Ecological objectives, targets and environmental water requirements for the South Australian River Murray floodplain priority environmental asset

DEWNR Technical report 2015/15

Government of South Australia
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

Aquatic zone	Defined here as that part of the floodplain that retains, rather than sheds, water (*cf.* the shedding zone)
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.
e-water	Environmental water (see below)
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
EWP	Environmental Water Provisions are that part of the environmental water requirements that can be met. They may refer to: • unregulated flows in rivers and water in wetlands and aquifers • specific volumetric allocations and/or releases from storages • water levels maintained in wetlands • water in transit for other users, the pattern of flow of which may be defined to meet an environmental need.
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.
LLCMM	Lower Lakes, Coorong and Murray Mouth
LTWP	Long Term Watering Plan, to be developed for priority environmental assets identified under the *Basin Plan*
Managed floodplain	That part of the floodplain that may be influenced by active management of environmental water either through releases of held environmental water from storages or changes in dam storage operations. MDBA modelling indicates that QSA 80,000 ML/day is the maximum flow at which this can occur (subject to constraints measure in upstream areas). *For the purposes of this document, the managed floodplain is equivalent to the floodplain priority environmental asset.*
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.*
SAAE	South Australian Aquatic Ecosystems (Wetland Classification Project) (Jones and Miles, 2009)
SARM	South Australian River Murray
SARM channel	The South Australian River Murray main channel, defined for the purposes of this document 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 this document 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.
Shedding floodplain	Defined here as that that part of the floodplain that will shed, rather than retain water (*cf.* the aquatic zone)
QSA	The River Murray's discharge at the New South Wales–Victorian–South Australian border

Summary

South Australia is required to develop a Long Term Watering Plan (LTWP) for the South Australian River Murray (SARM) Water Resource Plan Area. The LWTP must identify priority environmental assets and priority ecosystem functions and associated objectives, targets and environmental water requirements (EWRs). Priority environmental assets (and objectives and targets) will provide the basis for environmental water planning and delivery within South Australia, and evaluating environmental outcomes of the Murray-Darling *Basin Plan*.

After consideration of a number of different spatial scales, to promote a holistic approach to management across the region the following have been defined for the SARM LTWP:

- The whole SARM floodplain, from the South Australian border to Wellington, above the area inundated by 40,000 ML.day^{-1} (QSA), will be considered a single *environmental asset*.

- Per the Basin Plan definition (s8.49), the *priority environmental asset* is that component of the floodplain that can be managed with environmental water (that is, the managed floodplain). Currently, the upper threshold for environmental water management through active releases or changes in storage operations is considered to be 80,000 ML.day^{-}1 (QSA). The SARM floodplain priority environmental asset is therefore the area that is inundated by flows between 40,000 and 80,000 ML.day^{-1} QSA.

In developing ecological objectives for the priority environmental asset a number of factors were considered: ecosystem responses to flow events on the SARM floodplain; the *Basin Plan* vision; the Basin-wide Environmental Watering Strategy (MDBA, 2014b); and consistency with existing ecological objectives and targets for floodplain sites within the SARM floodplain. Critical processes (considering life stages and characteristics) were identified when developing targets that will be used to assess the progress towards achieving ecological objectives. Twenty-two ecological objectives and 42 quantitative ecological targets were developed, focussing on vegetation, fish, other fauna and abiotic components.

The floodplain EWRs flow metrics were developed using the following procedure:

1. Timing and duration – broad values were identified based on the needs of floodplain biota and ecosystem processes. Spring/Summer was recommended as the best timing, and durations of 30, 60, 90 and 120 days were identified as key durations.

2. Discharge – discharges of 10,000 ML.day^{-1} increments were used to represent step-wise increases in the area of floodplain inundated (from 40,000 ML.day^{-1} to 80,000 ML.day^{-1}).

3. Frequency – the duration, timing and discharge metrics were used to model long-term average return frequencies based on modelled 'without development' flow data. This resulted in frequency metrics of 1 in 1.6, 2.0, 2.6, 3.6 and 7.6 years.

4. Rate of water level rise and fall – a rate at which the water level should change was identified based on the needs of floodplain biota and geomorphic processes. The recommended maximum rate of rise is 0.05 m.day^{-1}, and the maximum rate of fall is 0.025 cm.day^{-1}.

The following five floodplain EWRs were described.

EWR	Discharge range ($ML.day^{-1}$)	Median discharge ($ML.day^{-1}$)	Duration (days)	ARI (years)	Max rate of water level rise ($m.day^{-1}$)	Max rate of water level fall ($m.day^{-1}$)	Maximum interval (years)	Timing
FP1	45,000-55,000	50,000	30	1.6	0.05	0.025	5	Sep-Dec
FP2	55,000-65,000	60,000	30	2.0	0.05	0.025	5	Sep-Dec
FP3	65,000-75,000	70,000	30	2.6	0.05	0.025	5	Sep-Dec
FP4	75,000-85,000	80,000	30	3.6	0.05	0.025	5	Sep-Dec
FP5	75,000-85,000	80,000	60	7.6	0.05	0.025	8	Sep-Dec

A ranking system, based on that developed in Wallace et al. (2014b) was used to facilitate a rapid assessment of the expected contribution of each EWR to achieving the ecological targets. This assessment was performed using relevant experts within a workshop setting. The resulting assessment matrix can be used to support decisions about potential benefits or trade-offs of different flow and water level scenarios.

1 Introduction

1.1 Context

South Australia is required to develop a Long Term Watering Plan (LTWP) for the South Australian River Murray (SARM) Water Resource Plan Area, as described in Chapter 8 of the Murray-Darling *Basin Plan*. The LWTP should identify priority environmental assets and priority ecosystem functions and associated ecological objectives, targets and environmental water requirements (EWRs) (Section 8.19 of the *Basin Plan*). The objectives and targets of the priority environmental assets will provide the basis for evaluating environmental outcomes of the *Basin Plan* and environmental water (e-water) within South Australia. The EWRs will provide the basis for (e-water) planning and delivery for achieving these objectives and targets. The concept of EWRs stems from the recognition of the flow regime of a river (or water regime, in the case of a wetland) as the principal driver of the ecological condition of aquatic ecosystems (e.g. Bunn and Arthington, 2002), and thereby the principal driver for environmental outcomes of the *Basin Plan*.

The purpose of this discussion paper is to establish the ecological objectives and targets and EWRs for the floodplain priority environmental asset of the SARM. Enhanced flows are essential for achieving environmental outcomes within the SARM, but other factors (e.g. land management, environmental works and fishing quotas) may also influence environmental outcomes within the SARM. The paper does not consider planning for complementary management actions as they are beyond the scope of establishing EWRs.

The information presented here should be considered part of an adaptive management process and should be updated following monitoring and evaluation of environmental outcomes of the Basin Plan.

1.2 Recommended environmental asset

1.2.1 Background

Section 8.49 of the *Basin Plan* specifies that environmental assets should meet at least one assessment indicator for any of five criteria in Schedule 8 of the *Basin Plan*, namely:

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

The *Basin Plan* describes *priority environmental assets* as environmental assets that can be managed with environmental water (Section 8.49), but provides no guidance as to the appropriate spatial scale.

Using the above criteria, the *Guide to the Proposed Basin Plan* identified 130 Key Environmental Assets (KEAs) in the SARM. This site-based approach has some limitations for management, including overlap in the spatial scales (i.e. individual wetlands identified as KEAs were part of larger KEAs), increased effort required for planning and potential for water planning to be inconsistent with the scales at which ecosystems processes occur. The spatial scale for defining priority environmental assets has important implications for environmental water management, so that an assessment of the appropriate scale is warranted (see also Section 1.2.3).

1.2.2 Other priority environmental assets within the South Australian River Murray

There are currently two priority environmental assets defined for the SARM; the river channel, and the region of the Lower Lakes, Coorong and Murray Mouth (LLCMM). Neither of these cover the floodplain of the SARM.

The River Murray Channel is a priority environmental asset, extending from the South Australian Border to Wellington (Wallace *et al*., 2014a, b), and defined as the area inundated up to a discharge at the South Australian border (SA) border (QSA) of 40,000 ML.day^{-1}. The channel's importance to the SARM, its spatial extent, its inclusion as a TLM icon site (see also MDBC (2006) and the fact that it meets the criteria of priority environmental assets warrant its status as a priority environmental asset. A suite of objectives, targets and EWRs have been developed for the River Murray Channel (Wallace *et al*., 2014a, b).

The LLCMM is also a priority environmental asset within South Australia. The ecological importance of LLCMM to the SARM, its spatial extent and the fact that it meets the criteria of priority environmental assets (as well as being a The Living Murray (TLM) Icon site and Ramsar-listed *Wetland of International Significance*) warrant its status as a priority environmental asset. A suite of objectives, targets and EWRs have been developed through the Murray Futures LLCMM project and the Living Murray Icon Site programme (Lester *et al.,* 2011a, b; MDBA, 2014a).

1.2.3 Recommended spatial scale for floodplain environmental asset(s)

Various spatial scales could be used for defining environmental assets of the SARM floodplain for the LTWP. The selection of an appropriate scale is challenging, as there are multiple management 'levers' to deploy environmental water on the floodplain (e.g. flow provisions, weir pool manipulation, regulator operations, pumping), all of which operate at different spatial scales. Scales could include:

- Floodplain units – over 100 of these asset units were listed as Key Environmental Assets within the SARM for the *Guide to the Proposed Basin Plan*.
- Landscape scale hydrological management units – defined as the weir-pool reaches (e.g. Locks 1-6, barrages), as well as Chowilla (which has a separate environmental regulator).
- Geomorphic units – geomorphic tracts recognised within the SARM include: the Valley Tract, the Gorge Tract, the Swampland Tract and the Lower Lakes.
- Habitats – could be broken down into types (for example: "shedding floodplain", "temporary wetland" and "temporary channel").
- Flow bands – areas defined by specific flowbands, such as the areas inundated at flows between 50,000 and 60,000 ML.day^{-1}.
- Whole floodplain – from the New South Wales–Victorian–South Australian border to Wellington, and from the river bank to the limit of the 1956 flood level.

Each option has advantages and disadvantages for environmental water management (Appendix A).

In this paper, the whole SARM floodplain (from the SA border to Wellington) will be considered a single *environmental asset*, with the *priority environmental asset* being that component of the floodplain which can have environmental water delivered to it (the managed floodplain). Currently, this is considered the area inundated between 40,000 and 80,000 ML.day^{-1} (flows below 40,000 ML.day^{-1} define the River Murray Channel); it is not likely to be operationally feasible to deliver environmental water at flows above about 80,000 ML.day^{-1}.

The recommended spatial scale would ensure that a holistic approach is taken to water planning and evaluation, such that outcomes desired and achieved at smaller scales contribute to outcomes at the larger scale. This would allow for an objective evaluation of environmental outcomes of the *Basin Plan* on the SARM floodplain, as the evaluation would not focus solely on sites managed through the operation of infrastructure (weirs, regulators, pumps).

Alternatively, if the priority environmental assets were site-based and the sites were managed through the operation of regulatory structures (e.g. Chowilla, Pike and Katarapko), an evaluation of outcomes would not reflect the condition of the broader SARM floodplain. Other advantages are:

- It is at a consistent spatial scale influenced by environmental water provisions (the primary 'lever' of achieving environmental outcomes of the *Basin Plan*), but allows for the contributions of smaller scale levers to be scaled up.
- It is likely to be less intensive for planning and for reporting on outcomes (a large number of sites will require objectives, targets and EWRs to be developed and evaluated and may provide some challenges when implementing the environmental management framework). Furthermore, a large number of assets may provide challenges when implementing the environmental management framework (Part 4, Chapter 8 of the *Basin Plan*).
- It is less intensive for environmental water accounting.
- It is consistent with the scales of the SARM channel and LLCMM priority environmental assets (see Section 1.2.2).

The possible issues identified with this approach include:

- The risk of not representing variation in habitat distribution across the floodplain, or between geomorphic reaches.
- The ability to use management levers (such as weir pool manipulation or floodplain/wetland regulators) that produce localised spatial differences in outcomes may be reduced.
- It may be more difficult to secure water for localised watering actions if a whole floodplain approach is promoted.

On balance, the advantages of recommending a whole-floodplain approach are considered greater than potential issues.

1.3 Planning framework and methodology

To assist in the process of determining ecological objectives, targets and EWRs for the SARM floodplain, a planning framework was developed (Figure 1-1). Each component is discussed later, but a summary is provided here.

While 'the whole floodplain' meets the *Basin Plan* criteria for an environmental asset (as above), the capacity to deliver e-water (currently up to about 80,000 $ML.day^{-1}$) is used to distinguish between the *environmental asset* and the *priority environmental asset* (the managed floodplain).

Ecosystem responses to flow events on the SARM floodplain, as well as the *Basin Plan* vision and environmental watering strategy (MDBA, 2014b), are considered in developing ecological objectives for the priority environmental asset (the managed floodplain). Critical processes (such as life stages and characteristics) are considered when developing targets that will be used to assess the progress of the ecological objectives.

The flow regime (and the related water regime) is the critical driver of the SARM floodplain ecosystem. The environmental water requirements (EWRs) of the managed floodplain have been calculated by identifying key flow metrics of a modelled *without development* flow regime. The issue of how the EWRs will contribute to the likelihood of achieving the ecological objectives and targets is also explored.

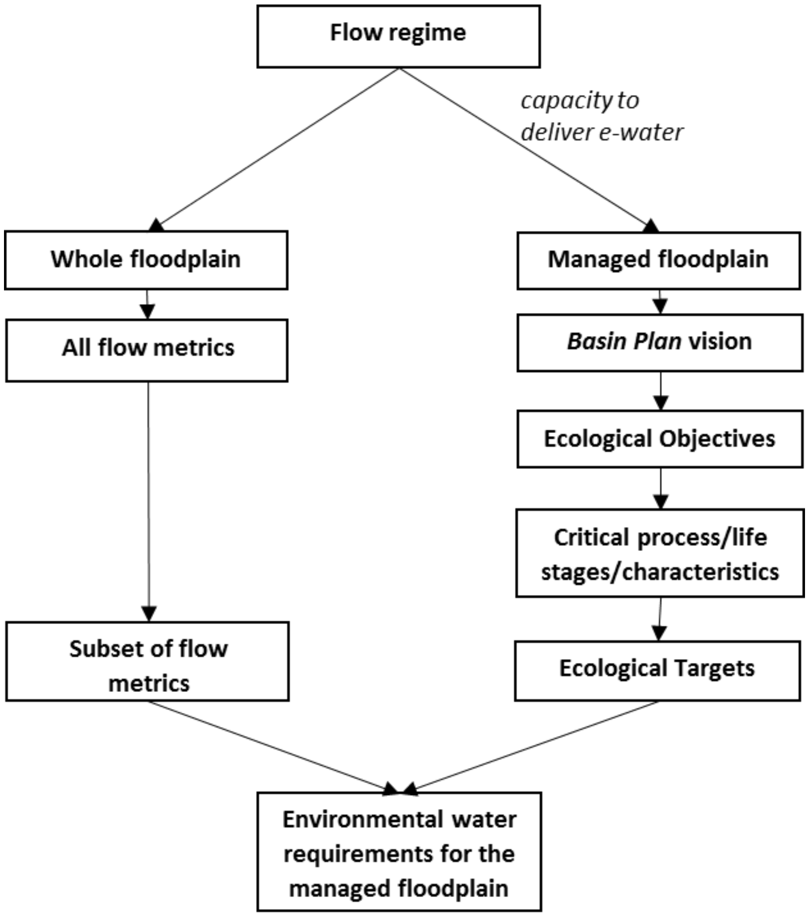

Figure 1-1 The planning framework used to develop the ecological objectives, targets and EWRs for the managed floodplain.

2 The South Australian River Murray floodplain

2.1 Overview

The SARM floodplain comprises a mosaic of water-dependent and terrestrial habitats, including temporary wetlands, River Red Gum woodlands, Black Box woodlands, Lignum shrublands, terrestrial shrublands and samphire shrublands. The flow regime of the River Murray has historically been a primary driver of the distribution and abundance of ecological communities in these habitats, interacting with the morphology of the channel and floodplain, shedding or retaining water and recharging groundwater. The floodplain (with the river channel) supports many water-dependent biota, including 22 species of native fish, 11 species of frogs, waterbirds and many macroinvertebrates, as well as woodland-dependent birds, reptiles and mammals.

Determining ecological objectives requires an understanding of the floodplain ecosystem, the historic *without development* flow regime, the ways that the ecosystem responds to flow events, the spatial distribution of habitats (vegetation and aquatic environment) with respect to inundation and the preferred water regime of ecosystem components.

2.2 The South Australian River Murray flow regime

The flow regime of a river refers to the long-term generalisation of the discharge at a site or region (Puckridge *et al.*, 1998). In an unmodified river system, the flow regime will directly influence the water regime – the long-term generalisation of water depth (level) at a site. On the floodplain it is often the water regime that has greater ecological meaning, being a direct expression of conditions experienced by floodplain biota (e.g. the water within a floodplain wetland) compared to the discharge per se. The interaction between flow regime and water regime within the SARM has been complicated by the presence and operation of weirs, whereby a change in discharge does not necessarily lead to a corresponding change in water level. This disconnect is felt most acutely at lower discharges, with the influence of weirs diminishing at higher discharges.

The flow regime of the SARM displays strong inter-year flow variability (Walker and Thoms, 1993); annual flows vary from 1530 GL to 46,195 GL (Figure 2-1), with wet spells (e.g. 1950s, 1974–75) and dry spells (e.g. Federation Drought, 1895–1902; Millennium Drought, 1997–2010). This variability has shaped the life-history characteristics of many of the native biota. Peak seasonal flows occur in spring; this was true of the historic natural regime, and the peak remains, although much reduced, as part of the present regime (Figure 2-2).

River regulation, including the operation of weirs and barrages and the extraction of water for irrigation, stock and domestic use, has profoundly changed the flow regime of the Murray (Leblanc *et al.* 2012; Maheshwari *et al.*, 1995; Walker and Thoms, 1993) (Table 2-1). One of the greatest impacts has been on the frequency and duration of mid-sized floods. For example, a discharge of 60,000 $ML.day^{-1}$ for 30 days formerly had a pre-development Average Return Interval (ARI) of 1 in 1.9 years, but this has reduced to the current (pre-*Basin Plan* implementation) level of 1 in 6.7 years. Similarly, a discharge of 80,000 $ML.day^{-1}$ for 30 days has reduced from an ARI of 1 in 4 years to 1 in 14.3 years. The same trend is highlighted by the average monthly flows shown in Figure 2-2, where the magnitude of the spring pulse has more than halved. The altered flow regime has reduced the frequency and extent of watering events for biota on the floodplain, affecting the condition, recruitment and demography of many species (e.g. Walker, 2006).

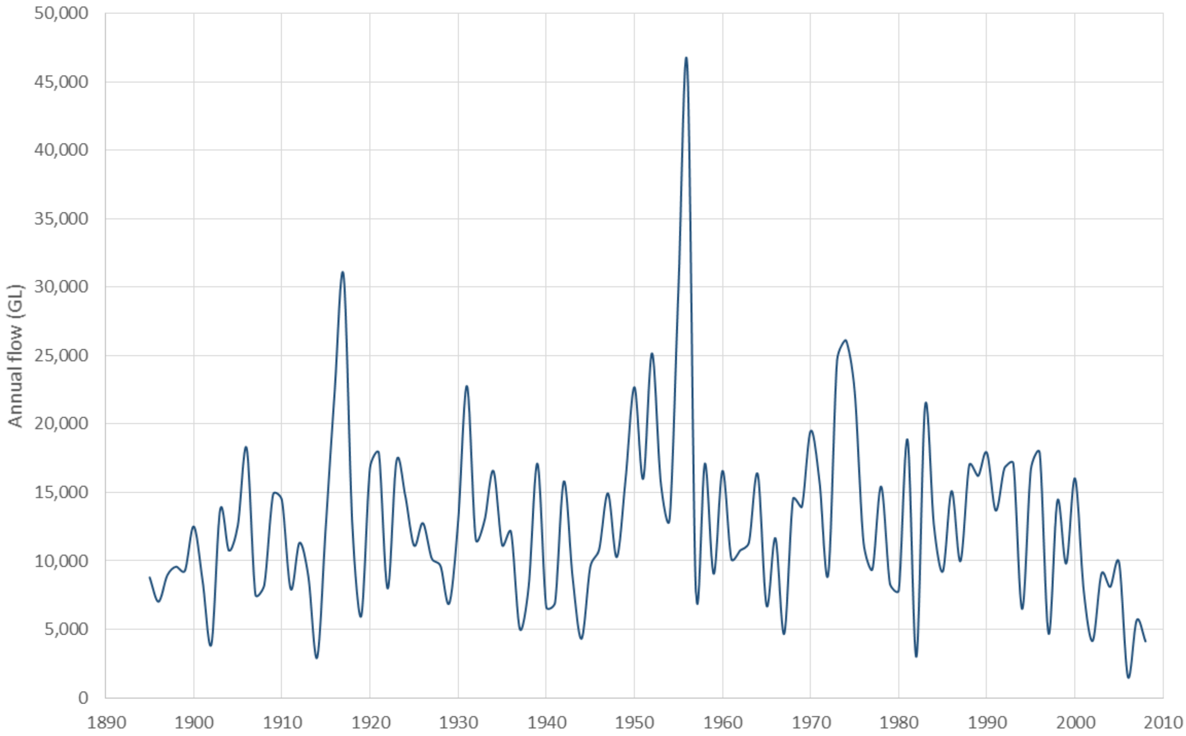

Figure 2-1 Annual flow (QSA; water year June-July) for modelled natural (without development) conditions from 1895–2008.

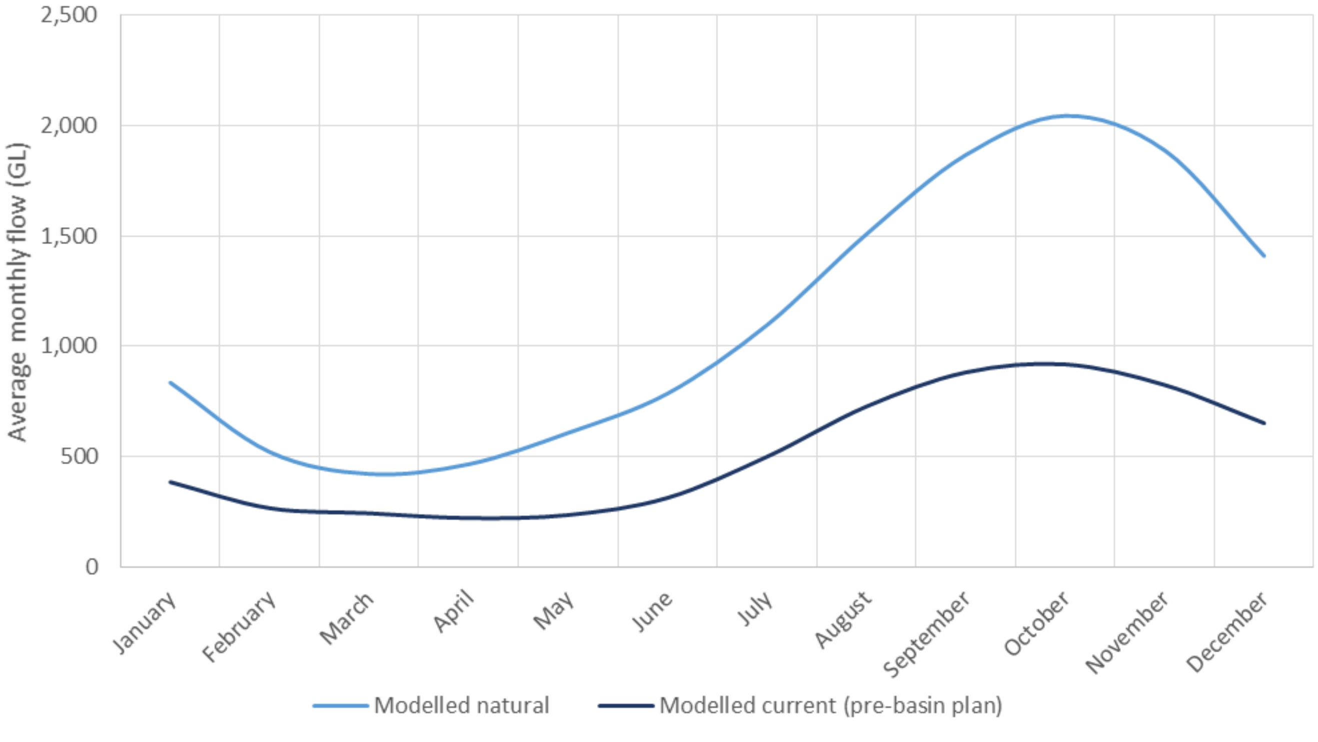

Figure 2-2 Average monthly flow (QSA) for modelled natural (without development) and modelled current (pre-*Basin Plan*) conditions (data from Maheshwari *et al.*, 1993).

Table 2-1 Comparison of flow metrics pre-development and currently (without *Basin Plan* implementation). **Average Return Interval*

Discharge ($ML.day^{-1}$)	Duration (days)	Pre-development ARI* (years)	Current (pre-*Basin Plan*) ARI* (years)	Reference
40,000	60	1.43	3.8	Wallace *et al.* (2014a, b)
	90	1.75	4.9	Wallace *et al.* (2014a, b)
	120	2.03	9.5	Wallace *et al.* (2014a, b)
60,000	30	1.9	6.7	Maheshwari *et al.* (1993)
80,000	30	4	14.3	Maheshwari *et al.* (1993)

2.3 Responses of floodplain biota to flow events

Bice *et al*. (2014) provides a recent synthesis of the current understanding of ecosystem response to flow in the SARM, including the development of hydro-ecological conceptual models for the following biotic/abiotic ecosystem components:

1. nutrients, carbon, biofilms and microbes
2. microbiota
3. vegetation
4. macroinvertebrates
5. frogs
6. fishes
7. waterbirds

The following overview of how the ecosystem components respond to flow events is primarily based on this synthesis, with regard for the factors required for the effective functioning of each component. Complementary information was on other synthesis' given in Wallace *et al*. (2014a, b) and DEWNR (2012a). More detailed conceptual models of the different ecosystem components are also provided in Wallace and Denny (in prep.) and Wallace (in prep.). Note that only native biota are considered here, and that in most cases, the time since last flow event will significantly influence the ecosystem response.

Flow events

On the SARM floodplain, the greater the discharge, the greater the area of inundation (Figure 2-3 and Figure 2-4). Biota and ecosystem processes respond both to the movement of water across the floodplain (that is, the velocity) and the depth of inundation (water level). Both are important for longitudinal and lateral connectivity, facilitating the movement of carbon between the floodplain and main channel, transporting vegetation propagules, invertebrates, tadpoles and fish larvae.

A drop in discharge will likely result in a drop in the river water level (dependent on weir operations as well) and a corresponding loss in inundation extent on the shedding floodplain. However, it may not result in an immediate loss of water from the aquatic zones (floodplain depressions, wetlands and creeks). The drop in water level and the length of time that the residual water is retained in aquatic zones will depend on interactions between flow regime, weir operations, wetland morphology (particularly sill levels), evaporation rates and soil type.

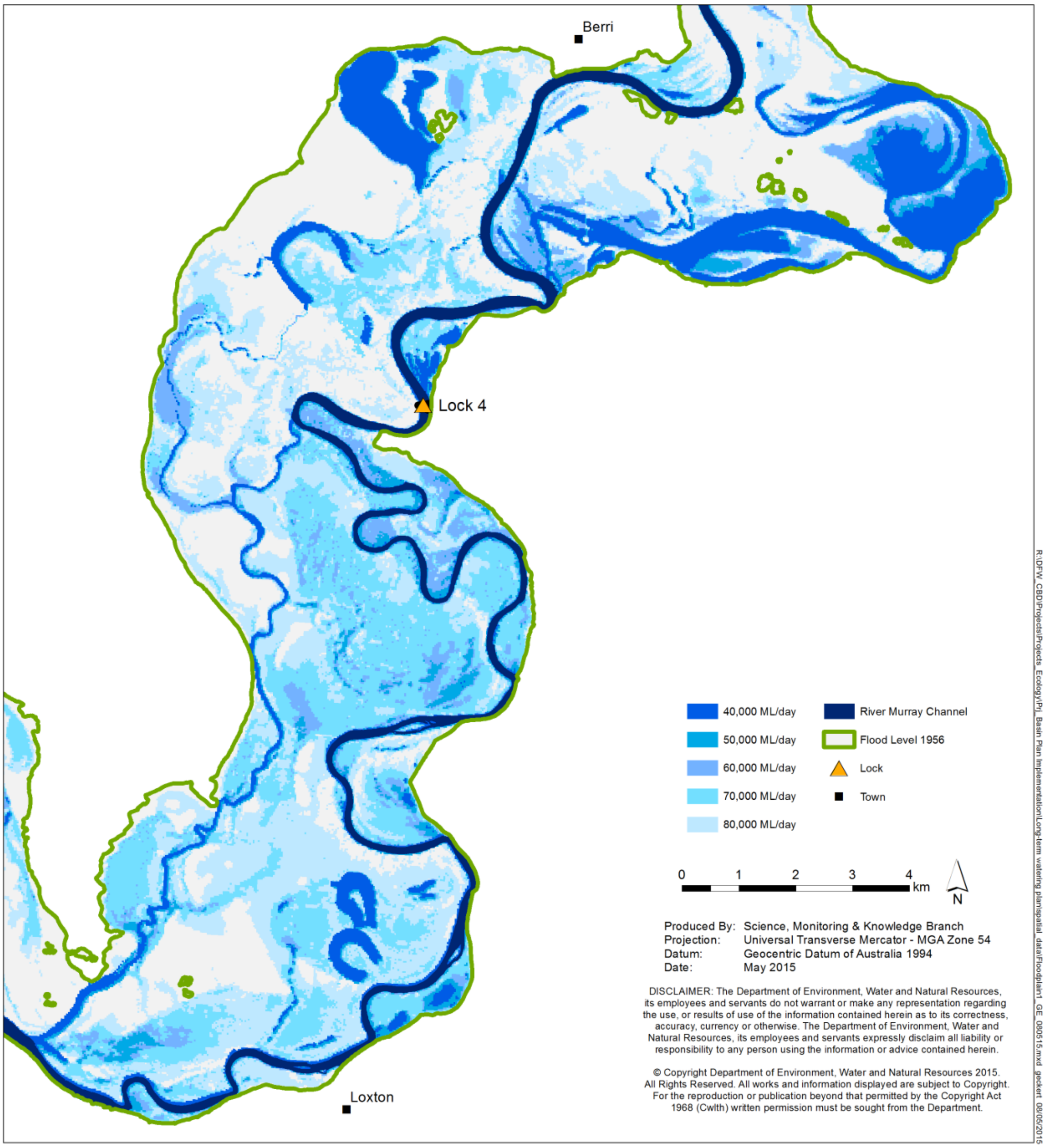

Figure 2-3 The increase in area of inundation with increasing discharge (shaded areas).
Here a small portion of the SARM around Lock 4 (yellow triangle) is shown.

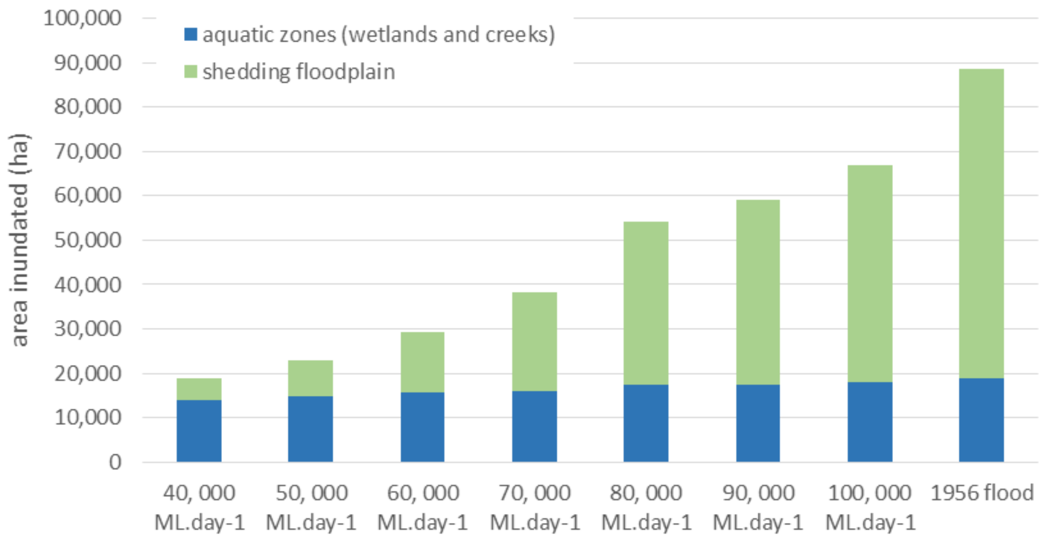

Figure 2-4 The areas of aquatic zones (floodplain depressions, wetlands and creeks) and shedding floodplain inundated on the SARM by increasing discharges.

Nutrients, carbon, biofilms and microbes

Inundation of River Red Gum and Black Box vegetation will contribute significant amounts of carbon (natural organic matter; NOM) and nutrients to the river, and eventually the Lower Lakes, Coorong and Murray Mouth; the amounts of carbon and nutrients mobilised are influenced by the extent of inundation (Bice *et al.,* 2014).

Inundation of the shedding floodplain and wetland basins will increase the surface area available for biofilm growth, which will likely remain in an early-successional state (dominated by algae) due to the relatively short duration of inundation and generally high turbidity of the water.

Important factors for nutrients, carbon, biofilms and microbial response to flow:

- inundation of River Red Gum dominated vegetation
- inundation of Black Box dominated vegetation
- inundation of shedding floodplain
- lateral connectivity
- longitudinal connectivity

Microfauna (zooplankton)

Newly inundated temporary wetlands (within the aquatic zones) support quite different microfaunal communities from the main river channel, including organisms imported from upstream and hatched or germinated from the sediments. Inundation of the shedding floodplain will provide further opportunities for microfaunal growth, promoted by increased primary productivity and NOM availability. Lignum inundation provides structurally complex habitats for many microfaunal species. The greatest responses to flow event swill occur in spring and summer (Bice *et al.,* 2014).

Important factors for microfaunal response to flow:

- inundation of temporary wetlands (within the aquatic zone)
- inundation of Lignum dominated vegetation
- carbon and nutrient availability
- lateral connectivity
- spring/summer timing

Macroinvertebrates

In general, the abundance and diversity of macroinvertebrates increase with increasing flow, due to the increased availability and diversity of habitats, increased primary productivity, microfaunal productivity and NOM availability. Some species respond to newly-created, fast-flowing off-channel habitats (e.g. creeks within the aquatic zone). Macroinvertebrates that normally reside in the slow-flowing main channel are likely to decrease in abundance in the fast-flowing water (Bice *et al.,* 2014).

Important factors for macroinvertebrate response to flow:

- total area of inundation
- carbon, nutrient and microfauna availability
- creation of off-channel, flowing habitats (creeks within the aquatic zone)

Vegetation

The response of floodplain vegetation to flow is best described by grouping species into functional groups (Table 2-2 and Figure 2-5). Vegetation does not respond to discharge *per se*, but indirectly via changes to inundation extent, duration, depth and water regime history. The greater the discharge, the greater the area of inundation of different vegetation communities/functional groups, and the more habitats available for colonisation. The responses of the functional groups to inundation are summarised in Table 2-2. For example, some species require inundation for germination and growth, others germinate on flood recessions, and some produce seed in a canopy seedbank during one flood event, but rely flooding the following year for seed release and germination (Jensen *et al.*, 2008). Regular inundation is important for maintaining the seedbank, while lateral and longitudinal connectivity is important for dispersal of propagules.

Important factors for vegetation responses to flow:

- inundation of temporary wetlands (including areas adjacent permanent wetlands) (aquatic zone)
- inundation of vegetated areas (and where vegetation could potentially grow) (shedding floodplain)
- lateral connectivity
- longitudinal connectivity
- for some species, spring/summer timing is important

Table 2-2 Functional group classification of plant species based on water regime preferences (adapted from Bice *et al.*, 2014a, b; Casanova, 2011, Blanch *et al.,* 2000).

Spatial zone	Functional group and examples	Water regime preference	Response to inundation on the SARM
Shedding floodplain	Terrestrial dry (TDr) *Atriplex vesicaria*, *Rhagodia spinescens*, *Enchylaena tomentosa*	Will not tolerate inundation and tolerates low soil moisture for extended periods.	Temporarily removed from newly inundated temporary wetlands; only present on higher elevations.
Shedding floodplain (aquatic zones during dry phase)	Terrestrial damp (TDa) *Paspalidium jubiflorum*, *Sporobolus virginicus*	Will tolerate inundation for short periods (<2 weeks) but require high soil moisture throughout their life cycle.	Temporarily removed from upper weir pool littoral zone, but recruitment should be on the recession of high flow on temporary wetlands and the shedding floodplain.
Shedding floodplain (aquatic zones during dry phase)	Floodplain (FP) *Epaltes australis*, *Centipeda minima*, *Glinus lotoides*, *Brachycome basaltica*	Temporary inundation, plants germinate on newly exposed soil after flooding but not in response to rainfall.	Temporarily removed from upper weir pool littoral zone, but widespread recruitment should occur on the recession of high flow on temporary wetlands and the shedding floodplain.
Shedding floodplain/ aquatic zone	Amphibious fluctuation tolerators – emergent (AFTE) *Cyperus gymnocaulos*, *Juncus kraussii*, *Schoenoplectus pungens*	Fluctuating water levels, plants do not respond morphologically to flooding and drying and will tolerate short-term complete submergence (<2 weeks).	Recruitment in inundated temporary wetlands and low-elevation floodplain. Those plants currently existing below pool level will be extirpated if inundation is longer than 30 days. Species may persist in the seed bank or in dormant rhizomes.
Shedding floodplain/ aquatic zone	Amphibious fluctuation tolerators – woody (AFTW) *Eucalyptus camaldulensis*, *Melaleuca halmaturorum*, *Duma florulenta*	Fluctuating water levels, plants do not respond morphologically to flooding and drying and are large perennial woody species.	There will be improvement of condition of inundated plants (both in temporary wetlands (aquatic zone) and on the shedding floodplain). Plants growing on the edges of permanent water bodies or areas where groundwater is being freshened will remain in good condition. Recruitment generally occurs on the recession of inundation.
Shedding floodplain/ aquatic zone	Amphibious fluctuation tolerators – low growing (AFTLG) *Crassula helmsii,*	Fluctuating water levels, plants do not respond morphologically to flooding and drying and are generally small herbaceous species.	Recruitment in inundated temporary wetlands (aquatic zone) and low-elevation floodplain. Those plants currently existing below pool level will be extirpated if inundation is longer than 60 days.

Spatial zone	Functional group and examples	Water regime preference	Response to inundation on the SARM
Shedding floodplain/ aquatic zone	Amphibious fluctuation responders – plastic (AFTP) *Persicaria lapathifolia, Myriophyllum verrucosum*.	Fluctuating water levels, plants respond to flooding and drying (e.g. increasing above to below ground biomass ratios when flooded).	Recruitment in inundated temporary wetlands (aquatic zone) and low-elevation floodplain (shedding floodplain); some germinate whilst inundated, others require exposure.
Shedding floodplain/ aquatic zone	Emergent (E) *Typha* spp., *Phragmites australis, Schoenoplectus validus*	Static shallow water <1 m or permanently saturated soil.	Recruitment in inundated temporary wetlands (aquatic zone) and low-elevation floodplain (shedding floodplain). Those plants growing around pool level likely extirpated at higher flows.
Aquatic zone	Floating (F) *Azolla* spp., *Lemna* spp., *Spirodela punctata*	Static or fluctuating water levels, responds to fluctuating water levels by having some or all organs floating on the water surface. Most species require permanent water to survive but may persist on mud for short periods.	Present in inundated areas.
Aquatic zone	Submergent *r*-selected (S-*r*) *Ranunculus trichophyllus, Chara fibrosa*	Temporary wetlands that hold water for >4 months.	Recruitment will occur in temporary wetlands (aquatic zone) if duration long enough.
Aquatic zone	Submergent *k*-selected (S-*k*) *Vallisneria australis, Potamogeton crispus, Myriophyllum salsugineum*	Permanent water.	Temporary removal of plants growing immediately upstream of weirs, and potential change in distribution and abundance in permanent wetlands on the floodplain.

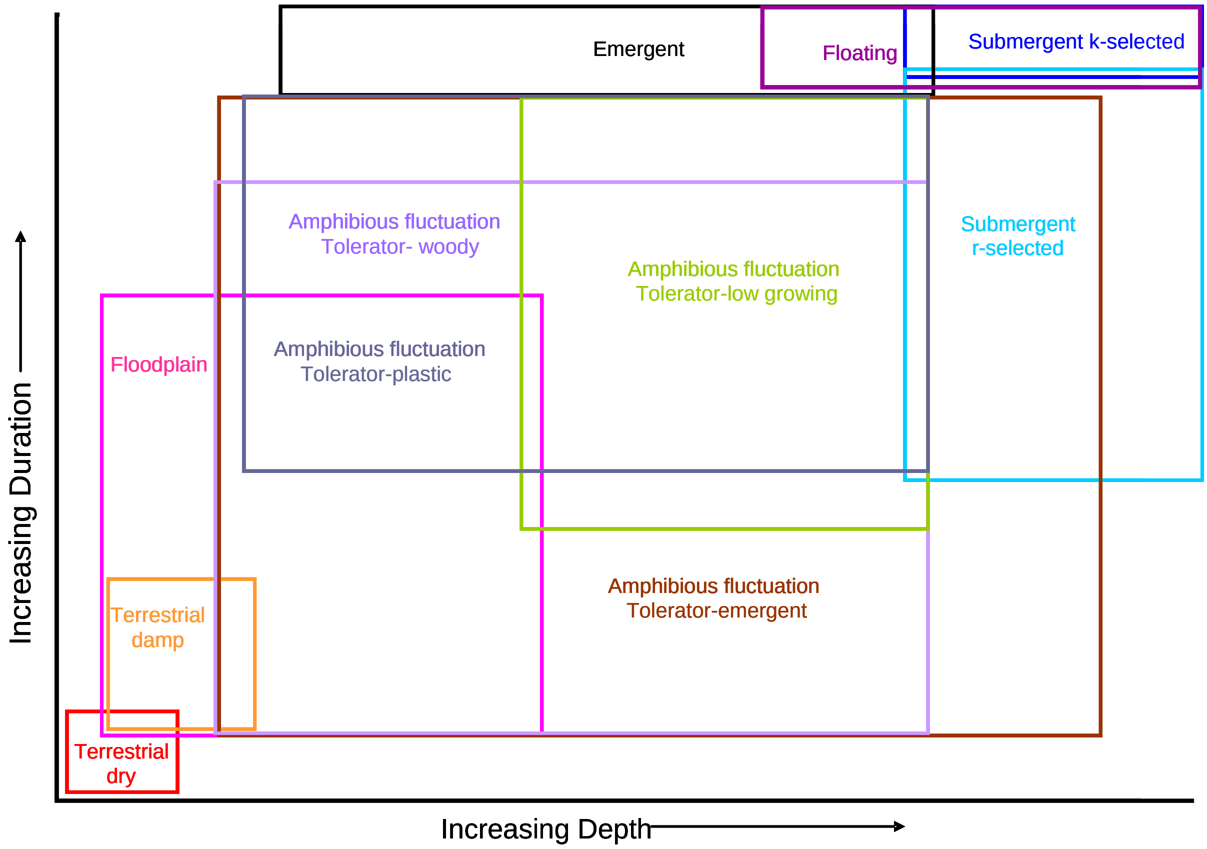

Figure 2-5 Plant water regime functional groups in relation to depth and duration of flooding (from Bice *et al.*, (2014)).

Frogs

Increased areas of inundation, particularly River Red Gum, Black Box and Lignum-dominated vegetation, increase the area of preferred breeding habitat for all species. Frogs and tadpoles strongly associate with vegetation in aquatic zones (see Table 2-6) (DEWNR, 2012a). Increased areas of wetland habitat (particularly associated with inundated vegetation communities) lead to successful recruitment (assuming water is retained in the wetlands for long enough) and possibly more than one breeding event. Many species anchor eggs to vegetation, and there is a risk of desiccation if water levels drop before hatching. Tadpoles can move with falling water levels, but require water of suitable quality and sufficient cover for successful metamorphosis. The required duration is species dependent. All species will breed during spring and summer, with a few opportunistically breeding at other times if conditions are right. The nationally threatened Southern Bell Frog (*Litoria raniformis*) (listed as Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999*) is the most sensitive of the 11 frog species in the River Murray corridor to frequency, timing, extent and duration of water regime (DEWNR, 2012a).

Important factors for frog response to flow:

- inundation of temporary wetlands (within aquatic zones)
- inundation of vegetation areas (including areas adjacent permanent wetlands), particularly River Red Gum, Black Box and Lignum-dominated vegetation
- spring/summer timing

Fish

The response of riverine fish to high flows and floodplain inundation is best described using a *guild* approach, akin to the functional groups for vegetation. The response to high flows is dependent on the guild, described in Table 2-3, and is highly dependent on season (and, in case, temperature), particularly in relation to spawning and recruitment strength. The spawning times of some common native and non-native fish are shown in Table 2-4.

Table 2-3 Fish guilds of freshwater fishes in the SARM channel and floodplain (from Bice *et al.*, (2014))

Guild and examples	Description	Response to high flows/floodplain inundation
Circa-annual spawning nester e.g. Murray cod (*Maccullochella peelii*), Freshwater catfish (*Tandanus tandanus*)	Spawn annually over defined periods irrespective of flow conditions and lay eggs within a nest or similar structure (e.g. hollow logs). Habitat preference dependent on species; generally prefer main channel or flowing environments, but may use connected wetlands.	Although they spawn irrespective of flow conditions, recruitment strength increases with increasing discharge – if over spawning season. Increased areas of flowing habitat (anabranches/reaches) will increase area of favourable habitat for juveniles and adults.
Flow dependent specialist e.g. Golden perch (*Macquaria ambigua ambigua),* Silver perch (*Bidyanus bidyanus*)	Require increases in within-channel discharge or flooding to stimulate spawning. Typically main channel or flowing environment preference, but will use connected off-channel environments, including temporary inundated floodplain.	Spawning will occur if the right temperature/ season. Recruitment strength increases with flow. Generally stay in main channel, but will use off-channel habitats. Downstream drift of larvae occurs.
Foraging generalist e.g. Bony herring (*Nematalosa erebi),* Australian smelt (*Retropinna semoni*), Carp gudgeon complex (*Hypseleotris* spp.).	Typically have generalist/flexible habitat requirements, diets and reproductive strategies. Found in a range of environments, including river main channel, connected wetlands and anabranches, and inundated floodplain. Recruitment likely enhanced during low-flow years.	Increased areas of inundation (wetland and floodplain) increases potential habitat areas, and promote lateral movement between populations.
Wetland/floodplain specialist e.g. Murray hardyhead (*Craterocephalus fluviatilis),* Yarra pygmy perch (*Nannoperca obscura*)	Require specific off-channel floodplain/wetland habitats, with populations fragmented within the basin. Associated with specific physical (e.g. submerged vegetation) or physic-chemical (e.g. elevated salinity) conditions.	Increased areas of inundation (wetland and floodplain) increases potential habitat areas, and promote lateral movement between populations. Potential spawning and recruitment dependent on local conditions.

Table 2-4 A 'spawning calendar' for native and non-native fish; grey bars represent detection of larval stages.

*Note that these data include mid and upper Murray observations, and may not directly reflect the SARM; there may be regional variation in thresholds and timing (*for example, Silver perch may spawn at temperatures of 16–17°C: King* et al.*, 2013). Data from King* et al. *(2009) in Wallace* et al.*, (2014a, b).*

	Species	Minimum temperature (°C)	Month											
			Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Flow dependent specialist	Golden perch	22				■	■	■	■	■				
	Silver perch	22*				■	■	■	■					
Circa-annual spawning nester	Murray cod	17				■	■	■	■	■				
	Freshwater catfish	21					■	■	■					
Foraging generalist	Bony herring	16			■	■	■	■	■	■	■			
	Australian smelt	15	■	■	■	■	■	■	■	■				■
	Flatheaded gudgeons spp.	15	■		■	■	■	■	■	■	■	■	■	■
	Carp gudgeons spp.	15	■	■	■	■	■	■	■	■	■	■	■	■
	Unspecked hardyhead	17	■			■	■	■	■	■	■	■	■	■
	Murray-Darling rainbow fish	17				■	■	■	■	■	■			
Non-native	Common carp	15			■	■	■	■	■	■	■			
	Redfin perch	16			■	■	■							
	Eastern gambusia	20				■	■	■	■	■	■			
	Goldfish	15				■	■							

Important factors for fish response to flow:

- inundation of temporary wetlands
- creation of flowing creeks (lotic environments)
- slow rate of rise and fall of discharge
- spring/summer timing
- high velocity conditions
- lateral connectivity
- longitudinal connectivity

Waterbirds

Australian waterbirds are highly mobile, utilising habitat at a variety of scales (Bice *et al.*, 2014). For Australian continental nomads (e.g. Banded Stilt (*Cladorhynchus leucocephalus)*, Grey Teal (*Anas gracilis)* and Australian Pelican (*Pelecanus conspicillatus*)), individual birds respond to hydrological events at continental scales. International migratory species operate at larger spatial scales again, and require highly productive wetlands for both the breeding and non-breeding phases of their life cycle. Regional residents (e.g. Chestnut Teal (*Anas castanea)* and *Environment Protection and Biodiversity Conservation Act 1999* listed Australasian Bittern (*Botaurus poiciloptilus)*) also move across the landscape, although their movements are smaller (typically between wetlands, based on local conditions).

As well as different residency modes, waterbirds will use aquatic habitat in different ways, dependent on their dietary preferences and breeding requirements. These preferences can broadly be broken into seven functional groups (based on Wallace and Denny (in prep.) and DEWNR (2012a)). A summary of these functional groups, their habitat, dietary and breeding preferences is shown in Table 2-5.

Understanding the response of waterbird populations to local (even Basin-wide) management of water resources and flow events is complicated by issues of scale and residency, in particular because population dynamics are sensitive to environmental changes occurring beyond the influence of local management. Given this, it is thought that the SARM provides habitat and refuge for the maintenance of adult Australian nomad populations, and provides regular, but relatively small, recruitment opportunities to partially offset adult mortality, rather than the large "boom" breeding events provided by large wetlands and lakes elsewhere in the continent (Bice *et al.*, 2012; Wallace and Denny, in prep.). Conversely, regional residents may have a greater reliance of flow events at the local scale to support a sustainable demographic structure.

Temporary inundation of aquatic zones and the shedding floodplain will increase habitat availability and provide wetland-scale breeding opportunities for waterbirds, providing the duration is long enough (this is species dependent). Breeding events are likely to be interrupted if inundation drawdown occurs too quickly, or if there are large fluctuations in water level (Rogers and Paton, 2008; Wallace and Denny, in prep.). Inundation of living River Red Gum and Lignum dominated vegetation is important for colonial nesting birds (Ecological Associates, 2010).

Important factors for local waterbird response to flow:

- duration of inundation
- inundation of the aquatic zone, particularly temporary wetlands and the vegetated littoral edge of permanent wetlands
- inundation of Lignum-dominated vegetation
- inundation of River Red Gum dominated vegetation
- slow rate of water level fall
- conditions/habitat elsewhere in the continent

Table 2-5 Functional groups of SARM waterbirds, their habitat associations, dietary/foraging preferences and breeding requirements. Residency modes are also included.

Functional group	Habitat associations							Residency			Dietary preference and foraging mode	Breeding requirements
	Deep open water	Shallow edge	Mud flats, herblands	Inundated reedbeds	Inundated Lignum	Inundated shrublands	Inundated woodlands	International migrants	Continental nomads	Regional residents		
Waterfowl (e.g. swans, ducks, geese)	✔✔	✔		✔					✔	✔	Most waterfowl: submerged vegetation and associated aquatic invertebrates. Australian Wood Duck and shelduck: terrestrial foragers.	Many require nesting sites surrounded by water, including tree hollows or other emergent vegetation. Members have medium to long required inundation periods to complete breeding, e.g. swans may require inundation for up to 6 months, others from 4–5 months.
Piscivores (e.g. grebes, darters)	✔✔	✔					✔	✔	✔	✔	Mostly small-bodied and juvenile large-bodied fish; some adult large-bodied fish. Diving birds that hunt for fish while flying over or sitting upon a water body.	Nesting in trees surrounded by water, or other emergent vegetation. Typically long breeding cycles requiring long duration of inundation (at least 6–8 months).
Large waders (e.g. spoonbills, egrets)		✔✔		✔	✔	✔	✔		✔	✔	Forage by walking in shallow water (up to 30 cm); diverse diet, many are omnivorous, wader height and bill-specialisations determine diet and depth of water exploited.	Many of the group build platform nests over water, which are often anchored to emergent vegetation. Flooded Lignum is highly valuable to many species in this group. Minimum flood durations of 3–5 months.
Small waders (e.g. sandpipers, dotterels)		✔	✔✔					✔✔	✔	✔	Forage by walking in exposed mud or very shallow water (up to several cm); wader height and bill specialisations determine diet and depth of mud probed. Typically depend on benthic invertebrates.	International migrants do not breed in Australia. They may use productive Murray-Darling Basin floodplains as layover areas on their return journeys. Typically, small waders nest on the ground, sometimes well away from the water's edge. Successful breeding is supported by a spatially complex pattern of inundation where suitable nest areas are protected from predator access by standing water. May require up to 5 months of inundation to support breeding.

Functional group	Habitat associations							Residency			Dietary preference and foraging mode	Breeding requirements
	Deep open water	Shallow edge	Mud flats, herblands	Inundated reedbeds	Inundated Lignum	Inundated shrublands	Inundated woodlands	International migrants	Continental nomads	Regional residents		
Rallids (e.g. Australasian bittern, crakes, coots, hens)		✔		✔ ✔					✔	✔ ✔	Rails and crakes: invertebrates. Terrestrial and palustrine rallids: omnivorous, mainly carnivorous. Often reliant on dense fringing vegetation for cover.	Nest in rushes, dense grasses or under shrubs, near water's edge. Inundation of at least 3–4 months required.
Reed-dwelling passerines (e.g. reed warblers and grassbirds)				✔ ✔					✔	✔ ✔	Use reed beds for habitat. Can forage on floating vegetation. Insects form a major part of diet.	Nest built in dense inundated reeds. Inundation duration unknown. Some species migrate, e.g. Australian Reed Warblers, are continental migrants, breeding in the spring in the south and migrate north in non-breeding period.
Gulls and terns	✔			✔		✔		✔	✔ ✔		Diet comprises insects, amphibians, small fish, crustaceans	Floating nests or on submerged vegetation, including inundated trees. Shorter inundation duration of 2–4 months. May not commonly breed in southern Murray-Darling Basin.

✔ ✔ = dominant habitat association / many species within group

✔ = strong habitat association / some species within group

Other fauna

Other fauna may not rely directly on high flow conditions or inundated areas, but rely on healthy woodlands, and/or the mosaic of aquatic zones within woodland areas. For example, the Large-footed Myotis Bat (*Myotis macropus*) preys on insects and small fish in still waterbodies and shelters in woodland tree hollows. Similarly bats often forage on insects from the riparian zone. The inland Carpet Python (*Morelia spilota metcalfei*) hibernates in tree hollows (particularly Black Box), and preys on frogs and nestling waterbirds on the fringes of adjacent wetlands. Turtles (most commonly *Chelodina longicollis*) will also use temporarily inundated wetlands. Feathertail Glider (*Acrobates pygmaeus*) requires healthy woodlands with tree hollows, and the Water Rat (*Hydromys chrysogaster*) also uses riparian woodland. Some woodland birds may be strongly associated with River Red Gum (e.g. Regent Parrot *Polytelis anthopeplus*) or Black Box (where the transition to Mallee habitat is important) (Ecological Associates, 2010). When floodplain trees are in poor condition, the bird community changes from a floodplain woodland community (such as foliage specialists) to those typical of dryland terrestrial and open agriculture systems (Blackwood *et al.,* 2010).

Important factors for 'other fauna' responses to flow:

- productivity boom caused by inundation of temporary wetlands
- healthy River Red Gum-dominated vegetation
- healthy Black Box-dominated vegetation
- connectivity with upland habitats

2.4 Spatial inundation of the SARM floodplain

This section considers what discharges (QSA) are required to inundate different habitats. The SARM floodplain has a total area of 88,573 ha. For this spatial analysis, the floodplain has been split into the *shedding floodplain* (that part of the floodplain that will shed, rather than retain water) and the *aquatic zone* (that part of the floodplain that retains, rather than sheds, water).

The SA vegetation spatial layer was used to represent the shedding floodplain, as it covers most of the SARM floodplain except towns, farming land and aquatic zones. The South Australian Aquatic Ecosystems (SAAE) Wetland Classification Project (Jones and Miles, 2009) spatial layer was used to represent the aquatic zone. To ensure that an area was not calculated as both a 'shedding floodplain' and 'aquatic zone' (where the vegetation and aquatic layers are overlaid), the latter took precedence because the area was considered to have aquatic characteristics (e.g. retention rather than shedding of water) even if it included vegetation. While discrepancies may occur between the spatial information and what is 'on the ground', the spatial information provides regional-scale statistics that are adequate to inform management objectives and targets. Inundation spatial data were from the River Murray Flood Inundation Model (RiMFIM: Overton *et al.*, 2006) and, where applicable, other hydraulic modelling (DEWNR 2012b, c). Details of the method for spatial analysis are in Appendix B.

2.4.1 The shedding floodplain

The vegetation spatial layer used to represent the shedding floodplain describes more than 60 vegetation associations. For this analysis, these associations were reduced to 10 groups, based on a classification of dominant species and water-regime functional groups (Table 2-6) (see Appendix B for details).

Table 2-6 An overview of the 10 groups used to classify vegetation associations from the floodplain vegetation shapefile (for the shedding floodplain).

Functional groups are based on the definitions in Table 2-2.

**Note that the associated species' functional groups are based on data in the shapefile — what is present on the floodplain is dynamic and will be responsive to the water regime.*

Vegetation group	Dominant species	Dominant species' functional group	Associated species' functional groups*
River Red Gum woodland	*Eucalyptus camaldulensis*	AFTW	AFTE, AFTW, E, FP, TDr
Lignum shrubland	*Duma florulenta*	AFTW	AFTE, FP, TDa, TDr
Black Box woodland	*Eucalyptus largiflorens*	AFTW	AFTE, AFTW, TDr, FP
River Cooba woodland	*Acacia stenophylla*	AFTW	AFTW, TDr
Ti tree woodland	*Melaleuca halmaturorum*	AFTW, TDr	AFTE, AFTW, AFTL, TDa, TDr
Mallee shrubland	*Eucalyptus brachycalyx, Eucalyptus dumosa,*	TDr	TDr
Emergent sedgeland	emergent *Duma florulenta, Phragmites australis, Typha domingensis*	E, (E - AFTW)	E, FP, AFTW, AFRP, TDa, TDr
Flood dependent grassland	*Agrostis avenacea* var. *avenacea (NC), Eragrostis australasica*	FP, TDa	AFTE, AFTW, FP, TDr
Samphire shrubland	*Sarcocornia quinqueflora, Tecticornia* spp.	TDr, AFTE	AFTE, AFTL, TDa.
Terrestrial dry shrubland	*Atriplex* spp.*, Chenopodium nitrariaceum, Maireana* spp.*, Lycium australe, Dodonea viscosa, (emergent) Acacia victoriae, Disphyma crassifolium* ssp. *clavellatum*	TDr	AFTE, FP, TDr

Figure 2-6 to Figure 2-9 show the spatial distributions of the different groups across the shedding floodplain, and the groups inundated under discharges of 40,000–100,000 ML.day^{-1}.

Figure 2-6 shows that:

- The greater the discharge, the greater the area inundated.
- 36,954 ha of the vegetated shedding floodplain (53%) is inundated at 80,000 ML.day^{-1}.
- The greatest increase in inundated area for a discharge of 10,000 ML.day^{-1} occurs between 70,000 and 80,000 ML.day^{-1}, when an additional 14,790 ha are inundated (cf. 4,926 ha additional area inundated between 80-90,000 ML.day^{-1}).

Figure 2-7 shows that:

- River red gum woodland has the greatest total area on the floodplain, and dominates the vegetation groups in areas inundated under all flow bands.
- Black box woodlands have the second greatest area on the total floodplain, but only 28% (4,333 ha) of the total area is inundated at 80,000 ML.day^{-1}.
- Lignum shrubland has the second greatest area inundated under flows of 50-80,000 ML.day^{-1}, but is fourth greatest in total area of the floodplain. Note that the Lignum shrubland here is where Lignum is the dominant species (Lignum is also an understorey species to River Red Gum, and to a lesser extent, to Black Box).

Figure 2-8 demonstrates how River Red Gum woodlands dominate the vegetation inundated at 40,000 ML.day^{-1}; their dominance decreases with increasing discharge (and consequently extent of area inundated).

Figure 2-9 shows that:

- At 80,000 ML.day^{-1}, 28% of Black Box woodland, 65% of River Red Gum woodland and 81% of Lignum shrub land are inundated.
- An increase from 70,000 to 80,000 ML.day^{-1} more than doubles the area of Black Box inundated (12% to 28%). Lignum shrubland area also increases substantially in this flow band (49% to 81% inundated).
- Increasing from 80,000 to 90,000 ML.day^{-1} also produces large percentage increases in the inundated area of a number of vegetation groups.

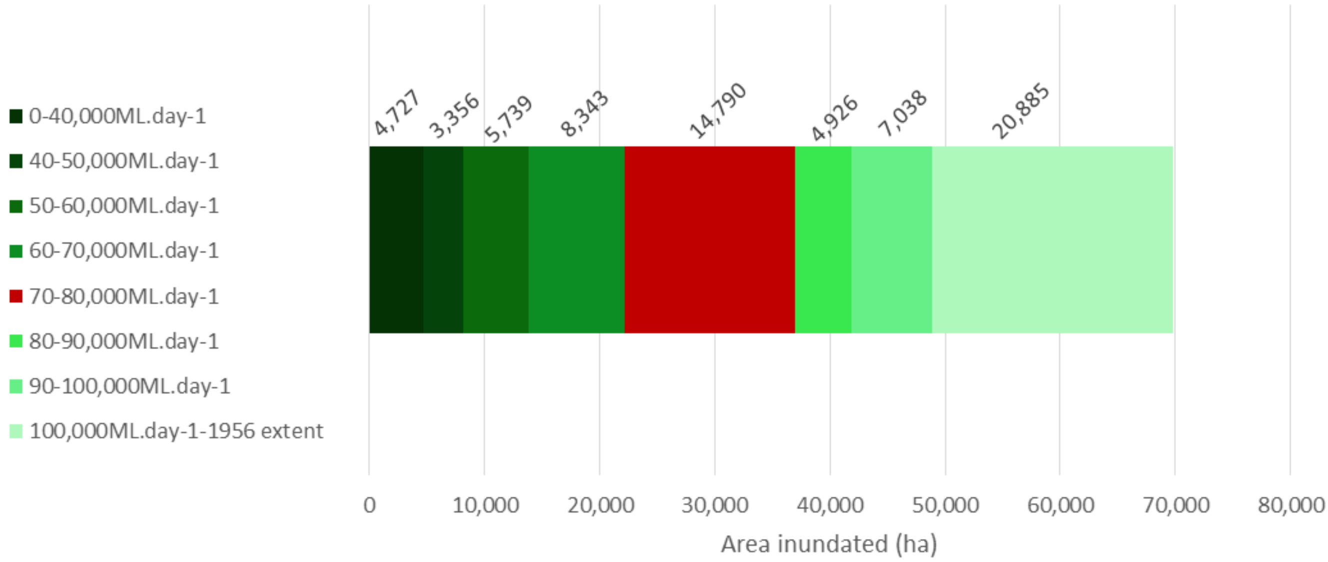

Figure 2-6 The cumulative shedding floodplain vegetated area (excluding wetland areas, towns and farmland) inundated by different flow bands.

The figures at the top of the column show the area for just that flow band; for example the area inundated by 70,000 ML.day^{-1} is 22,165 ha (bottom axis), of which 8,343 ha comes from the flow band 60-70,000 ML.day^{-1}. The red shading highlights the extent of the priority environmental asset (the managed floodplain).

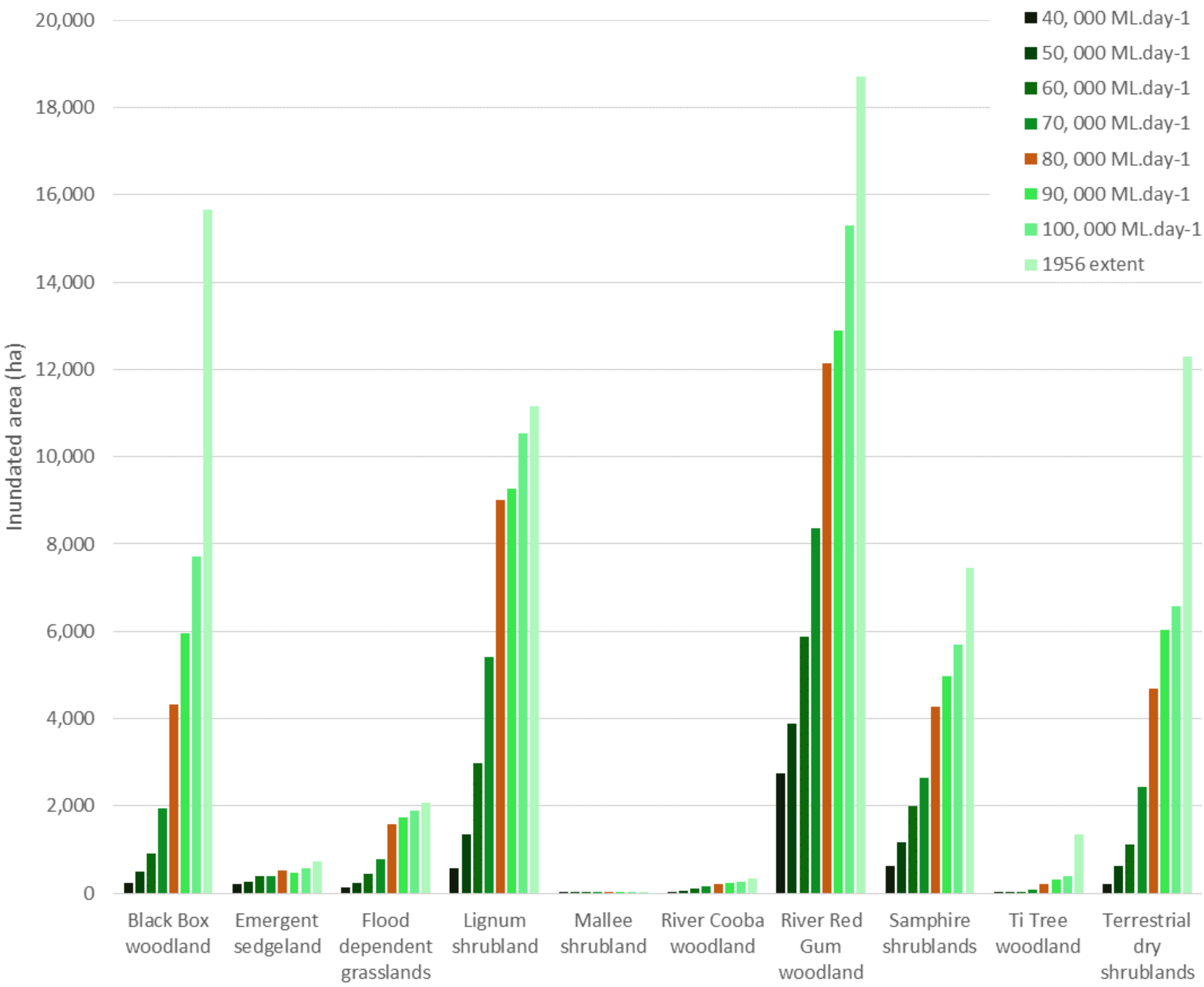

Figure 2-7 The cumulative vegetation group area inundated by different discharges, compared to the total area for the vegetation group on the whole shedding floodplain (the 1956 extent).

The red bars highlight the extent of the priority environmental asset (the managed floodplain).

Figure 2-8 The composition of the vegetation groups inundated at discharges from 40,000-100,000 ML.day^{-1} (a-g), compared to the whole shedding floodplain (h) (the 1956 extent).

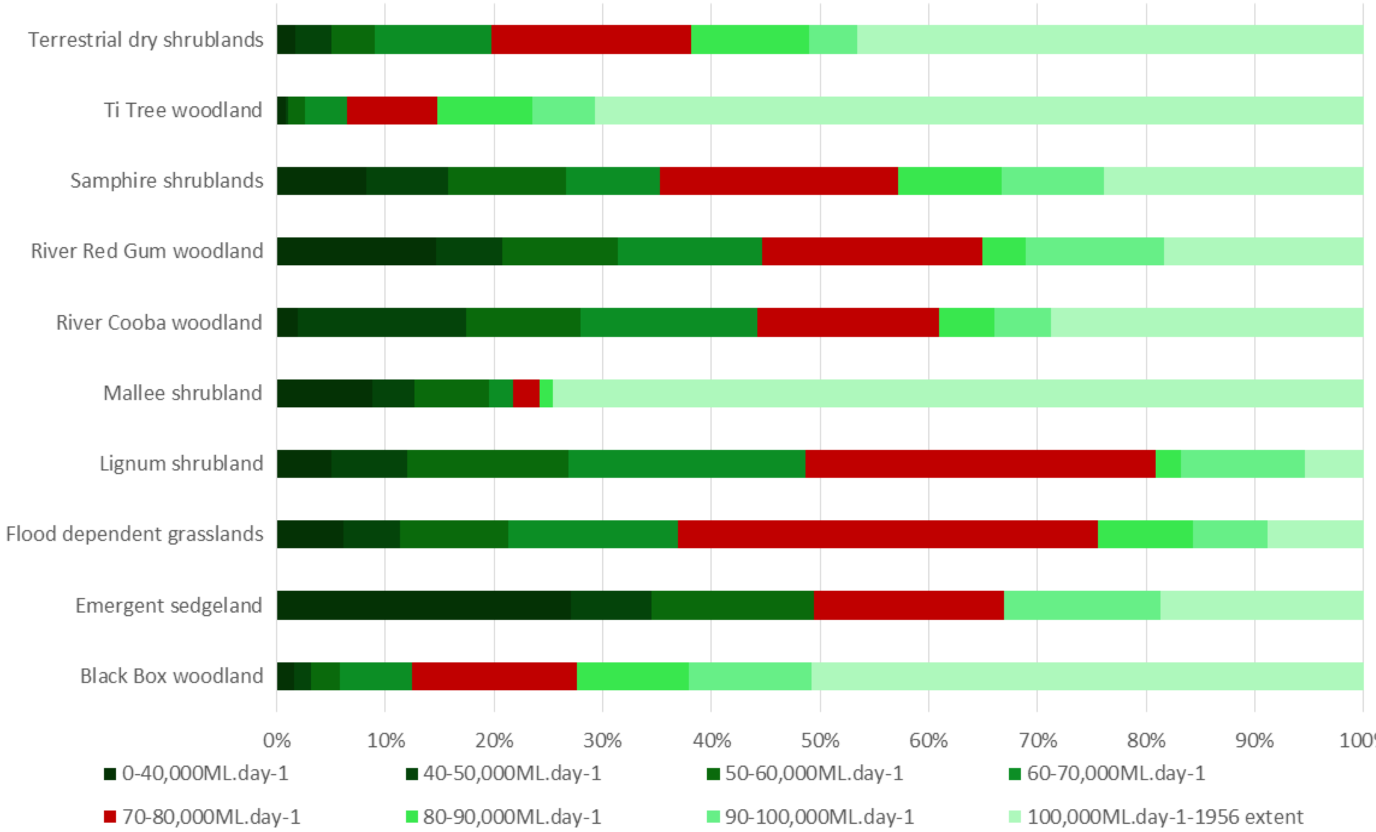

Figure 2-9 The percentages of the total area of different vegetation groups inundated under different flow bands.

The red shading highlights the extent of the priority environmental asset (the managed floodplain).

2.4.2 The aquatic zone

The SAAE spatial layer used to represent the aquatic zone describes 12 aquatic ecosystem wetland categories (Jones and Miles, 2009). For this analysis, the 12 categories were reduced to four primary categories based on their hydrologic regime and other physico-chemical conditions (Table 2-7), as these are assumed to elicit similar ecosystem responses. Note that the SAAE spatial layer may not consistently reflect on-ground experience. For example, some aquatic zones labelled "temporary" may be inundated at low discharges, and could have been considered "permanent". Despite some discrepancies, the spatial information provides adequate regional-scale statistics to inform development of management ecological objectives and targets.

Figure 2-10 and Figure 2-11 describe the spatial distribution of the aquatic zones on the floodplain, and the effect of inundation.

Figure 2-10 shows that:

- The greater discharge, the greater the area inundated.
- Permanent wetlands have a far greater area than temporary, saline and reach categories.
- The increase in area inundated with increasing flow varies between aquatic zone types – for permanent aquatic zones, the increase in area between 40,000 $ML.day^{-1}$ to 80,000 $ML.day^{-1}$ is 861 ha (being the riparian habitat surrounding permanent wetlands), compared to an increase of 2,944 ha for temporary aquatic zones.

Figure 2-11 shows the contribution of different flow bands to the areas of inundation of the different aquatic zones. Only 27% of temporary wetlands are inundated at 40,000 ML.day^{-1}, and every subsequent addition of 10,000 ML.day^{-1}, up to 70,000 ML.day^{-1}, increases the inundated area by approximately 10%. Increasing the flow from 70,000 to 80,000 ML.day^{-1} inundates an additional 20%. Seventy-eight percent of the area of temporary wetlands are inundated at 80,000 ML.day^{-1}. The increase in area is caused by inundation of riparian zones around permanent waterbodies, as well as the inundation of temporary aquatic zones.

Table 2-7 SAAE wetland classes included in the four aquatic zone categories used in the spatial analysis.

Aquatic zone category	Included SAAE classes	Generalised description
Permanent	Permanent Lake - Terminal Branch (PLTB), Permanent Lake - Throughflow (PLTF), Permanent Swamp - Terminal Branch (PSTB), Permanent Swamp - Throughflow (PSTF)	Permanent wetlands generally hold permanent water, even at low discharges in the main channel, and are usually closely connected to the channel. Increased discharge will inundate surrounding vegetation. Many of these wetlands do not have a 'dry phase' for vegetation to reproduce and germinate, and are regarded as low-productivity wetlands.
Temporary	Temporary Wetland - Overbank Flow (TWOB), Temporary Wetland - Terminal Branch (TWTB), Temporary Wetland - Throughflow (TWTF), Floodplain (FP)	Temporary wetlands are generally dry between periods of inundation, and exhibit large productivity booms when inundated. Length of inundation will depend on flow magnitude and wetland morphology.
Creeks	Seasonal Reach (SR), Ephemeral Reach (ER), Permanent Reach (PR)	Creeks are generally characterised by flowing water (cf. the lentic environment of wetlands), and comprise biota preferring flowing hydraulic environments.
Saline	Saline Swamp (SSw)	The saline environment drives different ecosystem responses and distinctive, salt-tolerant biota compared to permanent and temporary wetlands.

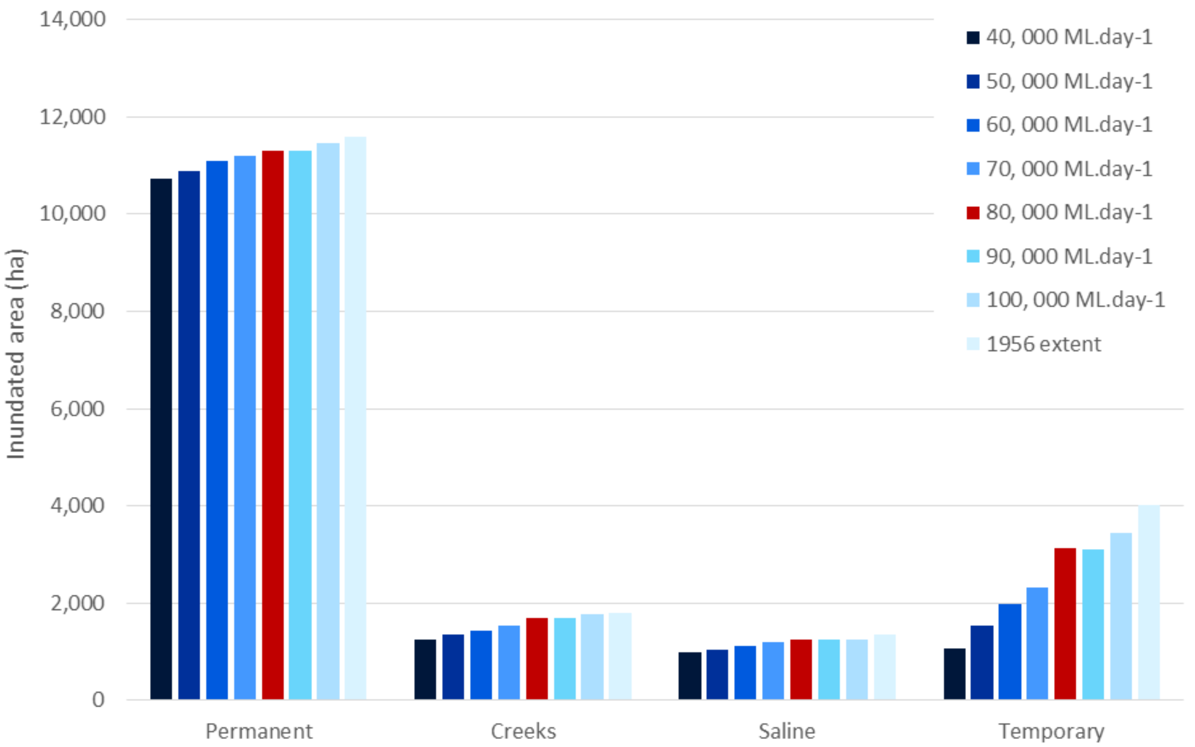

Figure 2-10 The area inundated (ha) of different aquatic zone categories on the SARM floodplain by different discharges.

The red shading highlights the extent of the priority environmental asset (the managed floodplain).

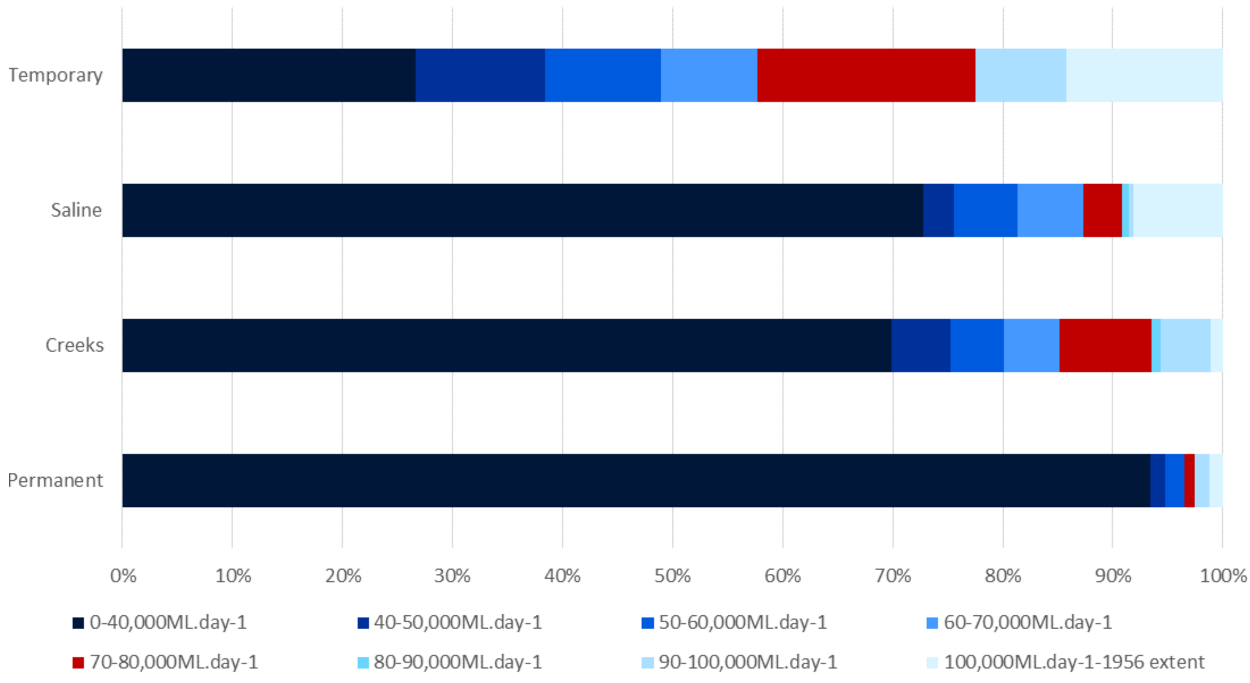

Figure 2-11 The percentage of the aquatic zone inundated by different flow bands, compared to the total aquatic zone area on the SARM floodplain.

The red shading highlights the extent of the priority environmental asset (the managed floodplain).

2.5 Water regime preferences of floodplain biota

Table 2-8 briefly summarise the current knowledge of water regime preferences for floodplain biota, based primarily on the consolidated information provided in published Murray-Darling flow-ecology summaries (Bice *et al*., 2014; Roberts and Marston 2011; Rogers and Ralph 2010), with complementary data provided by other sources (as listed within the table). The values given generally represent those needed to sustain the biota throughout the Basin in 'good' condition (communities/populations in a degraded condition may require more water to enable a recovery). The water preferences are those of a community/population within a broad environmental setting, but in reality there will be spatial differences. For example, the requirements of biota will vary with local conditions such as proximity to watercourse, groundwater depth and salinity conditions. Also, individuals may endure a sub-optimal water regime for the short term, but succumb in the long-term. Further, the response to a flow event will be moderated by the time since last flow event.

In summarising water preferences, some biota have been grouped into functional groups (Table 2-2 and Table 2-3). Key points include:

- The optimal regimes for the dominant AFTW species vary (Table 2-2; Amphibious fluctuation tolerators – woody):
  - River red gums (condition, not recruitment) have a preference for a duration of 30–120 days during spring-summer, an ARI of 1–4 years, and a maximum interval of 5–7 years.
  - Black box have a preference for a duration of 30-90 days during spring-summer, an ARI of 3–7 years and a maximum interval of 8 years.
  - Both River Red Gum and Black Box require supplementary flooding (or significant rainfall) of germinants for successful recruitment (typically in the following year).

    - Lignum requires a duration of 30–270 days during spring-summer, an ARI of 1–10 years and a maximum interval of 7–10 years. Lignum also requires supplementary flooding for regeneration within three years (not necessarily in the following year).

- Frog eggs require 1–3 weeks' inundation to hatch, preferably on woody vegetation. Tadpoles require a longer inundation to metamorphose (3–5 months), but they can complete metamorphosis in disconnected wetlands provided that water quality is maintained.

- For fish, both flow-dependent specialists and circa-annual nester spawners recruit strongly in discharges over 40,000 $ML.day^{-1}$ (the greater the flow the stronger the recruitment). Flows over this magnitude during spring–summer are required, on average, once every 2.5 (flow dependent specialists) to 4 years (circa annual nester spawners) to maintain healthy population age structures.

Table 2-8 Summary of preferred water regime (duration, timing, frequency of inundation) for floodplain biota, primarily based on the published summaries of Bice *et al*. (2014), Roberts and Marston (2011) and Rogers and Ralph (2010).

The preferred water regime from literature for plants in this table is assumed to be independent of position on the floodplain, and in general refers to vegetation that is in good condition on a non-degraded floodplain.

** vegetation functional group shown in brackets– see Table 2-2 and fish guild – see Table 2-3.*

*** MFAT: Murray Flow Assessment Tool (Young et al., 2003).*

Biota/ functional group*	Duration	Timing	Frequency	Max interval	Comments	References
River red gums (AFTW) – for condition	1–4 months; <2 years	spring–early summer	1–4 years	5–7 years	Condition improves with greater duration and frequency of inundation (within preferred range). The revised MFAT** curves lists optimal inundation as 39–96 days. Inundation greater than 2–4 years likely to cause tree death. Maximum interval dependent on prior tree condition, local conditions (e.g. groundwater salinity) and access to other water sources (including rainfall); if conditions are favourable this could be longer, but likely to be less than 5 years on the SARM (and would result in a large decrease in condition). .	Dexter (1978); Young *et al.* (2003); Jensen (2008); Rogers and Ralph (2010); Roberts and Marston (2011); Doody *et al* (2014)
River red gums – for recruitment	2–6 weeks	spring–early summer	Ideally 1st and 2nd year after germination		River red gums have a canopy seedbank; in dry times River Red Gums will set seed. Trees in poor condition produce less seed which may not lead to reproduction (germination). Supplementary first year (ideally, second year too) shallow (20–30 cm) flooding (or rainfall) important for successful recruitment (primarily to maintain soil moisture). Most successful recruitment often occurs after large floods.	Jensen *et al.* (2007); Jensen (2008); Rogers and Ralph (2010); Roberts and Marston (2011)
Black box (AFTW) – for condition	1–6 months; <13 months	spring–summer	3–7 years	8 years (in some cases possibly longer)	Black box peak seed rain is in summer; flowering times may vary between sites. Vigorous crown and flowering associated with inundation of 3–6 months, although others note reduced vigour > 4 months. The revised MFAT curve has an optimal inundation duration of 41–56 days. Acute stress noticed in trees inundated >13 months.	Briggs and Townsend (1993); Young *et al.* (2003); Jensen (2008); Ecological Associates (2010); Rogers and Ralph (2010); Roberts and Marston (2011)
Black box – for recruitment	1–1.5 months	spring–early summer	Ideally 1st and 2nd year after germination		Supplementary first year shallow (20–30 cm) flooding, or rainfall, important for recruitment. Regeneration associated with discharges of ≥80,000 $ML.day^{-1}$.	Rogers and Ralph (2010); Roberts and Marston (2011)

Biota/ functional group*	Duration	Timing	Frequency	Max interval	Comments	References
Lignum (AFTW) – for condition	1–7 months	Aug–Dec	1–7 years	7–10 years	Lignum prefer water depth less than 1 m. Vigorous growth associated with inundation 3–7 months. Frequency requirements will depend on depth to, and salinity of groundwater; access to non-saline groundwater will result in longer tolerances. Less frequent flooding may be tolerated, but growth will not vigorous, and shrubs small and sparse; small shrubs are not suitable as nesting platforms for birds. The modified MFAT curve suggest 41–81 days. Maximum interval assumes current good condition.	Young *et al.* (2003); Jensen (2008); Ecological Associates (2010); Rogers and Ralph (2010); Roberts and Marston (2011)
Lignum – for recruitment	1–4 months	spring–summer			Supplementary shallow (5–15 cm) flooding (or rainfall) within first 3 years of germination important for recruitment (excluding clonal reproduction).	Chong and Walker (2005); Rogers and Ralph (2010); Roberts and Marston (2011)
River cooba (AFTW) – for condition	2–3 months		3–7 years	7 years	Maximum interval possibly up to 10–15 years for trees in good condition, with access to other water sources (likely near water courses). Optimal recruitment conditions not known.	Roberts and Marston (2011)
Floodplain grassland (FP)	1–6 months (<9 months)		<7 years (3–5 years)		Flooding depth preference 10–50 cm. Optimal frequency to maintain seedbank unknown; it is possible flooding needed every 7 years based on seed longevity; but will vary between species and local conditions.	Nicol (2004); Roberts and Marston (2011); Bice *et al.* (2014)
Vegetation (AFTL)	<2 months				Prefer littoral zone shallow water, but will withstand deeper inundation for up to 60 days.	Bice *et al.* (2014)
Vegetation (AFTE)	<1 month				Prefer littoral zone shallow water, but will withstand deeper inundation for up to 30 days.	Bice *et al.* (2014)
Vegetation (r-selected) (aquatic)	4 months		1–4 years		Submerged species, requires 4 months for lifecycle. Prefer annual flooding >10 cm, but persist as dormant propagules for a number of years in temporary wetlands.	Bice *et al.* (2014)
Frog - eggs	1–3 weeks	spring–summer	2 years	3 years	Inundation needed to avoid desiccation. Hard structural vegetation inundation preferred. Some frog species (e.g. southern bell frog) may live up to 5 years but require more recruitment opportunities for population regeneration.	
Frog - tadpoles	3–6 months in wetlands	spring–summer	1-in-2 years	3 years	For some species (such as *Crinia* spp.), shorter periods (6 weeks) may be sufficient for tadpoles to achieve metamorphosis, while other species (such as southern bell frog, eastern banjo frog) require 6 months .	Bice *et al.* (2014); Ecological Partners (2009); Anstis (2007).

Biota/ functional group*	Duration	Timing	Frequency	Max interval	Comments	References
Flow dependent specialist fish	1 month	October–end February	~2.5 years	4 years	Spawning of these species is stimulated by within-channel or overbank flows, and fish spawn when temperature is above a certain threshold (Table 2-4). Within the range of managed flow events, the larger the discharge the stronger the recruitment. Slow rates rise and fall of discharge beneficial. 30 days refers to peak discharge; suggested that 90 days over 20,000 $ML.day^{-1}$ needed for fish to respond physiologically (including gonadal development phases, migration, spawning, egg and larval drift phases) to discharge increase.	Bice *et al.* (2014); Wallace *et al.* (2014a, b)
Circa-annual spawning nester fish	1 month	October–end February	~4 years	5 years	Do not need flow to trigger spawning, but larger discharges will facilitate recruitment. Within the range of managed flow events, the larger the flow the stronger the recruitment. Slow rates rise and fall of discharge beneficial.	Bloss *et al.* (2012); Bice *et al.* (2014), Wallace *et al.* (2014a, b)
Foraging generalists and wetland/floodplain specialists	3–12 months in wetlands	Late-spring–early summer	1–2 years	2 years	Depends on species, but many eggs adhere to submerged vegetation, and hatching occurs 2–14 days, maturing can take up to 12 months. Some species are annual species, others up to 5 years.	Lintermans (2007); Bice *et al.* (2014) Wallace *et al.* (2014a, b)
Waterbirds	2–12 months	Variable	1–2 years	2–7 years for large flood frequency	Water regime requirements (including ideal depths, vegetation inundation and duration) vary between species.	Rogers and Ralph (2010)

3 Ecological objectives and targets for a healthy, functioning SARM floodplain

The vision for the Murray-Darling *Basin Plan* is a *healthy, working Basin*, which, by extension, requires a *healthy, working floodplain*. The *Basin Plan's* overall environmental objectives are to:

1. Protect and restore water-dependent ecosystems (e.g. rivers, wetlands and floodplains and their plants and animals)

2. Protect and restore the functions of water-dependent ecosystems (e.g. salt export, connectivity)

3. Ensure that water-dependent ecosystems are resilient to climate change and other risks and threats.

The terms "*objective*" and "*target*" are often used interchangeably by ecologists, managers and stakeholders. Here, *ecological objectives* are statements that specify what planned management actions (the delivery of environmental water) are intended to achieve. An example is "*to maintain a viable, functioning River Red Gum population within the managed floodplain*". For biota in multiple habitats (e.g. river, anabranch, wetlands), the ecological objectives should be consistent across the asset.

Ecological targets are a means to evaluate progress towards achieving the objectives. Where possible, the wording should needs to be 'specific, measurable, achievable, realistic and time bound' (i.e. SMART: Doran, 1981). An example is "*in standardised transects that span the floodplain elevation gradient and existing spatial distribution, >70% of trees have a Tree Condition Index Score (TCI) ≥10 by 2019*".

The ecological objectives and targets have been developed for the priority environmental asset (the managed floodplain), as required by the *Basin Plan* (separate objectives and targets have not been developed for the environmental asset/whole floodplain). For their development the following issues were considered:

1. Response of floodplain biota to flow events

2. Consistency with the ecological objectives and targets for existing floodplain sites within the managed floodplain (e.g. Chowilla, Pike and Eckerts-Katarapko). Maintaining consistent objectives and targets will promote holistic management of the SARM floodplain, and allow for up- and down-scaling on monitoring data between site scales to whole of floodplain.

3. Consistency with objectives of the Basin-wide environmental watering strategy and *Basin Plan* vision (a healthy, working Basin). The ecological objectives and targets show progress towards this vision, to inform management, and are not intended as a 'pass/fail' assessment.

The responses of the floodplain ecosystem to flow events (Section 2.3) suggest components to be included in the ecological objectives.

Ecological objectives and targets have been developed for the Chowilla floodplain (Wallace, 2014), the Pike and Eckerts-Katarapko floodplain (Wallace and Denny, in prep.) and the River Murray channel (Wallace *et al.*, 2014a), and were assessed for possible application to the larger managed floodplain. These have undergone external review, and community review in some cases, and are considered technically robust. They were consolidated to include ecological components relevant to the managed floodplain, and adapted to scale of the managed floodplain. The new ecological objectives were then externally reviewed (see Appendix C).

For the managed floodplain, many of the ecological targets developed do not specify a time component, as baseline data are not yet available. Further, the targets are based on those developed for the Chowilla floodplain, where baseline data are available. This highlights the importance of reviewing the targets once monitoring data are available, via the adaptive management process. For other targets, the time component included extends past the life of the LTWP, but is at an ecologically relevant time scale.

This document is not a monitoring strategy, so that specific monitoring methods are not provided, but a few points warrant mention:

1. The condition of trees should follow the standardised TLM tree condition method (Souter *et al*., 2009), which considers 30 trees along a transect within a 0.25 ha quadrat (100 m x 25 m). The "70%" proportion is defined not on ecological criteria (Wallace, in prep.), but on a pragmatic recognition that, within the existing spatial distribution of trees, a substantial proportion within a transect will have either (i) senesced as a result of natural mortality, or (ii) died as a result of water stress. Therefore, a target of "100% of trees" could not be achieved unless dead trees were excluded from the analysis. This would bias the results. For example, if only live trees were assessed and over time all but one tree in the transect (or quadrat) died from water stress, the target could still be achieved despite a critical loss of habitat value (Wallace, in prep.). The 70% proportion does not suggest that only 70% of the managed floodplain or vegetation community should be inundated. Rather, 100% needs to be inundated, but acknowledges that not necessarily all individuals will be in good condition, or are required for a viable population.

2. Targets for the understorey vegetation (developed for ecological objectives EO5, EO6 and EO7) are based on experience of the Chowilla floodplain, following Gehrig *et al*. (2014). Broadly, this methodology comprises measurement of 45 1 m x 1 m cells at each site, distributed across three elevation bands (15 cells per band), 50 m apart.

3. The targets for fish (circa-annual nester spawners and flow-dependent specialists) listed here for the floodplain are as for the channel asset. Although it is likely that the targets will be monitored within the channel, they are include here to highlight the importance of overbank flows to recruitment and the sustainable population structure of these species.

4. The ecological objectives should not be viewed in isolation of each other as the achievement of one objective is often dependent on the achievement of another. For example, EO1 (*Maintain a viable, functioning River Red Gum population within the managed floodplain*) is influenced by EO16 (*Establish groundwater conditions conducive to maintaining a diverse native vegetation community across the managed floodplain*) and EO17 (*Establish soil conditions conducive to maintaining a diverse native vegetation community across the managed floodplain*). A table showing potential interactions between ecological objectives is provided in Appendix D.

Note that a number of ecological objectives, targets and EWRs previously have been developed for the SARM floodplain and Chowilla and the Riverland Ramsar Site (see Pollino *et al*., 2011) (Appendix E).

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Table 3-1 Recommended ecological objectives, the critical processes that influence the achievement of them, and the recommended ecological targets for the SARM managed floodplain (the priority environmental asset).

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
	VEGETATION			
EO1	Maintain a viable, functioning River Red Gum population within the managed floodplain	• Good tree condition is required for high seed production and successful germination. • Improved recruitment (from current) is required for a sustainable demographic.	1. In standardised transects that span the managed floodplain elevation gradient and existing spatial distribution, >70% of all trees have a Tree Condition Index Score (TCI) ≥10. 2. A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient.	• Here, "*viable*" is defined via (i) the condition of the tree crown; and (ii) presence of a sustainable population demographic. • Here, "*population*" is defined as trees located across (i) the managed floodplain elevation gradient, and (ii) existing spatial distribution. • The spatial distribution is across the whole managed floodplain. • Soil moisture availability needs to be within ranges beneficial to trees.
EO2	Maintain a viable, functioning Black Box population within the managed floodplain	• Good tree condition is required for high seed production and successful germination. • Improved recruitment (from current) is required for a sustainable demographic.	1. In standardised transects that span the managed floodplain elevation gradient and existing spatial distribution, >70% of all trees have a TCI ≥10 2. A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient	• Here, "*viable*" is defined via (i) the condition of the tree crown; and (ii) presence of a sustainable population demographic. • Here, "*population*" is defined as trees located across (i) the managed floodplain elevation gradient, and (ii) existing spatial distribution. • The spatial distribution is across the whole managed floodplain. • Soil moisture availability needs to be within ranges beneficial to trees.
EO3	Maintain a viable, functioning River Cooba population within the managed floodplain	• Good tree condition is required for high seed production and successful germination. • Improved regeneration (recruitment and/or clonal expansion) is required for a sustainable demographic.	1. In standardised transects that span the managed floodplain elevation gradient and existing spatial distribution, >70% of all trees have a TCI ≥10 2. A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient	• Here, "*viable*" is defined via (i) the condition of the tree crown; and (ii) presence of a sustainable population demographic. • Here, "*population*" is defined as trees located across (i) the managed floodplain elevation gradient, and (ii) existing spatial distribution. • The spatial distribution is across the whole managed floodplain. • Soil moisture availability needs to be within ranges beneficial to trees.

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
EO4	Maintain a viable, functioning Lignum population within the managed floodplain	• Good Lignum condition is required for high seed produce and clonal expansion. • Improved regeneration (recruitment and/or clonal expansion) is required for a sustainable demographic.	1. In standardised transects that span the floodplain elevation gradient and existing spatial distribution, ≥70% of Lignum plants have a Lignum Condition Score (LCI) ≥6 for colour	• Here, "*viable*" is defined via a visual assessment of the condition of the above ground biomass of Lignum plants. • Here, "*population*" is defined as plants located across (i) the managed floodplain elevation gradient, and (ii) existing spatial distribution • The spatial distribution is across the whole managed floodplain. • Soil moisture availability needs to be within ranges beneficial to Lignum.
EO5	Establish and maintain diverse water dependent vegetation within aquatic zones across the managed floodplain	• Water dependent vegetation requires opportunities to complete life cycle while inundated (germination, growth, flowering, seed development) to maintain a viable and diverse seedbank	1. In aquatic zones, a minimum of 40% of cells either inundated or dry containing inundation- dependent or amphibious taxa once every two years on average with maximum interval no greater than 4 years. Native water dependent species richness >30 across the managed floodplain. 2. In aquatic zones, a minimum of 80% of cells either inundated or dry containing native flood dependent or amphibious taxa once every four years on average with maximum interval no greater than 6 years. Native water dependent species richness >50 across the managed floodplain.	• Aquatic vegetation within aquatic zones comprises functional groups found within aquatic zones on the floodplain - including those being inundated-dependent for growth (E, F, S-r & S-k; see Table 2-8), as well as amphibious species (AFTE, AFTW, AFTLG & AFTP; see Table 2-8) • Lateral and longitudinal connectivity is required to distribute propagules between the floodplain and main channel.

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
EO6	Establish and maintain diverse native vegetation comprising native flood dependent and amphibious species within the shedding floodplain zones across the managed floodplain	• High soil moisture (from a receding flood event) is required to initiate germination; soil moisture needs to be maintained long enough for seed production. • Flood events need to be of sufficient frequency to maintain seedbank.	1. In shedding floodplain zones, a minimum of 20 % of cells containing native flood dependent or amphibious taxa once every three years on average with maximum interval no greater than 5 years. Native flood dependent and amphibious species richness >20 across the managed floodplain. 2. In shedding floodplain zones, of 40% of cells containing native flood dependent or amphibious taxa once every five years on average with maximum interval no greater than 7 years. Native flood dependent and amphibious species richness >30 across the floodplain. 3. In shedding floodplain zones, of 65 % of cells containing native flood dependent or amphibious taxa once every seven years on average with maximum interval no greater than 10 years. Native flood dependent and amphibious species richness >50 across the managed floodplain.	• Functional groups found within the shedding floodplain zone include those that prefer shorter periods of inundation and/or germinate after flooding (TDr, TDa & FP; see Table 2-8) as well as amphibious species (AFTE, AFTW, AFTLG & AFTP; see Table 2-8) • Lateral and longitudinal connectivity is required to distribute propagules between the floodplain and main channel.
EO7	Limit the extent of invasive plant species including weeds across the managed floodplain	• A diverse water regime that does not provide a competitive advantage to invasive species will be beneficial.	1. In aquatic zones, a maximum of 10 % of cells containing exotic taxa in any given survey across the managed floodplain. 2. In shedding floodplain zones, a maximum of 5 % of cells containing exotic taxa in any given survey across the managed floodplain.	

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
	FISHES			
EO8	Restore resilient populations of circa-annual nester-spawners within the SARM	• Overbank flows promote strong recruitment. • The frequency of overbank flows influences the population age structure.	1. Population age structure of Murray cod includes recent recruits, sub-adults and adults in 9 years in 10. 2. Population age structure of Murray cod indicates a large recruitment event 1 year in 5, demonstrated by a cohort representing >50 % of the population. 3. Abundance, as measured by Catch Per Unit Effort (CPUE), of Murray cod increases by ≥50 % over a 10-year period. 4. Population age structure of Freshwater catfish includes Young OF Year (YOY), with sub-adults and adults in 9 years in 10. 5. Population age structure of Freshwater catfish indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30 % of the population. 6. Abundance (CPUE) of Freshwater catfish increases by ≥30 % over a 5-year period.	• Population structure (demographic) should include a full range of age/size class fish. • A well-mixed water column with complex hydraulics is required to maintain passively drifting larval life stages in suspension. • Access to off-channel habitats including the lotic environments created in creeks and anabranches are important for spawning and juvenile habitat.

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
EO9	Restore resilient populations of flow-dependent specialists within the SARM	• Flow-dependent specialists require high discharges (and sufficient temperature) as a cue for spawning. Higher discharges result in stronger recruitment. • The frequency of overbank flows influences the population age structure.	1. Population age structure of Golden perch and Silver perch includes YOY with sub-adults and adults in 8 years in 10. 2. Population age structure of Golden perch and Silver perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30 % of the population. 3. Abundance, as measured by CPUE, of Golden perch and Silver perch increases by ≥30 % over a 5-year period.	• Population structure (demographic) should include a full range of age/size class fish. • A well-mixed water column with complex hydraulics is required to maintain passively drifting larval life stages in suspension. • Access to off-channel habitats including the lotic environments created in creeks and anabranches are important for spawning and juvenile habitat. • Lateral and longitudinal connectivity is important given the scale of their life history.
EO10	Restore resilient populations of wetland/floodplain specialists within aquatic zones across the managed floodplain during floodplain flow events	• Requires opportunities for dispersal, establishment and recruitment within aquatic zones across the managed floodplain, especially within inundated temporary wetlands	1. The length-frequency distributions for wetland/floodplain specialists within aquatic zones across the managed floodplain include size classes showing annual recruitment 2. Increase range and abundance of wetland/floodplain specialists within aquatic zones across the managed floodplain	• The population structure (demographic) should includes a full range of age/size class (noting that many species are annual for these guilds). • Lateral and longitudinal connectivity is important for dispersal and movement.
EO11	A low proportion of total fish community, measured as abundance and biomass, is comprised of non-native species	• Requires flow events that do not provide a competitive advantage to non-native species (for example, an August flow event will likely benefit the non-native carp).	1. The relative abundance and biomass of non-native species does not increase in the absence of increases in abundance and biomass of native fish.	• Non-native fish species control and management plans will strongly influence this objective as well.

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
	OTHER BIOTIC			
EO12	Provide habitat conducive to supporting diverse communities of riparian frogs within the managed floodplain	• Requires high discharges to inundate the aquatic zone and riparian vegetation to provide spawning habitat, for a long enough duration to support recruitment.	1. Each of 8 riparian frog species present within the managed floodplain will be recorded across the floodplain in any three year period. 2. Tadpoles will be recorded from 8 species in later stages of metamorphosis across the managed floodplain in any three year period.	• Eight species (not 11) are more consistently found across the SARM floodplain.
EO13	Create conditions conducive to successful, small scale breeding events for waterbirds across the managed floodplain	• Requires sufficient inundation length to support breeding, including a slow rate of water level fall. • The preliminary minimum recommended duration is 120 days (see Table 2-8).	1. Minimum inundation periods required for successful breeding by a range of water bird species are provided during 80 % of floods. Preliminary minimum 120 days.	• Success will be influenced by availability of habitat for nesting habitat (e.g. inundated woody vegetation for some species), and availability of food resources in the vicinity.
EO14	Provide refuge for the maintenance of adult populations of waterbirds across the managed floodplain	• Requires sufficient habitat and food resources to maintain adult populations of colonial birds and visiting continental nomad and international migrants.	1. During continental dry periods an increase in the observed to expected ratio of waterbird species	• Expected bird species are the bird species known to utilise the different habitats within the managed floodplain, and could be expected at the field site.

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
EO15	Provide habitat conducive to supporting communities of native woodland birds, reptiles and mammals across the managed floodplain	• Floodplain woodlands (primarily River Red Gum and Black Box woodlands) are the critical habitat for woodland birds, reptiles and mammals. The better the condition of the woodlands, the more birds, reptiles and mammals they can support.	1. Each of the bird species known to utilise similar floodplain woodland habitats in the region will be recorded at 50 % sites across the managed floodplain in any three year period. 2. Each of the reptile species known to utilise similar floodplain/woodland habitats in the region will be recorded at 50 % sites across the managed floodplain in any three year period. 3. Each of the native mammal species known to utilise similar floodplain/woodland habitats in the region will be recorded at 50 % sites across the managed floodplain in any three year period.	• As well as woodland habitat, many species rely on proximity to aquatic zones for food resources or habitat (creeks, temporary wetlands).
	ABIOTIC			
EO16	Establish groundwater conditions conducive to maintaining diverse native vegetation across the managed floodplain	• Requires periods of inundation sufficient in frequency and duration to recharge groundwater.	1. Establish and maintain freshwater lenses in near-bank recharge zones	• May require >60 days for lens maintenance.

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
EO17	Establish soil conditions conducive to maintaining diverse native vegetation across the managed floodplain	• Requires periods of inundation sufficient in frequency and duration to prevent an increase in salinity conditions, and to maintain soil moisture conditions.	1. Maintain soil water availability, measured as soil water potential at soil depth 20-50 cm, greater than -1.5 MPa in order to sustain the recruitment of long-lived vegetation 2. Reduce soil salinity (EC 1:5) to below 5,000 µS/cm to prevent shifts in understorey plant communities to salt tolerant functional groups 3. Maintain soil sodicity below the exchangeable sodium percent (ESP) value of 15 (highly sodic)	• Higher elevation species such as Black Box and *Atriplex* may be able to tolerate -3MPa.
EO18	Maintain sedimentation and erosion processes within normal ranges during overbank flows within the managed floodplain	• Drawdown rates to not exceed bank stability criteria.	1. Limit the maximum rate of drawdown (averaged over 3 consecutive days) to ≤0.025 $m.day^{-1}$ (0.05 $m.day^{-1}$ in any one day) to minimise risk of bank failure	
EO19	Provide diverse hydraulic conditions and complex habitat for flow dependent biota and processes	• Lotic (flowing) conditions generally require higher discharges (which will also be influenced by weir operations).	1. Deliver flows in a manner that increases the proportion of moderate velocity (≥0.15 $m.s^{-1}$) habitat	
EO20	Implement a seasonal and multi-year hydrograph that encompasses variation in discharge, velocity and water levels	• The ecosystem of the SARM floodplain has historically been driven by a variable flow regime - a variable flow regime can favour native species and promote a diversity of habitats and species	1. Discharge, water level and duration metrics of planned e-water represent a seasonally variable hydrograph	
EO21	Provide for the mobilisation of carbon, nutrients and propagules from the managed floodplain to the river	• Requires inundation of the floodplain to mobilise stores of natural organic matter and release DOC and nutrients into the water column to be able to be assimilated into the foodweb.	1. During inundation periods, record an increase in the abundance and diversity of invertebrate food resources, nutrients and DOC relative to those available during base flow	

	Managed floodplain ecological objective	Critical processes that influence the achievement of the ecological objective	Managed floodplain ecological targets	Comments and other important processes
EO22	Maintain water quality to support water dependent biota and normal biogeochemical processes	• Dissolved oxygen (DO) concentrations need to be within parameters necessary for continued survival of many water dependent biota.	1. Maintain DO above the State Environment Protection (Water Quality) Policy (2003) limit of >6 $mgO_2.L^{-1}$	

4 Environmental water requirements for the SARM floodplain

This section describes the environmental water requirements (EWRs) needed to maintain the SARM floodplain as a healthy, functioning floodplain. In general, EWRs can be expressed through a combination of the following flow metrics:

- Discharge – the required discharge (generally measured as $ML.day^{-1}$).
- Duration – the duration (generally measured in days) a specified discharge needs to remain at (or above).
- Timing – the seasonal timing of the EWR (for example, "spring to summer").
- Frequency – the average frequency of an event which is represented as Average Return Interval (ARI) i.e. how often the specified discharge, duration and/or timing should occur on average (generally expressed in years; for example an ARI of "2" should occur once every two years on average). This should be calculated as a rolling average and does not represent a desired regular pattern.
- Maximum interval – the maximum interval between flow events of the specified discharge, duration and timing (generally expressed in years, and is often greater than the ARI)
- Rate of rise and fall of either the discharge or water level – a rate specifying how fast the discharge rises or falls, or how fast the water level rises or fall. For the River Murray, the interaction between the discharge and water level is influenced by weir operations.

A variety of methods have been used to calculate the EWRs for rivers, from focussing on specific requirements of specific biota at specific locations, to a broader approach of addressing the needs of the whole riverine ecosystem by identifying important flow metrics for major attributes (Arthington, 1998; Tharme, 2003). In line with the latter approach, important flow metrics for attributes of the whole floodplain ecosystem were identified, based on the modelled *without development* historic flow of the SARM. Floodplain EWRs were developed using the following process (described in more detail below):

1. Timing and duration – broad values are identified based on the needs of floodplain biota and ecosystem processes
2. Discharge – discharges of 10,000 $ML.day^{-1}$ increments are used to represent step-wise increases in the area of floodplain inundated.
3. Frequency – the duration, timing and discharge metrics are used to model long-term average return frequencies based on modelled 'without development' flow data.
4. Rate of water level rise and fall – a value of how quickly the water level should change is identified based on the needs of floodplain biota and geomorphic processes.

This approach assumes that the floodplain ecosystem is in a condition that will respond following the reintroduction of more nearly-natural flow conditions, although this may not be so for areas affected by stressors such as increased salinity (Lamontagne *et al.*, 2012).

Timing

Table 2-8 shows that spring to summer is the optimal period for a flow event. Before spring (that is, late winter) a flow event may benefit some invasive species (e.g. Common carp) more than native species (DEWNR, 2012a). The timing is also consistent with the preferred timing for Lake Alexandrina barrage outflows to the Coorong (being Spring to early summer, rather than late summer: Lester *et al.,* 2011a, b; MDBA, 2014a), promoting the multiple-asset watering events. Therefore, it is recommended that the preferred timing is September to December. Flow events past December also bring a greater risk of blackwater/hypoxia events, (caused in part by higher water temperatures affecting oxygen levels, although this is likely to be ameliorated by dilution flows provided by the high flow event (Whitworth *et al.*, 2011).

Recommended timing metric:
September to December

Duration

Important durations and their contributions to floodplain biota and processes are shown in Table 4-1, based on the information presented in Table 2-8).

Table 4-1 Important durations for key floodplain biota and processes, based on Table 2-8.

Duration	Floodplain biota/processes
<30 days	Carbon, nutrient and propagules mobilisation, transport and distribution.
30 days	Minimum requirements for River Red Gum and Black Box woodlands and Lignum shrublands for growth (assuming in current good condition), frog egg hatching, AFTL vegetation, AFTE vegetation, flood dependent grassland, circa-annual and flow-dependent fish spawning
60 days	River red gum woodland, Black Box woodland, Lignum shrubland (longer durations preferable for condition improvement and maintenance), River Cooba woodland
≥ 90 days	Frog tadpole maturation
≥ 120 days	*r*-selected plants – longer duration preferred in reaching temporary wetlands and allowing for growth of vegetation, tadpoles and larval fish. May also encourage breeding for some bird species (mainly some large wader and rallid species).

Recommended duration metrics:
30, 60, 90 and 120 days

Discharge

Figure 2-6 to Figure 2-11 demonstrate that while the proportions of each vegetation group and aquatic zone inundated at different discharges differ, all are present at each discharge within the managed floodplain. For this reason, all discharges are within the managed floodplain are considered important to the functioning of the floodplain ecosystem, notwithstanding the large increase in inundated area from 70,000 to 80,000 ML.day^{-1}. Increments of 10,000 ML.day^{-1} increments were chosen to reflect practical increases in discharge and area of floodplain inundated.

Delivering a regular, predictable flow allocation is not consistent with the inherent variable of the River Murray's historic flow regime, and may not produce optimal ecological benefits. Therefore, for each EWR, a target discharge range is given, to promote variability within the watering event, as well as inter-year variability. The discharge should stay within this range for the desired duration, and should also include some days at the top of the range to promote extensive mobilisation of carbon, nutrients and propagules. An average discharge is provided to encourage the full distribution of the discharge range.

Recommended discharge metrics:

- **45,000-55,000 ML.day^{-1} (median 50,000 ML.day^{-1})**
- **55,000-65,000 ML.day^{-1} (median 60,000 ML.day^{-1})**
- **65,000-75,000 ML.day^{-1} (median 70,000 ML.day^{-1})**
- **75,000-85,000 ML.day^{-1} (median 80,000 ML.day^{-1})**

Frequency

The ARIs of the 16 recommended flow events (based on the four discharges for four durations each) were calculated from modelled flow data for 1895–2008 at the South Australian border (QSA) assuming *without development* (Bloss *et al.,* 2012; Gibbs *et al.*, 2012). This models actual flows with all current diversions and development (such as dams, weirs and irrigation extractions) removed (Bloss *et al.,* 2012), to mimic historic "natural" flow. For the calculations, a flow event had to take place during spring/summer (August-March inclusive), consistent with in-channel calculations (Wallace *et al.,* 2014a, b). The ARIs for the 16 combinations of flow metrics are given in Table 4-2.

Table 4-2 ARIs for different combinations of discharge and duration based on *without development* modelled data on the managed floodplain (Bloss *et al.,* 2012; Gibbs *et al.*, 2012).
Greyed numbers indicate those with ARIs greater than the maximum return interval of Black Box.

Duration Discharge	30 days	60 days	90 days	120 days
50,000 ML.day^{-1}	1.5	2.0	2.4	3.2
60,000 ML.day^{-1}	2.0	2.6	3.3	6.3
70,000 ML.day^{-1}	2.5	3.6	5.7	12.7
80,000 ML.day^{-1}	3.4	7.6	12.7	28.5

Some ARIs for the flow metrics (shaded grey in Table 4-2) are greater than the maximum interval requirements of floodplain biota (8 years for Black Box; Table 2-8). These flow metrics are excluded as EWRs, but should be reviewed in future through an adaptive management process.

Table 4-2 and Figure 4-1 indicate different discharge-duration combinations with the same ARI; for example, both "50,000 ML.day^{-1} for 60 days" and "60,000 ML.day^{-1} for 30 days" have an ARI of 2. These results indicate that historically, on average, flows were at or above 50,000 ML.day^{-1} for 60-days and at or above 60,000 ML.day^{-1} for 30-days every two years. Further analysis indicated that for any given ARI there was a pattern of decreasing duration with increasing discharge.

Table 4-3 groups the discharge/duration combinations based on equivalent or similar ARIs; the ARIs used for a group of flow metrics is for the least frequent ARI within the grouping (for example, "60,000 ML.day^{-1} for 90 days" has an ARI of 3.3, but has been grouped with ARI = 3.6).

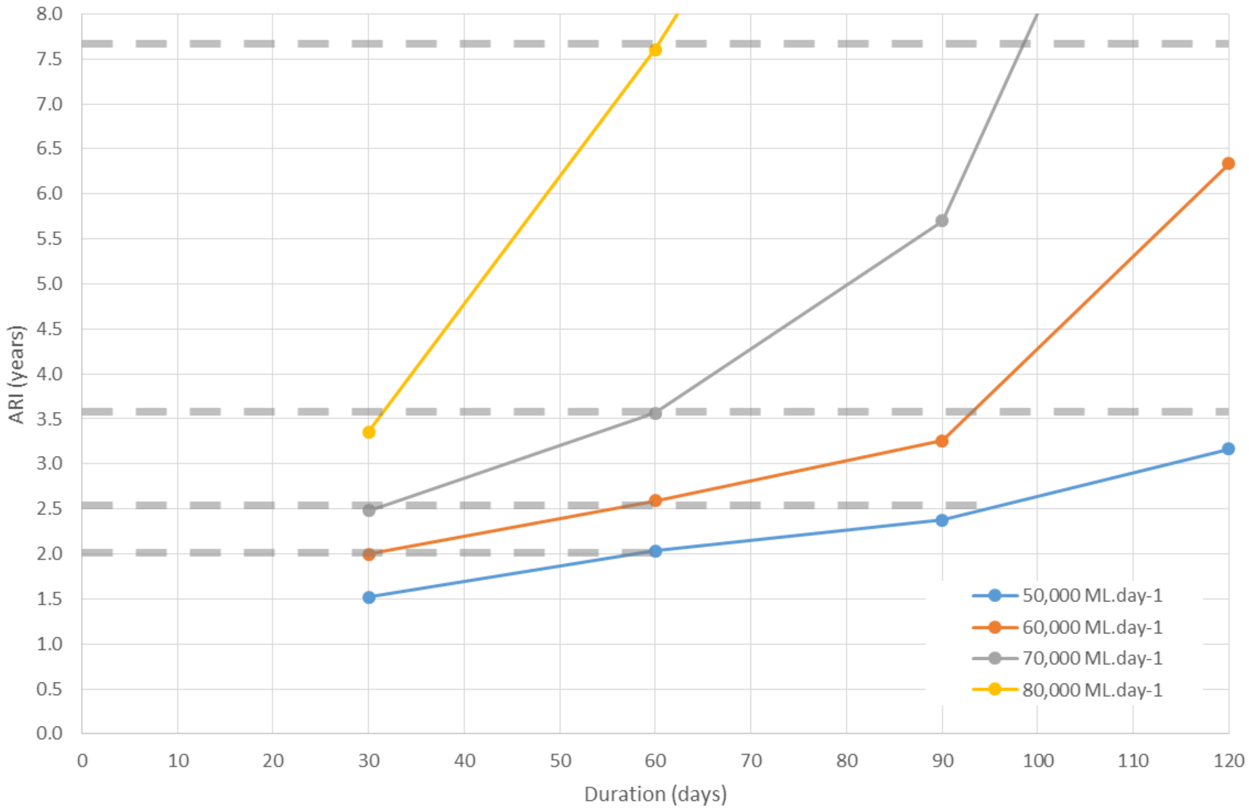

Figure 4-1 The ARI values of different duration and magnitude combinations based on without development modelled data.

Combinations with ARIs similar to 2.0, 2.6, 3.6 and 7.6 years are highlighted.

Table 4-3 Flow metrics grouped together based on ARI. Data from 'without development' modelled historical data (Bloss *et al.,* 2012; Gibbs et *al.*, 2012).

ARI (years)	Discharge/duration combinations included
1.6	50,000 $ML.day^{-1}$ for 30 days
2.0	60,000 $ML.day^{-1}$ for 30 days
	50,000 $ML.day^{-1}$ for 60 days
2.6	70,000 $ML.day^{-1}$ for 30 days
	60,000 $ML.day^{-1}$ for 60 days
	50,000 $ML.day^{-1}$ for 90 days
3.6	80,000 $ML.day^{-1}$ for 30 days
	70,000 $ML.day^{-1}$ for 60 days
	60,000 $ML.day^{-1}$ for 90 days
	50,000 $ML.day^{-1}$ for 120 days
7.6	80,000 $ML.day^{-1}$ for 60 days
	70,000 $ML.day^{-1}$ for 90 days
	60,000 $ML.day^{-1}$ for 120 days

<u>Recommended frequency metrics:</u>
ARI 1.6, 2.0, 2.6, 3.6 and 7.6 years.

Maximum interval

The maximum interval is based on the water requirements of River Red Gums (Table 2-8), given their critical ecological role on the SARM floodplain (see Section 2) and that they have the most demanding maximum interval requirements (5 years: see Table 2-8). Given the current poor condition of River Red Gums, exceeding this may result in further deterioration, tipping the trees into a condition where they can no longer respond to watering events. This maximum interval does not meet the requirements of some biota (e.g. fishes, frogs: Table 2-8), but it is assumed that these mobile species would find refuge within the channel and connected wetlands in intervening periods.

For higher elevations on the floodplain, a maximum interval of 8 years has been specified for longer duration events. This is nearing the upper limit for most key plant species, but it is assumed that vegetation will persist in sub-optimal conditions due to more frequent short-duration events, and that infrequent longer duration events will improve condition and promote recruitment.

Recommended maximum interval metrics:
5 years (smaller flow events, where ARI≤5 years) and 8 years (larger flow events, where ARI>5 and ≤8 years)

Rate of water level rise and fall

For many biota and ecosystem processes, the rate of rise and fall of water level influences the ecological response; for example, a rapid fall may cause desiccation of fish eggs and frog spawn, and may cause waterbirds to abandon their nests (see Section 2.3). A fast drop in water level can also lead to soil bank failure. Experience on the Chowilla floodplain (within the SARM floodplain) indicates that the following limits should apply (in line with EO18, target 1 in Table 3-1).

Recommended rate of water level rise and fall:

- **Maximum rate of rise to be average target of 0.05 $m.day^{-1}$ (averaged over three days, with a maximum of 0.1 m in any one day).**
- **Maximum rate of fall to be average target of 0.025 $cm.day^{-1}$ (averaged over three days, with a maximum of 0.05 m in any one day).**

Consolidation of EWRs

Backwater curves (E&WS, 1975), based on historical floods, were used to translate these rates of water level rise and fall to an equivalent change in discharge. Given that the discharge is measured as QSA (discharge at the SA border), the Border site was used to calculate an equivalent change of water level. As the channel meanders through the floodplain, and the topography changes, different values are expected for the equivalent calculations, which are also likely to be significantly influenced by weir operations at lower discharges. Site to site variation should be considered during operations, and should be reviewed through the adaptive management process.

Table 4-4 shows that to achieve a maximum change in water level of 0.05 $m.day^{-1}$ when increasing discharge, it takes, on average, about 10 days to increase the discharge by 10,000 $ML.day^{-1}$ (noting variation between discharge increments). Achieving a maximum decrease in water level of 0.025 $cm.day^{-1}$, it will take, on average, about 20 days to decrease the discharge by 10,000 $ML.day^{-1}$. In effect, for the discharge to increase and then decrease by 10,000 $ML.day^{-1}$, at the desired rates of water level rise and fall, it should take on average 30 days.

Table 4-4 Calculating the maximum daily change in discharge to meet the target change in water level at the SA border between different discharges (water level data based on E&WS (1975).

	40,000 ML.day^{-1}	50,000 ML.day^{-1}	60,000 ML.day^{-1}	70,000 ML.day^{-1}	80,000 ML.day^{-1}
Water level at SA border (m AHD)	20.2	20.58	21.1	21.64*	22.27**
		40-50,000 ML.day^{-1}	**50-60,000 ML.day^{-1}**	**60-70,000 ML.day^{-1}**	**70-80,000 ML.day^{-1}**
Change in water level (m) for change in 10,000 ML.day^{-1} (m)	-	0.38	0.52	0.54	0.63
Change in discharge to achieve rise of 0.05 m.day^{-1} (ML.day^{-1})	-	1,316	962	926	794
Change in discharge to achieve fall of 0.025 cm.day^{-1} (ML.day^{-1})	-	658	481	463	397
Number of days to increase 10,000 ML.day^{-1} (days)	-	8	10	11	13
Number of days to decrease 10,000 ML.day^{-1} (days)	-	15	20	22	25

**Based on 1970 flood of 68,500 ML.day^{-1}. Note that a flood in 1983 of 69,400 ML.day^{-1} only reached 21.46 m AHD.*

***Based on 1953 flood of 79,700 ML.day^{-1}. Note that a flood in 1958 of 81,000 ML.day^{-1} reached 21.9 m AHD.*

This duration – 30 days to rise and fall 10,000 ML.day^{-1} – is comparable to the flow metrics grouped together in Table 4-3. That is, to achieve "60,000 ML.day^{-1} for 30 days" (as shown for an ARI of 2.0 years), the discharge will need to be at or above 50,000 ML.day^{-1} (between 50,000 and 60,000 ML.day^{-1}) for an additional 30 days, thereby meeting the other flow metric in the ARI 2.0 grouping of "50,000 ML.day^{-1} for 60 days". The same is true for the other flow metrics grouped by similar ARIs in Table 4-3. This information can be used to consolidate the flow metrics, to identify the key EWRs.

Recommended floodplain EWRs

Combining the preceding information identifies five key EWRs for the priority environmental asset (the managed floodplain), as in Table 4-5.

Table 4-5 EWRs for the priority environmental asset (the managed floodplain).

EWR	Discharge range (ML.day^{-1})	Median discharge (ML.day^{-1})	Duration (days)	ARI (years)	Max rate of water level rise (m.day^{-1})	Max rate of water level fall (m.day^{-1})	Maximum interval (years)	Timing
FP1	45,000-55,000	50,000	30	1.6	0.05	0.025	5	Sep-Dec
FP2	55,000-65,000	60,000	30	2.0	0.05	0.025	5	Sep-Dec
FP3	65,000-75,000	70,000	30	2.6	0.05	0.025	5	Sep-Dec
FP4	75,000-85,000	80,000	30	3.6	0.05	0.025	5	Sep-Dec
FP5	75,000-85,000	80,000	60	7.6	0.05	0.025	8	Sep-Dec

5 Linking EWRs to ecological objectives and targets

5.1 Contribution of grouped EWRs to ecological targets

A ranking system (Table 5-1) based on Wallace *et al*. (2014a) was used to facilitate a rapid assessment of the expected contribution of each EWR to achieving the ecological objectives and targets. This assessment was performed using advice from a workshop of expert advisors (Appendix G).

The resulting assessment matrix (Table 5-2) can be used to support decisions about potential benefits or trade-offs of different flow and water-level scenarios. As this ranking system only includes three categories, it can yield only an estimate of expected contributions towards the targets. Further information and comments from the workshop are provided in Appendix G.

Table 5-1 Ranking system for rapid assessment of the expected contribution of floodplain EWRs towards ecological objectives and targets (Wallace *et al.,* 2014a).

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 5-2 Contribution of floodplain EWRs (FP1-FP5) towards the achievement of floodplain ecological objectives and targets. Refer Table 5-1 for ranking description.

	Managed floodplain ecological objective	Ecological targets	FP1	FP2	FP3	FP4	FP5
	VEGETATION						
EO1	Maintain a viable, functioning River Red Gum population within the managed floodplain	1. In standardised transects that span the managed floodplain elevation gradient and existing spatial distribution >70 % of all trees have a TCI ≥10	3	3	2	1	1
		2. A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient	3	3	3	2	1
EO2	Maintain a viable, functioning Black Box population within the managed floodplain	1. In standardised transects that span the managed floodplain elevation gradient and existing spatial distribution, >70 % of all trees have a TCI ≥10	3	3	2	2	1
		2. A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient	3	3	3	2	1
EO3	Maintain a viable, functioning River Cooba population within the managed floodplain	1. In standardised transects that span the managed floodplain elevation gradient and existing spatial distribution, >70 % of all trees have a TCI ≥10	3	3	2	1	1
		2. A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient	3	3	3	2	1
EO4	Maintain a viable, functioning Lignum population witin the managed floodplain	1. In standardised transects that span the floodplain elevation gradient and existing spatial distribution , ≥70 % of Lignum plants have a LCI ≥6 for colour	3	3	3	1	1
EO5	Establish and maintain diverse water dependent vegetation within aquatic zones across the managed floodplain	1. In aquatic zones, a minimum of 40 % of cells either inundated or dry containing inundation-dependent or amphibious taxa once every two years on average with maximum interval no greater than 4 years. Native water dependent species richness >30 across the managed floodplain.	3	2	1	1	1
		2. In aquatic zones, a minimum of 80 % of cells either inundated or dry containing native flood dependent or amphibious taxa once every four years on average with maximum interval no greater than 6 years. Native water dependent species richness >50 across the managed floodplain.	3	3	2	1	1
EO6	Establish and maintain diverse native vegetation comprising native flood dependent and amphibious species within the	1. In shedding floodplain zones, a minimum of 20 % of cells containing native flood dependent or amphibious taxa once every three years on average with maximum interval no greater than 5 years. Native flood dependent and amphibious species richness >20 across the managed floodplain.	2	2	1	1	1

	Managed floodplain ecological objective	Ecological targets	FP1	FP2	FP3	FP4	FP5
	shedding floodplain zones across the managed floodplain	2. In shedding floodplain zones, of 40 % of cells containing native flood dependent or amphibious taxa once every five years on average with maximum interval no greater than 7 years. Native flood dependent and amphibious species richness >30 across the floodplain.	3	2	1	1	1
		3. In shedding floodplain zones, of 65 % of cells containing native flood dependent or amphibious taxa once every seven years on average with maximum interval no greater than 10 years. Native flood dependent and amphibious species richness >50 across the managed floodplain.	3	3	2	1	1
EO7	Limit the extent of invasive plant species including weeds.	1. In aquatic zones, a maximum of 10 % of cells containing exotic taxa in any given survey across the managed floodplain.	1	2	3	3	3
		2. In shedding floodplain zones, a maximum of 5 % of cells containing exotic taxa in any given survey across the managed floodplain.	1	2	3	3	3
	FISHES						
EO8	Restore resilient populations of circa-annual nester-spawners within the SARM	1. Population age structure of Murray cod includes recent recruits, sub-adults and adults in 9 years in 10.	2	2	1	1	1
		2. Population age structure of Murray cod indicates a large recruitment event 1 year in 5, demonstrated by a cohort representing >50 % of the population.	2	2	1	1	1
		3. Abundance (CPUE) of Murray cod increases by ≥50 % over a 10-year period.	2	2	1	1	1
		4. Population age structure of Freshwater catfish includes YOY, with sub-adults and adults in 9 years in 10.	2	2	1	1	1
		5. Population age structure of Freshwater catfish indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30 % of the population.	2	2	2	1	1
		6. Abundance (CPUE) of Freshwater catfish increases by ≥30 % over a 5-year period.	2	2	2	1	1
EO9	Restore resilient populations of flow-dependent specialists within the SARM	1. Population age structure of Golden perch and Silver perch includes YOY with sub-adults and adults in 8 years in 10.	1	1	1	1	1
		2. Population age structure of Golden perch and Silver perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30 % of the population.	1	1	1	1	1
		3. Abundance (CPUE) of Golden perch and Silver perch increases by ≥30 % over a 5-year period.	1	1	1	1	1
EO10	Restore resilient populations of wetland/floodplain specialists within aquatic zones across the managed	1. The length-frequency distributions for wetland/floodplain specialists within aquatic zones across the managed floodplain include size classes showing annual recruitment.	3	3	2	1	1

	Managed floodplain ecological objective	Ecological targets	FP1	FP2	FP3	FP4	FP5
	floodplain during floodplain flow events	2. Increase range and abundance of wetland/floodplain specialists within aquatic zones across the managed floodplain	3	3	2	1	1
EO11	A low proportion of total fish community, measured as abundance and biomass, is comprised of non-native species	1. The relative abundance and biomass of non-native species does not increase in the absence of increases in abundance and biomass of native fish.	2	2	1	1	1
	OTHER BIOTIC						
EO12	Provide habitat conducive to supporting diverse communities of riparian frogs within the managed floodplain	1. Each of eight riparian frog species present within the managed floodplain will be recorded across the floodplain in any three year period.	2	1	1	1	1
		2. Tadpoles will be recorded from eight species in later stages of metamorphosis across the managed floodplain in any three year period.	2	2	1	1	1
EO13	Create conditions conducive to successful, small scale breeding events for waterbirds across the managed floodplain	1. Minimum inundation periods required for successful breeding by a range of water bird species are provided during 80 % of floods by 2020. Preliminary minimum 120 days.	3	3	2	1	1
EO14	Provide refuge for the maintenance of adult populations of waterbirds across the managed floodplain	1. During continental dry periods an increase in the observed to expected ratio of waterbird species.	2	2	1	1	1
EO15	Provide habitat conducive to supporting communities of native woodland birds, reptiles and mammals across the managed floodplain	1. Each of the bird species known to utilise similar floodplain woodland habitats in the region will be recorded at 50 % sites across the managed floodplain in any three year period.	3	3	3	2	1
		2. Each of the reptile species known to utilise similar floodplain/woodland habitats in the region will be recorded at 50 % sites across the managed floodplain in any three year period.	3	3	3	2	1
		3. Each of the native mammal species known to utilise similar floodplain/woodland habitats in the region will be recorded at 50 % sites across the managed floodplain in any three year period.	3	3	3	2	1
	ABIOTIC						

	Managed floodplain ecological objective	Ecological targets	FP1	FP2	FP3	FP4	FP5
EO16	Establish groundwater conditions conducive to maintaining diverse native vegetation across the managed floodplain	1. Establish and maintain freshwater lenses in near-bank recharge zones	2	1	1	1	1
EO17	Establish soil conditions conducive to maintaining diverse native vegetation across the managed floodplain	1. Maintain soil water availability, measured as soil water potential at soil depth 20-50 cm, greater than -1.5 MPa in order to sustain the recruitment of long-lived vegetation	2	2	1	1	1
		2. Reduce soil salinity (EC 1:5) to below 5000 μScm^{-1} to prevent shifts in understorey plant communities to salt tolerant functional groups	2	2	1	1	1
		3. Maintain soil sodicity below the exchangeable sodium percent (ESP) value of 15 (highly sodic)	2	2	1	1	1
EO18	Maintain sedimentation and erosion processes within normal ranges during overbank flows within the managed floodplain	1. Limit the maximum rate of drawdown (averaged over 3 consecutive days) to ≤0.025 $m.day^{-1}$ (0.05 $m.day^{-1}$ in any one day) to minimise risk of bank failure	1	1	1	1	1
EO19	Provide diverse hydraulic conditions and complex habitat for flow dependent biota and processes	1. Deliver flows in a manner that increases the proportion of moderate velocity (≥0.15 $m.s^{-1}$) habitat	1	1	1	1	1
EO20	Implement a seasonal and multi-year hydrograph that encompasses variation in discharge, velocity and water levels	1. Discharge, water level and duration metrics of planned e-water represent a seasonally variable hydrograph	1	1	1	1	1
EO21	Provide for the mobilisation of carbon, nutrients and propagules from the managed floodplain to the river	1. During inundation periods, record an increase in the abundance and diversity of invertebrate food resources, nutrients and DOC relative to those available during base flow	2	1	1	1	1
EO22	Maintain water quality to support water dependent biota and normal biogeochemical processes	1. Maintain DO above the State Environment Protection (Water Quality) Policy (2003) limit of >6 mgO_2L^{-1}	1	1	1	1	1

5.2 Linking discharges to ecological objectives

To show how different discharges specified in the EWRs may contribute to the achievement of the ecological objectives, information is provided on the areas of habitat relevant to objectives at different discharges (Table 5-3). For example, for EO1 (*Maintain a functioning, viable River Red Gum population*), the area of River Red Gum woodland inundated for different discharges has been calculated. The area is shown in both absolute terms (hectares) and as a comparison with the whole floodplain (the environmental asset) and the managed floodplain (the priority environmental asset). For some objectives only one key habitat type is provided, although different habitats will be important for determining the ecological response. For example, EO21 (*Provide for the mobilisation of carbon, nutrients and propagules from the floodplain to the river*), River Red Gum woodlands contribute the most Natural Organic Matter per hectare, but inundation of the whole floodplain is important for mobilisation of propagules (and hence was used for the inundation calculations).

Table 5-3 How the different discharges contribute to the different ecological objectives, based on the area inundated relevant to that objective.

Total relevant area given in hectares, and compared to total on the Whole Floodplain (WF; the 1956 extent – the environmental asset), and the total on the Managed Floodplain (MF; to 80,000 ML.day^{-1} – the priority environmental asset).

EO#	Ecological objective for whole floodplain	Relevant inundated area	50,000 ML.day^{-1}	60,000 ML.day^{-1}	70,000 ML.day^{-1}	80,000 ML.day^{-1}
EO1	Maintain a viable, functioning River Red Gum population within the managed floodplain	Area of River Red Gum woodland	3880 ha (21% WF; 32% MF)	5870 ha (31% WF; 48% MF)	8350 ha (45% WF; 69% MF)	12,150 ha (65% WF; 100% MF)
EO2	Maintain a viable, functioning Black Box population within the managed floodplain	Area of Black Box woodland	490 ha (3% WF; 11% MF)	910 ha (6% WF; 21% MF)	1,950 ha (12% WF; 45% MF)	4,330 ha (28% WF; 100% MF)
EO3	Maintain a viable, functioning River Cooba population within the managed floodplain	Area of River Cooba woodland	61 ha (17% WF; 29% MF)	98 ha (28% WF; 46% MF)	155 ha (44% WF; 73% MF)	214 ha (61% WF; 100% MF)
EO4	Maintain a viable, functioning Lignum population within the managed floodplain	Area of Lignum shrubland	1340 ha (12% WF; 15% MF)	2990 ha (27% WF; 33% MF))	5420 ha (49% WF; 60% MF)	9010 ha (81% WF, 100% MF)
EO5	Establish and maintain diverse water dependent vegetation within aquatic zones across the managed floodplain	Area of temporary wetlands, plus area of creeks, plus increased area of permanent wetlands[1]	3051 ha (46% WF; 57% MF)	3771 ha (56% WF; 70% MF)	4322 ha (65% WF; 80% MF)	5374 ha (80% WF; 100% MF)
EO6	Establish and maintain diverse native vegetation comprising native flood dependent and amphibious species within the shedding floodplain zones across the managed floodplain	Area of flood dependent grassland and emergent sedgeland	506 ha (18% WF; 24% MF)	828 ha (30% WF; 40% MF)	1144 ha (41% WF; 55% MF)	2083 ha (74% WF; 100% MF)
EO7	Limit the extent of invasive plant species including weeds across the managed floodplain		-	-	-	-
EO8	Restore resilient populations of circa-annual nester-spawners within the SARM	Area of creeks[2]	1350 ha (75% WF; 80% MF)	1440 ha (80% WF; 86% MF)	1530 ha (85% WF; 91% MF)	1680 ha (94% WF; 100% MF)
EO9	Restore resilient populations of flow-dependent specialists within the SARM	Area of creeks[2]	1350 ha (75% WF; 80% MF)	1440 ha (80% WF; 86% MF)	1530 ha (85% WF; 91% MF)	1680 ha (94% WF; 100% MF)

EO#	Ecological objective for whole floodplain	Relevant inundated area	50,000 $ML.day^{-1}$	60,000 $ML.day^{-1}$	70,000 $ML.day^{-1}$	80,000 $ML.day^{-1}$
EO10	Restore resilient populations of wetland/floodplain specialists within aquatic zones across the managed floodplain during floodplain flow events	Area of temporary wetlands and increased area of permanent wetlands[1]	1697 ha (35% WF; 46% MF)	2330 ha (48% WF; 63% MF)	2790 ha (57% WF; 76% MF)	3690 ha (76% WF; 100% MF)
EO11	A low proportion of total fish community, measured as abundance and biomass, is comprised of non-native species		-	-	-	-
EO12	Provide habitat conducive to supporting diverse communities of riparian frogs within the managed floodplain	Area of temporary wetlands, plus area of creeks, plus increased area of permanent wetlands[1]	3051 ha (46% WF; 57% MF)	3771 ha (56% WF; 70% MF)	4322 ha (65% WF; 80% MF)	5374 ha (80% WF; 100% MF)
EO13	Create conditions conducive to successful, small scale breeding events for waterbirds across the managed floodplain	Area of temporary wetlands, plus area of creeks, plus increased area of permanent wetlands[1]	3051 ha (46% WF; 57% MF)	3771 ha (56% WF; 70% MF)	4322 ha (65% WF; 80% MF)	5374 ha (80% WF; 100% MF)
EO14	Provide refuge for the maintenance of adult populations of waterbirds across the managed floodplain	Area of temporary wetlands, plus area of creeks, plus increased area of permanent wetlands[1]	3051 ha (46% WF; 57% MF)	3771 ha (56% WF; 70% MF)	4322 ha (65% WF; 80% MF)	5374 ha (80% WF; 100% MF)
EO15	Provide habitat conducive to supporting communities of native woodland birds, reptiles and mammals across the managed floodplain	Area of river red gum and Black Box	4365 ha (13% WF; 26% MF)	6780 ha (20% WF; 41% MF)	10,300 ha (30% WF; 62% MF)	16,485 ha (48% WF; 100% MF)
EO16	Establish groundwater conditions conducive to maintaining diverse native vegetation across the managed floodplain	Total area of floodplain (excludes towns and agriculture)	22,890 ha (26% WF; 42% MF)	29,430 ha (33% WF; 54% MF)	38,405 ha (43% WF; 71% MF)	54,293 ha (61% WF; 100% MF)
EO17	Establish soil conditions conducive to maintaining diverse native vegetation across the managed floodplain	Total area of floodplain (excludes towns and agriculture)	22,890 ha (26% WF; 42% MF)	29,430 ha (33% WF; 54% MF)	38,405 ha (43% WF; 71% MF)	54,293 ha (61% WF; 100% MF)
EO18	Maintain sedimentation and erosion processes within normal ranges during overbank flows within the managed floodplain		-	-	-	-
EO19	Provide diverse hydraulic conditions and complex habitat for flow dependent biota and processes		-	-	-	-
EO20	Implement a seasonal and multi-year hydrograph that encompasses variation in discharge, velocity and water levels		-	-	-	-

EO#	Ecological objective for whole floodplain	Relevant inundated area	50,000 $ML.day^{-1}$	60,000 $ML.day^{-1}$	70,000 $ML.day^{-1}$	80,000 $ML.day^{-1}$
EO21	Provide for the mobilisation of carbon, nutrients and propagules from the managed floodplain to the river	Total area of floodplain (excludes towns and agriculture)	22,890 ha (26% WF; 42% MF)	29,430 ha (33% WF; 54% MF)	38,405 ha (43% WF; 71% MF)	54,293 ha (61% WF; 100% MF)
EO22	Maintain water quality to support water dependent biota and normal biogeochemical processes		-	-	-	-

[1]Increased area of permanent wetlands is the area inundated above that inundated at 40,000 $ML.day^{-1}$ – often the inundation of fringing littoral vegetation.

[2]For this calculation the area of "creeks" (as described by Table 2-7) was used, as flowing off-channel environments are important for some juvenile fish and other recruitment processes; many of the adults are expected to stay in the main channel. The categorisation of "creeks" is subjective, and may not provide the required hydrodynamic environment - but are the only landscape data available, and give an indication of the most-likely lotic areas (cf. lentic wetlands) inundated.

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7 Appendices

A. Assessment of different spatial scales for the environmental asset

Table A-7-1 presents a summary of advantages and disadvantages of different spatial scales used to define the floodplain environmental asset(s). These are presented for the options of spatial scale for defining environmental assets for the River Murray Floodplain and their fit with different aspects of environmental water management, including:

- Planning (the identification of objectives, targets and environmental water requirements for each asset)
- Delivery (the allocation and delivery of environmental water to an individual asset)
- Monitoring, evaluating and reporting on ecological outcomes (response to environmental watering at an asset-scale)
- Environmental water accounting (reporting where possible at an asset-scale, on the volumes of held and planned water delivered).

Due to the broad nature of the criteria that must be used to identify environmental assets, all of the possible options presented could be used when defining environmental assets. Thus, the selection should be based on what is the most efficient and effective means of planning for environmental flows provisions and evaluating outcomes of the *Basin Plan*.

Table A-7-1 Advantages and disadvantages of different spatial scales used to define the floodplain environmental asset(s).

Floodplain asset option	Considerations	Advantages	Disadvantages
FLOODPLAIN UNITS	**BP criteria to identify assets**	Work already completed	
>100 asset units identified (Key Environmental Assets - as listed in Guide to Proposed BP)	**Planning (Objectives, Targets and EWRs)**	Can single out Ramsar sites and threatened species locations[1]	Each asset will require objectives, targets and EWRs to be developed, and likely to be similar/ highly repetitive
	E-water allocation and delivery	Easier to align with water delivery through pumping and regulator operations	Not possible to direct landscape-scale watering to an individual floodplain unit
	Reporting on ecological outcomes (Matter 8)	Floodplain units could be grouped or 'classified' to enable monitoring of a subset of representative sites	Not feasible to monitor and report for >100 assets May be difficult to scale-up to represent outcomes at regional scale (potential to underestimate outcomes)

[1] *Basin Plan* Section 8.49 (1) (c) states the ecological objectives for the assets are to be consistent with the criteria used to identify those assets

Floodplain asset option	Considerations	Advantages	Disadvantages
	Reporting on e-water delivery to assets (Matter 9)[2]		Intensive modelling may be required to estimate water-use at each asset May need to calculate return flows from each floodplain unit
	Fit with LLCMM and channel assets		Poor fit with LLCMM as the LLCMM 'floodplain' is not broken down into smaller units Poor fit with channel asset
LANDSCAPE-SCALE HYDROLOGICAL MANAGEMENT UNITS *~8 asset units (Lock reaches + Chowilla)*	**BP criteria to identify assets**	Outline of work begun	May be issues using localised records as evidence for landscape-scale assets
	Planning (Objectives, Targets and EWRs)	Consistent with major management levers in SA	Objectives, targets and EWRs likely to be similar/ repetitive
	e-water allocation and delivery	Water can be delivered to individual units through weir manipulation and operation of Chowilla regulator	May be difficult to secure water for localised watering actions
	Reporting on ecological outcomes (Matter 8)		Likely to be multiplicative in effort
	Reporting on e-water delivery to assets (Matter 9)		Modelling may be required to translate QSA volume to volume per lock reach May need to calculate return flows from each reach
	Fit with LLCMM and channel assets		Channel may need to be divided into lock reaches No management lever between Lock 1 and LLCMM
GEOMORPHIC TRACTS *4 asset units (Valley, Gorge, LM Swamps, Lower Lakes)*	**BP criteria to identify assets**	Outline of work begun	May be issues using localised records as evidence for landscape-scale assets
	Planning (Objectives, Targets and EWRs)	Can represent variation in habitat distribution between geomorphic reaches	
	E-water allocation and delivery		Some consistency with management levers but e-water

[2] *Basin Plan* Schedule 12 Reporting Guidelines Indicator 9.3 states that where possible the volume of water delivered to each asset should be reported

Floodplain asset option	Considerations	Advantages	Disadvantages
			provisions to individual unit not possible May be difficult to secure water for localised watering actions
	Reporting on ecological outcomes (Matter 8)	Reduced multiplication in effort (compared to all but whole SA River Murray Floodplain)	
	Reporting on e-water delivery to assets (Matter 9)		Modelling may be required to translate QSA to volume per geomorphic reach May need to calculate return flows from each reach
	Fit with LLCMM and channel assets	Most consistent with LLCMM (distinct geomorphic unit)	Channel may need to be divided into geomorphic reaches
WHOLE SA RIVER MURRAY FLOODPLAIN	**BP criteria to identify assets**		May be issues using localised records as evidence for landscape-scale assets
1 asset unit (Border to Wellington)	**Planning (Objectives, Targets and EWRs)**		Risk of not representing variation in habitat distribution between geomorphic reaches or the ability to use management levers for spatial differences in outcomes
	E-water allocation and delivery	Best fit with e-water delivery through enhancing QSA	May be difficult to secure water for localised watering actions
	Reporting on ecological outcomes (Matter 8)	Least intensive	Incompatible with major management levers within SA
	Reporting on e-water delivery to assets (Matter 9)	Water use can be based on QSA	
	Fit with LLCMM and channel assets	Generally consistent with LLCMM in terms of habitat although there is no management lever at Wellington Consistent with channel	
HABITAT TYPE	**BP criteria to identify assets**		Difficult to relate to BP criteria for identifying an asset

Floodplain asset option	Considerations	Advantages	Disadvantages
3 asset units (floodplain, temporary wetland, temporary channel) or could be broken into more detailed habitat types	**Planning (Objectives, Targets and EWRs)**		Can already be represented through establishing habitat-based targets for an asset
	E-water allocation and delivery		Not possible to target specific habitat types (except pumping to discreet locations)
	Reporting on ecological outcomes (Matter 8)	Reduced multiplication in effort	
	Reporting on e-water delivery to assets (Matter 9)		Difficult to report at an asset-scale due to the mosaic of habitats on the floodplain
	Fit with LLCMM and channel assets	Some consistency with LLCMM	Poor fit with channel
FLOW BANDS *~7 asset units (10,000ML/day increments from 40,000 ML/day to >100,000 ML/day)*	**BP criteria to identify assets**		Difficult to relate to BP criteria for identifying an asset
	Planning (Objectives, Targets and EWRs)		Already represented through EWRs
	E-water allocation and delivery	Good fit with e-water delivery through enhancing QSA	
	Reporting on ecological outcomes (Matter 8		Likely to be multiplication in effort
	Reporting on e-water delivery to assets (Matter 9)		Modelling may be required to translate QSA into volume per flow band
	Fit with LLCMM and channel assets		Poor fit with LLCMM Channel may need to be divided into flow-band based assets

B. ESRI® ArcGIS methodology

1. Inundation Calculations

This procedure uses a similar procedure as outlines in DEWNR (2012b).

BASE LAYERS

Spatial Layers used:

- SA_VEG_FP.shp (held by DEWNR, metadata through iShare, number 422)
- RM_WetlandPrioritisation_Final2010B.gdb; prio_entre_RM_LL_Final_2010 (attribute table) (held by DEWNR)

Methodology:

1. Floodplain vegetation layer:
    a. Delete all polygons <0.01ha or unlabelled
    b. Create new attribute field 'func_group'. Categorise polygons into one of ten 'func_groups' based on first (dominant) species listed in attribute 'SAVEG_DESC', as outlined in Table B-7-2.
    c. New shapefile fpveg.shp
2. Wetland layer:
    a. Union attribute table to 2010_SAAE_wetlands.shp
    b. Delete all polygons <0.01ha or unlabelled.
    c. Create new attribute field 'LTWP_class'. Categorise polygons into one of three classes based on attribute 'WETCODE', as outlined in Table 2-7.
    d. New shapefile; Wetlands_final.shp
3. Floodplain vegetation layer:
    a. Intersect fpveg.shp and Wetlands-final.shp – new layer Fpveg_wetland_intersect.shp
    b. Select by location those areas that are identical between fpveg.shp and fpveg_wetland_intersect.shp. Delete selected polygons -– new layer Veg_final.shp
    c. Create new field, calculate new areas. Delete areas <0.01ha.
    d. New shapefile Veg_final.shp

Summary:

Base floodplain information consisting of two, non overlaying layers:

- Veg_final.shp
- Wetland_final.shp

INUNDATION CALCULATIONS

Inundation data from River Murray Floodplain Inundation Model (RiMFIM; Overton *et al.,* 2006), including data from more recent hydraulic modelling (DEWNR, 2012c) where available. The RiMFIM shapefiles were dissolved into one polygon for inundation calculations.

Spatial layers used:

- FIM_*GL_(Hydromodelling_)Dissolved.shp
- Veg_final.shp
- Wetland_final.shp

Methodology:

1. Different flows
    a. FIM_*GL_(Hydromodelling_)Dissolved.shp with Veg_final.shp – create a new layer Intersects*_veg.shp
        i. Create new attribute field and calculate polygon sizes.
        ii. Delete polygons ≤0.01 ha
    b. Repeat process for Wetland_final.shp

Calculations of area for different vegetation functional groups and wetland types done in Microsoft Excel.

2. Vegetation Attributes

All species listed in the vegetation shapefile were assigned to a water regime functional group based on Nicol *et al*. (2010) (modified from Casanova (2011)), as described in Table 2-2 and Figure 2-5. The water regime functional group was not known for a few species; however, these species were rare and so did not affect the classification of the 60 shapefile vegetation associations into the ten vegetation groups. A list of all associated species for each vegetation group and the water regime functional group is presented in Table B-7-2.

Table B-7-2: Dominant and other species associated with the ten vegetation groups used for this analysis, as based on the data in the shapefile.

Vegetation Group	Dominant species (based on shapefile attribute SAVEG_DESC)	Associated species (in different combinations of) (based on shapefile attribute SAVEG-DESC)
River red gum woodland	*Eucalyptus camaldulensis*	*Acacia stenophylla, Enchylaena tomentosa var. tomentosa, Eucalyptus largiflorens, Cyperus gymnocaulos, Duma florulenta, Phragmites australis , Senecio cunninghamii* var. *cunninghamii, Setaria jubiflora.*
Lignum shrubland	*Duma florulenta*	*Enchylaena tomentosa var. tomentosa, Sporobolus mitchellii, Sporobolus virginicus, Suaeda australis, Tecticornia pergranulata* ssp. *pergranulata.*

Vegetation Group	Dominant species (based on shapefile attribute SAVEG_DESC)	Associated species (in different combinations of) (based on shapefile attribute SAVEG-DESC)
Black Box woodland	*Eucalyptus largiflorens*	*Acacia stenophylla, Atriplex rhagodioides, Callistemon brachyandrus, Chenopodium nitrariaceum, Disphyma crassifolium ssp. clavellatum, Enchylaena tomentosa var. tomentosa, Eremophila divaricata ssp. divaricata, Eucalyptus camaldulensis var. camaldulensis, Maireana pyramidata, Duma florulenta, Setaria jubiflora, Tecticornia indica ssp. leiostachya, Tecticornia pergranulata ssp. pergranulata.*
River Coobah woodland	*Acacia stenophylla*	*Chenopodium nitrariaceum, Enchylaena tomentosa var. tomentosa, Duma florulenta*
Ti tree woodland	*Melaleuca halmaturorum, Melaleuca lanceolata*	*Disphyma crassifolium ssp. clavellatum, Enchylaena tomentosa var. tomentosa, Eucalyptus largiflorens, Frankenia pauciflora var., Juncus kraussii, Samolus repens, Sarcocornia quinqueflora, Suaeda australis.*
Mallee shrubland	*Eucalyptus brachycalyx, Eucalyptus cyanophylla, Eucalyptus dumosa, Eucalyptus gracilis, Eucalyptus leptophylla, Eucalyptus porosa*	*Acacia stenophylla, Atriplex vesicaria ssp., Austrostipa sp., Beyeria opaca, Chenopodium desertorum, Danthonia sp., Enchylaena tomentosa var. tomentosa, Eucalyptus dumosa, Eucalyptus gracilis, Eucalyptus leptophylla, Eucalyptus oleosa ssp. ampliata, Eucalyptus oleosa ssp. oleosa, Eucalyptus socialis* spp., *Grevillea huegelii, Helichrysum leucopsideum, Lepidosperma concavum, Maireana pentatropis, Maireana pyramidata, Melaleuca lanceolata, Duma florulenta, Olearia mueller, Senna artemisioides ssp. petiolaris (NC), Sclerolaena diacantha/uniflora, Triodia irritans, Zygophyllum apiculatum.*
Emergent sedgeland	*emergent Muehlenbeckia florulenta, Phragmites australis, Typha domingensis, Typha orentalis, (Salix babylonica)*	*Aster subulatus, Bolboschoenus caldwellii, Paspalum distichum, Paspalum vaginatum, Phragmites australis, Suaeda australis, Schoenoplectus validus, Typha domingensis.*
Flood dependent grassland	*Lachnagrostis filiformis var. avenacea (NC), Eragrostis australasica, Juncus krausii, Gahnia filum, Sporobolus virginicus*	*Gahnia trifida, Juncus kraussii, Muehlenbeckia florulenta, Samolus repens, Sarcocornia quinqueflora, Sclerolaena tricuspis, Senecio glossanthus (NC), Sporobolus mitchellii, Suaeda australis, Trichanthodium skirrophorum.*
Samphire shrubland	*Sarcoconia quinqueflora, Tecticornia* spp., *Suaeda australis*	*Disphyma crassifolium ssp. clavellatum, Hordeum marinum, Samolus repens, Sarcocornia quinqueflora, Suaeda australis, Tecticornia spp.*

Vegetation Group	Dominant species (based on shapefile attribute SAVEG_DESC)	Associated species (in different combinations of) (based on shapefile attribute SAVEG-DESC)
Terrestrial dry shrubland	*(emergent) Acacia victoriae, (emergent) Alectryon oleifolius ssp. canescens, Angianthus tomentosus, Atriplex* spp., *Chenopodium nitrariaceum, Dodonea viscosa ssp. angustissima, Disphyma crassifolium ssp. clavellatum, Geijera linearifolia, Lomandra effusa, Lycium australe, Maireana spp., Myoporum platycarpum, Polycalymma stuartii, Sclerolaena tricuspis*	*Acacia sp., Alectryon oleifolius ssp. canescens, Atriplex lindleyi ssp. lindleyi, Atriplex paludosa ssp. cordata, Atriplex rhagodioides, Atriplex semibaccata, Atriplex stipitata, Atriplex vesicaria ssp., Austrostipa sp., Austrodanthonia caespitosa, Brachycome lineariloba, Calotis hispidula, Carrichtera annua, Disphyma crassifolium ssp. clavellatum, Dissocarpus paradoxus, Enchylaena tomentosa var. tomentosa, Enneapogon avenaceus, Enneapogon intermedius, Enneapogan nigricans, Eragrostis australasica, Eremophila sturtii, Eriochiton sclerolaenoides, Lycium australe, Maireana aphylla, Maireana astrotricha, Maireana brevifolia, Maireana pentatropis, Maireana pyramidata, Maireana sedifolia, Maireana trichoptera, Myoporum platycarpum ssp., Nitraria billardierei, Plantago cunninghamii, Rhagodia spinescens, Rhagodia ulicina, Rhodanthe pygmaea, Schismus barbatus, Sclerolaena brachyptera, Sclerolaena dicantha, Sclerolaena muricata var. muricata, Sclerolaena obliquicuspis, Sclerolaena tricuspis, Sclerolaena ventricosa, Senna artemisioides ssp., Tetragonia eremaea/tetragonoides, Tecticornia pergranulata ssp. pergranulata, Tecticornia tenuis, Zygophyllum spp.*

C. List of technical experts used to review the ecological objectives and targets

Table C-7-3 list the technical experts that were asked to review the floodplain ecological objectives and targets, their affiliation, and their area of expertise.

Table C-7-3 List of the technical experts that reviewed the ecological objectives and targets

Name	Affiliation	Area of expertise
Dr Jason Nicol	SARDI Aquatic Sciences	Floodplain vegetation, aquatic vegetation
Dr Susan Gehrig	SARDI Aquatic Sciences	Floodplain vegetation, aquatic vegetation
A/Professor Qifeng Ye	SARDI Aquatic Sciences	Fish biology
Dr Todd Wallace	River Water Life	Ecosystem processes, Chowilla floodplain
Dr Daniel Rogers	DEWNR	Birds

D. Potential interactions between ecological objectives

The success of many ecological objectives relies on the success of other ecological objectives, as shown Table D-7-4. For example, ecological objective one (EO1 – *Maintain a viable, functioning river red gum population within the managed floodplain*) is influenced by the success of EO16 (Establish groundwater conditions conducive to maintaining a diverse native vegetation community across the managed floodplain) and EO17 (Establish soil conditions conducive to maintaining a diverse native vegetation community across the managed floodplain).

Table D-7-4 Potential interactions between ecological objectives

Managed floodplain ecological objective		The success of the shaded ecological objectives influences the success of the ecological objectives listed on the left hand side																					
		EO1	EO2	EO3	EO4	EO5	EO6	EO7	EO8	EO9	EO10	EO11	EO12	EO13	EO14	EO15	EO16	EO17	EO18	EO19	EO20	EO21	EO22
Maintain a viable, functioning river red gum population within the managed floodplain	**EO1**																■	■					
Maintain a viable, functioning black box population within the managed floodplain	**EO2**																■	■					
Maintain a viable, functioning river cooba population within the managed floodplain	**EO3**																■	■					
Maintain a viable, functioning lignum population witin the managed floodplain	**EO4**																■	■					
Establish and maintain diverse water dependent vegetation communities within aquatic zones across the managed floodplain	**EO5**							■				■									■		
Establish and maintain a diverse native vegetation community comprising native flood dependent and amphibious species within the shedding floodplain zones across the managed floodplain	**EO6**							■									■	■			■		
Limit the extent of invasive plant species including weeds	**EO7**	■	■	■	■	■	■														■		
Restore resilient populations of circa-annual nester-spawners within the SARM	**EO8**	■	■																		■	■	
Restore resilient populations of flow-dependent specialists within the SARM	**EO9**	■	■																			■	

Managed floodplain ecological objective		The success of the shaded ecological objectives influences the success of the ecological objectives listed on the left hand side																					
		EO1	EO2	EO3	EO4	EO5	EO6	EO7	EO8	EO9	EO10	EO11	EO12	EO13	EO14	EO15	EO16	EO17	EO18	EO19	EO20	EO21	EO22
Restore resilient populations wetland/floodplain specialists within aquatic zones across the managed floodplain during floodplain flow events	EO10	■	■			■		■			(self)	■	■								■	■	
A low proportion of total fish community, measured as abundance and biomass, is comprised of non-native species	EO11								■	■	■	(self)											
Provide habitat conducive to supporting diverse communities of riparian frogs within the managed floodplain	EO12	■	■		■	■		■				■	(self)								■	■	
Create conditions conducive to successful, small scale breeding events for waterbirds	EO13	■			■	■		■	■	■	■	■		(self)							■	■	
Provide refuge for the maintenance of adult populations of waterbirds	EO14	■			■	■		■	■	■	■	■			(self)						■	■	
Provide habitat conducive to supporting communities of native woodland birds, reptiles and mammals across the managed floodplain	EO15	■	■	■	■	■		■	■	■	■	■	■	■	■	(self)					■	■	
Establish groundwater conditions conducive to maintaining a diverse native vegetation community across the managed floodplain	EO16																(self)						
Establish soil conditions conducive to maintaining a diverse native vegetation community across the managed floodplain	EO17																	(self)					
Maintain sedimentation and erosion processes within normal ranges during overbank flows within the managed floodplain	EO18																		(self)				
Provide diverse hydraulic conditions and complex habitat for flow dependent biota and processes	EO19																			(self)			
Implement a seasonal and multi-year hydrograph that encompasses variation in discharge, velocity and water levels	EO20																				(self)		
Provide for the mobilisation of carbon, nutrients and propagules from the managed floodplain to the river	EO21	■	■	■	■	■	■		■	■	■		■							■		(self)	
Maintain water quality to support water dependent biota and normal biogeochemical processes	EO22																						(self)

E. Other ecological objectives and targets

1. Ecological Objectives and Targets for Basin Plan Assets

The South Australian River Murray Channel (priority environmental asset)

Table E-7-5 Channel Environmental Water Requirements for the lower River Murray.
* Percentage of years that discharge and duration are likely under BP2800 scenario (from Wallace et al., 2014 a, b).

EWR	Median discharge ($ML.day^{-1}$)	Discharge ($ML.day^{-1}$)	Duration (days)	Preferred timing	Average return frequency (years)	Percentage of years flow is required	Max interval (years)	BP2800 scenario *
IC1	10,000	7000 - 12,000	60	Sep-Mar	1.05	95	2	90
IC2	15,000	15,000 - 20,000	90	Sep-Mar	1.33	75	2	77
IC3	20,000	15,000 - 25,000	90	Sep-Mar	1.8	55	2	67
IC4	25,000	20,000 - 30,000	60	Sep-Mar	1.7	59	2	67
IC5	30,000	25,000 - 35,000	60	Sep-Mar	1.8	55	2	59
IC6	35,000	30,000 - 40,000	60	Sep-Mar	1.8	55	2	46
IC7	40,000	35,000 - 45,000	90	Sep-Mar	2.1	48	3	31

Table E-7-6 Channel ecological objectives and targets for the lower River Murray (from Wallace et al., 2014 a, b)

Ecological objective	Ecological target
Provide for the mobilisation of carbon and nutrients from the floodplain to the river to reduce the reliance of instream foodwebs on autochthonous productivity.	Open-water productivity shows a temporary shift from near zero or autotrophic dominance (positive Net Daily Metabolism) towards heterotrophy (negative Net Daily Metabolism) when QSA >30,000 ML day-1.
Provide diverse hydraulic conditions over the range of velocity classes in the lower third of weir pools so that habitat and processes for dispersal of organic and inorganic material between reaches are maintained.	Habitat across the range of velocity classes is present in the lower third of weir pools for at least 60 consecutive days in Sep–Mar, at a maximum interval of 2 years.
Maintain a diurnally-mixed water column to ensure diverse phytoplankton and avoid negative water quality outcomes.	Thermal stratification does not persist for more than 5 days at any time.
Ensure adequate flushing of salt from the Murray to the Southern Ocean.	*Basin Plan* Target: Salt export, averaged over the preceding 3 years, is ≥2 million tonnes per year.

Ecological objective	Ecological target
Maintain water quality to support aquatic biota and normal biogeochemical processes.	Biovolume <4 mm3 L-1 for all Cyanobacteria, where a known toxin producer is dominant.
	Biovolume <10 mm3 L-1 for all Cyanobacteria, where toxins are not present.
	Basin Plan Target: Maintain dissolved oxygen above 50% saturation throughout water column at all times.
Promote bacterial rather than algal dominance of biofilms and improve food resource quality for consumers.	Annual median biofilm composition is not dominated (>80%) by filamentous algae.
	Annual median biofilm C:N ratios are <10:1.
Throughout the length of the river channel asset (i.e. SA border to Wellington), establish and maintain a diverse native flood-dependent plant community in areas inundated by flows of 10,000–40,000 ML day-1.	In standardised transects spanning the elevation gradient in the target zone†, 70% of river red gums have a Tree Condition Index score ≥ 10.
	A sustainable demographic is established to match the modelled profile for a viable river red gum population in existing communities spanning the elevation gradient in the target zone.†
	Species from the Plant Functional Group 'flood-dependent/responsive' occur in 70% of quadrats spanning the elevation gradient in the target zone† at least once every 3 years.
Throughout the length of the river channel asset (i.e. SA border to Wellington), establish and maintain a diverse macrophyte community in wetlands inundated by flows up to 40,000 ML day-1.	Native macrophytes from the emergent, amphibious and flood-dependent functional groups occur in 70% of quadrats spanning the elevation gradient in the target zone† at least once every 3 years.
Maintain habitats and provide for dispersal of organic and inorganic material and organisms between river and wetlands.	Inundation periods in temporary wetlands have unrestricted lateral connectivity between the river and wetlands in >90% of inundation events.
Throughout the length of the river channel asset (i.e. SA border to Wellington), establish and maintain groundwater and soil moisture conditions conducive to improving riparian vegetation.	Establish and maintain freshwater lenses in near-bank recharge zones.
	Maintain soil water availability, measured as soil water potential > -1.5 MPa at soil depth 20–50 cm, to sustain recruitment of long-lived vegetation across the elevation gradient in the target zone.
	Reduce soil salinity (measured as EC 1:5) to <5000 µS cm-1 to prevent shifts in understorey plant communities to salt-tolerant functional groups across the elevation gradient in the target zone.

Ecological objective	Ecological target
Restore the distribution of native fish.	Expected1 species occur in each mesohabitat (channel, anabranch, wetlands) in each weir pool/reach.
Restore resilient populations of Murray cod (a long-lived apex predator).	Population age structure of Murray cod includes recent recruits, sub-adults and adults in 9 years in 10.
	Population age structure of Murray cod indicates a large recruitment event 1 year in 5, demonstrated by a cohort representing >50% of the population.
	Abundance (CPUE5) of Murray cod increases by ≥50% over a 10-year period.
Restore resilient populations of Golden perch and Silver perch (flow-dependent specialists).	Population age structure of Golden perch and Silver perch includes YOY with sub-adults and adults in 8 years in 10.
	Population age structure of Golden perch and Silver perch indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.
	Abundance (CPUE) of Golden perch and Silver perch increases by ≥30% over a 5-year period.
Restore resilient populations of Freshwater catfish.	Population age structure of Freshwater catfish includes YOY, with sub-adults and adults in 9 years in 10.
	Population age structure of Freshwater catfish indicates a large recruitment event 2 years in 5, demonstrated by separate cohorts representing >30% of the population.
	Abundance (CPUE) of Freshwater catfish increases by ≥30% over a 5-year period.
Restore and maintain resilient populations of foraging generalists (e.g. Australian smelt, Bony herring, Murray rainbowfish, unspecked hardyhead, Carp gudgeons, Flathead gudgeons).	The length-frequency distributions for foraging generalists include size classes showing annual recruitment.
Minimise the risk of carp recruitment.	The relative abundance and biomass of Common carp does not increase in the absence of increases in abundance and biomass of flow-dependent native fish.

Coorong, Lower Lakes and Murray Mouth (CLLMM priority environmental asset)

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

A healthier Lower Lakes and Coorong estuarine environment.

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

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

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

Table E-7-7 Summary of revised ecological targets and their contribution to icon site objectives

Target ID#	Ecological target	Icon site objective		
		Open mouth	Fish recruitment	Bird habitat
B1	Maintain or improve bird populations in the Lower Lakes, Coorong and Murray Mouth	Yes	No	Yes
F1	Maintain or improve recruitment success of diadromous fish in the Lower Lakes and Coorong	Yes	Yes	No
F2	Maintain or improve recruitment success of endangered fish species in the Lower Lakes	No	Yes	No
F3	Provide optimum conditions to improve recruitment success of small-mouthed hardyhead in the South Lagoon	No	Yes	No
F4	Maintain or improve populations of black bream, greenback flounder and mulloway in the Coorong	Yes	Yes	No
I1	Maintain or improve invertebrate populations in mudflats (both exposed and submerged)	Yes	Yes	Yes
I2	Provide freshwater flows that provide food sources for Goolwa cockles	Yes	No	No
M1	Facilitate frequent changes in exposure and submergence of mudflats	Yes	No	Yes
M2	Maintain habitable sediment conditions in mudflats	Yes	No	Yes
V1	Maintain or improve Ruppia megacarpa colonisation and reproduction	No	Yes	Yes
V2	Maintain or improve Ruppia tuberosa colonisation and reproduction	No	Yes	Yes
V3	Maintain or improve aquatic and littoral vegetation in the Lower Lakes	No	Yes	Yes
W1	Establish and maintain variable salinity regime with >30% of area below sea water salinity concentrations in estuary and North Lagoon	No	Yes	Yes
W2	Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity	Yes	Yes	Yes

Target ID#	Ecological target	Icon site objective		
		Open mouth	Fish recruitment	Bird habitat
W3	Maximise fish passage connectivity between the Lower Lakes and Coorong	No	Yes	No
W4	Maximise fish passage connectivity between the Coorong and the sea	Yes	Yes	No
Icon site objectives – Open mouth: an open Murray Mouth; Fish recruitment: more frequent estuarine fish recruitment; Bird habitat: enhanced migratory wader bird habitat in the Lower Lakes. Target ID – B: bird-related target; F: fish-related targets; I: invertebrate-related targets; M: mudflat-related targets; V: vegetation-related targets; W: water-related targets.				

Table E-7-8 Summary of how DEWNR's long term plan for the CLLMM targets complements The Living Murray LLCMM EWMP icon site's objectives

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

2. Ecological Objectives and Targets within the SARM Floodplain

Chowilla Floodplain Icon Site

Ecological objective	Ecological target
VEGETATION	
Maintain viable River Red Gum populations within 70% (2,414 ha) of River Red Gum woodland	>70% of trees will have a TCI ≥10 by 2020
	A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient by 2020
Maintain viable Black Box populations within 45% (2,075 ha) of Black Box woodland	>70% of trees will have a TCI ≥10 by 2020
	A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient by 2020
Maintain viable River Cooba (Acacia stenophylla) populations within 50% of existing River Cooba and mixed Red Gum and River Cooba woodland areas.	>70% of trees will have a TCI ≥10 by 2020
	A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient by 2020
Maintain viable Lignum populations in 40% of areas.	≥70% of Lignum plants will have a LCI ≥4 for colour by 2020
Improve the abundance and diversity of grass and herblands	Flood-dependent/responsive plant species are recorded in 70% of quadrats spanning the floodplain elevation gradient at least once every 3 years
Improve the abundance and diversity of flood-dependent understorey vegetation	Native macrophytes are recorded in 70% of quadrats spanning the elevation gradient within each of the recognised permanent and ephemeral wetlands at least once every 3 years
Improve the abundance and diversity of submerged and emergent aquatic vegetation.	Native macrophytes are recorded in 70% of quadrats spanning the elevation gradient within each of the recognised permanent and ephemeral wetlands at least once every 3 years
Maintain or improve the area and diversity of grazing sensitive plant species	*No target set*
Limit the extent of invasive (increaser) species including weeds	Cumbungi distribution is maintained within ±20% of the range recorded during the period 2004–10
	The relative abundance of weed species does not increase compared to mean levels recorded during the period 2004–10
FISHES	

Ecological objective	Ecological target
Maintain or increase the diversity and extent of distribution of native fish species	Expected species occur in each mesohabitat i.e. fast flowing, slow flowing, backwaters and the Murray River main channel
Maintain successful recruitment of small and large bodied native fish	The length-frequency distributions for foraging generalists† include size classes that demonstrate annual recruitment
	Population age structure for Murray cod includes recent recruits, sub-adults and adults in 9 years in 10,
	Population age structure for Murray cod indicates a large recruitment event 1 year in 5 as demonstrated by a cohort representing >50% of the population
	Abundance of Murray cod, as measured by CPUE, increases by ≥ 50% over a 10 year period
	Population age structure for Golden perch and silver Perch includes YOY with juveniles and adults in 9 years in 10
	Population age structure for Golden perch and Silver perch indicates a large recruitment event 2 years in 5 as demonstrated by separate cohorts each representing >30% of the population
	Abundance of Golden perch and Silver perch, as measured by CPUE, increases by ≥ 30% over a 5 year period
	Population age structure for Freshwater catfish includes YOY, with juveniles and adults in 9 years in 10.
	Population age structure for Freshwater catfish indicates a large recruitment event 2 years in 5 as demonstrated by separate cohorts each representing >30% of the population
	Abundance, of Freshwater catfish, as measured by CPUE, increases by ≥ 30% over a 5 year period
	Unrestricted lateral access to and from key off-channel (i.e. wetland) habitats is provided for native fish once every three years by 2020
Restrict the abundance and biomass of introduced fish species	The relative abundance and biomass of Common carp does not increase in the absence of increases in abundance and biomass of flow-dependent native species.
	Flow events do not result in new cohorts of carp entering the population in the absence of new cohorts of large bodied native fish
OTHER BIOTA	
Maintain sustainable communities of the eight riparian frog species recorded at Chowilla	Each of eight riparian frog species known to occur at Chowilla will be recorded at ≥ 3 sites in any three year period
	Improve the distribution and abundance of the nationally listed Southern Bell Frog at Chowilla

Ecological objective	Ecological target
Create conditions conducive to successful breeding of colonial waterbirds in a minimum of three temporary wetland sites at a frequency of not less than one in three years	A habitat mosaic comprising shallow water, open water, mud flat and littoral zones is provided simultaneously at a minimum of three large wetlands at least once every three years
	Minimum inundation periods required for successful breeding by a range of water bird species are provided during 80% of flood events
Maintain or improve the diversity and abundance of key bird species	Attempted breeding (nesting) by >500 pairs of colonial waterbirds more than three times in any ten year period
	Attempted breeding (nesting) by >10 pairs of at least five species of colonial water birds other than Australian White Ibis, Nankeen Night Heron and Cattle Egret in any five year period
	Each of the bird species known to historically utilise Chowilla will be recorded at ≥ 3 sites in any three year period
Maintain the current abundance and distribution of Regent Parrots	Abundance and distribution of threatened birds is maintained at or above levels recorded during 2004–10
Maintain the current abundance and distribution of the Bush Stone-curlew (*Burhinus grallarius*)	
Re-establish habitat condition to sustain high value fauna communities	Maintain breeding populations of the 17 mammals recorded in surveys undertaken prior to 1990
	Maintain the 5 listed reptile species recorded in surveys undertaken prior to 1990
ABIOTIC FACTORS	
Establish groundwater and soil conditions conducive to improving vegetation condition	Establish and maintain freshwater lenses in order to improve condition of overlying vegetation communities
Avoid fringe degradation due to soil salinisation in areas where ground water levels fluctuate in the absence of inundation	Maintain soil water availability, measured as soil water potential at soil depth 20–50 cm, greater than -1.5 MPa in order to sustain the recruitment of long-lived vegetation
	Reduce soil salinity (EC 1:5) to below 5,000 μScm^{-1} to prevent shifts in understorey plant communities to salt tolerant functional groups
	Maintain soil sodicity below the exchangeable sodium percent (ESP) value of 15 (highly sodic)
Avoid unacceptable salinity impacts to downstream users	Salinity to be <580 EC in River Murray downstream of Chowilla Creek A4260704).

Ecological objective	Ecological target
Maintain water quality within ranges that support aquatic biota and normal biogeochemical processes	Total Phosphorus <100 μgL^{-1}
	Total Nitrogen < 1000 μgL^{-1}
	pH = 6.5-9.0
	Biovolume <4 mm^3L-1 for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume
	<10 mm^3L-1 total biovolume of all cyanobacteria where known toxins are not present
	Thermal stratification is not allowed to persist for more than 5 days in the anabranch creeks or adjacent reach of river channel
	Turbidity during base flows = <40 NTU for water from Murray system, <76 for water from Darling system
	Maintain dissolved oxygen above 50% saturation* (4 mg O_2L-1) throughout water column at all times
Provide processes for the mobilisation of carbon and nutrients from the floodplain to the river in order to reduce the reliance of in-stream foodwebs on autochthonous productivity	During September–March, open water productivity measurements reflect a temporary shift from near zero or autotrophic dominance (positive Net Daily Metabolism) towards heterotrophic conditions (negative Net Daily Metabolism)
	Increase the abundance and diversity of invertebrate food resources for higher order organisms
	Provide unrestricted lateral exchange between the channel and the off-channel (i.e. wetland) habitats during >90% of inundation events
Maintain the flow mosaic characteristic of the Chowilla Anabranch system	Maintain flows >0.18 ms^{-1} in 75% of core fish habitat at all times
Establish a flow regime with distinct variability in components of the flood pulse	Successive events do not repeat the preceding hydrograph with respect to (i) magnitude, (ii) duration and (iii) timing

Proposed draft Katfish Reach (Katarapko Floodplain) and Pike Floodplain ecological objectives (Wallace and Denny, in prep.)

Recommended ecological objective	Interim ecological target(s)
Maintain a viable river red gum population	In standardised transects that span the floodplain elevation gradient and existing spatial distribution, >70% of trees will have a TCI ≥10 by 2020
	A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient by
Maintain a viable Black Box population	In standardised transects that span the floodplain elevation gradient and existing spatial distribution, >70% of trees will have a TC) ≥10 by 2020
	A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient by
Maintain a viable River Cooba population	In standardised transects that span the floodplain elevation gradient and existing spatial distribution, >70% of trees will have a TCI ≥10 by 2020
	A sustainable demographic that matches the modelled profile for a viable population is established within existing communities across the floodplain elevation gradient by
Maintain a viable Lignum population	In standardised transects that span the floodplain elevation gradient and existing spatial distribution, ≥70% of Lignum plants will have a LCI ≥6 for colour by 2020
Limit the extent of invasive species including weeds (temporary wetlands)	In temporary wetlands, a maximum of 1% of cells containing *Xanthium strumarium* in any given survey.
	In temporary wetlands, a maximum of 10% of cells containing exotic taxa in any given survey.
Limit the extent of invasive species including weeds (floodplain)	In shedding floodplain zones, a maximum of 1% of cells containing *Xanthium strumarium* in any given survey.
	In shedding floodplain zones, a maximum of 5% of cells containing exotic taxa in any given survey.
Limit the extent of invasive species including weeds (native species in creeks and	Cumbungi distribution is maintained within ±20% of the range recorded during the baseline survey period (e.g. 2015)

Recommended ecological objective	Interim ecological target(s)
Establish and maintain a diverse plant community comprised of native flood dependent and amphibious species (Temporary wetlands)	In temporary wetlands, a minimum of 40% of cells either inundated or containing native flood dependent or amphibious taxa once every two years on average with maximum interval no greater than 4 years.
	In temporary wetlands, a minimum of 80% of cells either inundated or containing native flood dependent or amphibious taxa once every four years on average with maximum interval no greater than 6 years.
	1 in 2 years, native flood dependent and amphibious species richness will be >20
	1 in 4 years , native flood dependent and amphibious species richness will be >40
Establish and maintain a diverse plant	Minimum of 20% of cells contain native flood dependent or amphibious taxa once every three years on average with maximum return interval no greater than 5 years.

community comprised of native flood dependent and amphibious species (Floodplain)	Minimum of 40% of cells contain native flood dependent or amphibious taxa once every five years on average with maximum return interval no greater than 7 years.
	Minimum of 65% of cells contain native flood dependent or amphibious taxa once every seven years on average with maximum return interval no greater than 10 years.
	1 in 3 years, native flood dependent and amphibious species richness will be >15
	1 in 5 years, native flood dependent and amphibious species richness will be >25
	1 in 7 years, native flood dependent and amphibious species richness will be >40

Recommended ecological objective	Interim ecological target(s)
Create conditions conducive to successful, small scale breeding events for	A habitat mosaic comprising shallow water, open water, mud flat and littoral zones is provided simultaneously at least once every three years by 2020
	Minimum inundation periods required for successful breeding by a range of water bird species are provided during 80% of floods by 2020
Provide habitat conducive to supporting communities of native reptiles and mammals	Each of the bird species known to utilise similar floodplain woodland habitats in the region will be recorded at ≥ 3 sites in any three year period by 2020
	Each of the reptile species known to utilise similar floodplain/woodland habitats in the region will be recorded at ≥ 3 sites in any three year period by 2020
	Each of the native mammal species known to utilise similar floodplain/woodland habitats in the region will be recorded at ≥ 3 sites in any three year period by 2020
Provide habitat conducive to supporting communities of	Each of six riparian frog species will be recorded at ≥ 4 sites in any three year period
	Record tadpoles from 3 species in later stages of metamorphosis

Recommended ecological objective	Interim ecological target(s)
Maintain sedimentation and erosion processes within normal ranges	Limit the maximum rate of drawdown (averaged over 3 consecutive days) to ≤0.1 mday^{-1} whilst surface water levels are out of channel and to ≤0.05 mday^{-1} when surface water levels are within channel to minimise risk of bank failure
	Maintain velocity within creeks below critical threshold (e.g. 0.4 ms^{-1}) to minimise likelihood of excessive bank and channel erosion
Provide diverse hydraulic conditions and complex habitat for flow dependent biota and processes	Deliver flows in a manner that reduces the proportion of slow flowing habitat and increases the proportion of moderate velocity habitat thereby reinstating a diversity of velocity classes representative of natural conditions
	Maintain daily exchange rate within the impounded area at or above 20%
	Persistent (> 5days) density driven (thermal and salinity) stratification is not allowed to establish within (i) the creek system, or (ii) the adjacent river channel
	Maintain maximum retention time within the anabranch system below 15 days
Implement a seasonal hydrograph that encompasses variation in discharge, velocity and water levels	Promote bacterial rather than algal dominance of biofilms
	Discharge, water level and velocity metrics of planned seasonal hydrograph(s) are implemented

Ensure diverse phytoplankton and avoid negative water quality outcomes	Chlorophyll *a* < 20 µg/L
	Total algae count > 20,000 cells/mL, Cyanobacteria counts > 1,000 cells/mL Cyanobacteria – recreational guideline, 50,000 cells/mL
	<10 mm3L^{-1} total biovolume of all cyanobacteria

Recommended ecological objective	Interim ecological target(s)
Provide for the mobilisation of carbon and nutrients from the floodplain to the river to reduce the reliance of instream foodwebs on autochthonous productivity.	Open-water productivity shows a temporary shift from near zero or autotrophic dominance (positive Net Daily Metabolism) towards heterotrophy (negative Net Daily Metabolism) during periods when(i) QSA >30,000 ML/day, or (ii) managed
	During inundation periods, record an increase in the abundance and diversity of invertebrate food resources for higher order organisms relative to those available during base flow
Minimise real time and long-term salinity impacts to third parties / downstream users	*Values need to be identified and documented*
Maintain concentrations of nutrients and other water quality parameters within ranges that are (i) not problematic for users; and (ii) do not exceed statutory guidelines	Total Phosphorus (TP), Filterable Reactive Phosphorus (FRP) Total Kjeldahl Nitrogen, Nitrate and Nitrite (NOx), Total Nitrogen (TN), Ammonia are maintained below
	DOC < 10 mgL^{-1}
	Turbidity during base flows = <40 NTU for water from Murray system, <76 for water from Darling system
	Metals: Iron ≤ 1 mg/L, Manganese 0.5 mg/L (respective values for aluminium, cobalt, zinc, copper, nickel, chromium)
	pH = 6.5-9
Maintain water quality to support aquatic biota and normal biogeochemical	Maintain DO above the State Environment Protection (Water Quality) Policy (2003) limit of >6 mgO_2L^{-1}

Recommended ecological objective	Interim ecological target(s)
Establish groundwater and soil conditions conducive to maintaining a diverse native vegetation community	Establish and maintain freshwater lenses in near-bank recharge zones
	Maintain soil water availability, measured as soil water potential at soil depth 20–50 cm, greater than -1.5 MPa in order to sustain the recruitment of long-lived vegetation
	Reduce soil salinity (EC 1:5) to below 5,000 µS/cm to prevent shifts in understorey plant communities to salt tolerant functional groups

	Ensure soil salinity does not increase in those areas where groundwater levels fluctuate (i.e. increase) in response to managed inundation but are not within the inundated areas (fringe degradation)
	Maintain soil sodicity below the exchangeable sodium percent (ESP) value of 15 (highly sodic)
	Ensure sulfidic sediments are not exposed

Recommended ecological objective	Interim ecological target(s)
Restore and maintain resilient populations of large bodied native fish (i.e.Murray cod, Golden perch, Silver perch, and Freshwater catfish)	Expected[1] species occur in 60% of sites within each mesohabitat (channel, anabranch, wetlands).
	Abundance (CPUE) of Murray cod increases by ≥50% over a 5-year period (i.e. 2015–20)..
	Abundance (CPUE) of Golden perch and Silver perch increases by ≥30% over a 5-year period (i.e. 2015–20).
	Abundance (CPUE) of Freshwater catfish increases by ≥30% over a 5-year period (i.e. 2015- 2020).
Restore and maintain resilient populations of foraging generalists (e.g. Australian smelt, Bony herring, Murray rainbowfish, Unspecked hardyhead, Carp gudgeons, Flathead gudgeons)	The length-frequency distributions for foraging generalists include size classes showing annual recruitment.
Minimise the recruitment of introduced species	The relative abundance and biomass of Common carp does not increase in the absence of increases in abundance and biomass of flow-dependent native fish.
Facilitate biological connectivity within the anabranch, and between the anabranch and the River Murray	*To be determined*

3. Previous Ecological Targets and EWRS for the SARM Floodplain

Table E-7-9 Previous ecological targets and their EWRs for the SARM floodplain, used to assess the Proposed *Basin Plan* (Bloss et al. 2012; Gibbs et al., 2012).

Label	Target	Flow (ML.day^{-1})	Duration (days)	Timing	Average frequency (years)	Max interval
BB1	Maintain and improve the health of 80% of the Black Box woodlands	>100,000	20	spring or summer	1-in-6 years	8
BB2	Maintain and improve the health of ~60% of the Black Box woodlands	100,000	20	spring or summer	1-in-5 years	8
BB3	Maintain and improve the health of ~50% of the Black Box woodlands	85,000	30	spring or summer	1-in-5 years	8
BBr1	Successful recruitment of cohorts of Black Box at lower elevations	85,000	20	spring or early summer	1-in-10 (+ successive years1)	
BBr2	Successful recruitment of cohorts of Black Box at higher elevations	>100,000	20	spring or early summer	1-in-10 (+ successive years 1)	
FSr	Support spawning and recruitment by native fish that are characterised as flow-cued spawners (i.e. Golden perch and Silver perch)	15,000	60	Oct–Feb	1-in-3	5
FP	Stimulate fish spawning, provide access to the floodplain and provide nutrients and resources	80,000	>30	Jun–Dec	1-in-4	5
Lig1	Maintain and improve the health of ~50% of the Lignum shrubland	70,000	30	spring or early summer	1-in-3	5
Lig2	Maintain and improve the health of 80% of the Lignum shrubland	80,000	30	spring or early summer	1-in-5	8
MCr	Support spawning and recruitment by Murray cod	40,000	60	Sep–Dec	1-in-4 years	5
Mos1	Provide mosaic of habitats (i.e. larger proportions of various habitat types are inundated)	90,000	30	spring or early summer	1-in-5	6

Label	Target	Flow (ML.day^{-1})	Duration (days)	Timing	Average frequency (years)	Max interval
Mos2	Provide mosaic of habitats (i.e. larger proportions of various habitat types are inundated)	80,000	>30	spring or early summer	1-in-4	5
Mos3	Provide mosaic of habitats (i.e. larger proportions of various habitat types are inundated)	70,000	60	spring or early summer	1-in-4	6
Mos4	Provide mosaic of habitats (i.e. larger proportions of various habitat types are inundated)	60,000	60	spring or early summer	1-in-3	4
RG	Maintain and improve the health of 80% of the red gum woodlands and forests (adult tree survival)	80,000 to 90,000	>30	Jun–Dec	1-in-4	5
RGr	Successful recruitment of cohorts of red gums	80,000	60	Aug–Oct	1-in-5 (+ successive years1)	
TW1	Inundation of (~80%) temporary wetlands for large scale bird and fish breeding events	80,000	>30	Jun–Dec	1-in-4	5
TW2	Maintain and improve majority of lower elevation (~20%) temporary wetlands in healthy condition; and Inundation of lower elevation temporary wetlands for small scale bird and fish breeding events, and microbial decay/export of organic matter	40,000	90	Aug–Jan	1-in-2	3
WB1	Maintain Lignum inundation for waterbird breeding events	70,000	60	Aug–Oct	1-in-4	6
WB2	Provide habitat (red gum communities) for waterbird breeding events	70,000	60	Aug–Oct	1-in-4	6

F. Hydrological modelling data

WITHOUT DEVELOPMENT SCENARIO (THE NATURAL FLOW REGIME)

Table E-7-10 The discharges corresponding to different ARIs and durations, based on 114 years of flow data (the without development scenario).

Duration	30 days	60 days	90 days	120 days
ARI (years)	Magnitude ($ML.day^{-1}$)	Magnitude ($ML.day^{-1}$)	Magnitude ($ML.day^{-1}$)	Magnitude ($ML.day^{-1}$)
2	60,591	50,900	45,208	38,300
3	79,834	68,651	60,401	48,078
4	86,652	76,230	66,892	55,080
5	93,394	78,563	70,200	57,888
6	97,367	81,237	71,355	60,310
7	101,383	86,873	73,166	61,857

The extended list of flow metrics relevant to the SARM floodplain is shown in Table F-7-11. An EWR event may be considered to have been met if both its duration and discharge magnitude requirements have been met or exceeded during a flow event, and the ARI and maximum interval are met over a multi-year period. Given this, a flow event might meet the requirements of multiple EWRs and a specified EWR may meet the requirements of other EWRs. To encourage flow regime variability, historically an important driver of the SARM floodplain, the range of discharges acceptable around the mean discharge are identified.

Table F-7-11 Extended list of EWRs for the managed floodplain environmental asset.
ARI is average return interval, EWRs are environmental water requirements. The preferred timing for all the EWRs is spring/early summer.

Median discharge ($ML.day^{-1}$)	Acceptable discharge range ($ML.day^{-1}$)	Duration (days)	ARI (years)	Max interval (years)
50,000	45,000-55,000	30	1.5	5
50,000	45,000-55,000	60	2.0	5
50,000	45,000-55,000	90	2.4	5
50,000	45,000-55,000	120	3.2	5
60,000	55,000-65,000	30	2.0	5
60,000	55,000-65,000	60	2.6	5
60,000	55,000-65,000	90	3.3	5
60,000	55,000-65,000	120	6.3	7
70,000	65,000-75,000	30	2.5	5
70,000	65,000-75,000	60	3.6	5

70,000	65,000-75,000	90	5.7	7
80,000	75,000-85,000	30	3.4	5
80,000	75,000-85,000	60	7.6	8

G. Technical experts used to develop the EWRs' contribution towards the ecological objectives table

Workshop participants:

Name	Affiliation
A/Professor Qifeng Ye	SARDI Aquatic Sciences
Dr Jason Nicol	SARDI Aquatic Sciences
Dr Susan Gehrig	SARDI Aquatic Sciences
Brenton Zampatti (correspondence)	SARDI Aquatic Sciences
A/Professor David Paton	The University of Adelaide
Dr Scotte Wedderburn	The University of Adelaide
Dr Sabine Dittman	Flinders University
Dr Todd Wallace	River Water Life
Dr Daniel Rogers	DEWNR
Dr Kane Aldridge	DEWNR
Jason Higham	DEWNR
Adrienne Rumbelow	DEWNR
Rebecca Turner	DEWNR
Jan Whittle	DEWNR

In addition to developing the contribution table, a number of issues were raised and considered. Key points discussed are presented below.

VEGETATION TARGETS

1. Assumption is minimum 30 days for fair condition of woody vegetation across the floodplain (60 days for optimal condition). Only EWR4 and EWR5 meet the 30 day minimum across the whole managed floodplain.
2. 60 days required for optimum condition for recruitment of river red gums; only achieved by EWR5.
3. For Black Box, the optimum conditions to promote recruitment is 60 days; this is only met with EWR5 across the whole managed floodplain. Also assume a return event within 1-3 years for successful recruitment (if not, contribution ranking likely to drop).
4. EO5 assumes that water needs to be present for growth. 30 days minimum for some species to grow, but requires longer for others. Water does not cover enough aquatic zones within the managed floodplain in EWR1 and EWR2 to meet species richness target.
5. For EO6, vegetation grows upon flood recession, and may not need a long duration, but will need to reach the edge of the managed floodplain to achieve species richness targets.
6. The greater the extent of inundation, the greater the potential area for weeds to establish, which has influenced the ranking of EO7.
7. Targets to be considered in the future include bare soil targets and salt tolerant vegetation targets.

FISH TARGETS

1. EO8/T1 based on requirement of 90 days high flow needed for successful recruitment, but EWR1 and EWR2 ranking will only hold true if there isn't a sharp recession in flow.

2. For EO9 the ranking had already reached "good" for flows of 40,000 $ML.day^{-1}$ in the in-channel report, so that the ranking is continued as "good" for the floodplain.

3. Timing is critical for recruitment in the flow-dependent specialists. Requirements for Silver perch not as well-known as for Golden perch (except that they have different requirements), and monitoring of Silver perch harder than for Golden perch. Recommend exploring separating the Golden and Silver perch targets in the future.

4. Recommend investigating whether a separate congollis target for the floodplain should be developed in the future.

OTHER BIOTIC TARGET

1. Noted that the earlier the timing of the flow event, the better the frog response.

2. Woodland biota was not assessed at the workshop, but was included here as the same as for Black Box—Black Box being a critical part of the woodland vegetation.

ABIOTIC TARGETS

1. EO16 ranking is based on recharge requiring > 60 days for lens maintenance.

2. EO17 ranking based on requiring >30 days to infiltrate.

3. For EO21 there won't be full inundation (and therefore carbon and propagules mobilisation) until EWR3.

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