45ppt in the North lagoon[15], and from 60ppt to 100ppt in the South lagoon[15]	This salinity gradient should occur over a greater extent in three out of every five years, with brackish salinities extending well into the North Lagoon and beyond the Murray Mouth[3]. North Lagoon salinity ranges should support native fish as described in MDBA (2014c). The area between the Barrages and Murray Estuary is defined as: between discharge locations (e.g. Goolwa barrage and Tauwitchere barrage) and 1) the Murray Mouth and offshore, and 2) the North Lagoon, during all 12 months of the year The Coorong North Lagoon includes the area between Pelican Point and Parnka Point, and the South Lagoon is the lagoon south of Parnka Point.
EO8 **Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity between the Coorong and the sea**	3. Maintain an open Murray Mouth, as indicated 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[6,18]	Murray Mouth openness in any given year will be affected by preceding conditions.
	4. Maintain a minimum annual flow required to keep the Murray Mouth open (730–1090 $GL.y^{-1}$)[6,16]	Required annual volume is dependent on starting conditions in the Murray Mouth. 2000 ML/d barrage release is the minimum volume required to minimise sand ingress.
EO9 **Provide freshwater flows that provide food sources for Goolwa cockles**	5. Target to be determined pending a review of monitoring data and reports	

Source reference for target information: 1: Paton (2014a), 2: Expert opinion, R. Quin, J. Higham, J. O'Connor (DEWNR), 3: MDBA (2014c), 4: DEWNR (in prep.), 5: Bice and Zampatti (2014), 6: MDBA (2014b), 7: Wedderburn (2014), 8: Ye et al. (2014b), 9: Ye et al. (2014b), 10: Dittmann (2014), 11: Paton (2014b), 12: Nicol and Gehrig (2015), 13: Expert opinion, A. Rumbelow (DEWNR), 14: Heneker (2010), 15: Lester et al. (2011), 16: MDBA (2014a), 17: Heneker and Higham (2012), 18: DWLBC (2008), 18: Robinson (2014)

Table 2. Alignment of Components and Processes and Services (CPS) identified in the CLLMM Ramsar Site with objectives and targets for the LTWP (Numbers in brackets refer to corresponding ecological targets: see Table 1). CPS are described in more detail in DEWNR (in prep).

Components, Processes and Services (CPS)	Corresponding LTWP objectives and targets
Hydrology **– Lake Alexandrina water levels**	**EO7** (26)
Salinity **– Lake Alexandrina**	**EO7** (26)
Salinity **– Murray estuary, Coorong North and South Lagoons**	**EO7** (28-29)
Vegetation **–submergent freshwater plants**	**EO6** (25)
Vegetation **– submergent halophytes**	**EO5** (21–24)
Vegetation **–emergent freshwater plants**	**EO6** (25)
Vegetation **– emergent halophytes**	**EO6** (25)
Fish **– diversity (species richness)**	**EO2** (5), EO3 (13)
Fish **– diversity (biodisparity)**	**EO2** (5), EO3 (13)
Fish **- diadromous**	**EO2** (5–8)
Waterbirds **– diversity (species richness)**	**EO1** (1)
Waterbirds **- abundance**	**EO1** (1,4)
Waterbirds **- breeding**	**EO1** (2)
Waterbirds **– 1% populations**	**EO1** (4)
Pollution control and detoxification through trapping, storage and/or treatment of contaminants	**EO4** (20)
Provides physical habitat **– diversity and extent of wetland types**	**EO6** (25)
Special geomorphic feature **– Murray Mouth**	**EO8** (28-29)
Supports biodiversity	**EO1** (1–4), **EO2** (5–14), **EO3** (15–18), **EO4** (19–20), **EO5** (21–24), **EO6** (25)
Supports priority species	**EO1** (1–4)
Ecological connectivity	**EO2** (6–8)
Coorong food web **– *Ruppia tuberosa***	**EO2** (13–14), **EO3** (15–18), **EO5** (21–24)

3 Environmental Water Requirements for the CLLMM

3.1 Approach

Environmental Water Requirements (EWRs) were derived from the results of recent monitoring and modelling outputs for the CLLMM (Heneker 2010; MDBA 2010a,b; Lester et al. 2011, MDBA 2012; Ye et al. 2014). Heneker (2010) described rules for minimum lake inflow and barrage outflow volumes required to achieve target salinities in Lake Alexandrina. These rules described average annual barrage flows (over 3-year periods) of 4000 GL per annum to maintain salinities (as measured by electrical conductivity) in Lake Alexandrina at a mean level of 700 $\mu S.cm^{-1}$, and average flows of 2000 GL and 1000 GL per annum to maintain maximum salinities of 1000 $\mu S.cm^{-1}$ and 1500 $\mu S.cm^{-1}$, respectively (Heneker 2010). Hydrodynamic modelling by Lester et al. (2011) indicated that maintaining mean salinities of 700 $\mu S.cm^{-1}$ and maximum salinities of 1000 $\mu S.cm^{-1}$ in Lake Alexandrina corresponded with improved salinities and water levels in Lake Albert and the Coorong. Further analyses of the same flow scenarios using an ecosystem state model showed an 'improved mix' of ecosystem states in the Coorong when flows were adequate to support target salinities in Lake Alexandrina. The results of these analyses were used to define an EWR for maintaining the health, productivity, resilience and ecological character of the Coorong, Lower Lakes and Murray Mouth (Lester et al. 2011).

The EWR described by Lester et al. (2011) includes the following:

Low flow requirements (rolling 3-year average):

- Long-term average flows: ≥4000 $GL.y^{-1}$,
- Minimum average flow in 95% of years: 2000 $GL.y^{-1}$,
- Absolute minimum average flow in 100% of years: 1000 $GL.y^{-1}$.

High flow requirements:

- Every three years: ≥6000 $GL.y^{-1}$,
- Every seven years: ≥10,000 $GL.y^{-1}$.

Flows in any one year may fall below the average (but not below the specified minimum) if sufficient volumes are provided in following years to reach the average over a 3-year rolling period (Heneker 2010; Lester et al. 2011).

Environmental Water Requirements (EWRs) for the CLLMM LTWP consider the metrics developed in Lester et al. (2011) and Heneker (2010), but also incorporate metrics to describe water level requirements of the Lower Lakes and Coorong South Lagoon. Importantly, the EWRs for the LTWP include information on the timing of flows in order to achieve the desired ecological outcomes (Table 3) The seasonal timing of Coorong South Lagoon water levels is of critical importance to *R. tuberosa* (Nicol 2005; Paton and Bailey 2014; Ye et al. 2014), a submerged plant that forms a key element of Coorong food webs (DEWNR in prep.; Paton 2010). The feasibility of delivering the flow volumes described in each EWR at the given times of the year and with resulting Coorong water levels outcomes is yet to be tested and may be updated if suitable modelling outputs are available. The EWRs CLLMM 1 and CLLMM 2 both describe flows and water levels that could be achieved on an annual basis (Table 3). CLLMM 1 incorporates barrage flows at a 3-year average of 2000 $GL.yr^{-1}$ to maintain lake salinities ≤1000 $\mu S.cm^{-1}$. This is provided as an EWR in the MDBA Lower Lakes, Coorong and Murray Mouth Environmental Water Management Plan (MDBA 2014b). CLLMM 2 incorporates barrage flows at a three-year average of ≥4000 $GL.yr^{-1}$, which corresponds with the EWR suggested by Lester et al. (2011) to maintain target lake salinities ≤700 $\mu S.cm^{-1}$. These EWRs were presented as alternate options that should be considered within a broader flow regime (i.e. in conjunction with CLLMM 3 and CLLMM 4).

Flow metrics to support a maximum salinity of 1500 $\mu S.cm^{-1}$ in Lake Alexandrina (as described in Heneker 2010) were not included in the EWRs (Table 3), as they do not prevent extreme conditions in the Coorong during periods of drought (Lester et al. 2011), and also exceed the Basin Plan target of maintaining salinities ≤1000 $\mu S.cm^{-1}$ at Milang 95% of the time (s 9.14).

3.1.1 Assumptions

The EWRs presented in Table 3 align desired Coorong South Lagoon water levels with desired lake level and annual barrage flow requirements. However, current modelling approaches have not tested the relationship between these metrics; these are in development (J. Higham (DEWNR) 2015, pers. comm. April 27). Coorong water levels will also be impacted by other hydrological and geomorphological factors such as: Murray Mouth 'openness', local meteorological conditions, water-level variation in Encounter Bay and flows from the Upper South East Drainage scheme (USED) via Salt Creek, (Higham 2012). In the absence of specific data to relate Coorong South Lagoon water levels to barrage flows, modelling outcomes provided by Lester et al (2011) were used as a guide to understanding the potential impact of barrage flows on Coorong ecology. Specifically, the EWRs CLLMM 3 and CLLMM 4 specify higher flow volumes (6000 $GL.yr^{-1}$ and 10,000 $GL.yr^{-1}$, respectively), associated with the historical occurrence of improved Coorong 'ecosystem states' in Lester et al. (2011).

3.1.2 Frequency, timing and volume of annual barrage flows

Annual barrage flow represents the minimum volume (gigalitres) that is released from the barrages (all gates) over the course of a water-year (July–June). This volume is estimated via modelling rather than measured via flow gauges. For some EWRs this is represented as a rolling average (i.e. average volume over multiple years).

ARI is the desired frequency that the annual volume is released e.g. 1-in-3 ARI means once every three years on average (or 33% of years) and Is not intended to describe a regular pattern.

Maximum interval is the long-term average number of years between the occurrence of a flow event equal to or great than the selected event.

Timing – barrage releases should occur over the entire water-year, but the EWRs seek to vary the monthly outflow volume with peaks outflows in late spring/early summer in order to support seasonal ecological processes. This variation is described in Figure 1.

Average return intervals (ARI) and maximum intervals reflect the modelled intervals between flow events as presented in Lester et al. (2011) and Heneker (2010). A rolling average barrage outflow of 4000 $GL.yr^{-1}$ over a three-year period (i.e. not less than 12,000 GL over three years) with no less than 3150 $GL.yr^{-1}$ in any one of the three years will ensure that mean annual salinities of 700 $\mu S.cm^{-1}$ are maintained in the Lower Lakes (Heneker 2010; Lester et al. 2011). A rolling average barrage outflow of 2000 $GL.yr^{-1}$ per three year period (i.e. not less than 6000 GL over three years) with no less than 650 $GL.yr^{-1}$ in any one of the three years will ensure that maximum salinities of 1000 $\mu S.cm^{-1}$are maintained in the Lower Lakes (Heneker, 2010; Lester et al. 2011). Flows of at least 6000 $GL.yr^{-1}$ are to be delivered at least once every 5 years (preferably once every three years) and flows of at least 10,000 $GL.yr^{-1}$ are to be delivered at least once every 17 years (preferably every 7 years) to ensure a healthy Coorong (Lester et al. 2011).

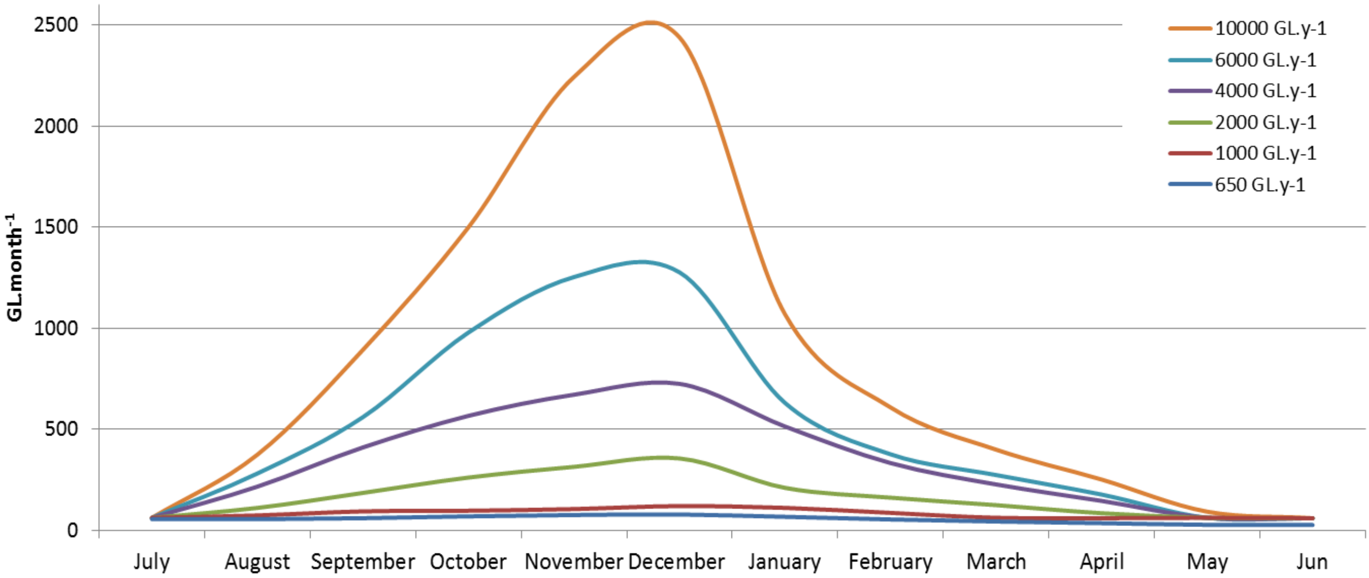

Figure 1 Hypothetical optimal timing of barrage releases for various annual flow scenarios (developed by J. Higham, CLLMM programme)

3.1.3 Water levels in Lake Alexandrina and Lake Albert

Lake water level metrics represent the minimum and maximum levels averaged across the Lower Lakes, rather than a minimum or maximum at any given location, and the desired range throughout the water-year.

The *Basin Plan* specifies that in order to meet the objective 'to protect and restore connectivity within and between water-dependent ecosystems' (Section 8.06), the levels of the Lower Lakes must be managed to ensure sufficient discharge to the Coorong and Murray Mouth, to help prevent riverbank collapse, acidification of lakes and other wetlands and maintain a connection between Lakes Alexandrina and Albert. In order to meet this requirement, it is specified that lake levels must be maintained >0.4 m AHD for 95% of the time, as far as practicable, and >0.0 m AHD 100% of the time (MDBA 2012a). The minimum lake level of 0.4 m AHD has been adopted in the EWRs in Table 3. Maximum lake levels can vary between 0.75 m AHD and 0.83 m AHD across each of the four EWRs, as described in Lester et al. (2011). Lester et al. (2011) states that maximum lake levels can vary up to a level of 0.75 m AHD annually, with higher lake levels of up to 0.83 m AHD every third year. Higher water levels have been associated with higher barrage outflow volumes in the EWRs (Table 3). A maximum lake level of 0.9 m AHD has been included along with the highest barrage flow volumes in CLLMM4. These higher water levels are expected to satisfy the inundation requirements of *Melaleuca halmaturorum* trees around the Lower Lakes and Coorong (J. Nicol (SARDI) 2015, pers. comm. 13 May).

3.1.4 Water levels in the Coorong South Lagoon

Coorong water levels represent the minimum water level at any given point rather than an average across multiple locations. They should be based on the level at the most southerly point (i.e. Salt Creek gauging station).

Coorong metrics within the EWRs (Table 3) mostly reflect conditions that support the complete life-cycle of *R. tuberosa*, a submerged halophyte that persists mainly in the Coorong South Lagoon. *R. tuberosa* provides vital habitat and food resources for Coorong biota (Paton 2010; DEWNR in prep.), and is an indicator of ecological condition. Coorong *R. tuberosa* populations are in serious decline, with consistent declines in the propagule bank (seeds and turions) since at least 2001 (Rogers and Paton 2009; Paton and Bailey 2013). The timing and duration of optimal water levels in the Coorong South Lagoon were derived from Ye et al. (2014) and expert opinion (D. Paton, D. Rogers and J. Nicol, 13/5/2015). *R. tuberosa* is highly sensitive to desiccation, and must be covered with water in spring–early summer in order for plants to reach sexual maturity and replenish the propagule bank (Paton and Bailey 2013; Ye et al. 2014). As such, water levels need to be higher (0.35-0.45 m AHD) in spring/early summer to support *R. tuberosa* reproduction (i.e. flowering and seed set). The estimated duration of these water levels to support *R. tuberosa* reproduction is ≥120 days (i.e. CLLMM 2). Higher water levels are likely to be maintained for longer periods under high flow EWRs, hence the duration of optimal water levels in spring/summer is estimated as ≥150 days under CLLMM 3 and ≥180 days under CLLMM 4. Coorong water levels are higher in winter due to seasonal sea-level rise and storm surges coupled with seasonal north-westerly winds. Maintaining these water levels throughout spring requires environmental water management. The presence and distribution of *R. tuberosa* will also be impacted by other factors such as salinity, seed bank viability, presence of filamentous green algae, sediment conditions and foraging birds (Paton 2010; Paton and Bailey 2013), which are not addressed here.

Under lower barrage-flow conditions (i.e. EWR CLLMM1), it is probable that the higher water levels needed to prevent desiccation of *R. tuberosa* over summer will be unachievable. This EWR is unlikely to achieve many ecological targets for the Coorong South Lagoon, but the delivery of some freshwater, and maintenance of low water levels, will provide some benefits over zero barrage flows. For example, freshwater flows from the barrages can provide: 1) salinity benefits by reducing intrusions of seawater to the Coorong via the Murray Mouth, 2) low water levels to maintain inundation of South Lagoon mudflats when temperatures and thus evaporation rates are high, and 3) connectivity between the Lakes, Coorong, and Murray Mouth. Water levels of 0.0–0.2 m AHD in September–November may also be adequate to provide some mudflat foraging habitat for migratory shorebirds (Brookes et al. 2009) that are typically present in the Coorong between September–March.

Table 3. CLLMM environmental water requirements for the LTWP.

Timing of barrage flows, lake levels and Coorong South Lagoon water levels include the entire duration of each month specified (i.e. from the beginning of the first month to the end of the final month).

EWR	Average return interval (years)	Maximum interval (years)	Annual barrage flow ($GL.yr^{-1}$)	Barrage flow timing	Lakes water level range (m AHD)	Lakes water level timing	Coorong South Lagoon water level (m AHD)	Coorong South Lagoon water level timing	Coorong South Lagoon duration
CLLMM 1	1-in-1	N/A	>650*	Jul-Jun, with peak barrage outflows in Oct–Dec	0.4–0.75	Maximum lake levels Dec–Feb and minimum lake levels in Mar–May	0.0 to 0.2	Sep– Nov	≥90 days
							-0.2 to -0.4	Feb–Mar	-
CLLMM 2	1-in-2	N/A	>3150**	Jul-Jun, with peak barrage outflows in Oct–Dec	0.4–0.83	Maximum lake levels Dec–Feb and minimum lake levels in Mar–May	0.35–0.45	Sep–Dec	≥120 days
							0 to -0.5	Mar–April	-
CLLMM 3	1-in-3	5	>6000	Jul-Jun, with peak barrage outflows in Oct–Dec	0.4–0.83	Maximum lake levels Dec–Feb and minimum lake levels in Mar–May	0.35–0.45	Sep–Jan	≥150 days
							0 to -0.5	Feb–April	-
CLLMM 4	1-in-7	17	>10,000	Jul-Jun, with peak barrage outflows in Oct–Dec	0.4–0.9	Maximum lake levels Dec–Feb and minimum lake levels in Mar–May	0.35–0.45	Sep–end Feb	≥180days
							n/a	n/a	-

** A total average barrage outflow of 2000 $GL.yr^{-1}$ over a 3-year rolling period (i.e. not less than 6000 GL over three years) and not less than $GL.yr^{-1}$ in any one of the three years (Heneker 2010; Lester et al. 2011)*

*** A total average barrage outflow of 4000 $GL.yr^{-1}$ over a 3-year rolling period (i.e. not less than 12,000 GL over three years) and not less than 3150 $GL.yr^{-1}$ in any one of the three years (Heneker 2010; Lester et al. 2011)*

3.2 Contribution of EWRs to ecological targets

The approach used to establish EWRs captured the requirements of multiple biotic groups and processes (Lester et al. 2011). It recognises the fact that biotic populations are dependent upon a water regime rather than individual events. This is consistent with the approaches of Wallace et al. (2014) and Kilsby and Steggles (2015). However, this means that individual EWRs are not aligned directly with individual ecological objectives and targets. To assist water planning, an expert panel was used to identify the contribution of individual EWRs to ecological targets. A ranking system (Table 4), based on that developed in Wallace et al. (2014), was used to facilitate a rapid assessment of the expected contribution of each EWR to achieving the ecological targets, in acknowledgement that not all EWRs would be expected to meet all targets. This was achieved by technical experts at a workshop held on 13th May 2015 at 100 Pirie St, Adelaide. Workshop participants were familiar with the ecological objectives, targets and EWRs. They were provided with an explanation of the ranking system (Table 4), which was used as a guide to populate Table 5 within five small groups. Each of these groups focused on a different set of targets: 1) waterbirds, 2) fishes, 3) macroinvertebrates, salinity and hydrology and 4) vegetation. Participants were also told to view the EWRs as a regime (i.e. a collective), with the assumption that over a long period the regime would result in the achievement of all ecological objectives and targets. Therefore the purpose was not rank the EWRs based on their contribution to objectives and targets, but to align targets to EWRs that will contribute most to achieving those targets within the broader EWR regime. Workshop participants and organisational affiliations included: Kane Aldridge, Adrienne Rumbelow, Jason Higham, Dan Rogers, Nadine Kilsby, Tracey Steggles, Rebecca Turner and Jan Whittle (DEWNR), David Paton, Todd Wallace, and Scotte Wedderburn (The University of Adelaide), Sabine Dittmann (Flinders University), Qifeng Ye, Jason Nicol and Susan Gehrig (SARDI).

Outputs of the workshop, including brief justifications of why EWRs were expected to contribute at a given ranking, are provided in Table 5. The resulting assessment matrix (Table 5) can be used to support decisions about potential benefits or trade-offs of different flow and water level scenarios. It must be noted that because this ranking system only includes three categories, it can only give an estimate of expected contributions towards the targets. Rank 3 is currently listed as having an unlikely or undetectable contribution, but this ranking may also indicate a decline in condition of some targets. A limitation of this ranking system is that it that all objectives and targets are equal, but in reality the failure to meet one critical requirement (i.e. salinity ranges or Murray Mouth openness) could affect the ability to meet most other targets.

Prior to scoring the contributions of EWR towards achieving ecological targets, a number of important assumptions were identified by workshop participants:

- Antecedent conditions will be a major determinant of the impact of all EWRs. The rankings provided in Table 5 assume that an appropriate flow regime has been provided in previous years (as described by the EWRs). The achievement of targets is based on implementing a flow regime over multiple years and does not reflect the outcome in any one year.
- Low water levels in the Coorong are avoided when temperatures and evaporation rates are high (i.e. in Summer)
- Annual flow regimes are based on annual planning, which considers antecedent climate and hydrological conditions and monitoring of ecological condition.

Thirty-one ecological targets were presented in the workshop, five of which were split and assessed separately by either: 1) fish species (Murray Hardyhead and Yarra pygmy perch) or 2) wetland area (Lower Lakes and Coorong). Consequently, 36 rankings were provided for each EWR (Table 5). Brief justifications of why EWRs were expected to contribute at a given ranking are provided in Appendix I.

Table 4. Ranking system for rapid assessment of the expected contribution of management actions towards ecological objectives and targets (Wallace et al. 2014).

Rank	Requirements or processes met	Contribution towards ecological objectives and targets
1	All or most	Large positive contribution
2	Some	Moderate positive contribution
3	Very few or none	Contribution unlikely to be detectable or expected

Table 5. Expected contribution of EWRs to ecological targets
Scores used to rank expected contributions are described in Table 4. EWR metrics are described in Table 3.

CLLMM Ecological Targets	Species or wetland	EWRs			
		CLLMM 1	CLLMM 2	CLLMM 3	CLLMM 4
1. Abundances, area of occupation, and extent of occurrence of TLM target waterbird species (Appendix D) to be above defined median reference values (median of data from the 15 years between 2000 and 2014)		3	2	1	1
2. Detect annual breeding activity in waterbird species that are expected to breed annually at the site (Appendix E), and frequent breeding activity (at least two breeding events in any four consecutive years) in species that breed regularly at the site (Appendix F).		3	2	1	1
3. Provide functional mudflat habitat to sustain active shorebird foraging behaviour during November–March with a foraging effort of <50%.		3	2	1	1
4. Maintain abundances of 12 waterbird species at or above 1% of the total flyway population size		3	2	1	1
5. A spatio-temporally diverse fish community is present, including representatives of all 23 fish families stated in the Ramsar site draft Ecological Character Description (Appendix H).		2	2	1	1
6. Annual detection of juvenile catadromous fish at abundances ≥ that of defined 'Recruitment Index' values (44.5 for Congolli, and 6.1 for Common galaxias).		2	1	1	1
7. Annual detection of migration for anadromous species (Short-headed and Pouched lamprey) at index values of >0.6.		3	2	1	1
8. Maximise fish passage connectivity between the Lower Lakes and Coorong, and between the Coorong and sea, by allowing fishways to operate year-round.		2	1	1	1
9. Maintain or improve abundances of Murray hardyhead and Pygmy perch so that 'Relative Abundance Index' values of ≥1 are achieved on an annual basis.	Murray hardyhead	1	2	2	2
	Yarra pygmy perch	2	1	1	1
10. Detect annual recruitment success of Murray hardyhead and Pygmy perch at least every second year 10. *(continued)* Detect recruitment success of Murray hardyhead and Pygmy perch at least every second year	Murray hardyhead	1	2	2	2
	Yarra pygmy perch	1	1	1	1
11. Maintain or improve abundances, distribution and recruitment of Black bream and Greenback flounder with population condition score ≥3.	Black bream	2	2	1	1
	Greenback flounder	3	2	1	1

CLLMM Ecological Targets	Species or wetland	EWRs			
		CLLMM 1	CLLMM 2	CLLMM 3	CLLMM 4
12. Facilitate regular recruitment and a broader distribution of juvenile Mulloway.		3	2	1	1
13. Maintain an average Catch-Per-Unit-Effort (CPUE) of Small-mouthed hardyhead sampled in spring–early summer of >120 CPUE for adults, and >790 CPUE for juveniles.		3	2	1	1
14. Maintain the proportional abundance of Small-mouthed hardyhead juveniles at >60% in 75% of defined monitoring sites within the CLLMM		2	1	1	1
15. Macroinvertebrate taxonomic distinctness falls within the expected ranges of a regional reference.	Lower Lakes	2	2	2	2
	Coorong	2	1	1	2
16. The distribution of macroinvertebrate species remains within or above the species-specific reference level for their index of occurrence.	Lower Lakes	2	2	2	2
	Coorong	2	1	1	2
17. The area of occupancy where abundance and biomass are at or above the reference level should be >20% of the monitoring sites.	Coorong	2	1	1	1
18. The macroinvertebrate community has a higher multivariate similarity to the community present in years with than without flow.	Lower Lakes	2	2	2	2
	Coorong	2	1	1	2
19. Median grain size of sediments in the Coorong and Murray Mouth will remain between 125–500 µm.		2	1	1	2
20. Sediment organic matter content between 1–3.5 % dry weight in the Coorong and Murray Mouth.		1	1	2	2
21. A continuous distribution of *Ruppia tuberosa* beds along a 50 km section of the southern Coorong (excluding outliers).		3	2	1	1
22. Within the abovementioned distribution, 80% of the monitored sites should have *Ruppia tuberosa* plants present in winter and summer.		3	2	2	1
23. 50% of sites with *Ruppia tuberosa* to exceed the local site indicators for a healthy *Ruppia tuberosa* population.		3	3	2	1

CLLMM Ecological Targets	Species or wetland	EWRs			
		CLLMM 1	CLLMM 2	CLLMM 3	CLLMM 4
24. Support a resilient *Ruppia tuberosa* population with seed densities of 2000 seeds/m^2 by 2019 and 50% of sites having 60% cover in winter and a seed bank of 10000 seeds/m^2 by 2029 in the Coorong South Lagoon.		3	2	1	1
25. Maintain or improve diversity of aquatic and littoral vegetation in the Lower Lakes as quantified using the CLLMM vegetation indices.		1	1	1	1
27. Barrage outflows sufficient to maintain electrical conductivity in Lake Alexandrina at a long term average of 700 µS.cm^{-1}, below 1000 µS.cm^{-1} in 95% of years and below 1500 µS.cm^{-1} 100% of the time		3	1	1	1
28. To support aquatic habitat: maintain a salinity gradient from 0.5 ppt to 35ppt between the Barrages and Murray Estuary area, <45ppt in the North lagoon, and from 60ppt to 100ppt in the South lagoon	Coorong	2	1	1	1
31. Maintain an open Murray Mouth, as indicated 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	Coorong	3	1	1	1
32. Maintain a minimum annual flow required to keep the Murray Mouth open (730–1090 GL.y^{-1})	Coorong	3	1	1	1

3.3 Ability of EWRs to meet ecological targets

The four EWRs (Table 3) were considered together within a variable hydrological regime to evaluate ecological objectives and targets for the CLLMM LTWP.

The 'low flow' EWR (CLLMM 1) included annual average barrage flows of 2000 $GL.yr^{-1}$ and relatively low spring water levels in the Coorong South Lagoon. Within the regime, this EWR contributed the least towards meeting ecological targets, with mostly low to moderate ranking scores and few large positive contribution scores. Large positive contributions were limited to targets that addressed: aquatic and littoral vegetation, maintaining lake salinities, sediment quality, and some Lower Lakes fish species. This EWR is unlikely to make any detectable contribution towards ecological targets for waterbirds, *R. tuberosa*, some diadromous and Coorong fish species, as well as Murray Mouth flows and openness.

The EWR CLLMM 2 included slightly higher flows of >4000 $GL.y^{-1}$, and higher Coorong South Lagoon water levels in spring–summer. Within the regime this EWR is expected to contribute to a number of additional targets compared to CLLMM 1, when delivered in conjunction with high flow EWRs every 3–17 years (i.e. CLLMM 3 and CLLMM 4). Within the regime, CLLMM 2 provided mostly moderate to large positive contributions towards ecological targets, with only one target (*R. tuberosa* health) assessed as unlikely to receive any ecological contribution.

Within the flow regime presented in Table 3, the approach suggested that large floods contribute significantly towards achievement of the ecological targets. The larger barrage flows provided under these EWRs are expected to result in lowered salinities and higher water levels in the short term. A major benefit of these large flows is to flush accumulated salt from the system, which, when provided at the recommended frequencies, is expected to have long-term benefits for the CLLMM.

The results of this expert assessment indicate that an appropriate flow regime for achieving ecological targets at a low level of risk would include the provision of annual average barrage flows of >4000 $GL.yr^{-1}$, with higher flows of >6000 $GL.yr^{-1}$ every 3–5 years and 10,000 $GL.yr^{-1}$ every 7–17 years. This flow regime would be expected to achieve the prescribed CLLMM ecological objectives and targets.

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5 Appendices

A. The Living Murray programme ecological objectives and targets

The three overarching ecological objectives (First Step Decisions) of the TLM programme in the CLLMM are:

B. An open Murray Mouth,

C. More frequent estuarine fish spawning and recruitment, and

D. Enhanced migratory waterbird habitat in the Lower Lakes and Coorong.

Ecological targets of the TLM programme:

Ecological target	Icon site objective		
	Open mouth	**Fish recruitment**	**Bird habitat**
Maintain or improve bird populations in the Lower Lakes, Coorong and Murray Mouth	Yes	No	Yes
Maintain or improve recruitment success of diadromous fish species in the Lower Lakes and Coorong	Yes	Yes	No
Maintain or improve recruitment success of endangered fish species in the Lower Lakes	No	Yes	No
Provide optimum conditions to improve recruitment success of Small-mouthed hardyhead in the South Lagoon	No	Yes	No
Maintain or improve populations of Black bream, Greenback flounder and Mulloway in the Coorong	Yes	Yes	No
Maintain or improve invertebrate populations in mudflats (both exposed and submerged)	Yes	Yes	Yes
Provide freshwater flows that provide food sources for Goolwa cockles	Yes	No	No
Facilitate frequent changes in exposure and submergence of mudflats	Yes	No	Yes
Maintain habitable sediment conditions in mudflats	Yes	No	Yes
Maintain or improve *Ruppia megacarpa* colonisation and reproduction	No	Yes	Yes
Maintain or improve *Ruppia tuberosa* colonisation and reproduction	No	Yes	Yes
Maintain or improve aquatic and littoral vegetation in the Lower Lakes	No	Yes	Yes
Establish and maintain variable salinity regime with >30% of area below sea water salinity concentrations in estuary and North Lagoon	No	Yes	Yes
Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity	Yes	Yes	Yes
Maximise fish passage connectivity between the Lower Lakes and Coorong	No	Yes	No
Maximise fish passage connectivity between the Coorong and the Southern Ocean	Yes	Yes	No

B. CLLMM monitoring framework objectives

The high-level objectives for this monitoring framework are to:

- Identify priority monitoring activities, budgets and timeframes in accordance with the Australian Government's Due Diligence Assessment Report
- Outline the process of performing monitoring activities for the CLLMM Programme, including fostering Ngarrindjeri and community-based monitoring
- Outline the process for incorporating results of monitoring activities to inform management decisions and actions within the CLLMM site.

By achieving these high level objectives, the monitoring activities identified in this Monitoring Framework will:

1) Gather information in order to provide, or improve the benchmark descriptions of Limits of Acceptable Change for drivers, levers, components and processes of the Coorong and Lower Lakes Wetland Ramsar site

2) Detect changes, or likely change in the ecological character of the site. This will be achieved by:

a) Monitoring extent and condition of wetland types

b) Monitoring Ramsar Significant Biological Components to assess progress in achieving CLLMM ecological objectives.

C. Alignment of TLM targets and ECD content (CPS).

TLM targets were derived from Maunsell (2009). CPS are described in DEWNR (in prep).

	TLM target	CPS
EO1	Maintain or improve bird populations in the Lower Lakes and Coorong	1. Waterbirds – diversity 2. Waterbirds – abundance 3. Waterbirds – breeding 4. Waterbirds – 1% populations 5. Supports priority species
EO2	Maintain or improve recruitment success of diadromous fish in the Lower Lakes Coorong	
EO3	Maintain or improve recruitment success of endangered fish species in the Lower Lakes	Fish – diversity (biodisparity)
EO4	Provide optimum conditions to improve recruitment success of Small-mouthed hardyhead in the South Lagoon	
EO5	Maintain or improve populations of Black bream, Greenback flounder and Mulloway in the Coorong	Fish – diversity (spp. richness)
EO6	Maintain or improve invertebrate populations in mudflats (both exposed and submerged)	
EO7	Provide freshwater flows that provide food sources for Pipis	
EO8	Facilitate frequent changes in exposure and submergence of mudflats	Hydrology – Lake Alexandrina water levels
EO9	Maintain habitable sediment conditions in mudflats	Pollution control and detoxification through trapping, storage and/or treatment of contaminants
EO10	Maintain or improve *Ruppia megacarpa* colonisation and reproduction	Vegetation – submergent halophytes
EO11	Maintain or improve *Ruppia tuberosa* colonisation and reproduction	1. Hydrology – Lake Alexandrina water levels 2. Coorong food web – Ruppia tuberosa
EO12	Maintain or improve aquatic and littoral vegetation in the Lower Lakes	1. Provides physical habitat – diversity and extent of wetland types 2. Vegetation – freshwater submergent communities 3. Vegetation – freshwater emergent vegetation 4. Vegetation – emergent halophytes
EO13	Establish and maintain variable salinity regime with >30% of area below sea water salinity concentrations in estuary and North Lagoon	Salinity – Murray estuary, North and South Lagoon Salinity – Lake Alexandrina
EO14	Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity	1. Special geomorphic feature – Murray Mouth 2. Hydrology – Lake Alexandrina water levels
EO15	Maximise fish passage connectivity between the Lower Lakes and Coorong	Hydrology – Lake Alexandrina water levels

	TLM target	CPS
EO16	Maximise fish passage connectivity between the Coorong and the Southern Ocean	
EO17	Maintain or improve invertebrate populations in mudflats (both exposed and submerged)	

D. TLM target waterbird species

Species list sourced from Maunsell (2009)

- Australasian Bittern (*Botaurus poiciloptilus*)
- Australian Pelican (*Pelecanus conspicillatus*)
- Australian Spotted Crake (*Porzana tabuensis*)
- Banded Stilt (*Cladorhynchus leucocephalus*)
- Black Swan (*Cygnus atratus*)
- Chestnut Teal (*Anas castanea*)
- Common Greenshank (*Tringa nebularia*)
- Curlew Sandpiper (*Calidris ferruginea*)
- Fairy Tern (*Sterna nereis*)
- Latham's Snipe (*Gallinago hardwickii*)
- Pied Oystercatcher (*Haematopus longirostris*)
- Red-capped Plover (*Charadrius ruficapillus*)
- Red-necked Avocet (*Recurvirosta novaehollandiae*)
- Red-necked Stint (*Calidris ruficollis*)
- Sanderling (*Calidris alba*)
- Sharp-tailed Sandpiper (*Calidris acuminata*).

E. Waterbird species that breed annually in the CLLMM

Species list sourced from DEWNR (in prep.)

- Australian Pelican (*Pelecanus conspicillatus*)
- Black Swan (*Cygnus atratus*)
- Caspian Tern (*Hydropogne* (*Sterna*) *caspia*)
- Crested Tern (*Thalasseus bergii*)
- Fairy Tern (*Sterna nereis nereis*)
- Hooded Plover (*Thinornis rubricollis*)
- Australian White Ibis (*Threskiornis molucca*)
- Australian Pied Oystercatcher (*Haematopus longirostris*)
- Sooty Oystercatcher (*Haematopus fuliginosus*)
- Red-capped Plover (*Charadrius ruficapillus*)
- Straw necked Ibis (*Threskiornis spinicollis*)

F. Waterbird species that breed regularly in the CLLMM

Species list sourced from DEWNR (in prep.)

- Pied Cormorant (*Phalacrocorax varius*)
- Royal Spoonbill (*Platalea regia*)
- Silver Gull (*Chroicocephalus novaehollandiae*)

G. 12 waterbird species that should be present at the site in abundances >1% of current flyway thresholds

Source O'Connor (2015)

Common name	Scientific name
Fairy Tern	*Sterna nereis nereis*
Australian Pelican	*Pelecanus conspicillatus*
Australian Pied Oystercatcher	*Haematopus longirostris*
Banded Stilt	*Cladorhynchus leucocephalus*
Chestnut Teal	*Anas castanea*
Curlew Sandpiper	*Calidris ferruginea*
Great Cormorant	*Phalacrocorax carbo carboides*
Red-necked Avocet	*Recurvirostra novaehollandiae*
Red-necked Stint	*Calidris ruficollis*
Sharp-tailed Sandpiper	*Calidris acuminata*
Red-capped Plover	*Charadrius ruficapillus*
Sanderling	*Calidris alba*

H. 23 common CLLMM fish families (and associated indicator species)

Families list sourced from DEWNR (in prep.)

Family	Scientific name	Common name
Anguillidae	*Anguilla australis*	Southern shortfin eel
Arripidae	*Arripis georgianus*	Australian herring
Arripidae	*Arripis truttaceus*	Western Australian salmon
Atherinidae	*Atherinosoma microstoma*	Smallmouth hardyhead
Atherinidae	*Craterocephalus fluviatilus*	Murray hardyhead
Atherinidae	*Craterocephalus stercusmuscarum fulvus*	Unspecked hardyhead
Bovichtidae	*Pseudaphritis urvillii*	Congolli
Clupeidae	*Hyperlophus vittatus*	Sandy sprat
Clupeidae	*Nematolosa erebi*	Bony herring
Clupeidae	*Sardinops sagax*	Australian pilchard
Clupeidae	*Spratelloides robustus*	Blue sprat
Eleotridae	*Hypseleotris spp.*	Carp gudgeon complex
Eleotridae	*Philypnodon grandiceps*	Flat-headed gudgeon
Eleotridae	*Philypnodon macrostomus*	Dwarf flat-headed gudgeon
Engraulidae	*Engraulis australis*	Australian anchovy
Galaxiidae	*Galaxias maculatus*	Common galaxias
Geotriidae	*Geotria australis*	Pouched lamprey
Gobiidae	*Afurcagobius tamarensis*	Tamar goby
Gobiidae	*Arenigobius bifrenatus*	Bridled goby
Gobiidae	*Favonigobius lateralis*	Southern Longfin Goby
Gobiidae	*Pseudogobius olorum*	Bluespot goby
Gobiidae	*Tasmanogobius lasti*	Lagoon goby
Hemiramphidae	*Hyporhamphus melanochir*	Southern garfish
Hemiramphidae	*Hyporhamphus regularis*	River garfish
Melaenotaenidae	*Melanotaenia fluviatilis*	Murray rainbowfish
Mordaciidae	*Mordacia mordax*	Short-headed lamprey
Mugilidae	*Aldrichetta forsteri*	Yelloweye mullet
Mugilidae	*Liza argentea*	Goldspot mullet
Mugilidae	*Mugil cephalus*	Sea mullet
Myliobatidae	*Myliobatis australis*	Southern eagle ray
Nannopercidae	*Nannoperca australis*	Southern pygmy perch
Nannopercidae	*Nannoperca obscura*	Yarra pygmy perch
Percichthyidae	*Macquaria ambigua*	Golden perch
Pleuronectidae	*Ammotretis rostratus*	Longsnout flounder
Pleuronectidae	*Rhombosolea tapirina*	Greenback flounder
Retropinnidae	*Retropinna semoni*	Australian smelt
Sciaenidae	*Argyrosomus japonicus*	Mulloway
Sparidae	*Acanthopagrus butcheri*	Black bream
Tetraodontidae	*Contusus brevicaudus*	Prickly toadfish
Tetraodontidae	*Contusus richei*	Barred toadfish
Tetraodontidae	*Tetractenos glaber*	Smooth toadfish
Tetrarogidae	*Gymnapistes marmoratus*	Soldier

I. Brief justifications of why EWRs were expected to contribute at a given ranking (Table 5)

The following brief justifications of EWR rankings should be considered within the broader flow regime (i.e. including both lower annual flows, and high flow events every 3–17 years).

EWR CLLMM 1

Suggested EWR CLLMM 1:

Average return interval	Max interval	Annual Barrage flow (GL)	Lakes water level range (m AHD)	Coorong South Lagoon water level (m AHD)	Coorong South Lagoon timing	Coorong South Lagoon duration
1-in-1	N/A	>650*	0.4–0.75	0.0 to 0.2	Sep–Nov	≥90 days
				-0.2 to -0.4	Feb–Mar	-

** A total average barrage outflow of 2000 GL.y^{-1} over a three year rolling period (i.e. not less than 6000 GL over three years) and not less than 650 GL.y^{-1} in any one of the three years (Heneker 2010; Lester et al. 2011)*

Expected ecological contribution

Waterbirds

Flows provided under this EWR are generally considered inadequate to maintain the abundance, distribution, breeding activity and foraging resources for CLLMM waterbirds. Annual barrage flows at an average 2000 GL.y^{-1} (minimum of 650 GL in any one year within a 3-year period) are likely to lead to long-term increases in CLLMM salinities and decrease the availability of primary prey resources (e.g. Ruppia, fishes and macroinvertebrates) required by waterbirds. Low water levels may also cause island nesting sites to become accessible to mammalian predators (i.e. foxes and cats), which is known to increase nesting failure for CLLMM waterbirds. It should be noted that annual variation in CLLMM waterbird populations is only partly driven by local conditions and may also be affected by conditions at wetlands at a regional, national or international scale. Differences in rankings for waterbird targets (for all EWRs) are based on changes within the Coorong, as it is considered to be a distinct, and highly responsive area within the MDB (D. Paton. (University of Adelaide), and D. Rogers (DEWNR) 2015, pers. comm. 13 May).

Fishes

Conditions provided by this EWR are likely to have a varied impact on the various fish taxa present within CLLMM wetlands. For example, minimal/no positive contribution is expected for diadromous fish if low winter flows result in decreased migration between saline–freshwater habitats. Poor outcomes are also expected for Small-mouthed hardyhead (Catch-Per-Unit-Effort) and Mulloway recruitment due to increased salinity in the Coorong. Other Coorong fish, such as Black bream and Greenback flounder are likely to show a moderate positive response to average annual barrage flows of 2000 GL.y^{-1}. Populations of Murray hardyhead and Yarra pygmy perch, however, are likely to be relatively abundant and experience regular recruitment success in the Lower Lakes if this EWR is achieved. The Murray hardyhead has unusual salinity preferences and is likely to have has a better ecological response within this low flow EWR.

CLLMM 1 has only a moderate contribution towards achieving the ecological target for juvenile Small-mouthed hardyhead abundance (all other EWRs have a large positive contribution towards this target. This ranking is based on expected outcomes in the Coorong South Lagoon, where low barrage flows are likely to lead to Coorong salinities in excess of 120ppt (which is above the preferred salinity range for this species).

Macroinvertebrates and mudflats

The flows provided by CLLMM 1 are likely to have a moderate positive effect on macroinvertebrates in the Lower Lakes and Coorong. Under these conditions, macroinvertebrate abundance, distribution, taxonomic distinctiveness and community similarity should show some improvement from baseline conditions, mainly due to improvements in salinity and water levels over benthic habitat. Macroinvertebrate populations in the Lower Lakes are unlikely to change in response to the different EWRs (and are ranked equally as having a 'moderate' contribution), however expert confidence in this ranking is low, and the relationship requires further investigation (S. DIttmann (Flinders University) 2015, pers. comm. 13 May). Mudflat quality is expected to be moderate-high under this EWR, with a high likelihood of containing adequate sediment organic matter.

Vegetation

The flows and lake levels provided by all four CLLMM EWRs are likely to have a large positive contribution to the maintenance or improvement of aquatic and littoral vegetation in the Lower Lakes. Lake levels can be effectively managed under all four EWRs, which will allow for the maintenance of appropriate water levels and lake salinities for vegetation communities of the Lower Lakes. These rankings were provided under the assumption that water level variability within all EWRs is appropriate for recruitment. Low and/or static water levels are likely to occur when annual barrage flows fall below 650 $GL.y^{-1}$, which may lead to poorer outcomes.

Salinity and Murray Mouth openness

CLLMM 1 provides conditions that are likely to lead to long-term salinities of 1000 $\mu S.cm^{-1}$ in Lake Alexandrina. This is higher than the optimal modelled salinity of 700 $\mu S.cm^{-1}$, which is unlikely to be met under this EWR. Barrage flows are, however, expected to provide moderate contributions towards maintaining the preferred salinity gradient within the Murray Mouth and Coorong Lagoons, but are inadequate to maintain Murray Mouth flows and 'openness' at expected levels. There is low certainty in the ranking given to target 23: 'Salinities within the North Lagoon should range from 3 to 70 ppt during all months of the year' because salinities will be at the upper end of the target range.

EWR CLLMM 2

Suggested EWR CLLMM 2:

Average return interval	Max interval	Annual Barrage flow (GL)	Lakes water level range (m AHD)	Coorong South Lagoon water level (m AHD)	Coorong South Lagoon timing	Coorong South Lagoon duration
1-in-2	N/A	>3150**	0.4-0.83	0.35–0.45	Sep–end Dec	≥120 days
				0 to -0.5	Mar–April	-

*** A total average barrage outflow of 4000 $GL.y^{-1}$ over a 3-year rolling period (i.e. not less than 12,000 GL over three years) and not less than 3150 $GL.y^{-1}$ in any one of the three years (Heneker 2010; Lester et al. 2011)*

Expected ecological contribution

Waterbirds

Conditions provided by CLLMM 2 were scored as having an overall moderate positive contribution toward maintaining the abundance, distribution, breeding activity and foraging resources for CLLMM waterbirds. This is largely due to similar improvements in rankings for salinity targets as well as prey resources including Coorong fishes, R. tuberosa, and Coorong macroinvertebrates.

Fishes

CLLMM 2 is expected to provide conditions that have a moderate to large positive contribution towards achieving fish targets. Significant improvements (a change from undetectable to moderate contribution) are expected for Small-mouthed hardyhead (Catch-Per-Unit-Effort) and Mulloway recruitment, due to improved salinity outcomes. Juvenile Small-mouthed hardyhead are expected to be abundant within the water-level and salinity conditions provided by this EWR. A similar improvement in ranking scores was also described for detection of migration for diadromous species, due to the increased likelihood of connectivity and adequate winter flows, which are required for winter migration. Fishways plus significant attractant flow can be operated year-round with the annual barrage flows provided by CLLMM 2.

Macroinvertebrates and Mudflats

Coorong macroinvertebrate populations are likely to improve as a result of the higher barrage flows and water levels provided under CLLMM 2 (compared to CLLMM 1). Grain size and organic matter content of sediment in the Coorong is most likely to be within the optimal ranges under CLLMM 2.

Vegetation

R. tuberosa distribution and resilience are likely to be improved under CLLMM 2 (compared to CLLMM 1), although there is still unlikely to be a detectable change in indicators of *R. tuberosa* health. Moderate contributions to distribution and resilience are expected mainly due to the increase in Coorong South Lagoon water levels over spring–summer so that plants remain submerged when flowering. Note there are two populations of *R. tuberosa* in the Coorong, and only one will remain inundated under CLLMM 2. Aquatic and littoral vegetation in the Lower Lakes is expected to be diverse and have high seedbank quality under all EWRs.

Salinity and Murray Mouth 'openness'

Lakes salinity targets are met under all four EWRs, but Coorong salinities should also be met under CLLMM 2, providing an appropriate salinity gradient from freshwater to hypersaline within the system. Murray Mouth flows and openness are significantly improved under the increased barrage flows provided by CLLMM 2 (compared to CLLMM 1). It must also be noted that Murray Mouth openness in any given year will be affected by preceding conditions (indeed, this statement applies to all EWRs).

EWR CLLMM 3

Suggested EWR CLLMM 3:

Average return interval	Max interval	Annual Barrage flow (GL)	Lakes water level range (m AHD)	Coorong South Lagoon water level (m AHD)	Coorong South Lagoon timing	Coorong South Lagoon duration
1-in-3	5	>6000	0.4–0.83	0.35–0.45	Sep–end Jan	≥150 days
				0 to -0.5	Jan–April	-

Expected ecological contribution

Waterbirds

CLLMM waterbirds are expected to be common, and present within expected distribution ranges within the CLLMM when long-term hydrological patterns include larger flows as described in CLLMM 3 and CLLMM 4. Large flows may reduce presence or activity of some waterbird species in the short-term, for example if Coorong water levels are too high for shorebirds to access benthic prey resources during peak wader visitation periods. However, the long-term benefits of these large flows (i.e. flushing accumulated salt) outweigh short-terms costs. As discussed previously, depending on their ecology, many waterbird species may be affected (positively or negatively) by conditions at other wetlands. The cause of local waterbird population changes may therefore include off-site factors.

Fishes

This EWR is expected to have the most significant positive contribution towards meeting ecological targets for fishes. Under these conditions, target species are expected to be common, with adequate recruitment and access to freshwater, estuarine and saline environments during different stages of their life cycle. Murray hardyhead are the only target species to only receive a moderate and not a large positive contribution from this EWR (due to its distinctive salinity preferences).

Macroinvertebrates and mudflats

As per CLLMM 2, but sediment organic matter is expected to receive only a moderate and not a large positive contribution from this EWR.

Vegetation

This EWR is expected to support a resilient *R. tuberosa* population (with adequate seedbanks), and a continuous distribution of *R. tuberosa* along a 50 km long section of the southern Coorong. *R. tuberosa* health is expected to have improved over conditions expected for CLLMM 1 and 2, but requires even larger barrage flows (and resulting Coorong water levels) to receive 'large' positive benefits. This EWR (and CLLMM 4) will provide long-term benefits for *R. tuberosa* in the Coorong by flushing out accumulated salt, and providing adequate water levels for long durations while *R. tuberosa* undergoes sexual reproduction. Aquatic and littoral vegetation in the Lower Lakes is expected to be diverse and have high seedbank quality under all EWRs.

Salinity and Murray Mouth openness

As per CLLMM 2

EWR CLLMM 4

Suggested EWR CLLMM 4:

Average return interval	Max interval (yrs)	Annual Barrage flow (GL)	Lakes water level range (m AHD)	Coorong South Lagoon water level (m AHD)	Coorong South Lagoon timing	Coorong South Lagoon duration
1-in-7	17	>10,000	0.4–0.9	0.35–0.45	Sep–end Feb	≥180 days
				n/a	Jan–April	-

Expected ecological contribution

Waterbirds

As per CLLMM 3

Fishes

As per CLLMM 3

Macroinvertebrates and mudflats

Some macroinvertebrate targets achieved slightly worse outcomes under a regime that includes large flow events, as large floods can be a significant disturbance to the salinity gradient within the Coorong. However, the long-term benefits of these large flows (i.e. flushing accumulated salt) outweigh short-terms costs.

Vegetation

The larger annual barrage flows, and resulting Coorong salinities and water levels provided by this EWR are expected to have the greatest positive impact on *R. tuberosa* populations. Large positive contributions are expected towards all four *R. tuberosa* targets.

Salinity and Murray Mouth openness

As per CLLMM 3, however the maintenance of a salinity gradient between discharge locations (i.e. Target 28) is expected to receive only a 'moderate' and not a 'large' positive contribution from this EWR.

Government of South Australia

Department of Environment, Water and Natural Resources