Australian Government

MURRAY–DARLING BASIN AUTHORITY

Draft Basin–wide environmental watering strategy

Second edition

August 2019

Published by the Murray–Darling Basin Authority
MDBA publication no: 42/19
ISBN (online): 978-1-925762-47-1

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Cataloguing data

Title: Draft Basin–wide environmental watering strategy, Murray–Darling Basin Authority Canberra, 2019. CC BY 4.0

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Acknowledgement of the Traditional Owners of the Murray–Darling Basin

The Murray−Darling Basin Authority pays respect to the Traditional Owners and their Nations of the Murray−Darling Basin. We acknowledge their deep cultural, social, environmental, spiritual and economic connection to their lands and waters.

The guidance and support received from the Murray Lower Darling Rivers Indigenous Nations, the Northern Basin Aboriginal Nations and our many Traditional Owner friends and colleagues is very much valued and appreciated.

Aboriginal people should be aware that this publication may contain images, names or quotations of deceased persons.

Contents

Figures

Summary

As a nation, we are working towards a sustainable future for the Murray–Darling Basin. Managing a water resource that spans such a large geographic area, across five state and territory borders and in a highly-variable and changing climate, is a significant undertaking. It requires the careful balancing of the needs of people and the environment—ensuring that the rivers, wetlands and floodplains of the Basin are restored to a healthy and resilient state, and in doing so are able to support strong communities, productive industries and the interests of First Nations people.

Under the plan of management for the Basin's water resources (the *Basin Plan 2012*), desired environmental *objectives* were identified. To achieve these, the Basin Plan sets sustainable diversion limits to restrict how much water can be taken for consumptive use, setting aside enough water to sustain water-dependent ecosystems. Following a number of amendments to the Basin Plan in 2018, the current water recovery target is for a long-term average annual yield of 2,075 gigalitres (GL) of water per year plus 450 GL per year of efficiency measures by 2024.

The Basin Plan is an adaptive management instrument. It is implemented using the best available knowledge of the day, but includes processes to improve that knowledge and adapt appropriately.

The Basin-wide environmental watering strategy (the Strategy) supports the implementation of the Basin Plan. The Strategy is a key component of the adaptive management of environmental water to achieve Basin Plan outcomes. Its purpose is to assist environmental water holders, Basin state governments and waterway managers to plan and manage environmental watering at a Basin scale and over the long term to meet the Basin Plan's environmental objectives.

The Strategy is only one element in the planning process—other important parts include long-term environmental watering plans and water resource plans (to be developed consistently with the Strategy) which Basin states are required to prepare and implement at a finer scale for each region.

The Strategy was first published in 2014. As part of the Plan's adaptive management framework, this 2019 update fulfils the requirement to review the Strategy no later than five years after it was first published. The Murray–Darling Basin Authority (MDBA) has reviewed the Strategy and decided to stage the updates in two editions: one to be published in late 2019 and the other expected to be published in 2022. The MDBA adopted this two-stage approach to avoid the need for States to immediately review the recently finalised long-term environmental watering plans (which is triggered when substantial changes are made to the Strategy); and to adjust the timing of Strategy reviews so that they occur between Basin Plan evaluations to support adaptive management of environmental water.

Since the publication of the Strategy, a number of significant developments have occurred that have informed this update. These include the Northern Basin review and toolkit measures, the Sustainable Diversion Limit (SDL) adjustment mechanism, progress with constraints management, implementation of pre-requisite policy measures, and development of both water resource plans and long-term environmental watering plans. The influence of these on the updated Strategy is described in *Policy developments in the last five years* while the main changes to the Strategy since 2014 are described in *Review and update of the 2014 Strategy.*

The Strategy sets out the MDBA's assessment of how four key components of the Basin's water-dependent ecosystems are expected to respond in the medium term given the available environmental water and the rules and arrangements in place for managing water in the Basin. The anticipated responses are expressed in terms of quantified 'expected environmental outcomes' (see Chapter 2). The four components – river flows and connectivity, native vegetation, waterbirds and native fish – are all important components of healthy, functioning water-dependent ecosystems and have all declined appreciably over time because of the way water is captured, managed and diverted. Hydrology is believed to be the primary driver influencing river health. Vegetation, fish and birds are key environmental outcomes valued by communities across the Basin that have both been affected by flow regulation and require a Basin-wide approach to manage effectively (Chapter 2). Any water in the system, regardless of its intended use or purpose, has the potential to contribute to environmental outcomes. For this reason, the Strategy relies on making best use of all the different types of water to achieve the expected environmental outcomes. This includes water reserved for the environment (i.e. held and planned environmental water), irrigation and other consumptive water flowing downstream to its place of use, and non-consumptive water not tagged as environmental water.

The Strategy sets out several management strategies to maximise the likelihood of achieving the expected environmental outcomes. Water managers should consider these strategies in the planning and delivery of environmental water. The strategies draw upon decades of adaptive management of environmental watering in the Basin, initially on a small scale but more recently at larger scales and with more complex arrangements (e.g. multi-site watering with multiple water holders).

The MDBA is seeking community feedback on this draft 2019 Strategy update. Comments can be provided by email to BWS@mdba.gov.au, by post to GPO Box 1801, Canberra ACT 2601, or via our Get Involved page. Comments received by midnight on Monday, 2 September 2019 will be considered in developing the final 2019 Strategy update.

For information about the Strategy or the consultation process, contact 1800 630 114.

1 Introduction

Understanding the Strategy

The Basin Plan began in 2012. Its broad intent is to ensure that the rivers, wetlands and floodplains of the Murray–Darling Basin (Figure 1) are restored to a healthy and resilient state, and in doing so are able to support strong communities, productive industries and the interests of First Nations people. This intent is captured in the overarching Basin Plan outcome of a healthy, working Murray–Darling Basin.

The Basin Plan includes an Environmental Watering Plan, which sets out the arrangements to be followed by the MDBA, Commonwealth Environmental Water Holder (CEWH) and Basin States to meet the Plan's environmental objectives. A key element of the Environmental Watering Plan is a Basin-wide environmental watering strategy (the Strategy). Broadly stated, its purpose is to assist the MDBA, environmental water holders, Basin states and river managers to plan and manage environmental watering to meet the environmental objectives of the Basin Plan. To maximise the opportunity to achieve these objectives, it is essential that best use is made of all water in the system including held and planned environmental water (HEW and PEW respectively), non-consumptive water that contributes to environmental outcomes but is not specifically tagged as environmental water, and consumptive water on route to its place of use.

The more detailed aims of the Strategy are to:

- guide the planning and delivery of water for the environment at the Basin scale over the long term
- clearly express the desired environmental outcomes, as quantitatively as possible, to be achieved by environmental water management at Basin scale
- maximise environmental outcomes through effective and efficient environmental water management and consideration of all water
- explain the context within which Basin annual environmental watering priorities will be set, and
- guide the development of consistent and complementary long-term environmental watering plans.

A major part of the Strategy is the expected environmental outcomes for four fundamentally important ecological components of the river system: river flows and connectivity, native vegetation, waterbirds and native fish. These outcomes are the MDBA's best assessment of what environmental water management under the Plan is expected to achieve in the medium term for the Basin's water-dependent ecosystems, given current operating rules and arrangements.

These expected environmental outcomes are developed so as to be as SMART (Specific Measurable Achievable Relevant and Time-bound) as practical – in order to provide a clear quantified picture of what is to be achieved and also to support improved evaluation of the Basin Plan's effectiveness. Quantified outcomes are a foundation of adaptive management and of accountability in delivery of environmental outcomes under the Plan as they enable an objective assessment of whether outcomes are being achieved. These can be contrasted to qualitative objectives, which are often used in water management for attributes of an ecosystem that are difficult to measure numerically.

The Strategy is one element in the planning and management of the Basin's water resources to achieve the Basin Plan's environmental objectives. Other important elements include long-term environmental watering plans, water resource plans, and annual environmental watering priorities developed by the Basin States (catchment scale) and the MDBA (Basin scale). The long-term environmental watering plans provide detail on environmental objectives and targets, and watering requirements for a range of environmental assets and functions at a regional scale. Water resource plans provide for environmental watering to occur consistently with this Strategy and the Environmental Watering Plan. Annual watering priorities provide shorter-term guidance on the actions that should be taken to achieve the longer-term objectives.

Box 1: Basin statistics

Home to 2.6 million people

An Aboriginal population of about 100,000 and more than 40 Aboriginal nations

Over 3 million people rely on the Basin for drinking water

Area of 1,059,000 km^2 – 14% of mainland Australia

Total annual average inflow of 32,500 gigalitres (billion litres); but highly variable (range 6,700 GL to 117,900 GL)

Rainfall is predominantly winter–spring in catchments of the southern Basin but generally summer rainfall in the northern Basin

The largest and most complex river system in Australia

23 river valleys; 77,000 km of rivers; 30,000+ wetlands, including 16 internationally recognised and protected (Ramsar) wetlands

35 wetland ecosystem types, 11 river ecosystem types, 8 lake ecosystem types, 9 estuarine ecosystem types

Figure 1: Murray–Darling Basin map showing average annual rainfall.

Box 2: Characteristics of a healthy, working river system

A healthy, working river is one in which the natural ecosystem has been altered by the use of water for human benefit, but retains its ecological integrity while continuing to support strong communities and a productive economy in the long-term.

For the many rivers in the Basin, water is captured, extracted or diverted to support communities, agriculture and other industries. Communities also value healthy and functioning river and floodplain ecosystems, which provide many important services. These include clean water for drinking and agricultural use, nutrient cycling between the river and floodplain, fish stock for anglers, and an environment that supports tourism, recreation and cultural values including for First Nations' communities. To achieve these multiple benefits, there needs to be a balance between the water available to the environment and the water that is used by communities and industries – hence the concept of a 'healthy, working river'.

Typically, working rivers have dams, weirs and other infrastructure; and towns, agriculture and developments on adjacent floodplains. These will continue to exist, although how they are managed may evolve. A healthy, working river also supports biological communities, habitats and ecological processes and is resilient to natural variability.

Review and update of the Strategy

The Strategy was first published in 2014. As part of the Plan's adaptive management framework, this 2019 update fulfils the requirement to review the Strategy five years after it was first published. The MDBA has reviewed the Strategy and decided to stage the updates in the next two editions: one to be published in late 2019 and the other expected to be published in 2022 (to align with other Basin Plan review processes). The MDBA adopted this two-stage approach to avoid the need for States to immediately review the recently finalised long-term environmental watering plans; and to adjust the timing of Strategy reviews so that they occur between Basin Plan evaluations to support adaptive management of environmental water. A report on the review of the Strategy can be found on the MDBA website.

As a result of the review of the Strategy, the MDBA has identified the following updates for 2019:

- Amendments to contextual and other explanatory text to capture recent policy developments, such as the Northern Basin Review and Sustainable Diversion Limit Adjustment Mechanism, as well as to capture new knowledge from recent research initiatives.
- The addition of a clear objective to 'maximise environmental outcomes through effective and efficient environmental water management' and greater consideration of 'all water'.
- A reinforcement of messaging around constraints relaxation, implementation of pre-requisite policy measures, and solving of water delivery issues to achieve Basin Plan objectives.
- Refinement of the expected environmental outcomes based on new Basin Plan settings where applicable.

- Refinement of water management strategies to promote greater collaboration between water managers across the Basin.
- References to any commitments made in the water resource plan process, such as recognising the environmental outcomes provided by non-consumptive water that is not tagged as environmental water.
- Clearer explanation of how monitoring, evaluation, reporting and improvement are undertaken in Basin Plan evaluations.
- A description of likely updates to be made to the Strategy in 2022.

These changes are not considered sufficiently material to trigger a review of states' long-term environmental watering plans.

The importance of a Basin perspective

Water connects across the landscape—it runs off catchments, along rivers, into billabongs, lakes and wetlands, across floodplains and ultimately to the ocean. Because of this connectivity, actions involving water taken in one place affect other parts of the Basin. Similarly, ecosystem functions and food webs are connected across administrative boundaries (such as state borders) and should be managed holistically.

The Basin contains water-dependent ecosystems of national significance and several sites are listed in international agreements for migratory waterbirds (i.e. Ramsar and Bonn conventions and bilateral agreements with China [CAMBA], Japan [JAMBA] and the Republic of Korea [ROKAMBA]). It is important that these are managed in the national interest. Given the patterns of connectivity described above, the condition of these sites can be influenced by water management decisions in seemingly distant parts of the Basin.

A Basin-scale approach to environmental watering is particularly required:

- where the water resources of multiple regions are needed to achieve desired outcomes; such as in the lower River Murray or along the Darling River
- where important ecosystems or organisms with a need for coordinated management are broadly distributed across state boundaries—such as native fish, migratory waterbirds and large floodplain forests, and
- for rare, threatened, unique or representative species or habitats, such as the estuary and the internationally-significant migratory bird sites.

The Strategy as an application of adaptive management

Adaptive management is a structured decision-making process that is widely used in environmental management. It uses an iterative process to test management approaches to see which are most effective at achieving specified environmental outcomes. Adaptive management allows for continual improvement, because management actions can be changed in response to a monitored system response.

Adaptive management is a formally required element of the Basin Plan and is taken to include:

- setting clear objectives
- linking knowledge, management, evaluation and feedback over a period of time
- identifying and testing uncertainties
- using management as a tool to learn about the relevant system and change its management
- improving knowledge, and
- having regard to the social, economic and technical aspects of management.

The Basin Plan has built-in review processes, a monitoring and evaluation program, and reporting requirements of Basin jurisdictions to enable adaptive management to happen; however, it remains challenging to apply.

The Murray–Darling Basin is a complex nested river system and achieving environmental outcomes from flow restoration has many uncertainties. Environmental flow delivery can be influenced by the weather, other water users, antecedent flows and constraints. Environmental assets vary in their starting condition and each responds differently to watering, often in ways that are unpredictable. More generally, while environmental flows are a critical driver of environmental asset condition, other factors like land use, climate change and pest species can all influence where, when and to what degree environmental outcomes are achieved.

One of the strengths of the Environmental Watering Plan is that it recognises the nested nature of the system it seeks to manage and the degree of uncertainty involved. The Environmental Watering Plan is set up as an adaptive management instrument, with the decision-making process occurring on multiple scales (Figure 2).

Environmental water planning and prioritisation occurs at two temporal scales (annual and multi-year) and two spatial scales (Basin and water resource plan area). In this multi-scale approach, long-term objectives, which are described by this Strategy and in long-term environmental watering plans, are achieved through the accumulated benefits of numerous smaller-scale, short-term interventions. The latter are described by annual watering priorities and enacted through delivery of environmental water (Figure 2).

At the Basin scale, the Strategy is a vital component in the multi-year adaptive management cycle. The first Strategy was released in 2014, and progress towards the expected environmental outcomes was assessed in 2017 as part of the interim Basin Plan evaluation (see Coorong Case study). The effectiveness of the multi-year adaptive management cycle was also assessed.

The interim Basin Plan evaluation found that notable progress has been made in the successful delivery or anticipated delivery of the major components of the Environmental Watering Plan. Water holders and managers have incorporated the key components into their planning processes, while maintaining the flexibility to respond to prevailing conditions.

Learnings from the completion of the first five-year loop are informing this second edition of the Strategy (discussed in *Policy developments over the last five years*) as well as the third edition to be published in 2022 (discussed in Chapter 7). It is expected that the Basin Plan Evaluation in 2020 will also inform the third edition of the Strategy.

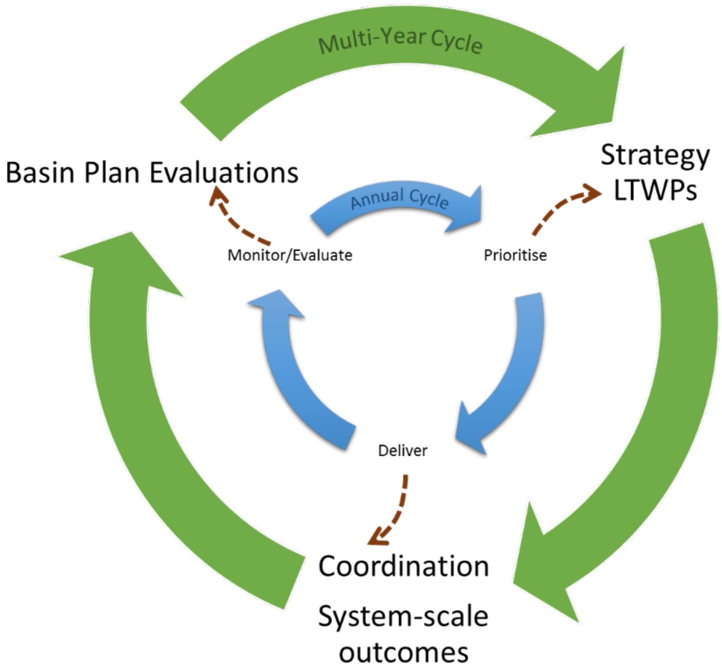

Figure 2: Stylised representation of multi-scale adaptive management in the Environmental Watering Plan. LTWP stands for long-term environmental watering plans.

Policy developments in the last five years

A number of significant developments have occurred since the initial Strategy, and these have guided what has been included in the updated Strategy. During this period, a significant amount of environmental watering has occurred and these experiences are also useful in refining elements of the Strategy. The following sections explain how these developments are important for maximising the outcomes of the Strategy, and how they have influenced this updated Strategy and may feed into a more detailed update in 2022.

Northern Basin review and toolkit measures

At the time the Basin Plan was made, it was recognised that the understanding of the northern Basin was far less robust than it was of the southern Basin. For this reason, the Plan provided for detailed new work to review the environmental and social and economic contexts of the northern Basin, including to review the potential impacts of the initial water recovery target of 390 GL/yr. The broad-ranging review looked at the importance of both flow related and non-flow related aspects of water management in the northern Basin.

A key learning gained from the review was that long-term management levers (such as SDLs) are a necessary, but alone insufficient, mechanism for achieving a sustainable northern Basin river system. The unique aspects of the northern Basin (highly variable climate, largely flat topography, and the relatively small capacity to regulate river flows using public storages) mean that long-term levers must be accompanied by improved water management arrangements.

The outcome of the review was a reduction in the recovery target to 320 GL/yr and an agreement to implement a series of toolkit measures to improve water management arrangements and environmental outcomes across the northern Basin. These measures include arrangements to protect environmental flows through active management of flow events, environmental works to promote fish movement, improvements to the coordination and delivery of environmental water, and removal of physical constraints to improve flows to wetlands. The review concluded that, when combined with toolkit measures, the lower water recovery would yield similar overall environmental outcomes to what would have been achieved with 390 GL/yr of water recovery.

The change in the amount of water to be recovered in the northern Basin and the associated implementation of toolkit measures means that an update will be required to the hydrological modelling used to inform the expected environmental outcomes in the Strategy. However, because the northern Basin toolkit measures are yet to be finalised and some may influence water flows (and therefore the expected environmental outcomes), the modelling and associated expected environmental outcomes are planned to be updated in the 2022 edition of the Strategy.

The knowledge gained in the northern Basin review has resulted in further refinements to the evidence base used to develop the water management strategies emerging from experience (Chapter 3).

SDL Adjustment Mechanism

The Basin Plan sets sustainable diversion limits to restrict how much water that can be taken in the Murray–Darling Basin for consumptive use, setting aside enough water to sustain water-dependent ecosystems. However, consistent with its adaptive management principles, the Basin Plan also provided a mechanism for these limits to change in response to the new knowledge. The SDL Adjustment Mechanism (SDLAM) was included in the Basin Plan to allow Basin state governments to propose a series of measures which would allow the desired outcomes to still be achieved, but with more efficient water use.

The Basin Plan recognises that efficiencies can be found in all types of water use. Some projects will allow equivalent environmental outcomes to be achieved, but with less water for the environment. Other projects will improve the efficiency of consumptive water use, releasing the savings back to the environment.

The effect of the SDLAM is to reduce the amount of water that needs to be recovered for the environment in the southern Basin. The change means that an update will be required to the hydrological modelling used to inform the expected environmental outcomes in the Strategy. However, because the projects are still being implemented, the modelling and associated expected environmental outcomes may be updated in the 2022 edition of the Strategy.

Pre-requisite policy measures

The baseline SDL modelling in the Basin Plan assumed that certain rules were in place to allow for the efficient use of environmental water. These were: being able to call environmental water from storage to ‘piggyback’ on unregulated flow events, and being able to credit environmental return flows for downstream environmental use (i.e. ensuring environmental water is able to be used on more than one site as it travels through the system). These policy settings for environmental water use are referred to in the Basin Plan as unimplemented policy measures.

The Strategy has been developed on the basis that the policy measures are in place. This applies particularly to the expected environmental outcomes set out in Chapter 2 and some of the management strategies in Chapter 3.

The Basin Plan requires the policy measures to be in effect by 30 June 2019 if these modelled assumptions are to be retained in the modelling of any reconciliation of the SDLs, conducted as part of the SDLAM. The measures are now referred to as pre-requisite policy measures (PPMs).

The PPMs were only included in the modelling for the southern Basin, and only apply to environmental water in New South Wales, Victoria, South Australia, and the River Murray (operated by the MDBA on behalf of these three states under the joint venture arrangements in the Murray–Darling Basin Agreement).

The MDBA considered the states' PPMs at its meeting on 28 June 2019 and determined that they were 'in effect', noting that each jurisdiction needs to commit to further work to refine and improve PPM implementation over time. Implementation of PPMs is a vital component for achieving the Strategy's expected environmental outcomes.

Constraints management

In some parts of the Basin, consumptive water use, developments on floodplains and regulation of flow by dams make it difficult to restore some of the ecologically important flows to the environment. Constraints include physical structures such as weirs, locks, dams, low-lying bridges and water pumps, and issues that arise from the policies and rules that determine how water is managed and infrastructure is operated. Introducing constraints to the river system has added to the disconnection between rivers and their associated floodplains, which has impacted the overall health of the system.

While many of these constraints serve the economic outcomes of the Basin, there is nevertheless scope for improving environmental outcomes by adjusting management and operational arrangements.

The MDBA developed the *Constraints Management Strategy 2013 to 2024* to help guide the work of identifying and removing or modifying physical and operational constraints. In 2018, the State governments nominated a number of projects that addressed some of these constraints (physical and operational) in the SDLAM. The suite of projects included those to address the physical constraints from Hume to Yarrawonga, Yarrawonga to Wakool Junction, South Australian Murray, Murrumbidgee, Goulburn (nominated as a Constraint Measure only), and Lower Darling (as part of the Menindee Lakes proposal). To achieve a lasting adjustment to the sustainable diversion limit these projects must be completed by 2024.

Delivery of constraints projects, together with the implementation of the pre-requisite policy measures and SDLAM projects such as the enhanced environmental water delivery project, are a vital component towards achieving the outcomes of the Basin Plan. These measures will provide greater flexibility for river operators and environmental water managers to organise the delivery of water to maximise opportunity to achieve the Strategy's expected environmental outcomes. The results will include reconnecting floodplains through more frequent overbank watering and allowing larger volumes of environmental water to be moved through the system at times (winter and spring) that are in less conflict with system operations required to deliver consumptive water. As with the SDLAM, overcoming constraints in the system may require an update to the hydrological modelling and associated expected environmental outcomes in the Strategy.

Community engagement is an important element of a successful constraints management program. Basin states will implement the Constraints Measures projects and hold detailed landholder discussions with a view to co-designing practical, on-ground solutions. General discussions about the benefits and implications of constraints flows will be held with a cross-section of the community and stakeholders.

Water resource plans

Under the Basin Plan, states are required to prepare water resource plans at a catchment scale and these must provide for environmental watering in a way that is consistent with the Strategy. Drawing on the content of the water resource plans, three issues have been identified that require a watching brief to understand how they may be affecting the ability to meet the outcomes of the Strategy.

The Basin Plan was developed on the premise that water would be recovered for the environment (held as entitlements) and that this water would be combined with other water in the system to meet the Plan's environmental objectives. A key part of the other water is PEW, which is water earmarked for environmental purposes in state instruments. Recognising the importance of PEW, the Basin Plan requires states to protect it.

Through the water resource plan process, it has become clear that jurisdictions may have an amount of water that is neither entitlement-based nor PEW. This pool of water is relied on to support environmental outcomes to different extents in different jurisdictions. However, this water may not be subject to the same Basin Plan protections as water that is clearly identified as PEW. Given this "non-PEW" water in the system can be supporting environmental outcomes, water resource plans might include other suitable mechanisms to ensure those outcomes continue to be realised. Where established in water resource plans, these mechanisms will be monitored to inform ongoing compliance, to ensure environmental outcomes are delivered, and to establish whether further safeguards are needed.

One of the purposes of the Strategy is to help co-ordinate the management of environmental water, while one of the tasks of water resource plans is to provide for the co-ordination of environmental watering between connected areas. Over the coming years, the effectiveness of the co-ordination arrangements in the water resource plans will be monitored to determine whether further co-ordination arrangements are needed in future editions of the Strategy.

In 2008, the CSIRO showed that most state water plans significantly protect entitlement holders from the impacts of future climate change, and shift the majority of the impact to non-entitlement water (e.g. PEW or other water that contributes to environmental outcomes). This represents a significant risk to the environment during future extended dry periods. As the recent suite of water resource plans under the Basin Plan draw heavily on existing state management arrangements, the risks to achieving the environmental outcomes under a drying climate remain. Ongoing monitoring will assist in determining the need for additional policy responses. Further work on climate change is discussed in Chapter 7.

Long-term environmental watering plans

One of the purposes of the Strategy is to guide the development of consistent long-term environmental watering plans. In effect, the long-term watering plans are to reflect the Strategy, but at the catchment scale. They must identify the priority environmental assets, priority ecosystem functions, and their associated environmental watering requirements. There are three reasons for this requirement:

1. to provide environmental water holders with the best information when they plan how to use their water
2. to assist environmental water holders, site managers and scientists with their monitoring, evaluation and reporting activities when they measure the local environmental response to watering events, and
3. to provide long-term planners (such as the MDBA and Basin states) with tangible on-ground measures against which they can test the effectiveness of their management and policy settings.

The identification of priority assets and functions in each catchment serves an important transparency and communication role—they allow the community to link large-scale long-term policies (such as the Basin Plan) to the environmental outcomes that are being achieved in their local area.

In the first editions of long-term watering plans, not all states have identified priority environmental assets, priority ecosystem functions and their environmental watering requirements in accordance with the Basin Plan. Where this has occurred, states have committed to reviewing long-term plans after the water resource plans are finalised and it is expected that updated plans will include a consolidated lists of assets, functions and water requirements.

While assets, functions and water requirements can also be identified in the Strategy (in which case they must then be reflected in the long-term plans), it is preferable that they are identified directly in long-term plans as states have a more detailed understanding of the relevant catchment-scale hydrological and ecological processes to inform the work.

Experience with environmental watering and new knowledge

The 2017 interim evaluation of the Basin Plan noted that there were more than 750 environmental watering events since 2013, many more occurred in the following two years, prior to the draft 2019 Strategy update. The experience gained has resulted in greater collaboration and coordination between those who manage environmental water, and has led to water holders combining their available water to reach larger areas and meet more priorities.

These experiences are reflected in the Strategy in refinements to the water management strategies described in Chapter 3 and in associated case studies.

Increased knowledge of native fish life cycle requirements has emerged over the past five years. One example is the growing body of evidence that the life cycles of some native fish species, such as golden perch, operate at the Basin scale. This has highlighted the need for the planning and coordination of the use of all environmental water (both HEW and PEW), along with other water in the system, to achieve these outcomes.

The Murray–Darling Basin Environmental Water Knowledge and Research project (EWKR) is also generating new knowledge that will help managers decide how to best use environmental water. For example, tracking of waterbirds is identifying critical foraging habitats and common flyways. In the coming years, this information will help Basin-scale management and has been reflected in the water management strategies in this document.

Structure of the Strategy

Following the introduction at Chapter 1, Chapter 2 of the Strategy describes the expected environmental outcomes for river flows and connectivity, native vegetation, waterbirds and native fish. Chapter 3 sets out water management strategies that can be employed by water managers to maximise the achievement of the environmental outcomes. The roles and responsibilities of the various agencies responsible for the planning and management of environmental watering are outlined in Chapter 4. Chapter 5 describes how the MDBA identifies annual environmental watering priorities. Measuring progress towards the expected environmental outcomes is the subject of Chapter 6. Finally, Chapter 7 describes a work program for the MDBA from 2019 to 2022 to inform what is expected to be a major update of the Strategy in 2022.

2 Expected environmental outcomes

Context

The implementation of the Basin Plan is seeking to alleviate some of the adverse effects of river regulation and consumptive use of water in a way that also provides water users with security and supports communities. With a combination of environmental water available in entitlements and other water in the system, the goal is to reinstate and protect where possible the ecologically-important flows that support the rivers, wetlands and floodplains of the Basin.

Restoring seasonal components of the flow regime so that rivers are better connected to their floodplains is important not only for the plant communities that depend on inundation for germination, seedling survival and growth; but also in delivering nutrients and providing habitat and feeding opportunities for animals. Such flows also act as breeding triggers for organisms. Connecting the Basin's system of creeks, streams and rivers to the estuary, and ultimately the sea, also provides many benefits, for example, exporting salt from the system and allowing organisms to fulfil life cycle requirements for movement and migration between different habitats and catchments.

These processes underpin complex food webs and lead to an increase in the number and diversity of habitats. Invertebrates (such as insects and crayfish), vertebrates (such as fish, waterbirds, frogs and turtles) and vegetation respond to more natural flow regimes through reproduction, growth and survival. This, ultimately, improves biodiversity (see Figure 3 and the River flows and connectivity section for more information). Water managers use the most contemporary information about the links between flow and environmental outcomes, as well as local knowledge, to target environmental outcomes through the types of interactions identified in Figure 3.

The particular outcomes sought from environmental watering will change from year to year depending on a range of factors including the amount of water available in storage, the condition of different ecosystem components, the climatic and catchment conditions from the recent past and the prevailing climate. Optimising the outcomes of environmental flows often requires cooperation among water managers or capitalising on opportunities created by water flowing through the system such as PEW, unregulated flows and water on route for consumptive use.

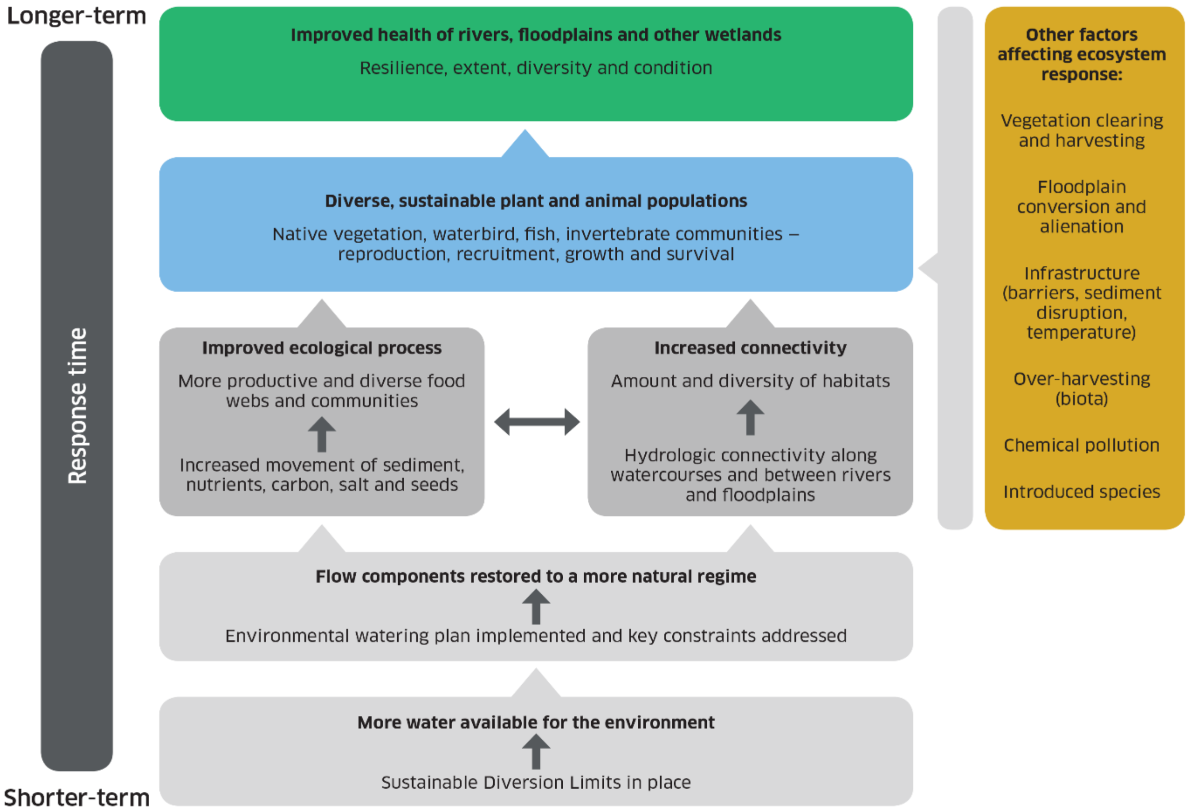

Figure 3: Relationship between flow and outcomes.

The approach to environmental watering will vary between the different river systems of the Basin:

- In some parts, water resources are undeveloped and water-dependent ecosystems are largely undisturbed because of the near-natural flow regime – such as in the Paroo and Ovens catchments. In these areas there is little need and limited capacity (e.g. lack of water delivery infrastructure) to actively manage environmental flows.
- In unregulated systems (i.e. rivers without large dams) with significant water extraction, targeted water recovery can restore or protect flow components that improve water-dependent ecosystems. These may be main stem rivers such as the Condamine-Balonne or smaller tributary streams in upland areas such as Tarcutta Creek in the Murrumbidgee catchment. The water recovered from consumptive use simply stays in the river, with rules required to ensure it is not extracted as it flows through the system.
- In many Basin catchments, rivers are highly developed and flows are significantly modified by regulating structures and water extraction; with consequently higher impacts on river health. The Goulburn, Murray and Murrumbidgee rivers exemplify this. These systems have complex management arrangements and multiple stakeholders with competing interests. In these rivers, water can be recovered for the environment and actively managed by releasing it from storages at suitable times to 'piggy-back' on, or to top up, existing flows.

The northern part of the Murray–Darling Basin has a higher proportion of unregulated rivers than the south and therefore less active management of environmental water. These factors, combined with a highly variable climate, mean that there needs to be a greater reliance on event-by-event rules and operations in the unregulated systems to achieve a sustainable pattern of river flows and protect environmental outcomes.

Environmental objectives, targets and outcomes of the Basin Plan

Within the context of a healthy, working river system, chapter 8 of the Basin Plan (the Environmental Watering Plan) sets out three broad environmental objectives for water-dependent ecosystems and ecosystem functions (see Figure 4). The Basin Plan (Schedule 7) also sets out high-level targets by which to measure progress towards the objectives.

The Basin-wide environmental watering strategy further elaborates on these objectives and targets by describing the expected outcomes for four ecological components of the river system: river flows and connectivity, native vegetation, waterbirds and native fish.

Together the objectives, targets and outcomes form what is known as an objectives hierarchy (see Figure 4), with expected environmental outcomes being the most specific. The development of an objectives hierarchy is best management practice as it guides development of the Plan's components, such as long-term environmental watering plans, and enables adaptive management.

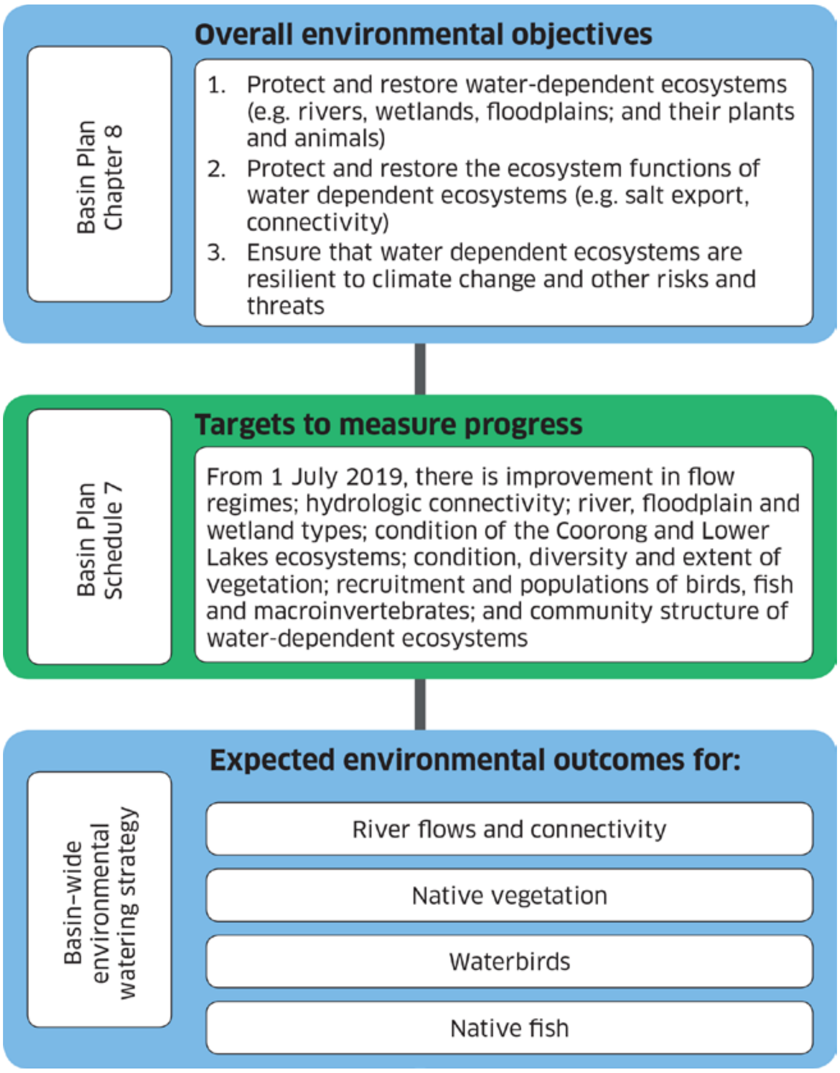

Figure 4: The hierarchy of environmental objectives established for the Murray–Darling Basin.

The Strategy focusses on river flows and connectivity, native vegetation, waterbirds and native fish for the following reasons:

They are good indicators of the health of a river system and are measurable. *Waterbirds, for instance, inhabit the full spectrum of freshwater environments; with different functional groups using different parts of the ecosystem (e.g. fish-eating and wading birds). The status of their populations therefore reflects the flow regimes of a range of environments and habitats within the river system. Waterbird populations are also measurable using existing scientific tools, so that it is possible to monitor progress in achieving the expected environmental outcomes across the Basin. Monitoring and evaluation is addressed in more detail in the Chapter Measuring progress.*

They are important components of healthy functioning water-dependent ecosystems. *For instance, Longitudinal connectivity enables organisms to move between habitats along the length of the river; while Lateral connectivity plays an important role in maintaining water quality, in addition to being important for the productivity of river-floodplain ecosystems.*

They are responsive to environmental flows. *For example, environmental flows are thought to be one of the most important actions that managers can take to restore native fish populations in the short to medium term.*

They are highly valued by people. *For example, an estimated 430,000 Basin residents participate in recreational fishing, which depends upon a healthy native fish population. This activity generates around 10,000 jobs in the Basin and contributes $1.3 billion to the Basin's economy each year. Native fish have subsistence food, social, totemic and cultural values for Indigenous communities. The Basin's Traditional Owners recognise when there is sufficient seasonal water available for the environment they are able to gather to fish, and their cultural health and wellbeing improves: 'When our rivers are dying we are dying with our Country'.*

They have declined appreciably as a result of water resource development. *For example, waterbird numbers have declined by 70% since 1983, and a key functional group of waterbirds—migratory shorebirds—has been severely affected in places like the Coorong and Lakes Albert and Alexandrina. While waterbirds naturally respond to boom and bust periods driven by river flows and local rainfall, this overall long-term decline is particularly attributed to water extraction and capture that has prevented floodplain and wetland inundation (this is explained further in the Waterbirds section of this document).*

They require a Basin-wide approach to be managed effectively. *Native fish, migratory waterbirds and large floodplain forests are distributed across catchment and jurisdictional boundaries; and rare or unique communities require coordinated management across these boundaries.*

The four themes that were identified in the 2014 Strategy continue in this Strategy update. These are a subset of all themes that constitute a water-dependent ecosystem and additional themes may be included in the 2022 Strategy update. Further information on potential additional themes is provided in Chapter 7 on Future Work. Outcomes for water quality are already laid out within the Basin Plan (see Box 3 below), so only a few significant Basin water quality issues are covered in this Strategy.

The expected environmental outcomes described in this Strategy constitute the MDBA's best assessment of how the Basin's water-dependent ecosystems are expected to respond to environmental watering over the coming years. However, the various Basin ecosystem components will take differing amounts of time to respond to the additional environmental water, particularly in an already highly variable climate that is also being influenced by climate change. Other complementary actions, such as management of aquatic pests and removal of barriers to fish movement, will also impact on the ability to achieve these outcomes—as will broader changes in land management. This is discussed further in the section below Influence of other factors on expected environmental outcomes.

Monitoring against the expected environmental outcomes will be a priority for the MDBA. Many of the outcomes, such as those for river flows and waterbirds, have multi-decadal monitoring programs behind them, and these programs will continue. Other outcomes, such as those for native fish, are less well-serviced by current monitoring program. New investments are being made to boost the MDBA's monitoring capability in two thematic areas (i.e. native vegetation and native fish) and states are also undertake monitoring, however it is not expected that all of the expected environmental outcomes will be able to be monitored at this point in time.

Box 3: Water quality

A Basin Plan objective is to maintain appropriate water quality, including salinity levels, for environmental, social, cultural and economic activity in the Basin.

Water quality and salinity targets are outlined in the Basin Plan. They include targets for managing water flow, water-dependent ecosystems, irrigation water, recreational water and long-term salinity planning and management (not reproduced here). The Basin Plan also requires each Basin state to develop a water quality management plan for each of their water resource plan areas—so water quality management will receive dedicated effort across the Basin as the Basin Plan is fully implemented.

A salt export objective stated in the Basin Plan is to allow adequate flushing of salt from the River Murray system into the Southern Ocean. The additional water recovered under the Plan will contribute to this outcome; however, it will also be reliant upon other factors including the prevailing climate and active salinity management (including operation of salt interception schemes).

Environmental water managers must and do consider their impact on water quality for other downstream uses. They must have regard to water quality targets for dissolved oxygen, recreational water (cyanobacteria or blue–green algae) and salinity levels when making decisions about the use of environmental water. Further detail is provided in flow management guidelines which are currently being drafted.

However, more generally the objective for the use of environmental water is to protect and restore water-dependent ecosystems and their associated ecosystem functions.

Influence of other factors on expected environmental outcomes

Although flow restoration and environmental watering are necessary to achieve the outcomes of the Basin Plan, their effects can be enhanced by addressing other factors that limit the ecosystem response to hydrological change. The MDBA acknowledged this in its Northern Basin Review recommendations, which were contingent on commitments to implement a number of non-flow related improvements to enhance the outcomes achieved from delivering environmental water.

Some of the non-flow related factors that affect environmental outcomes are unique to particular components of the ecosystem. For example, native fish are affected by alien species (see Box 6), barriers to dispersal, poor water quality and overharvesting; while waterbirds are affected by predation from feral animals, poisoning by herbicides and pesticides, and diseases such as botulism. For migratory birds, clearing of wetlands along international flyways further impacts the health of the population.

Other factors that affect environmental outcomes are common across ecosystem components. Climate change, for example, will have significant and complex impacts on many aspects of the aquatic ecosystem. Temperature is one of the most important drivers of freshwater biotic responses, and increased temperatures, along with changes to precipitation, evaporation and runoff, will affect both the distribution of species and their capacity to reproduce, survive and prosper.

Complementary natural resource management measures that address threats to achieving environmental outcomes from environmental watering are many and varied. They include installation of fishways and fish diversion screens, control of pest species, investments to address cold water pollution, and riparian management activities and habitat restoration.

For the purpose of integrating environmental water and natural resource management, it is important that:

- environmental water managers link with other natural resource management groups and plan for integrated outcomes where activities are related (e.g. by adjusting annual watering priorities in response to other natural resource management actions to ensure that the use of water maximises outcomes)
- all environmental water managers, scientists and river operators communicate effectively with, and find opportunities to work with, local communities—so that environmental watering contributes to broader natural resource management outcomes
- the impact of non-water related threats to the environment are considered in management plans and watering actions (e.g. recent fire history or the impact from adjacent land uses)
- constraints currently restricting environmental outcomes are addressed as far as possible
- Australian, Queensland and New South Wales governments continue with their commitment to implement toolkit environmental works and measures in the northern Basin, and
- effective networks and activities are in place that facilitate all of the above.

Timelines

The decline in the condition of the Basin's water-dependent ecosystems has occurred over many decades and redressing it will take place at different timescales. Some ecosystem responses—such as flow connections across floodplains and movement of waterbirds and native fish—will occur relatively rapidly in response to environmental watering. These types of changes are already being observed, at both local and system scales. For example, the 2017 Basin Plan Evaluation noted that environmental water has helped improve river flows and connectivity in many parts of the system, primed habitat to support waterbird breeding in particular locations, and successfully supported native fish spawning and helped fish move through the system. Other responses—such as improved population structure of long-lived native fish and vegetation—will take longer to become evident as several recruitment events over time may be required and many species take years or decades to reach maturity. The different recovery trajectories of species and communities mean that while some improvements are happening now, widespread restoration of water-dependent ecosystems at the scale of the Basin is a long-term endeavour.

Impact of policy changes on the expected environmental outcomes

Since the first Basin-wide environmental watering strategy was released in 2014, the Basin Plan and the water recovery targets have been modified. These policy changes indicate that the Basin Plan is operating as intended — that is, as an adaptive management instrument that responds to improved knowledge. However, the impact of policy changes on the expected environmental outcomes is yet to be determined.

The SDLAM and Northern Basin Review have resulted in shifts to lower the water recovery targets. As a first principle, it would be expected that less water recovery should reduce the expected environmental outcomes. However, both of these programs linked the reduction in water recovery to a series of measures which will deliver equivalent (in the case of the SDLAM) or similar (Northern Basin Review) environmental outcomes.

These measures (such as implementation of works and measures, improved operating rules) are not yet in effect, so it is not yet clear how the expected environmental outcomes will change.
It is expected that these changes will result in a series of trade-offs—some of the expected environmental outcomes will be greater, while others will be reduced. But further information is required to provide a balanced assessment of the overall changes to expected outcomes, and a new methodology may be required to capture the benefits of these changes to the system.
This new information and methodology is expected to be included in the 2022 Strategy.

An exception to this were the indicators for the condition of the Coorong, Lower Lakes and Murray Mouth (CLLMM), which were potentially at risk of declining and would unlikely be balanced by the operation of new works or rules being included. For these indicators it was deemed important to check their achievement rates with the new recovery targets. The assessment showed that all the CLLMM indicators were maintained under the new model scenario and therefore the expected outcomes remain relevant.

Theme 1 — River flows and connectivity

The extraction of water for consumptive use, and the use of structures such as dams and weirs to provide a more reliable water supply, both have the effect of changing the pattern of river flows. Some components of the flow regime may experience decreases in frequency, magnitude or duration as a result of these actions (e.g. small to medium overbank flows in most systems) while other components may see increased flows (e.g. base flows in some systems). River regulation also affects timing through changes in the seasonality of flow, resulting in higher summer flows and lower winter-spring flows than would occur naturally.

Generally, the connectivity of rivers along their length, to the adjoining floodplain and to groundwater (see Figure 5 below), has been negatively affected by changes to flows - and these changes have impacted on the health, abundance and range of many water-dependent native species.

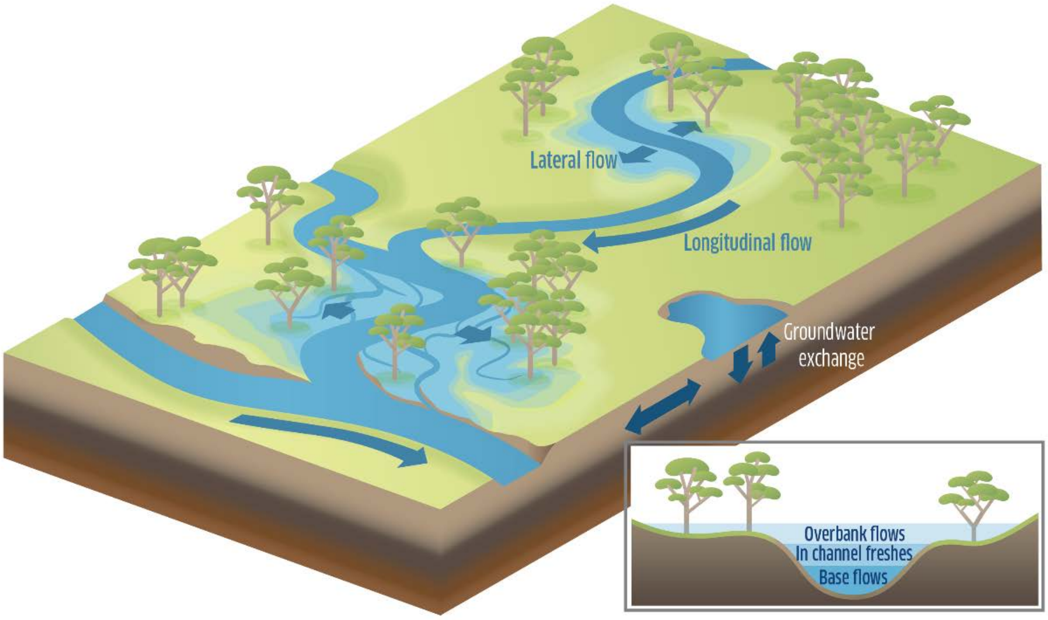

Figure 5: Hydrological connectivity and flows.

The use of environmental water recovered from the consumptive pool aims to restore ecologically significant parts of the flow regime to a more natural pattern. This is achieved by adding recovered water to existing flows, and by releasing the portion of recovered water stored in dams at ecologically appropriate times and rates. The improvements in flow and connectivity from these actions are expected to enhance environmental outcomes for native vegetation, waterbirds, native fish, other water-dependent biota and ecosystem functions across the Basin.

Longitudinal connectivity

The longitudinal connectivity of rivers (either as flows into downstream reaches or, in the case of fully-connected systems, flows through to the sea) varies across the Basin. Connectivity fulfils important environmental functions, among them distributing nutrients, sediments and carbon/energy, allowing organisms to disperse and migrate, expanding the range of feeding and breeding opportunities, supporting genetic diversity and flushing sediment and salt out to sea.

The impacts of river regulation and diversions often increase cumulatively downstream, resulting in reduced hydrodynamic diversity and diminished health and resilience of lowland ecosystems. Some of the largest impacts are seen in the connectivity of the Darling River with the River Murray and in the connectivity of various rivers that end in large lowland floodplains (e.g. Narran Lakes, Macquarie Marshes, Gwydir Wetlands, Lower Murrumbidgee Floodplain, and Lachlan Swamp).

At the end of the Murray–Darling Basin system, connectivity between the River Murray, its estuary (the Coorong) and the Southern Ocean is uniquely important as it is the conduit for the removal of accumulated salt, sediment and pollutants from the Basin and for species that move between fresh and salt water to complete their life cycle.

Figure 6 illustrates longitudinal connectivity between rivers in the Basin (based on modelled flow using data from 1895–2009). It shows the proportion of catchment inflows that would have flowed out of the end of each catchment before development (small blue bars); under levels of development before the Basin Plan (red bars); and under Basin Plan settings (green bars; excludes changes arising from the Northern Basin Review and the SDL Adjustment Mechanism as they are yet to be finalised)[1].

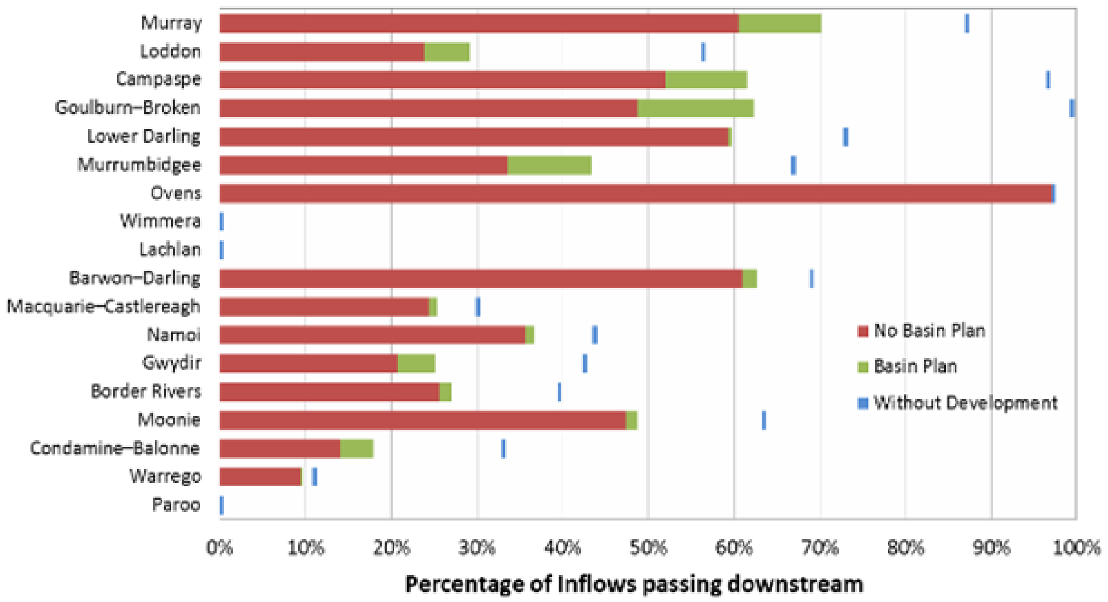

Figure 6: Proportion of catchment inflows flowing out the end of river catchments across the Basin.

[1] While not physically connected, the Bogan, Macquarie and Castlereagh rivers are grouped in the Basin Plan into one water resource plan area. The Bogan and Castlereagh rivers are largely undeveloped, whereas the Macquarie is highly developed. Accordingly, their combination in figure 6 may be misleading.

Figure 6 shows, as a general trend, that the impact of development on connections between rivers has been greater in the southern Basin compared to the northern catchments (i.e. a larger gap between the red and blue bars). This reflects the historically higher level of development and extraction present in the southern valleys. Similarly, the proportional improvement in longitudinal connectivity achieved by environmental watering under the Basin Plan will also be greatest in the more southern developed valleys (seen in longer green bars).

Longer-term changes in patterns of rainfall, temperature and inflows appear to be emerging in some parts of the Basin. For example, the pattern of flows in the Barwon-Darling system has always been variable, but the number and length of cease-to-flow periods have increased significantly in the past 18 years, while floods that follow them have been smaller. The Basin Plan is anticipated to provide improvements to longitudinal connectivity across the northern Basin through water recovery, reducing consumption water use and increasing river flows. Many of the northern Basin toolkit measures are aimed towards improving longitudinal connectivity during these dry periods.

In-stream infrastructure such as locks and weirs currently limits some of the beneficial effects of longitudinal connectivity, for example by preventing the movement of many aquatic species. However, progress with construction of fishways, delivery of higher flows that directly link upstream and downstream environments, and improvements to the operation of structures are expected to enhance connectivity events.

Figure 8 shows catchments where the Basin Plan should result in longitudinal connectivity improvements for different parts of the flow regime (base flows, freshes, bank-full events).
See Figure 10 and the section on flow regimes for further explanation.

Lateral connectivity

The connections between rivers and their floodplains (lateral connectivity) underpins many ecological processes and functions that are essential for healthy and resilient water-dependent ecosystems.

This level of connection naturally varies in frequency, extent and timing across the Basin, and is further affected by river regulation and diversions. While a few valleys have experienced little change, in most valleys the frequency, magnitude, timing and duration of flows which connect rivers with their floodplain has substantially declined in recent decades. In these rivers, the flows delivered from dams have almost always been in-channel—natural over-bank events have been reduced such that many floodplain ecosystems and the functions they support are at risk. This is illustrated in Figure 7 (for part of the Murray floodplain).

The pattern demonstrated in Figure 7 also occurs in the large unregulated valleys where water plans permit water to be pumped in most medium-sized events.

The Basin Plan aims to reinstate this connection between rivers and their floodplains to the extent possible given the constraints in the system and depending on availability of environmental water held in storages. Valleys with highly altered river flows and large areas of lowland floodplain provide the best opportunities to improve lateral connectivity. Priority river valleys include the Condamine–Balonne, Gwydir, Macquarie, Barwon–Darling, Lachlan, Murrumbidgee, Murray, Lower Darling and Goulburn.

Another group of the Basin's major river valleys have relatively intact high flow regimes, limited floodplains or their floodplains are at higher elevations (e.g. Border Rivers, Namoi, Campaspe, Loddon and Wimmera). In these systems, the improvements expected from the Basin Plan will largely be confined to in-channel flows or small over-bank events.

In the valleys where lateral connectivity is relatively unchanged by development (such as in the Paroo, Warrego, Moonie, Nebine and Ovens), the Basin Plan and associated water resource plans have the effect of ensuring this connectivity is maintained.

The degree of improvement in lateral connectivity throughout the Basin will be determined by the extent to which flows to the different parts of the floodplain can be managed. This is described in the section below on the managed floodplain.

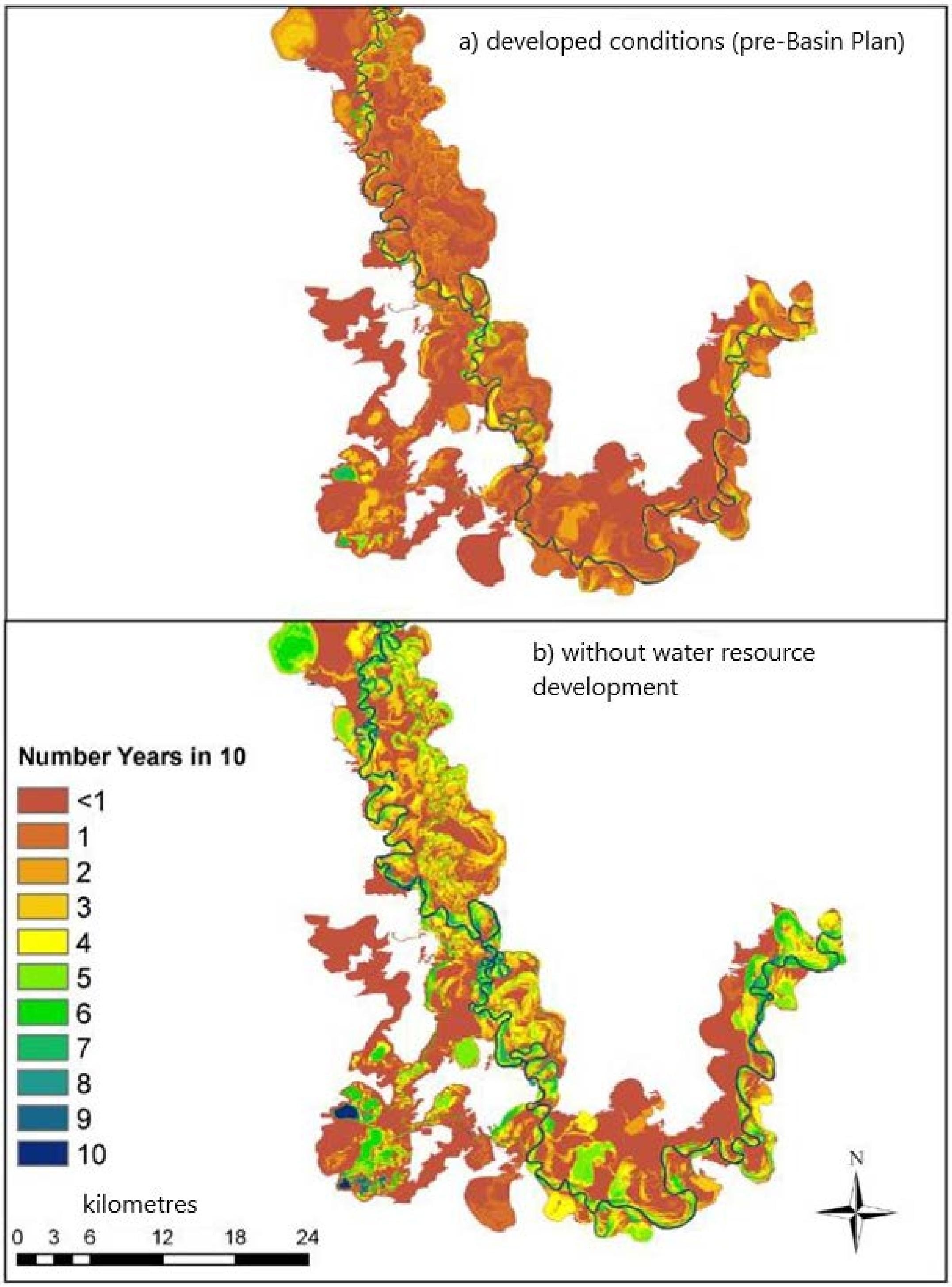

Figure 7: Frequency of inundation between Euston and Lock 10 on the River Murray under a) developed and b) without water resource development.

Legend

- Minimal water resource development, therefore no improvements sought – rather maintenance of all current flow components
- Improvements in connectivity are possible under the Basin Plan for base flows, low in-channel freshes and bank full/low floodplain over-bank flows
- Improvements sought in base flows and low in-channel flows only – as bank full and low floodplain over-bank flows are either relatively intact of there is limited floodplain

Figure 8: Level of flow component improvement expected under the Basin Plan.

Vertical connectivity

The connection between rivers, creeks and wetlands with groundwater (vertical connectivity) is important as it supports many ecological processes. The level of vertical connectivity varies across the Basin and depends on the nature of the aquifer (the geological structures below the ground that hold groundwater in their pores and cracks) and the watercourse above. An assessment of vertical connectivity across the Basin is shown in Figure 9.

When water moves down through a river bed to the semi-saturated and then saturated aquifer (water table), it is called a ‘losing’ stream. Groundwater can also move up and discharge into rivers and wetlands; this is called a ‘gaining’ stream. Some areas vary over time from ‘losing’ to ‘gaining’ depending on factors such as the prevailing climate, environmental watering and levels of surface or groundwater extraction.

Areas of the Basin are considered to have a high level of vertical connectivity when more than 30% of the water resources are shared (e.g. 30% of the water in a river is from a groundwater source). Often, upland reaches of fractured rock aquifers and alluvial aquifers have high connectivity with surface water systems, with one of the main risks being groundwater extraction inducing water to be drawn down from a river. In these areas, rules are required to protect environmental watering and hydraulic relationships.

Maintaining the natural water balance helps manage vertical connectivity in highly connected systems, supporting ecological processes above and below the ground and replenishing aquifers. It is also important for managing water quality, where sometimes an imbalance in connectivity can lead to detrimental outcomes, such as when saline groundwater and rising groundwater tables cause salinisation of the connected surface water resource and surrounding land.

While vertical connectivity is an important element contributing to surface flows and aquifer recharge, there are currently no expected environmental outcomes for this component of connectivity in the Strategy. Investigations into the feasibility of developing expected outcomes for vertical connectivity will be part of the work undertaken for the 2022 Strategy.

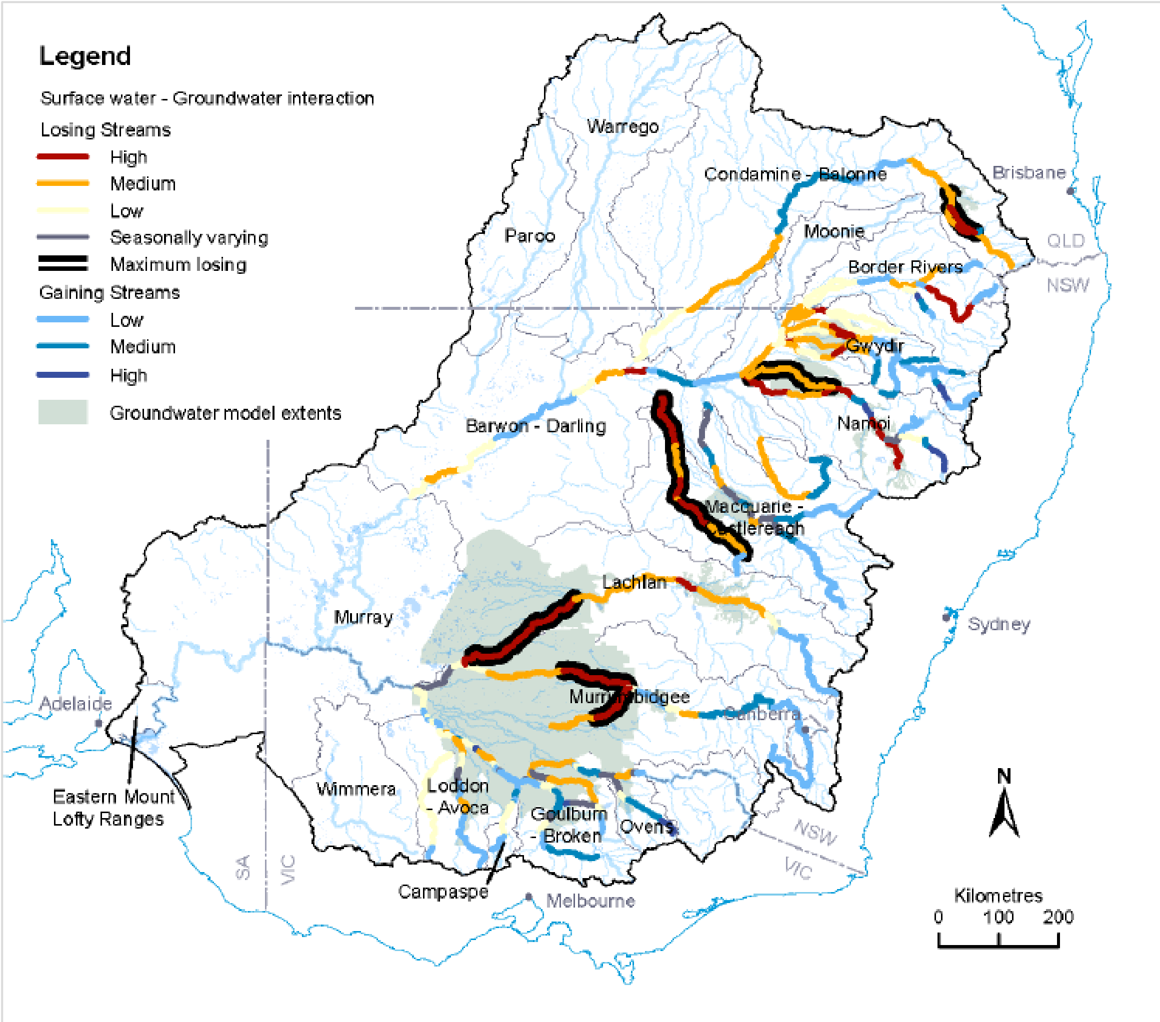

Figure 9: Surface-groundwater connectivity map across the Murray–Darling Basin (Parsons et al, 2008, p. 16).

The managed floodplain

In the context of a healthy, working river system (see Box 2) it is useful to think about the extent to which flows can be actively managed to inundate the floodplain versus flows that pass onto the floodplain as a result of passive management. This idea is captured in the concept of the managed floodplain, which differentiates those parts of the floodplain which can receive water through actively and passively managed flows.

Active management of flows occurs when decisions are made in the course of running a river. It includes decisions to release HEW from dams, use of the relatively small discretionary component of PEW (e.g. an environmental water allocation in a NSW water sharing plan), and the day-to-day decisions made in the course of operating a river to meet water user needs. Passive management includes rules in water plans which provide for environmental water to pass through the system (i.e. the majority of planned environmental water), rules which limit the amount of water extracted for consumptive use, and rules which limit the size of flows (i.e. rules that recognise operational and physical constraints in the system).

Actively managed flows of held environmental water are most effective at connecting the river to the inner floodplain, including riparian environments, lower-level wetlands and anabranch systems. To achieve these outcomes, held water is generally used to top up, or piggyback on, existing flows in the river.

Connections to most medium and higher-level floodplain environments are out of the scope of what can be achieved through actively managed flows due to a number of factors including the physical limits to the capacity to augment flows (e.g. restricted dam outlet capacity) and the need to protect towns and high-value agriculture or infrastructure. Therefore, these higher parts of the floodplain are only inundated through passive management.

The **actively managed floodplain** includes:

- Areas that are directly impacted by operational decisions to use environmental water. This may change from one year to the next, for example if flow constraints are overcome. It may also vary from one flow event to another, for example the actively managed floodplain can shrink and expand because the capacity to actively manage flows by piggybacking on passively managed flows varies depending on prevailing climatic conditions and the amount of water in storage.
- Areas that can be inundated using environmental works. This includes work by the Basin governments and the MDBA under the 'Living Murray' program to plan and build infrastructure (including channels, levees, flow regulators and pumping stations) to help get water efficiently to high conservation value sites on the River Murray floodplain. In the coming years, the number of these areas will increase significantly as SDLAM projects are implemented.

The **passively managed floodplain** includes:

- Areas where inundation relies on natural processes of uncontrolled flooding and the water is protected through rules in water resource plans (including planned environmental water rules and rules which limit extraction of water for consumptive use).

As noted above, the actively managed floodplain changes over space and time. So while the actively managed floodplain is a simple concept, in practice it does not have a definitive boundary, making it difficult to depict.

Flow regimes

Figure 8 shows the components of the flow regime that can be managed for improved connectivity as a result of the Basin Plan. It divides the flow regime into categories (also see Figure 10), each of which is important to ecosystem health. In addition to the flow categories in Figure 10, periodic drying (see Box 4) and hydrodynamic diversity (see Box 5) are important characteristics of healthy river systems that need water managers need to consider.

Base flows (or low, in-channel flows[2]) are an important component of the flow regime.
They maintain habitat for fish, plants, invertebrates and other aquatic species, and provide drought refuge during dry periods. These flows are provided by seepage from groundwater and low surface flows, the proportions of which vary across different parts of the Basin.

In-channel freshes are small-to-medium flow events which inundate benches or small anabranches, but stay in the river channel. They are generally relatively short in duration (i.e. a few days to a month). These events replenish soil water for riparian vegetation, maintain in-stream habitats and cycle nutrients between parts of the river channel. They also inundate snags and woody debris—important sites for fish spawning events. In many systems, freshes occur in most years, or possibly multiple times within a year.

Bank-full flows are the larger flow events that fill the river channel and in some cases inundate channel benches, the riparian zone and anabranches/flood-runners. They are important for the water-dependent ecosystems in and lining the channel, comprising various aquatic and semi-aquatic species, and vegetation communities such as river red gum, coolibah and lignum. These events also: provide opportunities for fish and other animals to move between the river and connected off-channel environments; support river forming processes that maintain pools, riffles and other in-channel features; and facilitate the transport of nutrients, sediments and organic matter down the river.

[2] The lowest 20% of flows

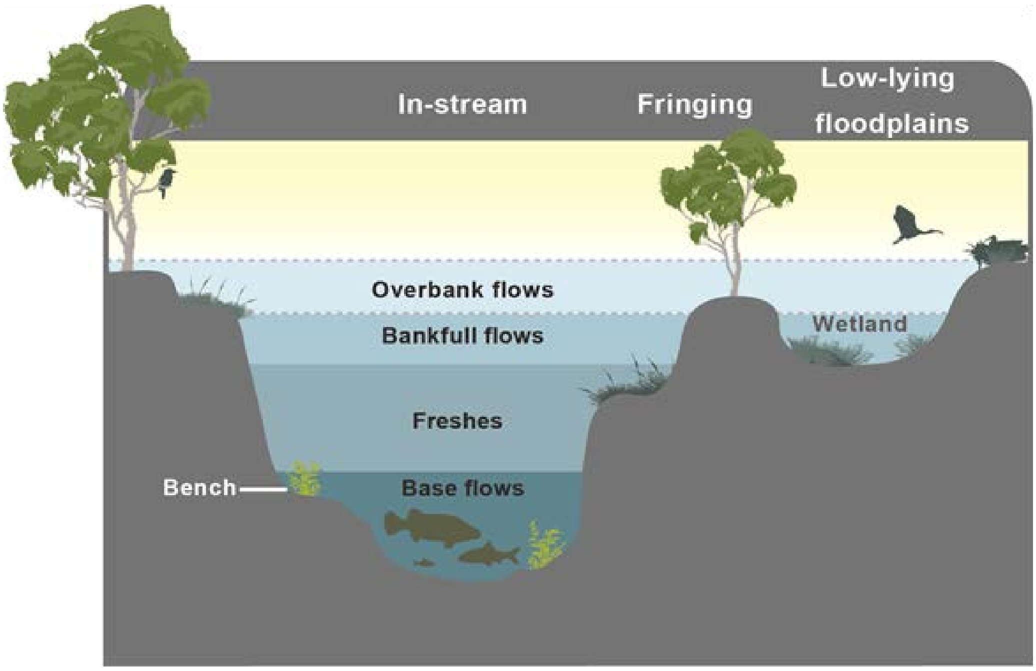

Figure 10: An illustrative river cross-section showing components of a flow regime.

Low and medium over-bank flows are substantial flow events that spill onto the inner parts of the floodplain and replenish local groundwater. They are important for the water-dependent ecosystems situated on the floodplain, comprising depressional wetlands and vegetation communities such as river red gum, black box and lignum. These events also provide opportunities for birds to breed and allow fish and other animals to move between the river and the wider floodplain. Large-scale nutrient, carbon and sediment cycling between the river and the floodplain is an important benefit from these types of events. Depending on the location in the Basin, these types of flows can sometimes be supported with recovered water, with further gains possible once physical and operations constraints in the system are addressed (see Constraints Management section).

Large over-bank flows are events with high volumes of water which inundate substantial parts of the floodplain including higher areas. These only occur irregularly and cannot be actively managed with water recovered under the Basin Plan.

Box 4: Periodic drying and disconnection

Ecosystems are well adapted to the natural flow variability in the Basin. Periodic drying (following inundation), and disconnection of wetlands and billabongs from the main stem of rivers, are both important elements in the flow regime for many parts of the Basin.

Accordingly water management, particularly in drier periods, should consider drying phases (where these would have been a natural characteristic of that waterway; and if the health of the native plants and animals that now occupy the area can be improved). In some cases, drying phases have been lost because of regulation of rivers. Where possible, reinstating them will be important.

In other cases, river regulation has extended drying phases such that they are harmful. Water management should also seek to address these impacts.

Flow seasonality

Storages can have the effect of changing the seasonal pattern of flows. For example in the southern Basin, naturally higher flows predominantly occurred in response to winter–spring rainfall; now flows are primarily released from dams to meet irrigation demand in the hotter months. The effect of river regulation on seasonal flow patterns differs throughout the Basin and depends, in part, on the distance downstream from storages, the location of significant irrigation off-takes and the quantum of unregulated tributary inflows.

Water-dependent species that have evolved in response to the natural patterns of flow have been negatively impacted by river regulation. Environmental water releases from storages are able to reinstate a portion of the winter-spring flows consistent with natural seasonality, however most major dam releases will still coincide with spring-summer irrigation demands.

Water for the environment can sometimes contribute to higher summer flows but generally, environmental water is not delivered through the floodplain forests in summer unless it is in response to naturally high flows. In these cases, ecological responses are likely to have been triggered (e.g. a colonial waterbird breeding event) and environmental water is delivered to extend the duration of beneficial inundation. Outside these events, limiting the delivery of water overbank in summer supports the natural drying regimes of wetlands and forests, and mitigates against risks such as hypoxic blackwater making its way to the river and carp breeding on the floodplain.

Box 5: Hydrodynamic diversity

Rivers vary in the speed at which water flows. This is a result of the interaction between flows and the physical structure of the river channel, known as hydrodynamic diversity. This variability creates pools, runs and riffles along the river channel, as well as variability across the channel with slower-flowing edges and faster-flowing mid-sections. Hydrodynamic diversity is critical for many species of aquatic biota.

Hydrodynamic diversity has been significantly affected across the Basin by a range of factors including the construction of weirs, which have created pool habitats and eliminated fast-flowing habitats. The lower 800 km of the River Murray has been most affected by development—it has continuous weir pools that maintain low to moderate flows.

Hydrodynamic diversity can be restored by delivering varying flows, changing how weirs are operated and through actions such as reintroducing in-stream roughness (snags, trees, branches and root masses, which break up the flow, restoring stream complexity and providing rest sites and shelter).

Expected environmental outcomes for river flows and connectivity

All the outcomes for flow and connectivity set out below are expected to occur by 2024.

Longitudinal connectivity

With the overall changes to flow volumes linking the Basin's rivers, the environmental watering outcomes expected are:

- ***to keep base flows at least 60% of the natural level[3] (note: this will be especially important during dry years)***
- ***a 10% overall increase in flows in the Barwon–Darling***: from increased tributary contributions from the Condamine–Balonne, Border Rivers, Gwydir, Namoi and Macquarie–Castlereagh catchments collectively
- ***a 30% overall increase in flows in the River Murray***: from increased tributary contributions from the Murrumbidgee, Goulburn, Campaspe, Loddon and Lower Darling catchments collectively
- ***a 30 to 40% increase in flows to the Murray mouth.***

Lateral connectivity

The improvements in lateral connectivity that are expected are:

- ***a 30 to 60% increase in the frequency of freshes, bank-full and lowland floodplain flows*** in the Murray, Murrumbidgee, Goulburn–Broken and Condamine–Balonne catchments

[3] Some less-developed rivers have base flows greater than 60% of natural. Where this is the case, the aim is to protect that current level of flow. In other catchments, base flows are currently well below the target 60% of natural flows, especially during dry times. Cease-to-flow events should not exceed natural, where possible.

- ***a 10 to 20% increase of freshes and bank-full events*** in the Border Rivers, Gwydir, Namoi, Macquarie–Castlereagh, Barwon–Darling, Lachlan, Campaspe, Loddon and Wimmera catchments
- ***current levels of connectivity maintained*** in the Paroo, Moonie, Nebine, Ovens and Warrego catchments.

The degree to which these outcomes can specifically target the lower floodplain will depend on current constraints in each region and the work underway to address them.

End-of-basin flows

Improvements in flows and connectivity in the Basin, and local management, will improve the connection of the river to its estuary (the Coorong) and to the sea.

The minimum outcomes expected are:

- ***the barrage flows are greater than 2,000 GL/yr*** on a three-year rolling average basis for 95% of the time, with a two-year minimum of 600 GL at any time
- ***the water levels in the Lower Lakes are maintained above:***
    - sea level (0m AHD) and
    - 0.4 metres AHD, for 95% of the time, as far as practicable, to allow for barrage releases
- ***salinity in the Coorong and Lower Lakes remains below critical thresholds for key flora and fauna*** including:
    - salinity in Lake Alexandrina is lower than 1,000 EC 95% of the time and less than 1,500 EC all the time
    - salinity in the Coorong's south lagoon is less than 100 grams per litre 95% of the time
    - the Murray mouth is open 90% of the time to an average annual depth of one metre.

In addition, improvements in flow and connectivity are expected to contribute towards the achievement of the Basin Plan salt export objective[4]. This is 'to ensure adequate flushing of salt from the River Murray system into the Southern Ocean' (see Box 3 Water quality).

Basis of expected flow and connectivity outcomes

The MDBA used flow models developed for the Basin Plan to predict how flow and connectivity would respond to environmental water. Longitudinal connectivity, end-of-basin flows and lateral connectivity were modelled under different flow scenarios, including:

- a no-development scenario, which is the best available estimate of the natural river system but without accounting for land use changes and on-farm development

[4] Section 9.09 of the Basin Plan, 2012.

- a baseline scenario, which represents the Basin with the consumptive use and the rules and sharing arrangements as at June 2009, and
- the Environmentally Sustainable Level of Take, set at 10,873 GL/y (representing a reduction in take of 2,750 GL).

To calculate the expected outcome, the MDBA compared the model's prediction for baseline with the model's predictions for the 2,750 GL/yr scenario. For example, in the Murrumbidgee the model predicted a 40% increase in flows at or above 9,000 ML/d (equating to small over-bank flows) under the 2,750 GL/yr scenario, compared to the baseline scenario.

It should be noted that the models take into account a substantial range of climate variability by using historical inflow data from 1895 to 2009, and assume the major physical and operational constraints in the southern connected system are in effect for the entire model period.

For a list of sources used to develop expected environmental outcomes, see Appendix 1.

Theme 2 — Native vegetation

The riverine, wetland and floodplain environments of the Murray–Darling Basin support hundreds of native plant species, including many threatened ones. Extensive and diverse vegetation in and around rivers, wetlands and floodplains provides food and habitat for many groups of species including waterbirds, woodland birds, frogs, turtles, fish and macroinvertebrates. Vegetation also cycles nutrients and carbon, contributes organic matter to rivers and plays an important role in maintaining water quality, and soil and bank stability.

People value the Basin's native vegetation. It has cultural significance for Aboriginal people, aesthetic appeal, and provides opportunities for recreation. It is also important for tourism, grazing and (in some places) forestry.

The outcomes described in the Strategy are focused on the riverine, wetland and floodplain vegetation communities which depend on permanent or periodic inundation from the river as well as rainfall and groundwater, particularly the dominant overstorey species that require inundation for part or all of their life cycle (i.e. river red gum, black box and coolibah), lignum (a significant floodplain shrub) and the many aquatic and semi-aquatic plant species. For the purpose of the Strategy, these vegetation communities have been combined into the 'structural groups' of: forests and woodlands, shrublands and non-woody vegetation.

River red gum (*Eucalyptus camaldulensis*), which can be hundreds of years old, line many of the Basin's rivers and have a life cycle dependent upon periods of inundation. Depicted in Australian art and literature, this species is valued as part of our cultural identity. In arid central Australia the species is considered sacred, representing life and water and often providing vital refuge for many animals in an otherwise hostile environment. In more temperate parts of the Basin, particularly low-lying floodplains in the southern part, the species forms extensive forests and woodlands with Barmah-Millewa Forest for example containing the largest river red gum forest anywhere in the world.

On higher parts of many floodplains where inundation is infrequent, black box (*Eucalyptus largiflorens*) and coolibah (*Eucalyptus coolabah*) are often the dominant overstorey species. They are also found along watercourses in the more arid areas.

Under these dominant overstorey species are diverse plant communities. Lignum (*Duma florulenta*) for example occurs on the floodplains and riparian zones of almost all the major rivers in the Basin, except in the south-east. These species can provide significant habitat and nesting areas (rookeries) for waterbirds such as the straw-necked ibis.

Non-woody water-dependent vegetation forms narrow fringes or grows within river channels and wetlands. It includes grasslands, sedgelands/rushlands, herblands, and emergent and fully-submerged species (for example Moira grass, common reed, cumbungi, water couch and marsh club-rush). In some places non-woody vegetation can be found across more extensive areas—often in terminal wetlands and frequently-inundated floodplains. *Ruppia tuberosa* (Ruppia) is a seagrass also known as tuberous seatassel, which provides food and habitat for macroinvertebrates and fish, including the small-mouth hardyhead. It is also an important food source for migratory waterbirds, particularly in the Coorong.

Figure 11 provides a conceptual picture of the required watering frequency for different vegetation communities on the floodplain. It should be noted that the actual watering regime required for vegetation communities depends on their location in the Basin and the local composition of plant species.

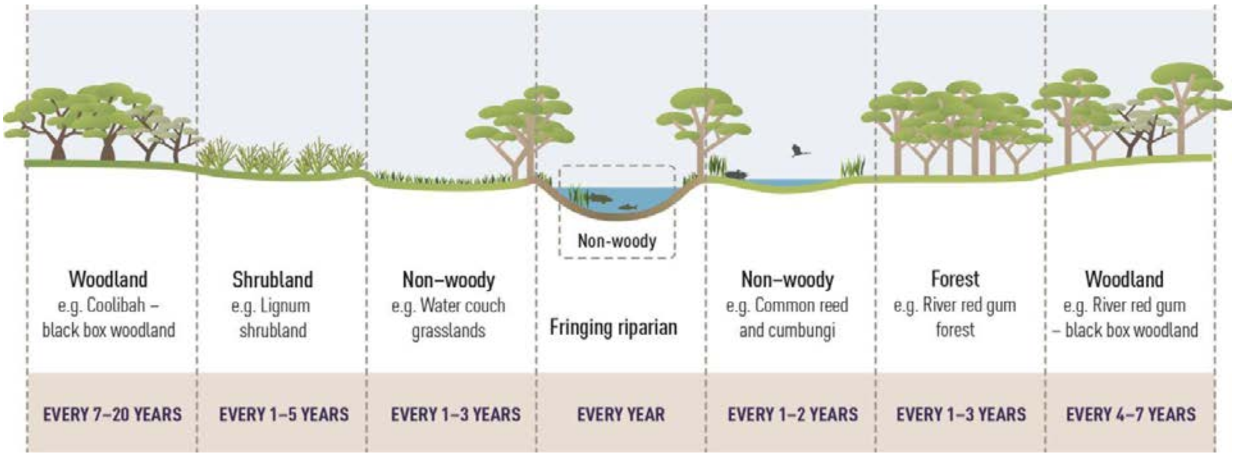

Figure 11: A conceptual view of structural groups of vegetation, their position on the floodplain and their required watering frequency.

Condition of water-dependent vegetation in the Basin

The condition of water-dependent vegetation across the Basin has generally declined over time. This is primarily a result of water resource development and land management practices. The decade-long millennium drought also had a significant impact in some areas, with large areas of tree death.

Over the period 2008–2010, the *Sustainable Rivers Audit* rated riverine vegetation condition in the northern Basin catchments as 'moderate' on average. However, many of the unregulated catchments were rated as being in 'good' condition. Riverine vegetation condition in the southern more regulated catchments was, on average, 'poor'; and only one of the 13 southern catchments was rated in 'good' condition (the Central Murray).

Assessments of tree stand condition throughout the Basin in 2013 and 2017 have shown how floodplain forests and woodlands have responded to environmental conditions and management over time. River red gum forests and woodlands that line waterways and low-lying areas have generally responded well to management, while the condition of communities higher up on the floodplain (such as black box woodlands) or where constraints limit flows continues to decline.

Decline in condition of forests and woodland communities can eventually lead to tree death over significant areas. These changes occur slowly over a number of years, and it may take many decades for these communities to either re-establish or transition to other community types. Changes in extent in non-woody vegetation communities occurs more frequently in response to changing environmental conditions. The extent of these short-lived species can decline relatively rapidly as habitat conditions deteriorate, but they can also re-establish quickly when conditions improve. Therefore, maintaining healthy viable populations of such species may require frequent interventions to provide a suitable watering regime.

During the millennium drought *Ruppia tuberosa* in the Coorong's south lagoon experienced a critical decline due to low flows and unfavourable salinity and water levels. *Ruppia tuberosa* and *Ruppia megacarpa* once formed an extensive vegetation community that provided habitat for macroinvertebrates and fish, and an important food source for migratory shorebirds.

Despite its reduced abundance, *Ruppia tuberosa* still plays a critical functional role in the food web, and is an important indicator of the health and resilience of the Coorong system. *Ruppia megacarpa*, a key health indicator species for the north lagoon, is now absent from the Coorong because of unfavourable flows, water levels and salinities. These issues also characterise the south lagoon and highlight the ongoing threats for remnant *Ruppia tuberosa* populations.

Expected environmental outcomes for water-dependent vegetation

The vegetation outcomes expected under this Strategy are, at a minimum, to maintain the extent[5], and maintain or improve the condition of water-dependent vegetation on the managed floodplain and those parts of the unmanaged floodplain with largely free-flowing rivers. The unmanaged floodplain in systems with headwater storages will continue to support diverse vegetation communities, however their extent and condition will be heavily influenced by factors outside the influence of the Basin Plan (e.g. natural flooding, climatic conditions, land use decisions, fire).

Achieving these outcomes depends on reinstating lateral and longitudinal connectivity. The previous section on River flows and connectivity details the level of connectivity that is expected to be achieved. The specific expected outcomes for Basin vegetation groups, based on the expected improvements in flows, are as follows.

Forest and woodlands

The expected outcomes for forests and woodlands in the Basin are:

- ***to maintain the current extent of forest and woodland vegetation (see 'Appendix 2 – Expected vegetation outcomes by region' for a regional breakdown) including approximately[6] :***
    - 360,000 ha of river red gum
    - 409,000 ha of black box
    - 310,000 ha of coolibah
- ***no decline in the condition of river red gum, black box and coolibah across the Basin[7]***

[5] Extent to be maintained in this Strategy is specified at a Basin and catchment scale. Some change to extent including increases and/or decreases of certain types of vegetation, is expected to occur at local scales. However, the degree of such change is likely to be minor and, therefore, more appropriate for regional plans to address.

[6] The areas specified for river red gum, black box and coolibah are within a range of plus or minus 10%.

[7] Limitations in the data available in many areas of the Basin, particularly in the north, mean that it is not yet possible to specify the current condition of the river red gum, black box and coolibah communities. As additional data becomes available it will be possible to accurately calculate the condition at 2014 and to describe the expected outcomes for these species across the Basin.

- ***by 2024, improved condition of river red gum in the Lachlan, Murrumbidgee, Lower Darling, Murray, Goulburn–Broken and Wimmera–Avoca*** (see Appendix 2 for a regional breakdown)
- by 2024, improved recruitment of trees within river red gum, black box and coolibah communities—in the long-term achieving a greater range of tree ages. (River red gum, black box and coolibah communities are presently comprised primarily of older trees which places them at risk).

Shrublands

The expected outcomes for shrubland vegetation are:

- ***to maintain the current extent of the large areas of lignum shrubland within the Basin***
- ***by 2024, improvement in the condition of lignum shrublands.***

These outcomes apply to lignum communities across the following regions (at a minimum): Lower Lachlan, Lower Murrumbidgee, Lower Darling, Lower Condamine–Balonne (including Narran Lakes), Lower Gwydir, Macquarie Marshes, Lower Border Rivers and the River Murray from the junction of Wakool River to downstream of Lock 3 (including Chowilla and Hattah Lakes).

Non-woody vegetation

The expected outcomes for non-woody vegetation are:

- ***to maintain the current extent of non-woody vegetation***
- ***by 2024, increased periods of growth for communities that:***
    - closely fringe or occur within the main river corridors (see Appendix 2 – Expected vegetation outcomes by region)
    - form extensive stands within wetlands and low-lying floodplains including Moira grasslands in Barmah–Millewa Forest; common reed and cumbungi in the Great Cumbung Swamp and Macquarie Marshes; water couch on the floodplains of the Macquarie and Gwydir rivers; and marsh club-rush sedgelands in the Gwydir
- ***a sustained and adequate population of Ruppia tuberosa in the south lagoon of the Coorong, including:***
    - *Ruppia tuberosa* to occur in at least 80% of sites across at least a 43 km extent (refer to Coorong case study)
    - by 2029, the seed bank to be sufficient for the population to be resilient to major disturbances[8].

Basis for expected vegetation outcomes

The current extent of vegetation is based on 2013 Landsat data and represents the vegetation that is or may be able to be inundated on the managed floodplain with 2,750 GL/yr of environmental water, assuming current constraints are maintained. The MDBA used modelling to predict the area of the floodplain which can be influenced with environmental water. The current condition is based on

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[8] Advice suggests that this would require at least 10,000 seeds/m^2 within the bed of the core population of *R. tuberosa*.

2013 '*RapidEye*™' satellite imagery data. When calculating condition in the future, the MDBA will ensure that any comparative assessment uses datasets with equal coverage.

Outcomes for *Ruppia tuberosa* were developed using expert scientific advice and published papers. For a list of sources used to develop expected environmental outcomes, see Appendix 2 – Expected vegetation outcomes by region.

Case study: Expected outcomes achieved in the Coorong and Lower Lakes

In the first Basin-wide environmental watering strategy (2014), the MDBA set expected environmental outcomes for a range of ecological themes across waterbirds, native fish and native vegetation. For the Coorong and Lower Lakes area, 2019 targets were set for migratory shorebird species and health of *Ruppia tuberosa* (Ruppia). This case study examines to what extent these expected outcomes have been achieved over the past five years in the Coorong and Lower Lakes.

The Coorong and Lower Lakes is a complex ecological site, and a Ramsar site of international importance. The Coorong and Lower Lakes is one of Australia's top refuges for wading birds, and supports the greatest waterbird species richness of the Murray–Darling Basin. Managers of the Coorong are able to influence ecological outcomes at the Coorong through River Murray environmental flow provisions, barrage operations, Murray Mouth dredging and flows from the south-east of South Australia. The South Lagoon has been high-quality habitat for waterbirds due to the shallow mudflats and abundance of invertebrates, fish and aquatic plants. However, declines in inflows from the River Murray can impact the maintenance of appropriate water levels on the extensive mudflats.

Monitoring programs have quantified waterbird abundance, species richness, brooding, nesting and breeding occurrence. Extensive monitoring has also been performed on vegetation that can survive the hypersaline environment and support waterbird populations in the region. Ruppia is a key component of the Coorong system ecology, and directly related to supporting foraging waterbird populations. Ruppia is monitored for extent of occurrence, area of occupation, population vigour and population resilience (seed counts per m^2).

Initial analysis for the 2019 expected outcomes for shorebirds at the Coorong indicates that the long-term average (2000 to 2019) of the four species is largely maintained at levels seen between 2000 and 2014. However, since 2014, the average abundance of curlew sandpipers and common greenshank have dropped while abundance of red-necked stint and sharp-tailed sandpiper have largely been maintained. Interestingly, while, on average, abundance of red-necked stint and sharp-tailed sandpiper has been maintained since 2014, both species also recorded their lowest numbers during this period (see Figure 12).

In a given year, the abundances of migratory shorebirds will be influenced by the extent of breeding and successful migration, and by whether other ephemeral wetlands hold water and are available for waterbird use on arrival (Paton, Paton & Bailey, 2018). Migratory shorebirds that visit the Coorong during migration are influenced by environmental conditions at the stop-over points in the East

Asian-Australasian Flyway in their migratory journey. Species with a high reliance on the tidal mudflats (such as the curlew sandpiper) have experienced a large decline, whereas species with a low reliance on Yellow Sea tidal mudflats (such as the red-necked stint) have experienced a small decline (Studds et al, 2017). This relationship is also reflected in migratory shorebird abundance long-term averages recorded at the Coorong (Figure 12).

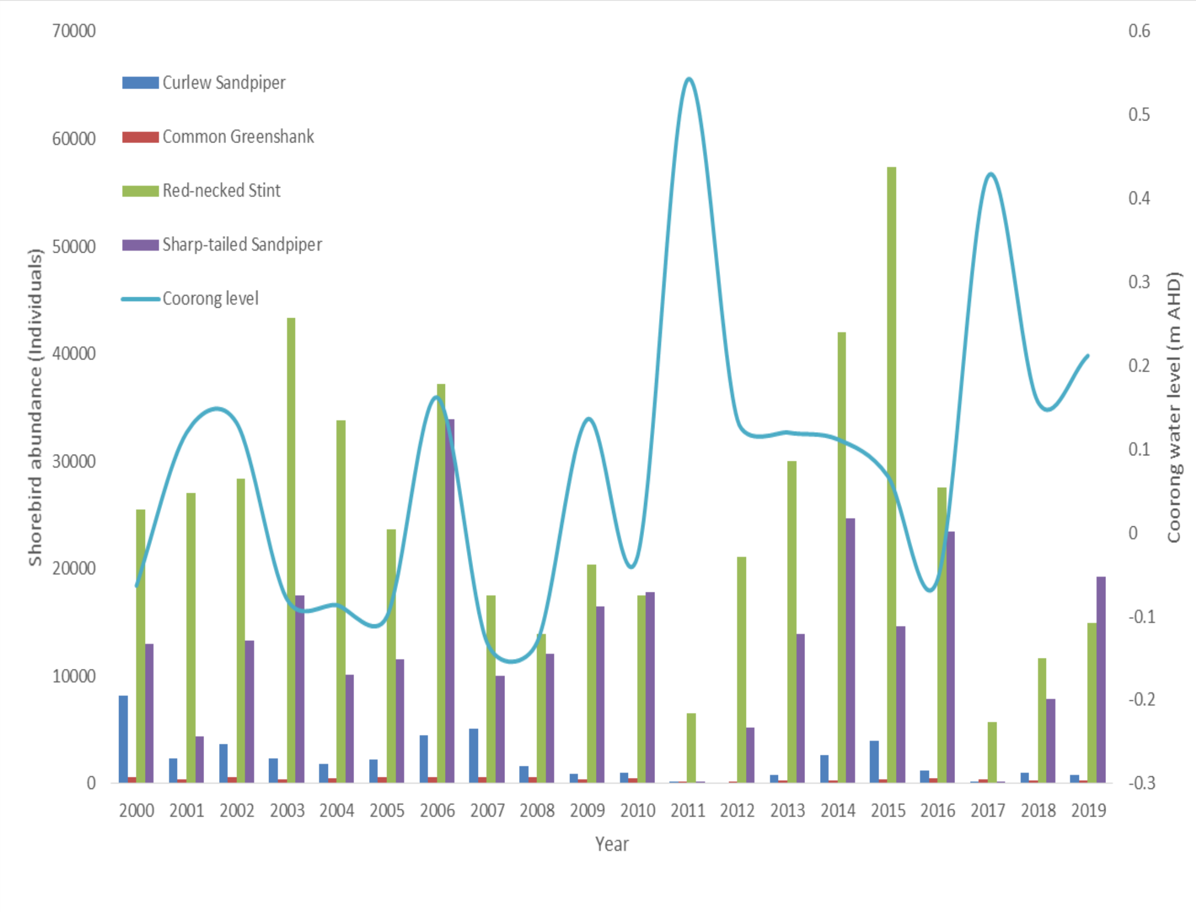

Figure 12: Abundance of four shorebird species (curlew sandpiper, common greenshank, red-necked stint and sharp-tailed sandpiper) and Coorong water level over the period of 2000 to 2019.

Conditions in the south lagoon have supported the growth of the Ruppia plant. The expected outcome for extent of occurrence of Ruppia in the south lagoon was met in 2018 and 2019, with plants distributed along 43 km[9] of the southern Coorong in winter and summer. The regional target for *Ruppia tuberosa* being present at 80% of sites monitored was met in the 2018 summer and winter survey period. In the 2019 summer period, the target for area of occupation was only close to being met, with *Ruppia tuberosa* present at only 78% of the monitored sites.

However, the population resilience and reproduction of Ruppia have still not recovered fully from the millennium drought and extreme salinity levels. The regional population vigour target (% of sites with live shoots and >30% cover and >10 live shoots per core) was met in 2014 and 2017 only. *Ruppia tuberosa* failed to meet three local, site-scale targets for flowering, seeds and turions

[9] The extent of occurrence expected outcome in the previous edition of the Strategy referred to a 50 km extent. This has been revised to 43 km because the spread of regular monitoring sites where *Ruppia tuberosa* was expected to occur and perform was 43 km and not 50 km (Paton *et al.* 2015, 2017).

alongside the regional target for population resilience for the past eight years (Paton, Paton and Bailey, 2019). These results indicate, that although *Ruppia tuberosa* has met its 2019 target, its progress towards the 2029 target of 'the seed bank to be sufficient for the population to be resilient to major disturbances' is at risk of non-attainment. Additionally, the turions detected during the 2018-19 summer surveys were all Type I, rather than the more robust Type II turions needed for population resilience. Two major factors are thought to inhibit *Ruppia tuberosa* producing seeds. First, falling water levels in spring exposing growing plants to desiccation prior to reproduction (Paton, Paton & Bailey, 2018). Second, filamentous green algae (mainly *Ulva* spp) destroys flowering *Ruppia tuberosa* by snapping floral stalks (Paton, Paton & Bailey, 2018). This indicates a continued effort to control spring water levels, salinity and algal blooms is required to be on track towards *Ruppia tuberosa*'s long-term resilience goals at the Coorong and Lower Lakes.

In sum, the expected environmental outcomes at the Coorong and Lower Lakes for 2019 assessment are on track for migratory shorebirds and Ruppia. The health of these two key ecosystem biota at a key terminus Basin site is an important monitoring tool for Basin-wide environmental watering strategy outcomes. Water management at these locations requires balancing upstream and downstream environment requirements, and between the competing watering requirements of waterbirds, fish and vegetation in the system.

Theme 3 — Waterbirds

Waterbirds are birds that are ecologically dependent on wetlands. They are highly mobile, moving between catchments and basins in search of suitable habitats as conditions change. More than 120 species have been recorded in the Murray–Darling Basin. They depend on rivers and wetlands to provide breeding, roosting and nesting habitat, as well as food and protection from predators. Many of the wetlands upon which they depend are listed under the Ramsar Convention on Wetlands of International Importance; and as such, there is an obligation to conserve them.

Waterbirds can be grouped together into ‘functional groups’ based on shared behavioural or physiological characteristics. Aerial surveys of waterbirds in the Basin, for instance, adopt five functional groups - shorebirds, ducks and grebes, herbivores, piscivores (fish eaters), and large waders - based on their feeding preferences. Each group has a different habitat requirement. For example, ducks need habitat ranging from deep water to vegetated shorelines; while shorebirds require large expanses of mudflat with shallow water to enable feeding.

The Murray–Darling Basin is a stronghold for colonial-nesting waterbirds (which fall into a number of the functional groups). They congregate in large numbers at sites, called colonies, during their breeding season. In the Murray–Darling Basin, this group includes egrets and herons; ibises and spoonbills; cormorants; darters and pelicans. Environmental watering can assist colonial-nesting waterbirds by maintaining wetland habitat, extending natural floods to improve breeding success, and providing drought refuges.

Waterbirds are important for the Basin’s Aboriginal communities. Some species hold spiritual significance—the Brolga has a role in dance and the Dreaming—and play a role in women’s and men’s cultural business. Waterbirds may be an indicator for water in a dry landscape. They are also a food source (meat and eggs). Aboriginal people previously used waterbird down for clothing and warmth; now feathers are used for artwork and ceremonies.

Condition of waterbirds in the Basin

More than 30 years of annual waterbird surveys have shown a 70% decline in total population (average abundance) of waterbirds between the first decade of the survey (1983 to 1992) and the third decade of the survey (2009 to 2018) (Figure 13). Abundance declined within each functional group, with shorebirds declining by 79% and large waders by 56%. The number of nests and broods and the number of species breeding declined significantly, the latter by 71%. Overall, the number of species was the only measure of the waterbird population that did not decline over the survey.

Other investigations have found this same pattern of decline. The Coorong and Lakes Albert and Alexandrina comprise the most important site in the Basin for shorebirds and the seventh most important site in Australia. Nine shorebird species of international significance and 10 species of national significance have been recorded in the Coorong. Studies have shown that the abundance of three common shorebirds—the sharp-tailed sandpiper, red-necked stint and curlew sandpiper—declined significantly between 1984 and 2007. Numbers have continued to be low since then (refer to Coorong Case study).

Waterbirds need periodic, widespread flooding of wetlands to maintain population numbers; and respond to 'boom and bust' periods driven by river flows and local rainfall. However, river regulation has diminished the extent and frequency of the flows that drive 'booms'. Moderate flows, important for habitat maintenance and provision of food resources, have also declined. While populations will be lower in drier years as birds disperse more widely in search of suitable foraging habitat, the reproductive response in the higher flow years has been less evident over the last three decades as suitable opportunities to breed decline. This has meant that the starting population at the beginning of each boom period is trending lower over time.

Certain wetlands in the Basin are very important for waterbird abundance, breeding and species richness. In any year, most waterbirds (80% of total abundance) can generally be found on 20 wetland complexes. The sites used vary from year to year according to where water is prevalent, but over time approximately 33 sites appear to be consistently important (refer Figure 14 and Appendix 3).
These sites are of Basin significance for waterbirds.

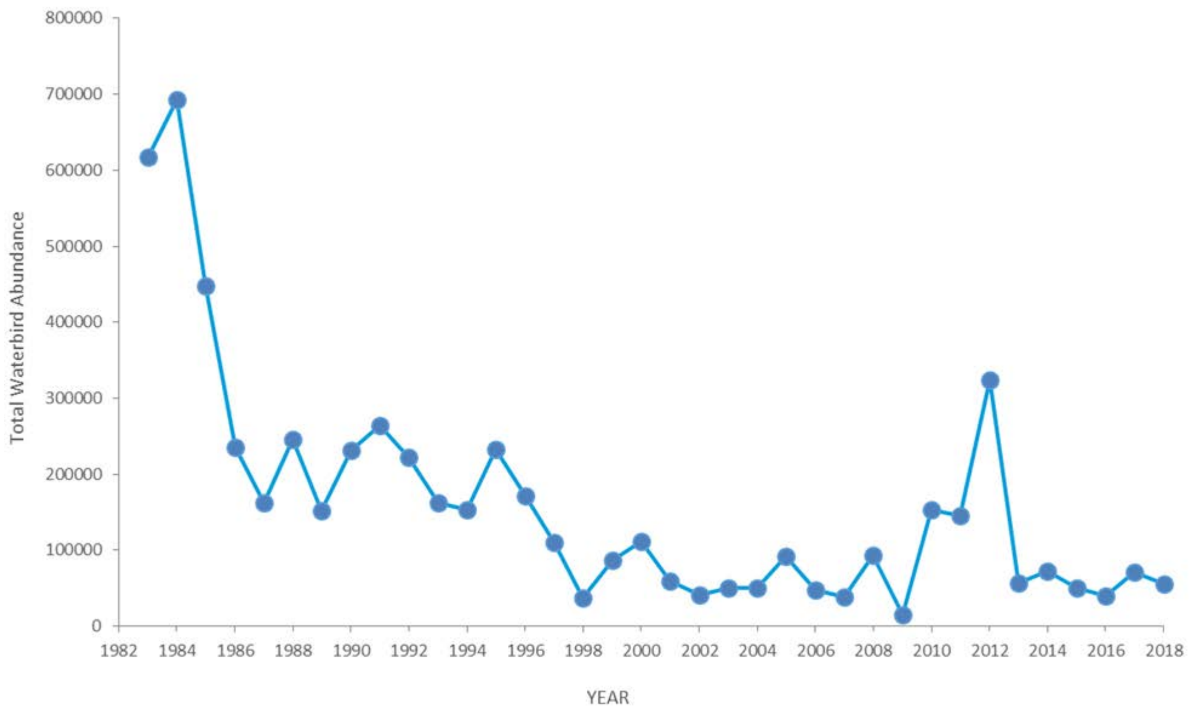

Figure 13: Abundance of all waterbirds in the Murray–Darling Basin.

Notes: Surveyed during annual aerial waterbird surveys of eastern Australia, 1983–2018 by University of NSW.
Survey bands cover about 13.5% of the land area of the Murray–Darling Basin.

Many of these sites are the large well-known wetlands – the Lower Murrumbidgee floodplain, Macquarie Marshes and Gwydir Wetlands. Other sites of importance include natural lakes that are used for water management, such as Menindee Lakes and smaller wetlands like Fivebough Swamp within the Murrumbidgee catchment.

The manageability of these sites with environmental water varies. Some sites, like the Gwydir Wetlands, can be managed actively with HEW, whereas others in unregulated catchments, like Narran Lakes, largely rely on passively delivered environmental flows. Some storages or water transfer basins that are not, or cannot be, managed for environmental outcomes are nonetheless important refuge for some species during drought—for example Coolmunda Dam, Split Rock Reservoir and Burrendong Dam.

While several sites are of Basin significance for waterbirds, there are many other sites of local or regional significance. These are identified in various state documents including long-term environmental watering plans.

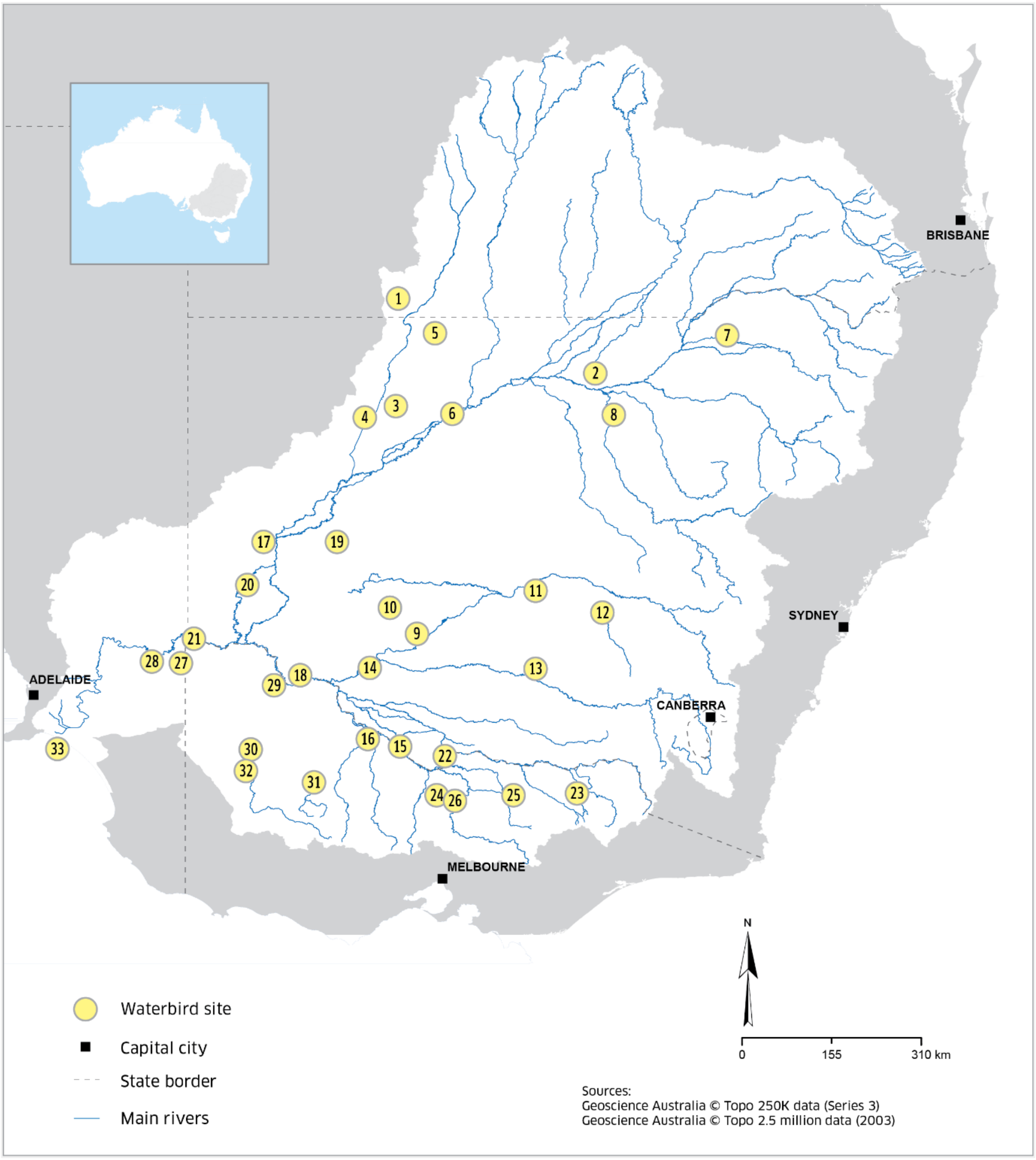

Figure 14: Significant sites for waterbirds in the Murray–Darling Basin. For more detail, see Appendix 3.

Expected environmental outcomes for waterbirds

The expected outcomes for waterbirds are increased abundance and the maintenance of current species diversity. From 2024 onwards, the expected outcomes are:

- ***that the number and type of waterbird species present in the Basin will not fall below current observations*** (annual average of 44 species, with 41 to 50 species acceptable, measured by the Eastern Australian Waterbird Survey)
- ***a significant improvement in waterbird populations in the order of 20 to 25% over the baseline scenario[10], with increases in all waterbird functional groups*** (annual average of between 202,000 and 214,000 waterbirds, measured by the Eastern Australian Waterbird Survey)
- ***breeding events (the opportunities to breed rather than the magnitude of breeding per se) of colonial nesting waterbirds to increase by up to 50% compared to the baseline scenario*** (annual average of 5.2 breeding events (opportunities), measured by achievement of Specific Flow Indicators for colonial waterbird breeding at subset of Umbrella Environmental Assets)
- ***breeding abundance (nests and broods) for all of the other functional groups to increase by 30–40% compared to the baseline scenario, especially in locations where the Basin Plan improves over-bank flows[11] (***annual average breeding abundance of 634 – 695 nests and broods, measured by Eastern Australian Waterbird Survey).

Achieving these outcomes would result in waterbird populations similar to those in the early 1990s, which is necessary to ensure resilience of populations across the Basin.

Achieving the outcomes for waterbird abundance and diversity relies upon successful breeding, a diversity of habitats in good condition to support life cycles, and protection of drought refuges so that waterbirds can survive dry times. The availability of breeding habitat and food resources is closely linked with floodplain inundation, which will increase with environmental watering under the Basin Plan.

Waterbird species prefer different habitats for feeding and resting, roosting and breeding; and must move between them to survive, reproduce and breed. A mosaic of wetland habitats is important in determining waterbird distribution and abundance, and is a prerequisite for a sustainable waterbird population.

Climatic variations affect water availability, and the size and condition of waterbird populations. Supporting refuges will provide feeding and roosting resources (Appendix 3).

The waterbird outcomes described above are Basin-wide. However, because of the importance for migratory shorebirds, for the Coorong, Lakes Albert and Alexandrina, the expected outcomes are:

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[10] Represents the Basin with the consumptive use and the rules and sharing arrangements as at June 2009.
[11] Refer to Figure 8.

- ***at a minimum maintain populations of the following four key species: curlew sandpiper, greenshank, red-necked stint and sharp-tailed sandpiper, at levels recorded between 2000 and 2014.***

Basis of expected waterbird outcomes

There is a strong relationship between waterbirds and flow. This relationship enabled the MDBA to predict how waterbirds would respond to environmental water using modelling scenarios developed for the Basin Plan.

Based on historic correlations between surveyed waterbird populations and flow in the Basin, waterbird populations were modelled under different flow scenarios, including:

- a 'no-development' scenario which represents the Basin as a natural system
- a baseline scenario, which represents the Basin with the consumptive use and the rules and sharing arrangements as at June 2009, and
- the Environmentally Sustainable Level of Take (ESLT) representing reductions in take of 2,400 GL, 2,800 GL and 3,200 GL per year.

To calculate the expected environmental outcome, the MDBA compared the model's prediction for baseline with the model's predictions for the various level of take scenarios (2,400 GL, 2,800 GL and 3,200 GL recovery). For example, under the baseline scenario, waterbird abundance **in the surveyed areas** was predicted to be, on average, 168,000 individuals; compared to the ESLT scenarios of between 202,000 and 214,000 individuals. This equates to a 20–25% increase.

The expected increase in waterbird breeding events was also based on the modelled scenarios. In particular, the flow conditions conducive to waterbird breeding (e.g. a certain flow that inundates waterbird habitat for over three months) can be identified in the modelled flows; and the change between the baseline scenario and what happens under the Basin Plan can be quantified as an increase in opportunity.

Outcomes for migratory shorebirds in the Coorong were derived from expert scientific advice and published papers, as there was less capacity to accurately model shorebird response using a flow model.

For a list of sources used to develop expected environmental outcomes, see Appendix 1.

Theme 4 — Native fish

More than 60 native fish species occur in the Murray–Darling Basin. This includes freshwater, estuarine, marine and migratory fish. Many of the Basin's 44 freshwater species are unique to Australia, with the home range of at least 16 species restricted to the Basin. Many of the Basin's native fish species are listed as rare or threatened under state and/or Commonwealth legislation.

Native fish play an important role in freshwater ecosystems and are a vital part of food webs. Some species are high-level predators, and many prey species consume algae, plants and invertebrates like insects and shrimp. In turn, fish are a vital source of food—for other fish, waterbirds, turtles, other aquatic fauna and people. They also play an important role in nutrient cycling.

Native fish are highly valued by people. Native fish are fundamental as a source of food, trade and commerce, recreation, spirituality and custom for many people. Aboriginal people value native fish for their totemic and cultural significance. To Aboriginal people, fishing provides connection with Country, and emotional and social benefits by contributing to wellbeing and health.

Social benefits are also experienced by the broader recreational fishing community. Throughout the Basin, recreational fishing is an important pastime that provides social, cultural and health benefits, while also resulting in expenditure of $1.3 billion annually (2011 value). A single commercial fishery operates in South Australia, generating around $2.54 million in 2016–17. The social and economic benefits of fish and fishing in the Basin depend upon healthy native fish populations and ecological communities.

Natural flow regimes, habitat and connectivity are all essential for healthy native fish populations. Fish need all these elements to survive and thrive (see Figure 15). Small bodied, short-lived species and some juvenile large-bodied fish favour wetlands, and habitats with good coverage of aquatic vegetation. Adult large-bodied species, such as the iconic Murray cod and golden perch, favour the main channels and anabranches of rivers, using snags, rock bars and undercut banks as habitat. These iconic species are particularly sought after by recreational fishers across the Basin.

Flows and flowing habitat are vital to restore and protect the Basin's native fish species. The interaction of flows with the physical structure of rivers creates sections of fast-flowing, slow-flowing and still water habitats at local through to landscape scales (hydrodynamic diversity, as explained in Box 5).Flows influence the quality, size, and persistence of refuge habitats during dry periods; and maintain aquatic vegetation upon which many fish depend.

Seasonal flows give fish physical access to a range of aquatic habitats and provide cues that stimulate movement—a key ecological process for native fish. In addition, seasonal flows that inundate benches (see Figure 10) and floodplains increase carbon input, which in turn drives productivity and stimulates food production. This is critical for larval and juvenile fish, as they have low energy reserves and need ready access to food in order to survive.

Connectivity and movement are important for maintaining native fish populations in the Basin. Fish move for the purposes of spawning, dispersal, feeding, and to seek refuge. Movement between habitats is important for the completion of life cycles for many species. Research also suggests that fish communities throughout the Basin require regular connectivity between populations. The scale of the connectivity requirement can vary with species; fish may undertake large-scale movements (up to 100s or 1000s of km), or smaller-scale movements (100s of metres to 10s of km). Barriers, like dams and weirs, and cease-to-flow periods, can prevent native fish from moving to where they need to be. Therefore, flows that support appropriate hydraulic connectivity and movement are critical to the persistence of viable populations of native fish.

Improved water management can achieve many positive outcomes for native fish.

Some examples:

- flows that maintain minimum water depths during the nesting season of Murray cod and trout cod increase the survival of offspring
- recruitment of silver perch and golden perch is improved by within-channel flow pulses in spring/summer, with juvenile survival improved through access to wetland nursery habitats
- spawning aggregations of mulloway form in response to freshwater discharge through the Murray mouth. Successful recruitment of this species often coincides with seasons of good flows from the River Murray.
- connection events and secondary connection events allow small-bodied wetland specialist fish species to access wetland habitats to recruit and survive.

In this Strategy, native fish of the Murray–Darling Basin are broadly categorised into three communities: southern Basin, northern Basin and estuarine (Appendix 4). The three categories are based on fish communities that have been shaped by different geographic, climatic and ecological characteristics of the Basin. They are not isolated from each other, for example golden perch are known to move between the northern and southern Basins, and connectivity between them is essential.

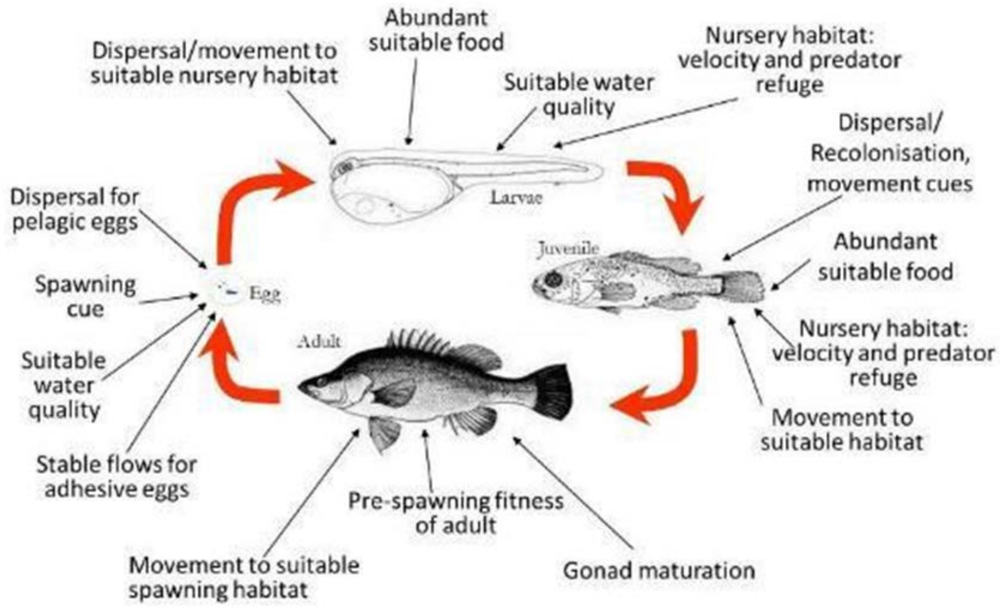

Figure 15: The influence of flows on the different stages within the life cycle of fish. (Figure courtesy of the Arthur Rylah Institute.)

Condition of native fish in the Basin

In 2003, the Native Fish Strategy estimated native fish populations in the Murray–Darling Basin to be around 10% of pre-European levels at the Basin scale. Many native fish species were once widely distributed, however, changes to natural flow regimes, degraded habitats and reduced connectivity across the Basin have led to a significant decline in the abundance and distribution of almost all native fish species.

Loss of hydrodynamic diversity is a major cause of decline for native fish species like Murray cod, silver perch, trout cod and Macquarie perch that all rely on flowing habitats. Silver perch was once a common species in the middle reaches of the River Murray, but during the 1990s numbers fell by 95%. Trout cod and Macquarie perch could once be found along nearly 1,000 kilometres of the Lower Murray, but now only occur in isolated populations and upper tributaries. Commercial fishing in the River Murray once targeted Murray cod before major declines from the 1950s reduced profitability. Catches of some target species in the Lakes and Coorong Fishery in South Australia have also declined.

The state of a number of short-lived native fish species is of particular concern. These species are highly dependent on off channel habitats. Current constraints on the capacity to deliver water to the floodplain is likely to impede recovery of many short-lived floodplain species. Smaller fish species—like Yarra pygmy perch, olive perchlet and southern purple-spotted gudgeon—have declined or been lost from whole catchments. At the same time, changes to rivers have favoured alien species like carp.

The 2008 Sustainable Rivers Audit (SRA) report card (SRA 1, 2004–2007) recorded the poor condition of fish communities across much of the Basin. Only three valleys had fish communities in moderate condition (Paroo, Condamine and Border Rivers), while 12 were in poor to very poor condition; and the remaining eight valleys were in extremely poor condition. SRA 2 (2008–2010) showed improved fish condition only in the Paroo, and continuing very poor and extremely poor condition in the majority of catchments.

The 2017 evaluation assessed a number of measures of success for native fish. The evaluation concluded that most of the Basin's fish species had been observed, although there were concerns for Yarra pygmy perch, flathead galaxias, Rendahl's tandan and short-headed lamprey. Of the measures where sufficient evidence was available, the 2017 evaluation found that catches of golden perch and Murray cod within 'legal take size' were being maintained, and a range of size classes (an indicator of population structure) for medium and long-lived fish species were present. The evaluation also found that populations of estuarine fish, including prey species, greenback flounder and black bream, were maintained, as was the overall diversity of estuarine-dependent species.

The 2017 evaluation found that the vast majority of the measures of success for native fish could not be evaluated due to either a lack of suitable evidence, or it being too early to determine the trajectory of the response. Subsequently, during the 2018–19 summer, there were a number of mass fish death events across the Basin. The implications of these events are yet to be understood, however it will take many years of good conditions for populations to recover. Follow-up surveys to detect Yarra pygmy perch in the Lower Lakes concluded that wild populations of Yarra pygmy perch are now likely absent from the Basin, or at best, extremely rare.

There is no evidence of a significant, Basin-scale, improvement in native fish populations since the 2003 assessment undertaken by the Native Fish Strategy.

Expected environmental outcomes for native fish

In the long-term, the overall expected outcome is a diverse native fish community with sustainable populations occupying a greater proportion of their historic distribution than is currently the case.

A number of factors have contributed to the decline of native fish across the Murray–Darling Basin. Recovery will require many of these to be addressed. Flow restoration and improved water management are key actions that will contribute to native fish recovery. Restoring flows can directly improve connectivity, benefitting native fish by connecting populations. Flows can also improve fishway operation, further improving connectivity for fish. Improved connectivity can provide access to greater areas of habitats or reinstate habitat types that have been reduced.

Improved water management can stimulate fish to breed and provide habitat and food for young fish. These can result in improved movement, recruitment and distributions. Flow can enable and improve complementary activities to provide greater outcomes for native fish (e.g. stocking threatened species in habitats reinstated and maintained by improved flows).

In the wake of mass fish death events across the Basin in the summer of 2018–19, the Commonwealth Government announced the development of a Native Fish Management and Recovery Strategy, which would serve as a Basin-wide strategy to facilitate actions that aid fish recovery. The Native Fish Management and Recovery Strategy, the Northern Basin toolkit measures and the SDLAM activities will complement improved flow management, and help address factors that have contributed to the decline of native fish.

The following broad outcomes are expected by 2024:

- *no loss of native fish species currently present within the Basin*
- improved population structure of key fish species (see Appendix 5) through regular recruitment
- increased movement of key fish species
- expanded distribution of key fish species and populations in the northern and southern Basin
- improved community structure of key native fish species

The following outcomes are expected (refer Table 6, Appendix 5 for further details):

- ***for short-lived species*[12]**:
    - ***restored distribution and abundance to levels recorded pre-2007*** (prior to major losses caused by extreme drought). This will require annual or biennial recruitment events depending on the species.
- ***for moderate to long-lived species***:
    - ***improved population structure*** (i.e. a range of size/age classes for all species and stable sex ratios where relevant) in key sites. This will require annual recruitment events in at least eight out of 10 years at 80% of key sites, with at least four of these being 'strong'[13] recruitment events.

[12] For flathead galaxias, this outcome will relate only to annual recruitment events, given incomplete knowledge of pre-2007 distributions and abundances.
[13] What constitutes a 'strong' recruitment event will depend on the species and its status at a given location.

- ***a 10–15% increase of mature fish (of legal take size) for recreational target species*** (Murray cod and golden perch) in key populations
- ***annual detection of species and life stages representative of the whole fish community through key fish passages;*** with an increase in passage of Murray cod, trout cod, golden perch, silver perch, Hyrtl's tandan, congolli, short-headed lamprey and pouched lamprey through key fish passages to be detected in 2019–2024; compared to passage rates detected in 2014–2019.

- ***for estuarine species*** – additional outcomes are:
  - ***detection[14] of all estuarine-dependent fish families[15] throughout 2014–2024***
  - ***maintenance of annual population abundance (Catch Per Unit Effort – CPUE) of key estuarine prey species*** (sandy sprat and small-mouthed hardyhead) throughout the Coorong
  - ***detection of a broad spatial distribution of black bream and greenback flounder***; with adult black bream and all life stages of greenback flounder present across >50% of the Coorong in eight out of 10 years
  - ***detection in nine out of 10 years of bi-directional seasonal movements of diadromous species*** through the barrages and fishways between the Lower Lakes and Coorong
  - ***increased rates of native fish passage*** in 2019–2024 compared to 2014–2019
  - ***improved population structure of mulloway,*** including spawning aggregations at the Murray mouth in six out of 10 years and recruitment in at least five out of 10 years.

By extending the range of existing populations and establishing additional populations, expanded distributions of key fish species are expected by 2024 (refer to Appendix 5 for details), including:

- ***a doubling of the current (mostly restricted) distributions of key species in the northern Basin***
- ***significant increases in the distributions of key species in the southern Basin.***

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[14] Detection is defined differently for each estuarine native fish species and should be guided by the most up-to-date Ramsar ecological character description for the Coorong, Lower Lakes and Murray mouth.
[15] Refers to taxonomic families.

Basis for expected fish outcomes

The fish outcomes were developed using expert opinion in conjunction with literature reviews, conceptual modelling, reviews of existing fish data sets and information on fish assets. A series of expert workshops were held to consider fish outcomes and water management strategies to improve native fish. Individual workshops covered the northern, southern and estuarine fish communities and additional workshops considered Basin-wide perspectives. Expert opinion also shaped the selection of final outcomes (movement, recruitment and distribution) – determining that these factors were likely to exhibit a measurable response to improved water management within the timeframes of the Strategy.

The selection of key fish species was informed by a conceptual modelling process, along with expert opinion, to identify the likelihood of their response to improved water management. This modelling process considered life history characteristics and habitat requirements of fish that would interact with water management. Priority was given to species with a threatened status in the Basin and social and economic value.

For a list of sources used to develop expected environmental outcomes, see Appendix 2 – Expected vegetation outcomes by region.

Box 6: Risks from alien fish

Alien fish (particularly carp) pose a risk to meeting some of the expected outcomes from environmental watering.

In some cases, it is not possible for water to benefit only native biota and exclude any benefit to carp. Therefore, decisions should give priority to achieving the objectives being sought for native biota; even where this may also benefit alien species. Complementary management actions should then be implemented to minimise the risk and impact of alien species, for example barriers, or physical removal.

Alien fish that predate on small native fish and/or their eggs (e.g. redfin, gambusia, and oriental weather loach) may also reduce the benefits of environmental watering actions for native fish.

The incursion of the pest fish tilapia into the northern Basin from surrounding catchments is an ever-present risk. If tilapia become established in the Basin they would be a risk to achieving most native fish environmental outcomes.

3 Water management strategies for maximising environmental outcomes

The strategies identified in the following pages have been developed to maximise the environmental outcomes that can be obtained from using environmental water in the Basin. They include overarching water management strategies and approaches that have emerged from experience gained from environmental watering over the preceding decades. These strategies align with many of the Basin Plan's *Principles to be applied in environmental watering*. Additional strategies focus on achieving outcomes for the four themes.

The strategies should be considered in all elements of planning and management of water across the Basin including water resource planning, environmental water planning and prioritisation, and river operations planning and management (including the delivery of consumptive, environmental and other water). The strategies will be most effective when combined with actions such as constraints relaxation and the implementation of the northern Basin toolkit, pre-requisite policy measures and some SDLAM projects.

Water management strategies emerging from experience

Environmental watering has been undertaken in the Basin for decades—the earliest actions occurred in 1980 in the Macquarie Marshes. Over this time much has been learned about how to manage environmental water effectively. The strategies and management approaches that have emerged from this experience should continue to be applied across the Basin, namely:

- harness local community land and water knowledge
- contribute to environmental benefit when managing all water
- manage water in harmony with natural biological processes
- collaborate on the planning and management of environmental watering to target multiple environmental assets and ecosystems functions
- manage risks associated with the delivery of environmental water, and
- apply adaptive management in the planning, prioritisation and use of environmental water.

These strategies are discussed further below.

Harness community land and water knowledge

Landholders, land managers, community groups and Aboriginal peoples often have detailed knowledge about rivers and wetlands in their valley. This knowledge can include observations about the condition of local wetlands, their water needs or movement of water through the landscape; where native fish are in the river; or possible risks with different types of flows and opportunities to achieve complementary social, cultural and economic outcomes. The outcomes from water use will be improved if this local knowledge and experience can be tapped.

Community input into environmental watering occurs through a range of mechanisms including: community reference groups; environmental and other water advisory committees; local and regional engagement officers; regional and local Indigenous engagement forums and facilitators; broad community engagement forums and direct engagement of industry groups, local government, non-governmental groups (including water trusts) and individual landholders. For example, the MDBA has engaged a number of regional engagement officers and opened regional offices across the Basin and the Commonwealth Environmental Water Holder has an established network of local engagement officers throughout the Basin.

Case Study: Achieving Ngiyampaa First Nation cultural outcomes in the Booberoi Creek through environmental flows

> *'Water is our survival and our connection to our culture; it is our life's blood. Without water we humans, our planet, and our animals cease to exist, and our Mother Earth is no more. Our people's health depends on the rivers flowing.'*
>
> – Peter Harris, Ngiyampaa First Nation Traditional Owner

The Ngiyampaa First Nation people have lived alongside the Lachlan (Galari) River for thousands of years. They value the river and its water as it is intertwined into all aspects of life, from culture and identity through historical connections, to cultural practices, storytelling and spiritual connections. They value water as a life-giving element, essential for health and wellbeing and necessary for their survival.

Elders in the community once used Booberoi Creek (a small tributary of the Lachlan River) to collect and cook bush tucker, such as catfish, ducks and kangaroos. However, poor water quality and irregular flows mean the community can no longer use Booberoi Creek as they did in the past. Many Elders who lived and worked on large stations along the Booberoi, before Wyangala Dam and other major re-regulating storages were built, have since lost access to culturally significant sites, as ownership and relationships between the local Aboriginal people and property owners have changed. Stations around Booberoi Creek were primarily cattle and sheep runs. Many Aboriginal people from Murrin Bridge (Ngiyampaa First Nation community near Lake Cargelligo and Booberoi Creek) were employed as domestic staff or stockmen on these stations. Having helped build these agricultural enterprises, it can affect the social and emotional wellbeing of Aboriginal communities if their contribution and connection to that land is no longer recognised and maintained.

Booberoi Creek also provides habitat for seven native fish species, including freshwater catfish, 26 water-dependent bird species, including white ibis and intermediate egrets, and three flow-dependent frog species, including Peren’s treefrog, spotted grass frog and the eastern sing-bearing froglet. River red gums, black box, and river cooba are the dominate vegetation in the riparian corridor, while lignum, sedges and nitre goosefoot are also prominent.

In November 2018, after a month of dry conditions for Booberoi Creek, Ngiyampaa First Nation Traditional Owner and Environmental Watering Advisory Group (EWAG) member Peter Harris expressed concern over the health of the shrimp, fish, water plants and overall water quality in the Booberoi Creek to the NSW water managers. He noted that historically, runoff from summer storms replenished the creek, and suggested that the recent rainfall in the upper Lachlan should be protected and provided to the Booberoi to improve its health and resilience. He requested the use of water for the environment in the Booberoi so that the creek could reconnect with the Lachlan River for as long as possible, to help remove accumulated silt, improve water quality, and support aquatic plants and the movement of catfish through the system. Ngiyampaa First Nation people often use the creek for cultural purposes in the summer months, and the community at Murrin Bridge and Lake Cargelligo wanted to be able to continue to do so via public land at Canon’s Bridge with the support of environmental flows.

In response to Peter’s request, advice from the EWAG, and the declining health of the Booberoi, the NSW Office of Environment and Heritage (OEH) delivered two small fresh events in late December 2018 and mid-February 2019 using an Environmental Water Allowance from Wyangala Dam. These flows focused on native fish populations. Due to its status as a culturally significant and threatened species, freshwater catfish (*Tandanus tandanus*) was of particular interest.

The first fresh event was delivered on 21 December 2018 at 70–100 megalitres (ML) per day for 14 days (using approximately 300 ML of water in total). Unfortunately, only a small amount of water made it all the way through to the return gauge, which registered 15cm depth for a few days before returning to less than 7cm once the delivery ended. While this was enough to provide much needed water to the aquatic plants and fill up some water holes, it only provided some low-level connectivity with the Lachlan and was not sufficient to allow fish movement between the two systems.

The second fresh event was delivered on 13 February 2019 at 70-113 ML/d for 12 days (using approximately 304 ML of water in total). This second flow was able to improve on the first, allowing more water to reach some shallow backwater areas and removing more silt from the creek. It also provided another opportunity for fish to move between the Booberoi and the Lachlan.

These environmental flows helped to provide connectivity between the Lachlan River and Booberoi Creek. While some fish species moved between Booberoi Creek and Lachlan River, there may not have been enough water for large bodied fish to move from the bottom of the Booberoi back into the Lachlan. However, even low-level connectivity can lead to productivity gains being transferred from the Booberoi anabranch into the Lachlan. Due to the complexity of off-river habitats, Booberoi Creek is highly productive and has a role in replenishing food resources in the Lachlan. The flows may have also assisted in inundating shallow, slack backwater areas off the main creek channel (less than 50 cm deep), which in late February were dominated by milfoils, water primrose, duckweed fern, and tape grass. An increase in the extent and diversity of aquatic macrophytes due to the sustained inundation of these habitats was an unexpected positive result.

Members of the Murrin Bridge community assisted in monitoring for catfish and the persistence of flows in the Booberoi following these water deliveries. By working closely together to design an environmental flow with multiple outcomes, an understanding and respect for each other's knowledge and values has emerged between the Aboriginal community, government and local service providers. The mutual understanding that has developed between the OEH water managers and Traditional Owners has allowed this knowledge to be shared among the EWAG members and incorporated into their advice on the use and management of planned and held environmental water during their regular meetings. The condition of Booberoi Creek is a standing agenda item for the Lachlan EWAG. Peter reports back to the EWAG members regularly on the outcomes of environmental flows and future water priorities for the creek.

One of the most important outcomes is the improved access to Country, which has allowed Elders to pass down knowledge to younger members of the community, and maintain and connect to Country. A community engagement event held in February 2019 at Mt Boorithumble on Booberoi Creek saw a commitment from six landholders to open river access for Peter and his community. The Down the Track youth program catered the event and this provided an opportunity for Peter to share his knowledge with Aboriginal youth from Lake Cargelligo, Murrin Bridge and Euabalong.

Contribute to environmental benefit when managing all water

Improved management of all water in the Basin has great potential to contribute to substantially improving the ecological condition of rivers, wetlands and floodplains. Consumptive water, while in the river, can often contribute to ecosystem outcomes without adding any further risks to the reliability of the associated entitlements. Similarly, water not tagged as consumptive or environmental plays a valuable role in supporting a healthy river, and in some places this can amount to a substantial amount of all flow in the river. For example the Ovens River has only a small portion of water set aside for consumptive use (<2% average surface water availability) and an even smaller portion that is identified as being either HEW or PEW - the remaining water contributes substantially to meeting the environmental watering requirements of the numerous important environmental assets in the Ovens river system.

Many of the Basin's rivers have been managed and operated for decades primarily to deliver water for consumptive use. The Basin Plan brings a new focus to achieving multiple outcomes in river management, including environmental outcomes. The development of water resource plans across the Basin consistent with the Basin Plan is a crucial step to help ensure environmental outcomes are considered in the planning and management of river systems across the Murray–Darling Basin. A systematic and cooperative process of reviewing the often long-standing river operating rules and arrangements under the Murray–Darling Basin Agreement is also underway to capture learnings about operating the river differently to achieve multiple outcomes. The aim is to embed these understandings into contemporary river management practice. Continued, and in some areas increased, collaboration and coordination between environmental water managers and river operators and managers is an important step to improving the management of all water in the Basin (refer to strategies: ‘Collaborate on the planning and management of environmental watering to target multiple environmental assets and ecosystems functions’).

Manage water in harmony with natural biological processes

Events such as fish spawning or migration and waterbird nesting are natural biological processes. These are typically triggered by physical or chemical cues such as changes in water levels, river flows, water temperature or carbon and nutrient input resulting from local rainfall or a flood upstream. Sometimes a cue occurs but its effect is dampened – for example when inflows from a rain event are largely captured in a dam but there is a small dam spill or some tributary inflows downstream of the dam. A biological response may also result from the absence of rain and flow—triggering ecological processes evolved over many thousands of years necessary for the survival of biota during a drying phase, such as fish movement to waterholes that provide refuge.

Managing water in harmony with natural biological processes (for instance reproductive processes) is an effective way to achieve the environmental outcomes sought by the Basin Plan. A project being scoped under the SDLAM is the enhanced environmental water delivery project (EEWD or Hydro-cues project). The key element of the project is to align the release of HEW with other flows to influence the peak and/or duration of a flow event. This aims to create a stronger biological response that is more synchronised with natural climate signals and to water more of the floodplain with the same volume of release. Providing for biological responses that are more synchronised with the natural climate can improve the likelihood of a successful biological outcome. The approach avoids for example, providing environmental water to trigger a waterbird breeding event in a particularly dry period that may result in unsuccessful recruitment because there is insufficient water in the landscape to provide foraging and roosting habitat.

Nevertheless, it may be necessary at times to manage water in the absence of physical and chemical cues which trigger these natural processes in order to arrest decline or avoid irretrievable loss. In these cases, water holders will consider the local circumstances and available evidence to make sure outcomes are achievable.

A further consideration in the more highly-developed parts of the Basin is the need to manage for environmental outcomes that are appropriate in that context. The aim is not to return to a natural system. Rather, managers are looking to use infrastructure (e.g. channels, locks, regulators, blocking banks, levees) to deliver water flows that support the health of particular elements of the ecosystem, for example, stimulating seedling germination and establishment of river red gum in an area that has had little recruitment for some time.

Further strategies to manage environmental water in harmony with natural biological processes in both regulated and unregulated catchments are outlined in the Water management strategies to achieve outcomes for river flows and connectivity section.

Collaborate on the planning and management of environmental watering to target multiple environmental assets and ecosystems functions

Each year, environmental water holders and managers have to make decisions about which ecosystems receive water. They draw upon local expertise, successful past practice and the opportunities that present themselves in order to make this happen. This has led to positive environmental outcomes for rivers, floodplains and wetlands at many different sites in the Basin.

Nonetheless, the larger watering actions of recent years that have led to system-scale and multi-year outcomes have required collaborative decisions and actions. Significant environmental benefit, not to mention efficiency, has been achieved by coordinating the planning and management of water so that it passes through multiple environmental assets while supporting a range of ecosystem functions. This is best achieved when environmental water managers and holders, owners and managers of environmental assets, and river operators and managers work together across site, catchment and state boundaries.

A range of forums and agreements are needed to coordinate environmental watering across the Basin. The ideal forum and the frequency of meetings depends on a range of factors including the size and complexity of the area being managed, its level of hydrological connectedness to other catchments, the degree of regulation and the number of interested parties.

Along with creative and constructive forums, a spirit of collaboration must continue to underpin the planning and delivery of environmental water across the Basin. Collaborative networks should be established, and successful models spread. In all aspects of environmental water management, it is important to involve all of the players and to nurture lasting relationships.

Traditionally, the benefits of coordination and collaboration at a system scale have been manifest in the southern connected Basin, but the need for some kind of arrangement in the northern Basin is becoming increasingly apparent. For example, in the Darling River, particularly as a result of the drought and the dry hot conditions over 2018 and 2019, there was a need to coordinate flows from unregulated catchments with releases from connected regulated catchments to limit ecological damage.

Establishment of a northern connected Basin environmental watering committee has been recommended through the 2017 Evaluation, as well as by the Productivity Commission in their five-year assessment of Basin Plan implementation. Improved coordination and delivery of environmental water in the northern Basin is also one of the agreed toolkit measures identified through the northern Basin review. The MDBA, CEWH and Basin governments are exploring suitable arrangements. Given the different nature of the northern Basin, any coordinating arrangement is likely to be different from that used in the southern connected Basin.

These coordination forums will assist system-scale integrated river management and help to maximise outcomes across multiple environmental assets and ecosystem functions with the use of all water (refer to the Strategy ‘Contribute to environmental benefit when managing all water’).

Manage risks associated with the delivery of environmental water

There are a number of potential risks from undertaking environmental watering actions including:

- negative water quality impacts associated with large watering events (e.g. hypoxic blackwater and salinity, see also Box 3 Water quality)
- loss of a stratified layer of oxygenated water in refuge pools under drying conditions
- breeding and spread of invasive species (e.g. weeds and alien fish)
- unauthorised inundation of private property or infrastructure, and
- environmental water taken for consumptive purposes.

The identification and management of risks associated with environmental watering needs to be undertaken throughout the relevant planning and delivery phases, to ensure that:

- people, property and cultural heritage are not subject to unintended impacts
- the environmental outcomes of water use are achieved or lessons learned are managed adaptively
- environmental water flowing through the system is protected from take
- the use of environmental water is efficient, and
- good stewardship of environmental water holdings is maintained.

Apply adaptive management in the planning, prioritisation and use of environmental water

Adaptive management is a structured decision-making process that is widely used in resource and environmental management. Its overall purpose is to foster robust decision-making in the face of uncertainty, with the aim of reducing this uncertainty over time. The process, therefore, meets the dual aims of delivering beneficial outcomes while accruing information to improve management over the long-term.

Adaptive management recognises that action is required, despite an imperfect information base, and it requires the user to embrace risk and uncertainty as a way of building understanding.

Adaptive management begins with clear management objectives, a hypothesis about the outcomes expected from a management action, and measurable indicators to assess how successful it has been. The activity is then undertaken (e.g. watering an environmental asset using a particular delivery pattern) and assessed against the indicators. Management can then be revised or improved in light of learnings identified through analysis of outcomes (Figure 2).

Adaptive management also benefits from:

- local knowledge, active involvement and long-term commitment from stakeholders
- clear roles and responsibilities
- good channels of communication between communities, water management agencies and scientists
- commitment by communities and government to long-term monitoring and evaluation

- a monitoring and evaluation process that is itself adaptive, and
- regard for the social, economic and technical aspects of management.

Water management strategies to achieve outcomes for river flows and connectivity

Environmental water holders and managers, and river operators, now have significant experience supplementing the impacted flow regime of rivers with additional environmental water from dams, generally by reinstating ecologically significant parts of the flow regime. Flow and connectivity outcomes are also achieved by protecting those parts of existing flows that have high ecological significance (e.g. low flows that fill refuge waterholes in ephemeral rivers).

To achieve the expected outcomes for flow and connectivity, environmental water holders and managers, and river operators, will need to provide for environmental watering using a variety of strategies including:

- Releasing water in a targeted fashion to add to the flow hydrograph in various ways (e.g. filling in what would otherwise by ‘dips’ or ‘troughs’, extending the ‘tail’ of events) to support the successful completion of natural biological processes, such as fish and waterbird breeding - this could be achieved by releasing water in-stream or using infrastructure (e.g. locks, regulators) to control the extent and duration of inundation on the floodplain.
- Operating rivers to improve and/or reinstate ecosystem functions such as supporting life cycle processes, providing carbon and nutrients to support food webs and providing diverse habitats for feeding, breeding and recruitment.
- Augmenting and coordinating tributary flows in regulated parts of the Basin (particularly those which naturally contribute large flows downstream) to help in meeting downstream environmental outcomes.
- Protecting patterns of flow in less-regulated rivers - this can be achieved using rules in water plans, one-off arrangements with third parties, or temporary purchases of water allocations.
- Delivering flows in a way that is seasonally appropriate and in patterns/flow sequences that provide cues for triggering ecological processes.
- Maintaining the integrity of flows throughout the length of the river and protecting flows from re-regulation, extraction or substitution with other water.
- Building upon a smaller event to achieve a higher peak flow.
- Operating rivers to reduce the frequency and length of artificial dry periods.
- Coordinating the use of planned and held environmental water with other water in the system.

By adopting an adaptive management approach, the cycle of planning, delivery, monitoring, learning and implementing changes should be applied to all strategies. This could involve tracking the contribution of environmental water to site, reach and Basin-scale outcomes. Sharing information and learnings between environmental water planners, river operators, and research areas should help strengthen any adaptive management processes and ensure best available science is being used to inform environmental water delivery.

Where possible, investments in new knowledge (such as satellite imagery, gauging and metering, modelling and analysis techniques) should be used to improve existing models of how environmental water is contributing to flow and the resulting impact on ecosystem functions and outcomes.

Addressing impediments to environmental water delivery is also an important strategy (this includes river operating practices and physical constraints). The expected outcomes identified in this Strategy can be achieved within current constraints. However, addressing physical constraints and reviewing operating practices to provide more flexible river operations (including associated legal arrangements) will improve the environmental outcomes that can be achieved with the water available. These issues are being addressed through the progressive implementation of the Constraints Management Strategy and River Operations Improvement program. SDLAM measures and the northern Basin toolkit will further assist in providing flexible ways to deliver water for the environment.

Water management strategies to achieve outcomes for native vegetation

To achieve the expected outcomes for native vegetation, environmental water holders and managers, and river operators, will need to provide for environmental watering through planning (including long-term environmental watering plans and water resource plans) and delivery mechanisms (including river operations) that:

- maintains healthy, diverse plant communities
- supports plant communities over the long-term
- protects threatened species and communities, and
- integrates water and land management.

Maintains healthy, diverse plant communities

Planning and management should:

- Recognise the water requirements of plant communities, not just those of a dominant species. For example, the water requirements of a river red gum community in a wetland area can differ greatly from river red gum woodlands associated with more drought-tolerant species.
- Support plant community diversity and mosaics by ensuring a variable flow regime.
- Manage for plant community mosaics across a range of scales. While site-scale diversity can be used to indicate plant community health, diversity at this scale is not always desirable. Monospecific communities such as the Moira grass plains in the Barmah-Millewa Forest are recognised as rare and unique communities of international importance. Sites such as these contribute to plant community diversity and mosaics at the landscape scale.
- Accommodate for plant communities that transition between states through wet and dry climate cycles or in ephemeral systems. This may include changes in the vegetative state of individual plants (including dormancy), or shifts in plant community composition.

- Incorporate learning from monitoring of site-based response to watering events to inform future management.

Supports plant communities over the long-term

Planning and management should:

- Support plant communities through each stage of their life cycle, from maintaining condition of adult plants, to flowering, seed set, and successful recruitment.
- Consider the longevity of species to ensure that recruitment (either as established juveniles or through production of seeds and propagules) balances the long-term attrition rates within plant communities.
- Target a diverse age structure in ephemeral species, particularly among trees in forests and woodlands.
- Maintain healthy seed banks to build resilience in non-woody vegetation communities.
- Recognise the range of timescales within which communities respond to changing environmental conditions. While a single inundation event can produce a green flush in non-woody vegetation communities, slow growing species such as black box can take years to transition between states of condition, and may require more sustained or serial inundation events to generate a condition response.
- Look beyond annual planning cycles to provide multi-year management for communities that require serial inundation to generate the desired response.

Protects threatened species and communities

Planning and management should:

- Incorporate the best available information on the water needs of threatened species and communities and prioritise them for management where necessary.
- Support high-value habitat. In heavily-modified landscapes, remnant plant communities such as riparian corridors can provide critical habitat for threatened fauna species. Plant communities known to support threatened species should be prioritised for management.
- Buffer the effects of drought on vulnerable threatened species and communities, where possible.

Integrates land and water management

Planning and management should:

- Coordinate with other complementary land management actions (e.g. managing grazing pressure from invasive species) to maximise outcomes from environmental water use.
- Include a determination of all factors driving the condition of vegetation in target communities, and consider how these factors are likely to influence the community’s response to environmental watering.

Water management strategies to achieve outcomes for waterbirds

To achieve the expected outcomes for waterbirds, environmental water holders and managers will need to provide for environmental water through planning (including long-term environmental watering plans and water resource plans) and delivery (including river operations) that:

- maintains and improves habitat
- supports breeding, in particular for colonial nesting waterbirds
- assists life cycle completion
- maintains habitat and water levels for migratory shorebirds in the Coorong and Lower Lakes, and
- takes a Basin-scale approach.

In applying the water management strategies for waterbirds, environmental water holders and managers should target the Basin-significant assets (listed in Appendix 3) and locally-significant assets identified in long-term environmental watering plans.

Maintains and improves habitat

Planning and management should:

- Maintain breeding habitat in event-ready condition by providing environmental water to maintain the distribution, structure and health of native riparian, floodplain and wetland vegetation.
- Create a mosaic of wetland habitats suitable for functional feeding groups, since a diversity of habitats, including mud flats, inundated vegetation and deeper water, will result in abundant and diverse waterbirds.
- Allow for appropriate drying periods in temporary wetlands to enhance productivity and breeding success in future years.
- Maintain foraging and roosting habitat at refuges, as these maintain species richness and abundance in dry years.

Supports breeding, in particular for colonial nesting waterbirds

Planning and management should:

- Support large breeding events from nest building through to post-fledging care by extending the duration of flooding and maintaining adequate and stable water depths in colony sites (90–120 days for most species).
- Respond to natural biological processes to support or trigger small breeding events from nest building through to post-fledging care either by extending the duration of flooding or creating artificial inundation to maintain adequate and stable water depths in colony sites (90–120 days for most species).

- Ensure a slow drawn down of water levels following a breeding event, to limit nest abandonment and allow more foraging opportunities after eggs have hatched.

Assists life cycle completion

Planning and management should support the whole waterbird life cycle (egg, chick, juvenile, sub-adult and adult) and in addition to strategies for breeding and habitat, this involves:

- Extending breeding site inundation until juvenile survival is apparent.
- Providing environmental water in the year following large breeding events to support the survival of juveniles.
- Managing over-wintering sites and nearby foraging habitats to support survival of juveniles and sub-adults.

Maintains habitat and water levels for migratory shorebirds in the Coorong and Lower Lakes

Planning and management in the Coorong and Lower Lakes should:

- Provide functional mudflat habitat to sustain shorebird foraging during November–March each year.
- Create water levels that are suitable for a variety of shorebird species, with most shorebirds preferring to forage at or near shorelines where mudflats are covered with only a few centimetres of water.

Takes a Basin-scale approach

With waterbirds able to move quickly, a Basin-scale approach to management is required to improve waterbird outcomes. Planning and management should be mindful of:

- Population movement strategies, such as migration, nomadism, and connectivity between the northern and southern Basin.
- Common flight routes within the Basin, the need to adapt for between-species differences, and to manage these differences accordingly.
- The need to coordinate environmental watering across catchments, such as by maintaining foraging grounds after the commencement of breeding in neighbouring catchments to support successful breeding and juvenile survival.

Water management strategies to achieve outcomes for native fish

To achieve the expected outcomes for native fish, environmental water holders and managers, and river operators, will need to provide for environmental watering through planning (including long-term environmental watering plans and water resource plans) and delivery (including river operations) that:

- supports native fish species to complete their life cycles
- supports the needs of the whole fish community, by identifying and delivering relevant environmental water requirements
- improves native fish habitat
- protects and improves existing populations of threatened species
- achieves system-scale connectivity that supports life cycle processes, and
- integrates environmental watering with other natural resource management actions.

More detail on each of these strategies is outlined below.

In applying the water management strategies for native fish, environmental water holders and managers must consider the broad-scale assets that are of Basin significance for native fish (listed in Appendix 6) and any regional and local-scale assets identified for native fish in long-term environmental watering plans, including where they relate to threatened species.

Supporting life cycle completion

Planning and management should:

- Consider spawning and recruitment outcomes for all native fish species, especially where flow affects critical parts of their life cycles (such as movement and dispersal).
- Align protection of first flushes, low flows, environmental flows and environmental water delivery with natural productivity, seasonality and timing of fish growth, movement and reproduction. (For example, late winter to early autumn is a critical time in the northern Basin, while a range of flows during winter are important for some species in the southern Basin).
- Enable fish to complete life cycle requirements that occur across site and catchment boundaries, and across multiple years.
- Pay particular attention to the connectivity requirements of native fish—such as access to, and exit from, off-channel habitats at the appropriate time.

Supporting the needs of the whole fish community

Planning and management should identify and deliver relevant environmental water requirements, including:

- Providing for fish outcomes on a decadal time scale. This may include identifying options for delivery of decadal flow regimes (including cease-to-flow, base flows, low flows, freshes and over-bank events) that outline inter-annual, annual, biennial and multi-year flow requirements for fish.
- Prioritising and protecting natural inflows, especially those that coincide with naturally high periods of in-stream productivity. Natural inflows trigger greater responses from native fish compared to water sourced from large dams and storages. For example, in the northern Basin, protecting the first post-winter flow event as it is one of the most biologically-significant events for the fish community.
- Focusing on opportunities to maximise longitudinal and lateral fish movement. This may include: performance indicators of fishway operation; periodic drown-out or removal, where

possible, of low-level natural and man-made barriers (e.g. weirs); facilitating connectivity to off-stream habitats; and facilitating secondary connection events that allow fish recruited in off-channel habitats to return to the river following natural hydrographs as much as possible when water levels need to change (both rising and falling). For example: implementing actions that allow water levels to fall gradually; extending the recession of natural and managed flows; and mitigating large daily fluctuations in water levels through river and channel management (including extraction). These actions will prevent fish stranding in off-channel habitats, abandonment of nests and loss of nursery habitats.

- Maintaining drought refuge habitats to build population resilience and to prevent catastrophic loss of fish populations during extended dry periods.

Improving native fish habitat

Planning and management should include:

- Protecting and improving unregulated systems (both larger mainstem rivers and the many smaller tributaries throughout the Basin) for native fish and recognising the importance of these areas for the overall biodiversity of the Murray–Darling Basin.
- Identifying and protecting priority dry period refuges (e.g. waterholes with high persistence levels) for fish in regulated and unregulated systems. Actions such as scouring flows prior to dry periods, maintenance of longitudinal connectivity between refuges, and protecting first flushes and low flows during dry conditions can be important.
- Reinstating in-channel flow variation, including at in-channel habitats with regulated stable water levels. Appropriately planned short-term flow variation can stimulate movement of juvenile fish, and gradual increases in normally stable water levels can trigger spawning responses in some species (e.g. silver perch can respond positively to a flow variation over just two days, with height changes up to 0.2m).
- Providing for delivery arrangements that reinstate hydrodynamic diversity and improved in-stream habitats (e.g. faster-flowing habitats are particularly important for Murray cod, trout cod, Macquarie perch, golden perch and silver perch).
- Maintaining a salinity gradient in the estuary, while ensuring that the spatial extent of the gradient varies.

Protecting and improving existing populations of threatened species

Planning and management should include:

- Encouraging range expansions in populations of threatened species through appropriate flow regimes generally; and through delivery of appropriate flow regimes to additional sites that could support the introduction of threatened species.
- Coordinating the planning and management of flows to support the recovery of threatened species that complete life cycles over large distances.

- Managing water quality risks to vulnerable populations and species. For example, cold water temperatures can limit reproduction and growth of native fish and should be mitigated where possible.
- Having regard to flow-related threats and actions listed in threatened species recovery plans.

Achieve system-scale connectivity that supports life cycle processes

Planning and management should:

- Provide connectivity between multiple catchments to achieve system-scale connectivity within and across multiple years.
- In regulated catchments, enable coordination of flows that allow fish to complete life cycle processes that occur across site, catchment and State boundaries (including supporting recruitment processes that commence in unregulated catchments).
- Protect the integrity of flows over large spatial scales (e.g. greater than 1,000km) that connect floodplains and wetlands that enhance larval fish survival and dispersal
- Consider how all water, e.g. consumptive water, transfers between storages, environmental flows, and flows for other purposes can be managed to support system scale connectivity.

Integrate environmental watering with other natural resource management actions.

Planning and management should:

- Consider the flow requirements to ensure return on investment of natural resource management actions (e.g. flow delivery is appropriate to support fishway operations)
- Align watering actions to support the establishment and maintenance of management actions such as revegetation and habitat restoration activities.
- Prioritise natural resource management actions in locations that have high ecological value and can be supported by water planning and delivery.
- Coordinate natural resource management actions and the planning and management of water to support the ecological needs of native fish.

Managing to prevailing conditions

The Basin's variable climate requires that environmental watering is responsive to both antecedent (historic) conditions and the forecast availability of environmental water.

The practice of managing environmental water in response to water resource availability scenarios has been adopted over the past 15 years by most environmental water holders in the Basin. Various combinations of climate condition and water availability result in different levels of flow from year to year and therefore different categories of resource availability i.e. very dry, dry, moderate, wet, and very wet. Different outcomes will be sought depending on the prevailing resource availability scenario.

Table 1 outlines environmental management objectives and outcomes appropriate for each resource availability scenario. In moderate years for example, environmental water might be used to connect the river to billabongs via high flows, whereas in a dry year this might not be possible. Annual strategies to achieve expected outcomes for native vegetation, native fish and waterbirds are given in Table 1 for each resource availability scenario. These strategies inform annual environmental watering priorities, which are explained in Chapter 5.

Case Study: Management actions to support system-scale connectivity for golden perch recruitment

Recent scientific evidence suggests that in the northern Basin's unregulated systems, regular golden perch recruitment is observed. In comparison, the golden perch populations of the northern Basin's regulated systems are dominated by adult fish, with little or no recruitment occurring.

Populations in regulated systems are now potentially reliant upon adult and juvenile golden perch moving into these systems from unregulated catchments. Management actions that promote connectivity between the northern Basin's systems will help maintain good numbers of golden perch across the northern Basin and, in wet years, potentially into the southern Basin.

Golden perch are a high-level predator, helping to maintain a functioning ecosystem. Golden perch also provide social and economic benefits to local communities through fishing for cultural and recreational purposes.

Golden perch are a flow pulse specialist. The golden perch recruitment cycle involves spawning in one or more of the unregulated northern tributaries in response to local flow events. The eggs, larvae and juveniles then drift and actively move downstream to suitable recruitment habitats. These habitats include off stream wetlands that, when inundated, provide greater food availability and shelter to support fast growth and improved chances of survival.

A recently developed conceptual model recognises that a functional golden perch population relies on hydrological connectivity from small, medium and large flow events that support its life cycle requirements. Small post-winter flows in unregulated tributaries result in spawning and recruitment at the local level (Figure 16). Medium and larger post-winter flows support spawning in the unregulated northern tributaries, downstream larval dispersal/ drift and recruitment down the Darling River into its tributaries and the Menindee Lakes (Figure 17). These large recruitment events provide important contributions to maintaining and improving golden perch populations across the northern Basin. When flood conditions occur over sequential years, these recruitment events can also contribute to the southern Basin's golden perch populations.

Our best available knowledge, including recent survey data, has shown that spawning and regular recruitment of golden perch occurs in the intermittent and largely unregulated tributaries of the northern Basin, including the Condamine, Moonie, Weir and Warrego rivers. Recruitment in these catchments may support the populations in the regulated systems of the Barwon, Macintyre, Macquarie and Namoi rivers. The Barwon-Darling River acts as a major upstream and downstream movement corridor. When flows support end-of-system connection events, adult fish can move upstream, while eggs and larvae move downstream. Juveniles can move into and out of systems in both directions.

Golden perch populations need a coordinated and active management approach to environmental water planning and delivery, to provide broad-scale connected flows when needed. In northern Basin rivers, all water within the river system can contribute to connectivity and native fish population recovery. A northern Basin flow coordinating group would help maximise system-scale connectivity by coordinating individual catchment flow plans, actively managing base-flows, small flushes and end-of-system flow targets and supporting system-scale connectivity that can lead to mass golden perch recruitment, and broader ecological outcomes across the northern Basin.

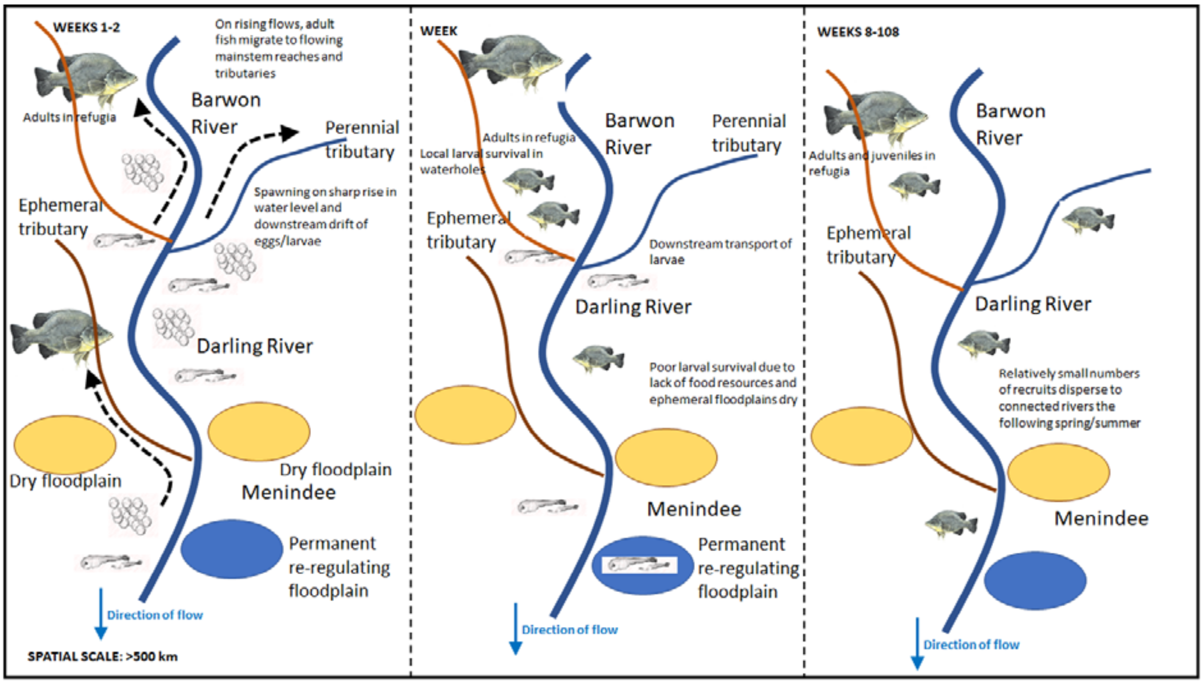

Figure 16: Conceptual model of golden perch life-history in the northern Basin with local tributary inflows but no broad-scale connectivity, resulting in limited localised recruitment. (Figure courtesy of the Arthur Rylah Institute.)

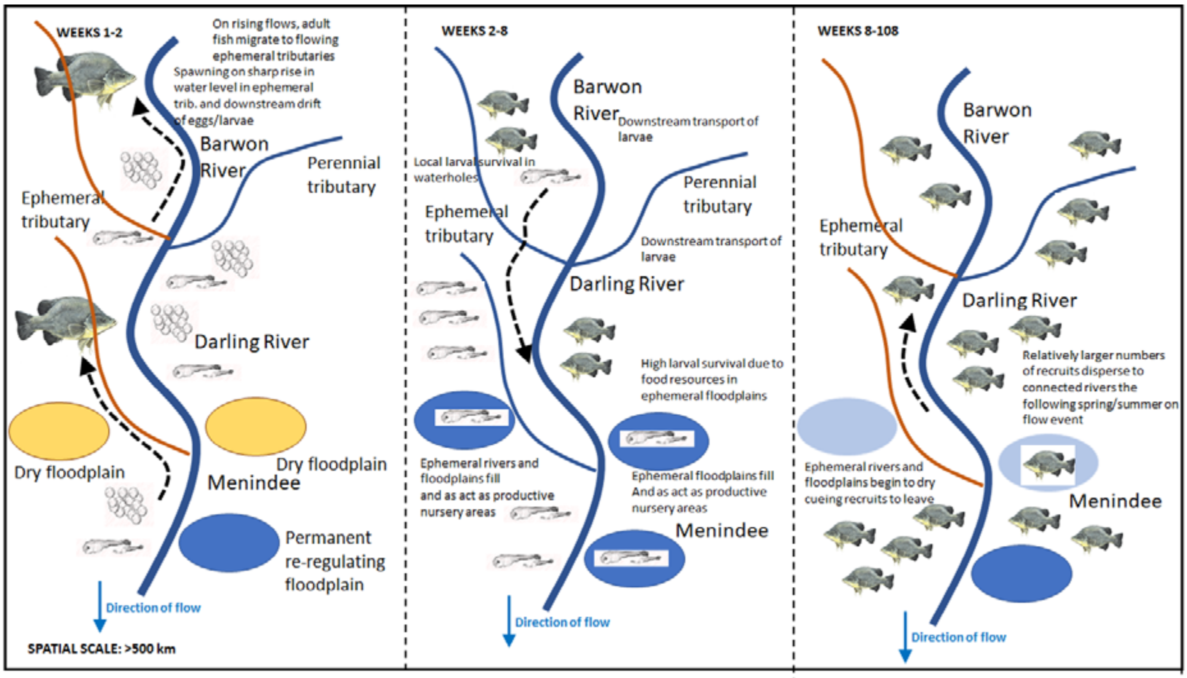

Figure 17: Conceptual model of golden perch life-history in the northern Basin with local tributary inflows, resulting in broad-scale connectivity and large scale multi-year mass recruitment. (Figure courtesy of the Arthur Rylah Institute).

Table 1: Resource availability scenarios, management objectives and outcomes, and strategies to achieve them

Objectives, outcomes and strategies	Scenario: Very Dry	Scenario: Dry	Scenario: Moderate	Scenario: Wet	Very Wet
Management objectives:	Avoid irretrievable loss of, or damage to, environmental assets	Ensure environmental assets maintain their basic functions and resilience	Maintain or improve ecological health, condition and resilience of water-dependent ecosystems	Improve ecological health, condition and resilience of water-dependent ecosystems	Improve ecological health, condition and resilience of water-dependent ecosystems
Management outcomes:	Critical loss of species, communities, and ecosystems is avoided. Irretrievable damage and catastrophic events are avoided. Vital habitat and critical refuges are maintained, including through supporting base flows.	Loss of native species is avoided. The capacity of threatened species and communities to survive and maintain viable populations is protected. Environmental assets and ecosystem functions are maintained, including by allowing drying to occur consistent with natural wetting–drying cycles. Vital habitat and critical refuges, are maintained, including through supporting base flows.	Growth, reproduction and small-scale recruitment for a diverse range of plants and animals is supported and viable populations and structure are maintained or improved. Structural, species and genetic diversity are maintained. Longitudinal connectivity is supported and ecosystem functions related to medium-level flows are maintained. Inundation of in-channel benches and river connectivity with low-lying floodplains and wetlands is supported, leading to maintenance of, or improvement in, related environmental assets and ecosystem functions.	Growth, reproduction and medium-scale recruitment for a diverse range of plants and animals are supported, leading to increased populations. Structural, species and genetic diversity are maintained or increased. Longitudinal connectivity is improved. Ecosystem functions related to higher-level flows are supported. Lateral connectivity between rivers, wetlands and low-lying floodplains is supported, leading to improved health and condition of environmental assets and ecosystem functions, including increased basal resources and productivity. Risks from environmental watering, such as hypoxic blackwater events, are mitigated.	Growth, reproduction and large-scale recruitment for a diverse range of plants and animals are supported, leading to increased populations. Structural, species and genetic diversity are increased. Longitudinal connectivity is improved. Ecosystem functions related to higher-level flows are improved. Lateral connectivity between rivers, wetlands and higher floodplains occurs, leading to improved health and condition of environmental assets and ecosystem functions on a broad scale, including increased basal resources and productivity. Risks from environmental watering, such as hypoxic blackwater events, are mitigated.
Annual strategies to achieve outcomes will include:	Allow drying to occur but relieve severe unnaturally prolonged dry periods. Manage unnaturally low flows and mitigate water quality issues that are likely to cause irretrievable damage. Prioritise watering for: water-dependent vegetation sites identified as critical refuges for other species waterbird drought refuges, particularly those identified in Appendix 3	Allow drying to occur consistent with natural wetting–drying cycles. Manage low flow levels to maintain base flows consistent with natural dry conditions, support hydrological connectivity within systems and to mitigate water quality issues that may cause irretrievable damage. Prioritise watering for: water-dependent vegetation to maintain condition especially for sites identified as critical refuges for other species waterbird drought refuges, particularly those identified in Appendix 3	Undertake watering events to promote longitudinal and lateral connectivity to: support successful recruitment or to assist in restoring and maintaining vegetation condition and extent in floodplain communities near river wetlands and anabranches (including but not restricted to communities in Appendix 2) support growth, reproduction and recruitment for waterbirds (particularly at sites listed in Appendix 3) including by providing river connectivity with low-lying floodplains and wetlands for foraging opportunities promote in-stream flows and low-lying floodplain–river connectivity for native fish breeding, foraging, growth and movement.	Build on natural flows and inundation events including managing flow recessions, to optimise longitudinal and lateral connectivity to: increase passage and dispersal of biotic and abiotic components between low-lying floodplains and rivers and between hydrologically connected valleys promote recruitment and improvement in vegetation condition and extent on low-lying floodplains (including but not restricted to communities in Appendix 2) promote growth, reproduction and large-scale recruitment for waterbirds, including watering for episodic productivity of larger wetlands that support breeding and foraging opportunities promote growth and recruitment of native fish, including providing opportunities for life	Build on natural flows and inundation events including managing recessions, to optimise longitudinal and lateral connectivity to: increase passage and dispersal on a larger scale of biotic and abiotic components between rivers and a broader extent of floodplain. and between hydrologically connected valleys support large-scale recruitment events and support improvement in vegetation condition and extent on broader parts of the floodplain (including but not restricted to communities in Appendix 2) support growth, reproduction and large-scale recruitment for waterbirds, including watering for episodic productivity of larger wetlands that support breeding and foraging opportunities

Objectives, outcomes and strategies	Scenario: Very Dry	Scenario: Dry	Scenario: Moderate	Scenario: Wet	Very Wet
	native fish drought refuges, particularly those which support threatened species, as identified in Appendix 6. Maintain water levels in the Coorong and Lower Lakes above sea level. Allow discharges through barrages, including to meet the Murray Mouth opening regime where possible.	native fish drought refuges, particularly those which support threatened species, as identified in Appendix 6, including opportunities to maintain refuge habitat. Maintain water levels in the Coorong and Lower Lakes above 0.4 m AHD 95% of the time, and above 0.0m AHD all of the time. Allow discharges through barrages, including to meet the Murray Mouth opening regime.	Manage water in the Coorong and Lower Lakes, including managing flows through the barrages to: maintain condition of the Coorong and Lower Lakes ecosystems and Murray Mouth opening regime maintain water levels above 0.4 m AHD 95% of the time, and above 0.0m AHD all of the time improve condition of geomorphic characteristics support upstream and downstream movement of diadromous fish.	cycle movements and increased distribution between catchments and across large scales. Manage water in the Coorong and Lower Lakes, including managing flows through the barrages to: improve condition of the Coorong and Lower Lakes ecosystems and Murray Mouth opening regime maintain water levels above 0.4 m AHD 95% of the time, and above 0.0m AHD all of the time improve condition of geomorphic characteristics support upstream and downstream movement of diadromous fish.	support growth and recruitment of native fish, including providing opportunities for life cycle movements and increased distribution, between catchments and across large scales. Manage water in the Coorong and Lower Lakes, including managing flows through the barrages to: improve condition of the Coorong and Lower Lakes ecosystems and Murray Mouth opening regime improve conditions of geomorphic characteristics support upstream and downstream movement of diadromous fish.

4 Roles and responsibilities

The management of water for environmental outcomes in the Basin is undertaken by a range of organisations under a framework which fosters coordination between local agencies, states and the Commonwealth, for both planning and real-time water delivery.

Figure 18 outlines the key parts of the process for managing environmental water. Planning and prioritisation at the Basin and regional scales informs the active delivery of water in real time.

Box 7 outlines the key government roles and responsibilities.

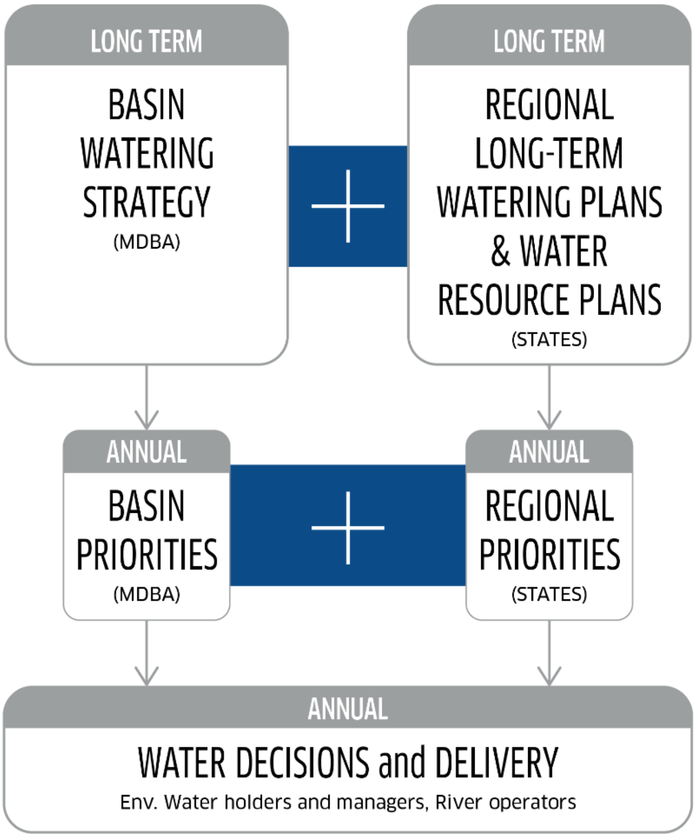

Figure 18: Key elements of the framework for environmental water in Murray–Darling Basin.

As local knowledge and experience can improve outcomes from the planning and delivery of environmental water, it is important that water holders and managers engage with a range of interested parties. First Nations, community groups (e.g. recreational fishers, Landcare groups), water-user groups and local landholders can bring new and innovative perspectives to environmental watering. More information about this is provided in 'Harness community land and water knowledge' and in Chapter 7 regarding First Nations environmental water guidance.

Box 7: Role of the Commonwealth and state governments in environmental water management and delivery

Murray–Darling Basin Authority:

- oversees and evaluates implementation of the Murray–Darling Basin Plan, including the Environmental Watering Plan
- identifies the longer-term Basin-scale environmental outcomes and annual environmental watering priorities to achieve the objectives of the Environmental Watering Plan
- manages the River Murray system on behalf of Basin governments so that to the extent possible, all water can contribute to environmental outcomes while meeting existing obligations (e.g. delivery of water for consumptive use, provision of conveyance water)
- manages The Living Murray Initiative (on behalf of the NSW, Vic, SA and Commonwealth governments), which delivers environmental water to improve the health of six ecologically-significant sites in the Murray catchment
- collaborates with all parties (Commonwealth, state and local) to coordinate the planning, prioritisation and use of environmental water.

Commonwealth Environmental Water Holder (CEWH):

- manages the Commonwealth's water holdings (entitlements and allocations), acquired through government investment in water-saving infrastructure and water buy-backs as part of national water reforms
- decides on use, carryover and trade of the Commonwealth's water holdings to maximise environmental outcomes at both local catchment and Basin scales. This is undertaken consistently with the Basin-wide environmental watering strategy and the Basin Plan's Environmental Watering Plan; and in consideration of Basin annual watering priorities
- collaborates with all parties (Commonwealth, state and local) associated with environmental water management to coordinate the planning, prioritisation and use of environmental water.

Basin states (NSW, VIC, QLD, SA and ACT):

- manage river systems in the Basin so that to the extent possible, all water can contribute to environmental outcomes while meeting existing obligations (e.g. delivery of water for consumptive use, provision of conveyance water)
- identify long-term and annual environmental outcomes, priorities and watering needs for environmental assets and functions in each catchment
- manage state environmental water, including planned environmental water (water set aside in water resource plans for environmental outcomes) and/or held environmental water entitlements and allocations
- determine the best ways to use (either through rules or active decisions on water use and delivery, carryover and/or trade) available water in the interests of achieving environmental outcomes at local catchment and Basin scales, in line with the Basin Plan's Environmental Watering Plan including the Basin-wide environmental watering strategy and in consideration of Basin annual watering priorities
- place orders for watering actions—including Commonwealth environmental water—with river operators
- collaborate with all parties associated with environmental water management at state and local levels including owners and managers of environmental assets - as well as with the MBDA and the CEWH - to coordinate the planning, prioritisation and use of environmental water.

Long-term planning for environmental watering

The Basin Plan sets out long-term planning for environmental watering at two geographical scales: the Basin scale and the catchment scale. The long-term planning instruments identified in the Basin Plan are the Basin-wide environmental watering strategy, water resource plans and long-term environmental watering plans. In addition, Basin states have a range of planning instruments that guide the management and use of water (e.g. NSW water sharing plans, Victorian bulk entitlements, South Australian water allocation plans, Queensland water plans). The various instruments interact to provide for environmental watering within catchments and across the Basin to achieve long-term outcomes.

The MDBA is responsible for the Basin-wide environmental watering strategy, which is reviewed at least every five years in consultation with stakeholders. The CEWH must manage its water consistently with the Strategy. Basin states are responsible for preparing long-term environmental watering plans and water resource plans for each water resource plan area (refer Figure 19).

Long-term environmental watering plans provide an opportunity to develop strategies at a catchment scale to maintain and improve the long-term health of the Basin. They guide management of the region's water-dependent ecosystems and environmental watering decisions, identify long-term risks, management strategies and operational constraints in the system, and identify cooperative arrangements for environmental watering. The watering plans also provide a basis for monitoring and evaluating progress towards achieving Basin Plan objectives, and outline to the community the environmental outcomes expected as the plans are implemented.

The long-term environmental watering plans are developed jointly with holders and managers of environmental water, owners and managers of environmental assets, state and Commonwealth government agencies, river operators, and First Nations and local communities. Where long-term environmental watering plans cross water resource plan areas or state boundaries, government agencies work together to ensure they are integrated.

When measuring progress towards achieving the environmental objectives in the Basin Plan, the MDBA must have regard to the ecological objectives and targets set out in the long-term environmental watering plans. Also, when preparing the Basin annual environmental watering priorities, the MDBA must have regard to the requirements in the watering plans.

Figure 19: Surface water resource plan areas in the Basin for which long-term environmental watering plans are developed.

Annual environmental watering

The annual planning process for using environmental water supports environmental water managers to make decisions throughout the water year. Annual planning processes consider environmental water demands across the Murray–Darling Basin, within catchments and across state and catchment boundaries.

A description of the current roles and responsibilities relating to the annual environmental watering process is provided below, noting that these may change following the first review of the Environmental Watering Plan scheduled for 2020.

Planning

Environmental water managers typically undertake planning between January and the end of June to identify potential environmental watering opportunities for the coming water year(s).

Throughout the planning process the MDBA, the CEWH and state environmental water managers consult closely with one another and with owners and managers of environmental assets and river operators. This consultation is critical for coordination and ensuring that proposed watering is feasible. Consultation is also undertaken with a range of stakeholders, including local environmental water advisory groups, Aboriginal representatives, local governments, irrigation groups, landholders, catchment natural resource managers and site managers.

To inform environmental water planning and support the coordination of environmental water across the Basin, states provide the MDBA with environmental watering priorities for each water resource plan area at the end of May each year. Annual environmental watering priorities consider the ecological condition of sites; prevailing climate; history of watering; forecasts for climate; and the outlook for water resources, including likely holdings of environmental water.

The *Basin annual environmental watering priorities* that are identified by the MDBA are informed by the state environmental watering priorities, as well as input from other relevant sources.

Published in June each year, the priorities describe important Basin environmental outcomes for the coming water year (see How MDBA will identify Basin annual environmental watering priorities for more detail on this process). These Basin annual environmental watering priorities are an input into the planning undertaken by water holders.

Environmental water holders (e.g. CEWH, NSW OEH, Victorian Environmental Water Holder and TLM) also produce annual plans. These set out how they anticipate their portfolios will be used, how they will coordinate with other holders and any river operational considerations or risk management issues that may need to be considered in the coming year.

More information is provided in 'collaborate on the planning and management of environmental watering to target multiple environmental assets and ecosystems functions' in Chapter 3.

Implementation

Towards the beginning of the new water year the focus shifts from planning to implementation. More detailed consideration is given to current and forecasted conditions and water availability, to determine which of the options identified during the planning process can feasibly be implemented. Local on-ground knowledge is important for detailing a specific watering action including the flow magnitude, timing, rates of rise and fall, the area to be inundated and triggers for commencement. It also provides critical input to the detailed risk assessment that is undertaken before a decision is made on a watering action.

Environmental water managers decide to commit water to an action in consultation with water managers and river operators. Local community input is also crucial at this stage of implementation and during water delivery, as conditions can change rapidly and may result in the need to adjust, suspend or even cancel the watering action.

A range of partners are involved in the delivery of environmental water including environmental water holders and managers, river operators, land and waterway managers and owners and local communities (refer Box 8).

In the southern Basin, governments cooperate to mobilise environmental water to achieve the best environmental outcomes, within the system's prevailing constraints. This includes coordinated planning and implementation to deploy the various water holdings in a way that maximises the effectiveness of combined water holdings and other water in the river system, such as consumptive water on its way to users. This work occurs through the Southern Connected Basin Environmental Watering Committee.

The ecological characteristics of the northern Basin, along with smaller environmental water holdings compared to the southern connected Basin, mean that there are fewer opportunities to coordinate environmental watering actions in the north. Nevertheless, coordinated watering actions to provide benefits for northern rivers are possible and have been undertaken, in particular in response to deteriorating conditions in recent years. Benefits of using environmental water holdings from the CEWH and Basin state governments have been supported by protecting these holdings on their way through the system.

When delivering environmental water, managers and holders jointly with river operators:

- respond to prevailing conditions and opportunities as they arise
- maximise environmental benefit (e.g. responding to natural flow events, coordinating the water delivery, and building on local and Aboriginal knowledge)
- coordinate operation of related infrastructure (e.g. releases from storages, operation of locks, weirs, regulators, related channel systems pumps and use of diversion banks), and
- manage and mitigate risks, including any impacts on third parties.

River operators have a critical role to play in the delivery of environmental water. Operators are required to deliver water to their customers within the river management practices agreed by various Basin governments. The river operators' responsibility is to deliver water to all entitlement holders, whether it is for environmental or consumptive use.

River operators manage environmental water with the same diligence and caution they use to deliver irrigation and town water. This includes continually appraising any risks, forecasting rainfall events and tributary inflows against peak regulated operating levels, and being careful to manage any possible impacts while delivering water. Environmental water holders work with operators in real time to manage adverse impacts, while still getting the best environmental outcomes.

Review

Upon completion of the watering action, a review process is undertaken by participating parties to inform future watering actions and long-term management. This review is informed by the operational monitoring, results of ecological monitoring, and feedback provided by site managers and the local community.

Box 8: Partners involved in water delivery

There are a number of stakeholders who actively work in partnership across the Basin to coordinate environmental water delivery. Currently this includes:

- Managers of held and planned environmental water
  - CEWH
  - NSW Planning and Environment Department
  - NSW Office of Water
  - QLD Natural Resources, Mines and Energy
  - Victorian Environmental Water Holder
  - Victorian Department of Environment and Primary Industries
  - The Living Murray (Vic, NSW, SA, ACT and Commonwealth governments)
  - South Australian Department of Environment, Water and Natural Resources
- River and infrastructure operators
  - State Water
  - Sun Water
  - MDBA
  - Goulburn-Murray Water, Lower Murray Water, Grampians–Wimmera–Mallee Water
  - SA Water
  - Snowy Hydro
  - Irrigation companies
- Land and waterway managers
  - National Parks in each state (e.g. Parks Victoria, NSW National Parks and Wildlife Service)
  - Forestry
  - Private landholders
  - Catchment Management Authorities/ Local Land Services/Natural Resource Management groups
- Local communities (community and environmental water advisory groups).

5 How the MDBA identifies Basin annual environmental watering priorities

Introduction

The Basin annual environmental watering priorities are the annual expression of this Strategy. Each year the MDBA publishes an environmental watering 'outlook' in the first quarter of the calendar year and Basin annual environmental watering priorities at the end of June. These provide guidance to water holders and managers on priorities for the coming water year from a whole-of-Basin perspective. The Basin priorities developed by the MDBA are not an exhaustive list of all important watering actions in the Basin, and are complemented by annual environmental watering priorities prepared by Basin states.

Since the first edition of the Strategy was published in 2014 the format of the priorities has changed. Rather than being an annual outcome at a specific site, the priorities now identify outcomes over multiple years at numerous sites. The priorities also provide for actions under different resource availability scenarios. Together, these two changes provide a more flexible approach and a longer-term view. Annual guidance continues to be provided, which highlights specific areas of focus for the particular year. Environmental water holders and managers will consider these priorities alongside priorities of local or regional significance.

Environmental water holders and managers make decisions throughout the year about the use of environmental water. In some years there may be more places or processes that need more water than there is available. In these circumstances choices will need to be made about the relative priority of sites or watering actions.

How watering priorities will be identified

The principles applied to determine Basin Priorities (Part 6, Division 1 of the Environmental Watering Plan of the Basin Plan) are:

1. consistency with the principles of ecologically sustainable development and international agreements
2. consistency with Environmental Watering Plan objectives
3. flexibility and responsiveness
4. condition of environmental assets and ecosystem functions
5. likely effectiveness and related matters
6. risks and related matters, and
7. robust and transparent decisions.

Guided by these principles, the process to identify Basin annual priorities will follow the broad steps identified below.

Identifying environmental watering need

A mid-year review of environmental condition is carried out to determine the environmental watering need of Basin-significant assets and functions. This includes:

- consideration of outcomes from previous watering and whether additional watering is required to consolidate outcomes
- assessment of flow data against environmental watering requirements for significant sites across the Basin, and
- consideration of ecological condition based on ecological monitoring data and information provided from regional, state and commonwealth agencies and other stakeholders.

This information is used to identify particular areas of focus that build upon the rolling multi-year priorities. The MDBA publishes an outlook statement in the first quarter of the calendar year which reflects these findings. Environmental watering need is considered again before the Basin annual environmental watering priorities are published in June to ensure they are still relevant.

Identify the resource availability scenario and management outcomes

The MDBA considers conditions in the previous season, current water availability, long-term weather forecasts, antecedent conditions and likely water availability to judge the upcoming resource availability scenario (see Table 1) in the Basin. Consistent with the outcomes and strategies identified in Chapter 2 and Chapter 3 of this Strategy, the MDBA identifies management outcomes and priorities consistent with the conditions expected in the coming year. Priorities are expressed in such a way that there is flexibility if seasonal conditions are different to what was expected.

Particular attention is paid to outcomes that need coordination across state borders, as these cannot be addressed by states acting alone. The assessment of sites is combined with an assessment of functions and consideration of desired outcomes.

Consider complementary outcomes and risks

Through various activities such as the First Nations Environmental Water Guidance Project (see Chapter 7) many First Nations throughout the Basin are expressing and documenting their objectives for environmental water. Considering the local knowledge and environmental objectives of First Nations communities in environmental water planning decisions helps to improve outcomes of environmental watering and the health of Country. Inclusion of cultural objectives in water planning will also strengthen cultural continuity, contribute to First Nations community wellbeing and support opportunities for managing and accessing water into the future.

Environmental outcomes may also lead to social and economic benefits. For example, improved water quality and reduced salinity levels lower the cost to treat water and reduce damage to water infrastructure associated with salinity. Environmental flows can also raise tourist numbers along waterways in regional communities by maintaining habitat for fish, as well as improving the aesthetic values associated with a healthy environment. The potential for complementary outcomes is considered at a broad level at the stage of identifying possible priorities. However, detailed consideration would also be given to this when a state or the CEWH is considering implementation.

The MDBA will also consider the broad risks associated with the delivery of a particular priority, to ensure that the priority is practical and feasible. However, environmental water holders make the final judgement about the level of acceptable risk in relation to environmental watering and which mitigating strategies are adopted.

Consider state annual environmental watering priorities

The priorities are informed by local experience and knowledge. The MDBA works with environmental water holders and managers to help identify regional priorities considered important at a Basin scale. The MDBA consults with environmental water holders and managers before publishing the Basin environmental watering outlook early in the calendar year. This provides a mid-year summary of progress, considers weather and water availability forecasts, and gives an early indication of possible priorities.

The MDBA formally considers state annual environmental watering priorities in early June. The Basin-wide significance of regional priorities is considered. This includes: the significance of the environmental benefit if the priority is met; the risk of not listing the priority; certainty and likelihood of benefit; and synergies and multiple outcomes. These assessments will help determine whether a site, environmental watering action or outcome should be included in the Basin annual environmental watering priorities.

Consult and collaborate

The Basin priorities are considered in the context of seasonal, operational, scientific and management knowledge.

Feedback from consultation with governments, water holders, owners and managers of environmental assets, river operators, peak groups, community representatives and people directly affected by environmental watering is gathered. Together with formal reporting from holders and managers of environmental water, this information is used to inform the development of priorities. Consultation with communities is undertaken in collaboration with existing state consultation processes.

As components of the Environmental Watering Plan are implemented and planning cycles between and within jurisdictions are integrated, the MDBA will adapt and improve how it identifies Basin priorities. Improvements will be underpinned by consultation and engagement, and improvements in knowledge and processes.

Priorities in very dry years

In some years there will be a lot of competition for where environmental water could be used in the Basin. This will be particularly evident in individual dry years and during droughts. As outlined in Table 1, the management objectives for delivery of environmental water in these years range from 'avoiding irretrievable loss of or damage to environmental assets' through to maintaining basic functioning, where possible. While all of the steps outlined in the sections above will still be appropriate, there will be a heightened need to compare potential benefits and risks of alternative watering options.

Experience from the millennium drought was that managers had to thoroughly and continually weigh up the outcomes and risks of using the small amounts of available environmental water in different places. One of the hardest decisions was whether to use small amounts of water on drought refuges in different parts of the Basin, or to provide water to keep the river running to the Coorong and the sea. There is no single answer which will be right for all similar dilemmas in the future. However, one aspect that Basin governments found useful was to consider the material difference that the available water could have at different sites versus the risk of catastrophic events.

More recent experiences, such as the fish deaths in Barwon-Darling river system in the summer of 2018–19, have reaffirmed the complexity of decision-making in drought conditions. Ideally, areas at high risk of fish deaths should have early warning systems and emergency response plans. Risk assessments may also help by determining how to best manage available environmental water during prolonged dry spells, and this should include refining flow requirements to aid in controlling stratification in high-risk weir pools.

Where there may be trade-offs involved in allocating water among competing priorities or conflicting views in the setting of Basin annual priorities, the MDBA will use its best endeavours to resolve these. This may include discussions with the states before publishing the Basin annual watering priorities. It is important to note that the MDBA's priorities provide guidance—the ultimate decision on use rests with the environmental water holders.

6 Measuring progress

The MDBA is responsible for evaluating the effectiveness of the Basin Plan, including the achievement of the environmental outcomes listed in Chapter 2. The first evaluation will occur in 2020, in collaboration with State and Commonwealth partner agencies, and in consultation with the community. Alongside the MDBA's evaluation, the CEWH will report on the effectiveness of environmental water at the Basin scale, and the States will report on the achievement of environmental outcomes at the asset scale.

Revised evaluation framework

An interim evaluation of the Basin Plan occurred in 2017 and provided the first opportunity to test the MDBA's evaluation framework. With respect to environmental outcomes, each theme was treated separately, with a technical assessment made for flows and connectivity, native vegetation, waterbirds and native fish. While this approach allowed progress to be assessed robustly for each theme, a range of challenges made it difficult to draw a link between flow and environmental response and therefore evaluate the Basin Plan's effectiveness.

To overcome this limitation, the MDBA has revised the Basin Plan Evaluation Framework. The new framework groups environmental outcomes according to those categories of flow and connectivity that will be altered by the Basin Plan, as follows:

- longitudinal connectivity in the northern Basin and subsequent environmental outcomes
- longitudinal connectivity in the southern Basin and subsequent environmental outcomes
- lateral connectivity at key wetlands across the Basin and subsequent environmental outcomes, and
- end-of-system connectivity and subsequent environmental outcomes, including water quality.

This approach will focus attention on the role of hydrology—the key management lever of the Basin Plan—in driving environmental outcomes. It will also allow for consideration of differences in: the levers available to deliver environmental water (greater in the southern Basin); climatological and ecological systems; environmental threats; and stakeholders' values.

The expected environmental outcomes in Chapter 2 will feature prominently in the evaluation. Progress will be assessed by the following test: that there should be no loss or degradation of the environmental outcomes being sought in the initial phase of the Basin Plan implementation (up until June 2019) and that there should be improvements thereafter (from July 2019). This response is illustrated in Figure 20, which shows that environmental response will initially be neutral or even negative before becoming positive from 2019 onwards and then tapering for the next 20 years.

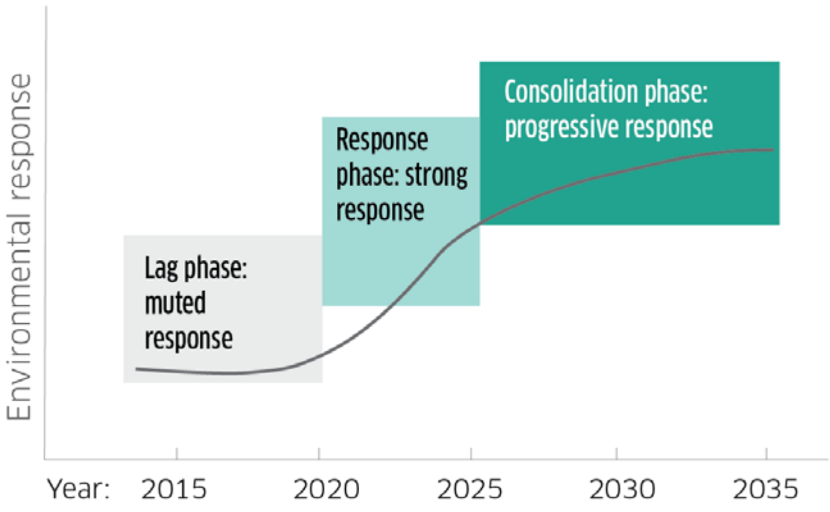

Figure 20: Illustrative environmental response to Basin Plan implementation. This is based on a sequence of average years, and periods of drought may delay recovery while wet periods may accelerate the response.

Evaluation of the Basin Plan will address two sets of questions, one relating to the condition and/or trend of various indicators, the other relating to the contribution of the Basin Plan to the performance of those indicators. An indicator is a measureable feature of an ecosystem, for example, the geographic range of a fish species, or the number of waterbird species in the Basin. Basin-scale datasets, collected by MDBA's monitoring program, will be the primary source of information to understand condition or trend. Asset-scale datasets, collected by the states, will be an important secondary source.

Identifying the contribution of the Basin Plan to environmental outcomes will be informed by multiple lines of evidence including intervention monitoring, flow-ecology models based on cause-effect relationships between ecosystem components, and the latest research. Data collected through intervention monitoring programs being implemented by the CEWH and states will be pivotal. Where possible, counterfactual modelling (i.e. what would have happened without the Basin Plan) will be used.

External factors, particularly climate, can impact on environmental outcomes. For example, over a sequence of dry years the observed environmental response would be expected to be muted relative to a sequence of wet years. Therefore, evaluation of the Basin Plan must address questions relating to the extent to which environmental outcomes have been maintained or improved as expected *given prevailing conditions*. During a sequence of dry years, if the available water has been used wisely, avoiding further degradation or a muted environmental improvement may be considered successful.

Further information for measuring progress will be provided through annual reporting on implementation of the environmental management framework, including:

- the purposes of environmental watering actions

- volumes of environmental water delivered and how it aligned with Basin annual environmental watering priorities, and
- how Commonwealth and states coordinated watering activities.

From this information it will be possible to identify the factors that enable or act as barriers to effective and efficient environmental watering.

Climate change is likely to have a significant impact on the Basin's rivers and water-dependent ecosystems. Direct impacts arising from changes in the climate (e.g. increasing air temperature and changing rainfall patterns) and indirect impacts on inflows, water availability and river hydrology (e.g. less frequent overbank flow events) will have significant and complex impacts on aquatic ecosystems. Longer-term projections associated with increasing greenhouse gas emissions indicate that the Basin's climate is likely to trend towards hotter and drier conditions, with the prevalence of longer droughts interspersed by more extreme rainfall events. These may not produce the same flows as occurred historically due to changes in their timing and catchment conditions.

If these trends eventuate, there is a significant risk that the Basin Plan will not achieve many of its intended environmental objectives and result in slower progress towards others. Consequently, the MDBA is taking steps to understand the impacts of climate change on the Strategy's expected environmental outcomes (see Chapter 7).

7 Future Work

Review and update of the Strategy

The MDBA has reviewed the Strategy according to the requirements of the Basin Plan. The key findings and recommendations of that review are published in a report via the MDBA's Get involved website.

This updated Strategy captures the recommendations of the review. As explained in Chapter 1, the changes here contemporise the Strategy, reflecting policy changes, new scientific knowledge and other updates. The 2022 update of the Strategy is expected to contain more substantive updates. These are briefly described below, noting that other matters may emerge that also warrant investigation.

Ongoing development

First Nations' objectives and outcomes for shared benefits of environmental water

Independent, culturally authoritative and strategic input from First Nations people into environmental water planning can improve environmental watering decisions. Managing environmental water in ways that incorporate First Nations people's objectives and considering the local knowledge of First Nations communities in environmental water planning decisions will help to improve outcomes of environmental watering and the health of Country. Inclusion of cultural objectives in water planning will also support cultural continuity, contribute to First Nation community wellbeing, and build capacity for managing and accessing water into the future.

First Nations environmental outcomes describe tangible physical benefits that can be derived from environmental watering for First Nations people, such as improved populations of culturally significant fish species or improved health of important cultural landscapes. When responsive to Traditional Owner objectives, environmental watering can provide complementary cultural benefits, but it is not able to provide all of the outcomes that cultural flows could provide. Cultural flows are water entitlements that are legally and beneficially owned by First Nations of a sufficient and adequate quantity and quality to improve the spiritual, cultural, natural, environmental, social and economic conditions of those Nations.

Many First Nations throughout the Basin have already articulated elements of their desired environmental outcomes and objectives through water resource plan consultation, Aboriginal Waterway Assessments, and site and State-based engagement programs. Where this information is available it is vital that it is incorporated into the information base for planning environmental water planning and decision-making.

The MDBA is committed to developing and improving processes to routinely incorporate First Nations' objectives and Traditional Owners' knowledge into environmental water planning. The First Nations Environmental Water Guidance (FNEWG) Project aims to develop a defined and transparent methodology for First Nations' environmental watering objectives to be incorporated in environmental water planning. This project is co-funded with the Commonwealth Environmental Water Office (CEWO).

By engaging First Nations in a collaborative design process, the MDBA and CEWO hope to foster a partnership with the Northern Basin Aboriginal Nations and the Murray Lower Darling Rivers Indigenous Network and establish an enduring mechanism for inclusion of First Nation objectives into Basin environmental water planning. The project will also have a focus on knowledge sharing and building capacity within federal agencies and First Nation organisations.

Water management strategies to improve flow coordination

The review of the Strategy identified strong support for including more specific water management strategies around complex watering actions as well as water management strategies that improve coordination of flows (including HEW, PEW and consumptive water) across the Basin.

In the southern connected system, flow coordination is common practice. Environmental flows are regularly coordinated from multiple tributaries and multiple environmental water holders, and build on unregulated and regulated flows to target multiple outcomes throughout the system. A good example is from the spring of 2017, when over 180 GL of environmental water from the CEWH, VEWH and joint-government water portfolios was coordinated to flood Barmah-Millewa Forest, and then reused at Hattah Lakes.

Flow coordination is a new practice in the north. However, in April-May 2018 the CEWO and the NSW Government coordinated the delivery of environmental water into the Barwon-Darling river system to mitigate a cease-to-flow event. This was the first event of this type to be actively managed through environmental releases and environmental flow protection, and had measurable benefits for endangered native fish.

Challenges remain, of course, in both parts of the Basin. In the south, these include the need to implement pre-requisite policy measures, relax constraints to allow water to reach priority environmental assets, and improve compliance systems. In the north, these include monitoring and tracking of flows; guarding against unauthorised take; timing releases from dams with unregulated flow events; and gathering the expertise of state governments, local councils, irrigators, Aboriginal communities and landholders along rivers. These will continue to make the science of flow coordination challenging but the benefits that result, both environmentally and socially, make the effort worthwhile.

The MDBA will consider including a strategy in the 2022 update on flow coordination in the northern Basin and the southern connected system, depending on how well long-term watering plans cover flow coordination between catchments and the rules in water sharing plans provide for environmental watering between connected systems.

Ensuring the best possible environmental outcomes from environmental watering while investigating opportunities to improve social and economic outcomes

The Basin Plan aims to achieve improvements to water-dependent ecosystems in the context of the Murray–Darling Basin being a working river. When the Basin Plan was being prepared, understanding of the impacts to communities and the economy of recovering water to improve the Basin's health was limited; it focused primarily on potential negative impacts on communities using long established economic tools and measurements. This reflected the lack of development of tools to measure the social and economic benefits of restoring the health of the Basin's environment. These benefits include the ecosystem services (services that healthy ecosystems provide) which underpin agricultural production, clean air, water and soil. This is a relatively new and evolving field of economics.

The MDBA recognises that more work is needed to give full effect to the provisions in the Basin Plan around optimisation of social and economic benefits arising from planning and delivering water for the environment to protect and restore the Basin's water-dependent ecosystems. Currently, the MDBA does not provide any guidance for water planners and managers about how social and economic information can be considered in decision-making processes. In the case of jurisdictions' water planning and delivery, while there is evidence of social and economic matters being considered in some cases, this appears to rely on local knowledge and relationships.

By improving our understanding of social and economic benefits arising from environmental watering, the MDBA and Basin states could give more consideration to these complementary outcomes in decision-making about environmental watering, and better articulate to communities the social and economic benefits that achieving environmental outcomes provide. These could include local benefits to tourist operators and recreational fishing enthusiasts, and contributions that a healthy river makes to human wellbeing and a strong community fabric. Water managers could give more consideration to these matters when planning and delivering water for the environment.

The MDBA is undertaking a work program to identify the best possible environmental outcomes from environmental watering that include opportunities to improve social and economic outcomes. The outcome of this work program will feed into the 2022 update of the Strategy.

Improved SMARTness of expected environmental outcomes and better links to Basin Plan objectives

Setting SMART targets is a necessary first step for adaptive management but is often avoided because it is difficult in a complex system or because the targets automatically inherit the uncertainty of today's science — they may set the bar too low or too high. Despite this, the first edition of the Strategy demonstrated that it is possible to identify SMART targets for a large river basin. By setting SMART expected environmental outcomes, the adaptive management cycle was initiated, providing measurable indicators for monitoring and evaluation, and making environmental water holders and managers accountable. The targets have also had the effect of communicating exactly what outcomes are being sought, thereby increasing public understanding and confidence.

The review identified a number of issues relating to the specificity, measurability and achievability of the expected environmental outcomes. Much of the concern was to do with uncertainties of achieving outcomes under climate change; constraints affecting delivery of environmental water; under-resourcing and poor design of monitoring and evaluation programs; and the desire to broaden the set of outcomes to include other themes, components and aspects within themes.

To address these issues, the next Strategy (2022) will improve the SMARTness of the current expected environmental outcomes. These improvements may include updating flow metrics so that they are more ecologically relevant and including the condition of vegetation types that were neglected in the first Strategy (e.g. lignum shrublands).

Another way of ensuring that SMART targets assist adaptive management is by widening their scope to include outcomes directly impacted by environmental water management. For example, the waterbird expected environmental outcomes concentrate on population measures, such as species richness and abundance, and neglect waterbird habitat extent and condition, when it is habitat that is often the focus of environmental water delivery. It has also become apparent that for all biota, be it waterbirds, vegetation or fish, management of the whole life cycle is essential, rather than just particular elements, such as spawning. Additional expected environmental outcomes may be added to address these issues.

Additional environmental themes where it can be demonstrated that they add value to Basin-wide environmental watering

The Strategy focuses on ecological components that are considered important and representative parts of healthy functioning water-dependent ecosystems in the Basin. The four existing themes (see Figure 5) are a subset of all themes that constitute a water-dependent ecosystem. Additional themes may be included in the next Strategy (2022) following a work program to investigate which new ecological themes, or which additions to existing themes, would enhance the effectiveness and utility of the Strategy. Preliminary analysis the MDBA has undertaken has identified the most prospective additional themes are ecosystem types, other vertebrates and ecosystem functions.

An ecosystem type classification has been completed for the Basin, providing an understanding of the distribution and uniqueness of the different ecosystems within and between catchments. Their protection and restoration has the potential to complement existing themes by preserving valued habitats and critical processes of ecosystems in their entirety. There are a number of existing and emerging tools, including large datasets collected by remote sensing satellites, becoming available that describe aspects of the condition of ecosystems. Novel analysis of these products has the potential to generate insights into the health of the many different ecosystem types across the Basin. This information can guide the effective use of environmental water and therefore contribute to enhancing the 2022 edition of the Strategy.

Ecosystem functions as a sub-theme of the flows and connectivity theme will be further explored for inclusion in the next Strategy. Ecosystem functions are embedded within both the *Water Act 2007* and Basin Plan legislation as an important part of a healthy water-dependent ecosystem. A number of Basin states have included objectives and targets for ecosystem functions in long-term environmental watering plans, and including them in the next Strategy would provide for consistency. For the purpose of this Strategy, ecosystem functions are defined as the interactions (events, reactions or operations) among biotic (living) and abiotic (non-living) elements of ecosystems. A challenge for incorporating ecosystem functions into environmental water planning, delivery and monitoring is the almost infinite number of ecosystem processes and interactions within freshwater and estuarine ecosystems.

Ecosystem structure and functions are intrinsically linked, with both being essential to an ecosystem (see Figure 4, Chapter 2). Achieving the Basin Plan's expected structural ecosystem outcomes of interest—such as healthy populations of native fish, vegetation and waterbirds—depends on a range of ecosystem functions being maintained and restored.

There are a number of cross-cutting ecosystem functions that contribute to the health and condition of water-dependent ecosystems more broadly and so are common across all themes. For example, lateral connectivity between rivers and floodplains is a critical ecosystem function that enables the transfer of energy/carbon and nutrients that supports productivity and food webs. Certain functions essential for fish, vegetation and waterbird outcomes will be unique to each ecological theme. Certain functions integrate the ecological themes as they demonstrate how the different ecosystem components interact.

In recent years there has been a growing emphasis on restoring the ecological functions of rivers with a number of research programs underway that will facilitate the progression of knowledge related to this theme over the coming years. It is intended that this knowledge will be used to improve coverage of expected environmental outcomes. Specifically, over the coming years to 2022, the MDBA will focus on developing and applying understanding of the flow requirements of cross-cutting ecological functions that relate longitudinal and lateral connectivity to ecological processes through the supply and transport of energy (carbon) and nutrients, and consequent linkage with productivity and food webs. The development of expected environmental outcomes for ecosystem functions relating to productivity will be explored to complement the ecological theme-specific outcomes that already explicitly and implicitly incorporate a suite of ecosystem functions that relate to life-cycle processes.

Assess climate risks to the expected environmental outcomes and water management strategies

The Basin's climate is inherently variable, with periods of drought and flood events common features of the climate. Water management strategies are developed to operate within this variability, in conjunction with other instruments that prioritise actions in accordance with different resource availability scenarios. The monitoring and research efforts of the MDBA, Basin governments and research institutions are progressively improving our capacity to manage environmental water in the context of extreme variability, facilitated through adaptive management.

Over the past two decades, however, the observed annual patterns of rainfall and inflow volumes appear to have been changing, with at least some of this change attributed to increasing concentrations of greenhouse gases, like carbon dioxide. These observations are largely consistent with the changes projected by the Australian government (Climate Change in Australia), which includes:

- higher average ambient air temperatures and more extreme heat events (heatwaves)
- changing seasonality of rainfall, declining in winter-spring but increasing in autumn and summer
- longer periods spent in drought, and lower average soil moisture, and
- less frequent but more extreme rainfall events.

Climate change is already having some influence on the Basin's climate and the hydrology of its rivers. It is therefore likely that climate change is also influencing the achievement of the Strategy's expected environmental outcomes. To what degree, is a complex question and one that requires more monitoring and research to be able to answer.

In February 2019 the MDBA released a discussion paper entitled 'Climate change and the Murray–Darling Basin Plan'. This paper outlined; the projected impacts of climate change, the future challenges likely to be encountered by environmental water managers, and a dedicated climate change program to progress the required research. As part of this program, the MDBA is holding a series of climate change workshops to engage with the research community on this issue and actively seek guidance on an approach to evaluate and address climate change risks during future reviews of the Basin-wide environmental watering strategy, Environmental Watering Plan and Basin Plan. While an approach is not expected to be finalised until later in 2019, it is expected that new research and capacity developed through this program will help:

- identify and evaluate climate change risks, and how these are shared between water users and the environment
- examine the potential impacts of climate change, and whether expected environmental outcomes and water management strategies need to be adjusted, and
- improve the MDBA's immediate responses to climate-driven events like the fish deaths during the summer of 2018-19.

The outcomes of this work will be used to inform the 2022 update of the Strategy, where appropriate.

How MDBA will prioritise future work

The actions described above will become a work program for the MDBA and the Basin governments during the period 2019–2022. This work is expected to result in a substantial update of the Strategy in 2022 and prompt a review of the states' long-term environmental watering plans.

The MDBA has a number of criteria to assess which outputs from the work program would be most likely to provide meaningful improvements to the Strategy, these being the extent to which the new information would:

- ensure that the Basin Plan's environmental objectives are met
- improve the Basin-wide approach to planning for environmental watering (without duplicating the regional and existing multi-jurisdictional approach, including that of the CEWH)

- improve management of environmental water and or/operational practice
- improve alignment with Basin Plan environmental objectives and targets
- strengthen connections with water resource plans and long-term environmental watering plans
- improve the evaluation of Basin Plan effectiveness
- better account for climate variability and change
- be feasible in the time available, and
- be cost effective.

The work foreshadowed in this chapter to further strengthen the Strategy exemplifies the adaptive management approach that the MDBA is taking to implementing the Basin Plan. The work program reflects that knowledge will continue to evolve as environmental water policy makers, planners and managers as well as river operators draw lessons from how the Basin's water-dependent ecosystems respond to increased water availability and the challenges of a changing climate. The work plan also reconfirms the MDBA's commitment to improving its approach to achieve the best possible outcomes for the Basin environment within the current operating constraints, to support Basin communities and the wider Australian public. Further strengthening the Basin-wide environmental water strategy will ensure that it retains its role, acknowledged by the Productivity Commission, as '*the key strategic plan governing environmental watering across the Basin'.*

Glossary

Anabranches	Branch of a river that leaves the main stream and re-joins it downstream.
Bank-full flows	The maximum amount of water a channel can hold without overflowing—a key factor in determining the shape of a river.
Base flows	The usual, reliable, background flow levels within a river channel, maintained generally by seepage from groundwater storage, but also by surface inflows.
CAMBA	China–Australia Migratory Bird Agreement.
Cease-to-flow periods	A time when there is no flow in the channel.
Cold water pollution	Occurs when relatively colder water is released from water storages into the river. This can have negative impacts on the environment by restricting the growth and reproduction of freshwater animals.
Diadromous	Fishes spending part of their life cycle in salt water and part in fresh water.
Ecosystem functions	The processes that arise from the interaction of biota with the physical environment and with each other, that maintain the integrity and health of an ecosystem.
Estuarine system	A coastal habitat (or body of water) characterised by the mixing of fresh and salt water. Estuaries are influenced by tide, wave and river processes.
Flood-runner	A stream that branches off and flows away from a main stream channel.
Flow components	The different volumes of water that make up a flow regime. They typically include ‘cease-to-flow’ periods, ‘base flows’, ‘freshes’, ‘bank-full flows’ and ‘over-bank flows’.
Flow regime	The description of the characteristic pattern of a river’s flow including the quantity, timing and variability.
Food web	The linking and inter-linking of multiple food chains, as may be found in a complex ecosystem (for example, river/lake/forest) with several stages in the food chains.
Freshes	A pulse of water in a river channel, usually caused by heavy rainfall upstream. Freshes deliver important nutrients and enable salt and sediment to move in the system.

Held environmental water	Water available under: a water access right, a water delivery right, or an irrigation right; for the purposes of achieving environmental outcomes (including water specified in a water access right to be for environmental use).
Hydrodynamic diversity	The way flows interact with the physical structure of rivers to create sections of fast-flowing, slow-flowing and still water habitats at local to landscape scales.
Hydrology	The study of the occurrence, distribution and movement of water.
Hydrological connectivity	The flow that links natural aquatic environments. Lateral connectivity is the flow linking river channels and the floodplain. Longitudinal connectivity relates to the consistent downstream flow along the length of rivers.
Hypoxic blackwater	Severely oxygen-depleted water caused by organisms consuming large amounts of oxygen during decomposition of organic matter in the water column. The black appearance of the water is due to the release of carbon compounds as the organic matter decays.
JAMBA	Japan–Australia Migratory Bird Agreement.
Over-bank flows	Flows that spill over the riverbank and onto floodplains. They benefit a broad range of biota (including floodplain vegetation communities, birds and native fish) and support important ecosystem functions.
Planned environmental water	Water that has the meaning as given by Section 6 of the *Water Act 2007*. In summary, it is water committed by: the Basin Plan, a water resource plan or a plan made under a state water management law, or any other instrument made under a law of a state for the purposes of achieving environmental outcomes.
Population structure	A healthy population structure has good fish numbers in a range of age and size classes (including sex ratios for some species). These populations demonstrate regular recruitment (younger classes) and good numbers of mature fish to breed future generations.
Propagule	A seed, spore or any portion of plant material capable of propagating a plant to the next stage of its life cycle, such as by dispersal.
Rapid-Eye	A proprietary name for a form of satellite imagery.

Ramsar Convention	An international treaty to maintain the ecological character of key wetlands.
Recruitment	Successful development and growth of juveniles; such that they have the ability to contribute to the next generation.
Representative species	Species whose habitat requirements are 'typical' of a wider suite of species within an ecosystem, such that they can act as surrogates.
Riparian	The part of the landscape adjoining rivers and streams that has a direct influence on the water and aquatic ecosystems within them.
Riverine system	An aquatic habitat within a channel that is characterised by a downstream flow.
ROKAMBA	Republic of Korea–Australia Migratory Bird Agreement.
Southern connected Basin	Rivers in the southern part of the Murray–Darling Basin – Murrumbidgee, Murray, Mitta Mitta, Kiewa, Ovens, Goulburn, Broken, Campaspe, Loddon, Edward-Wakool, Lower Darling
Submergent macrophyte	Plants that grow in the water and have roots in the soil with the majority of the plant being submerged.
Umbrella Environmental Assets	High ecological value places in the Basin that were used to help determine the Basin Plan's environmentally sustainable level of take (e.g. Gwydir Wetlands, Barmah–Millewa Forest).
Water-dependent system	An ecosystem or species that depends on periodic or sustained inundation, waterlogging or significant inputs of water for natural functioning and survival.

Appendices

Appendix 1 – Information used to develop expected environmental outcomes and water management strategies

Hydrology and connectivity

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Note re vegetation data: Initially data were acquired using Landsat7. Unfortunately this data was corrupted and alternative data were acquired through '*Rapid Eye'*. Landsat8 will be available for future data collection. This will improve the extent and accuracy of the data and will allow for condition of river red gum, black box and coolibah to be scored within five categories with confidence, Basin-wide.

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Other sources

The MDBA also ran nine workshops with subject matter experts from government, academia and private consulting firms. These were:

- vegetation expert workshops, held on 20 February 2014 in Adelaide and 15 April 2014 in Canberra
- waterbird expert workshops, held on 14 October 2013 and 13 March 2014 in Canberra
- native fish expert workshops, held on 11–12 February 2014 in Canberra; 25–26 March 2014 in Heidelberg (SA); 27–28 May 2014 in Brisbane; 5 June 2014 in Adelaide, and 23–24 September 2014 in Canberra.

Appendix 2 – Expected vegetation outcomes by region

The table below identifies the current best estimate of areas where outcomes are expected within current constraints and operational works and measures. The removal of constraints would result in greater outcomes because the area of forest and woodland receiving flows would increase. Naturally-occurring high flows (that are not affected by the Basin Plan) will also contribute to the outcomes listed below, subject to climatic variables.

Environmental assets and outcomes listed below must be considered in regional long-term environmental watering plans (in addition to regionally significant sites). This assessment is based on the best information available on the relationship between different flows and inundation of the river corridor and well-defined constraints. Areas could change if better information becomes available in the future.

Table 2: Expected extent and condition outcomes for communities of water-dependent vegetation as a result of the Basin Plan.

Basin region	Outcomes for water-dependent vegetation	Area of river red gum (ha)*	Area of black box (ha)*	Area of coolibah (ha)*	Shrublands	Non–woody water-dependent vegetation
Paroo	Maintain extent and condition** of water-dependent vegetation near river channels and on the floodplain	2,300	38,300	22,800		Closely fringing or occurring within the Paroo River
Warrego	Maintain extent and condition** of water-dependent vegetation near river channels and on the floodplain	7,300	80,400	121,400		Closely fringing or occurring within the Warrego, Langlo, Ward & Nive rivers
Nebine	Maintain extent and condition** of water-dependent vegetation near river channels and on the floodplain	200	28,800	15,400		Closely fringing or occurring within the Nebine Creek
Condamine–Balonne	Maintain extent and condition** of water-dependent vegetation near river channels and on areas of the floodplain	11,500#	36,100**	62,900**	Lignum in Narran Lakes	Closely fringing or occurring within the Condamine, Balonne, Birrie, Bokhara, Culgoa, Maranoa, Merivale & Narran rivers

Moonie	Maintain extent and condition** of water-dependent vegetation near river channels and on the floodplain	2,200	2,500	7,900		Closely fringing or occurring within the Moonie River
Border Rivers	Maintain extent and condition** of water-dependent vegetation near river channels and on areas of the floodplain	10,700	3,800	35,200	Lignum in the lower Border rivers region	Closely fringing or occurring within the Barwon, Dumaresq, Macintyre rivers & Macintyre Brook
Gwydir	Maintain extent and condition** of water-dependent vegetation near river channels and on low-lying areas of the floodplain.	4,500**	600**	6,500**	Lignum in the lower Gwydir	Closely fringing or occurring within the Gwydir River and marsh club-rush and water couch in the Gwydir Wetlands
Namoi	Maintain extent and condition** of water-dependent vegetation near river channels.	6,100	800	4,200		Closely fringing or occurring within the Namoi River
Macquarie–Castlereagh	Maintain extent and condition** of water-dependent vegetation near river channels and on low-lying areas of the floodplain	58,200	57,100	32,000	Lignum in the Macquarie Marshes	Closely fringing or occurring within the Bogan, Castlereagh, Macquarie and Talbragar rivers; and common reed, cumbungi and water couch in the Macquarie Marshes
Barwon–Darling	Maintain extent and condition** of water-dependent vegetation near river channels and on low-lying areas of the floodplain	7,800**	11,700**	14,900**		Closely fringing or occurring within the Darling River
Lachlan	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition[i] of black box and river red gum	41,300	58,000		Lignum in the lower Lachlan	Closely fringing or occurring within the Lachlan River and Willandra Creek; and common reed and Cumbungi in the Great Cumbung Swamp

Murrumbidgee	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition[i] of black box and river red gum	68,300	38,900		Lignum in the lower Murrumbidgee	Closely fringing or occurring within the Murrumbidgee River, Billabong and Yanco creeks
Lower Darling	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition[i] of black box and river red gum	10,300	38,600	600	Lignum swamps in the lower Darling region	Closely fringing or occurring within the Darling River, Great Darling Anabranch and Talyawalka Anabranch
Ovens	Maintain extent and condition** water-dependent vegetation near river channels and on the floodplain	10,200	<100			Closely fringing or occurring within the Ovens River
Goulburn–Broken	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition[i] of black box and river red gum	19,800	500			Closely fringing or occurring within the Broken Creek, Broken and Goulburn rivers
Campaspe	Maintain extent and condition** of water-dependent vegetation near river channels	1,900	<100			Closely fringing or occurring within the Campaspe River
Loddon	Maintain extent and condition** of water-dependent vegetation near river channels	2,200	700			Closely fringing or occurring within the Loddon River
Murray	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition[i] of black box and river red gum.	90,600	41,700		Lignum along the Murray River from the junction with the Wakool River to downstream	Closely fringing or occurring within the Murray, Edward, Kiewa, Mitta Mitta, Niemur and Wakool rivers and Tuppal Creek; Ruppia tuberosa in the Coorong and Moira grasslands in the Barmah– Millewa Forest

					of Lock 3, including Chowilla and Hattah Lakes	
Wimmera–Avoca	Maintain extent of water-dependent vegetation near river channels. Improve condition[i] of black box and river red gum.	6,500	3,100			Closely fringing or occurring within the Avoca, Avon, Richardson and Wimmera rivers
Eastern Mt Lofty Ranges	Maintain extent and condition of water-dependent vegetation near river channels	<100	<100			

*Area (ha) (+/- 10%) is based on Cunningham SC, White M, Griffioen P, Newell G and Mac Nally R 2013, 'Mapping Floodplain Vegetation Types across the Murray–Darling Basin', Murray–Darling Basin Authority, Canberra.

**Condition parameters is based on Cunningham SC, Read J, Baker PJ and Mac Nally R 2007, 'Quantitative assessment of stand condition and its relationship to physiological stress in stands of *Eucalyptus camaldulensis (Myrtaceae*) in south-eastern Australia', *Australian Journal of Botany*, 55, 692–699.

#the extent and area of forests and woodlands for the lower Condamine–Balonne, Barwon–Darling and Gwydir regions, and the Bogan River, are considered to be an underestimate due to current technical limitations in determining the lateral extent achieved through implementation of the Basin Plan.

[i]Condition is scored from 0–10 and classified within five categories for river red gum and two categories for black box in the Lachlan, Murrumbidgee, Lower Darling, Goulburn–Broken and Wimmera–Avoca. As the data capture improves across the Basin, five categories of condition will be used across the Basin.

Table 3: Current condition of black box trees in the Lachlan, Murrumbidgee, Lower Darling, Murray, Wimmera–Avoca and Goulburn–Broken.

Basin region	Vegetation with a condition[i] score 0 – 6	Vegetation with a condition[i] score >6 – 10	Percent of vegetation assessed (within the managed floodplain)[iii]
Lachlan	72%	28%	45%
Murrumbidgee	54%	46%	73%
Lower Darling	72%	28%	85%
Murray	33%	65%	28%
Wimmera–Avoca	42%	58%	26%
Goulburn–Broken	28%	72%	77%

Table 4: Current condition of river red gum trees in the Lachlan, Murrumbidgee, Lower Darling, Murray, Wimmera–Avoca and Goulburn–Broken.

Basin region	Vegetation with a condition[i] score 0 – 2	Vegetation with a condition[i] score >2 – 4	Vegetation with a condition[i] score >4 – 6	Vegetation with a condition[i] score >6 – 8	Vegetation with a condition[i] score >8 – 10	Percent of vegetation assessed (within the managed floodplain)[iii]
Lachlan	3%	8%	21%	41%	26%	93%
Murrumbidgee	3%	8%	22%	40%	27%	93%
Lower Darling	11%	5%	7%	41%	35%	92%
Murray	2%	1%	10%	51%	35%	51%
Wimmera–Avoca	3%	5%	18%	60%	13%	20%
Goulburn-Broken	1%	2%	7%	34%	55%	89%

Notes:

[i] Condition is scored from 0–10 and classified within five categories for river red gum and two categories for black box in the Lachlan, Murrumbidgee, Lower Darling, Goulburn–Broken and Wimmera– Avoca. As the data capture improves across the Basin, five categories of condition will be used across the Basin.

[ii] Condition is scored from 0–10 and classified within five condition categories, being: 0–2 'severely degraded'; >2–4 'degraded'; >4–6 'poor'; >6–8 'moderate'; >8–10 'good'.

[iii] The area of vegetation where condition has been assessed is based on the existing extent of RapidEye™ imagery purchased for this assessment because Landsat 7 data were corrupted. In future, the condition assessment will be extended to include the total managed floodplain through the use of Landsat 8.

Appendix 3 – Important Basin environmental assets for waterbirds

The MDBA's purpose in compiling this list has been to identify the environmental assets that are needed to achieve a sustainable population of waterbirds. Outcomes at these sites will not only be achieved through the use of environmental water, but through natural events and consumptive water. Environmental water holders and managers should use this list as an input into identifying those environmental assets that can be managed with environmental water (termed priority environmental assets by the Basin Plan). More detail on the criteria for inclusion is provided below.

The MDBA notes that drought refuges were identified as priorities when setting representation targets during dry times. Some of these sites are wetland complexes (e.g. Lowbidgee floodplain) that can be managed for environmental outcomes; some are storages or water transfer basins (e.g. Waranga Basin) that can't be managed for environmental outcomes but nonetheless provide refuge for some species.

Table 5: Important Basin environmental assets for waterbirds.

Environmental asset	Water resource plan area	Total abundance and diversity	Drought refuge	Colonial waterbird breeding	Shorebird abundance
1. Currawinya Lakes^	Warrego–Nebine	*			
2. Narran Lakes^	Intersecting streams	*		*	*
3. Cuttaburra channels	Intersecting streams	*		*	*
4. Paroo overflow lakes^	Intersecting streams	*		*	*
5. Yantabulla	Intersecting streams	*			
6. Upper Darling River	Barwon–Darling Watercourse	*	*		
7. Gwydir Wetlands^	Gwydir	*		*	
8. Macquarie Marshes^	Macquarie–Castlereagh	*		*	*
9. Booligal Wetlands	Lachlan	*		*	

Environmental asset	Water resource plan area	Total abundance and diversity	Drought refuge	Colonial waterbird breeding	Shorebird abundance
10. Great Cumbung Swamp	Lachlan	*		*	
11. Lake Brewster	Lachlan	*		*	
12. Lake Cowal	Lachlan			*	
13. Fivebough Swamp^	Murrumbidgee	*	*		*
14. Lowbidgee Floodplain	Murrumbidgee	*	*	*	*
15. Gunbower–Koondrook–Perricoota^	NSW Murray and Lower Darling/ Victorian Murray			*	
16. Kerang Wetlands^	Victorian Murray/ Wimmera–Mallee	*		*	
17. Menindee Lakes	NSW Murray and Lower Darling	*		*	
18. River Murray & Euston Lakes	NSW Murray and Lower Darling		*		
19. Talywalka system	NSW Murray and Lower Darling	*			
20. Darling Anabranch	NSW Murray and Lower Darling	*			
21. Lindsay–Walpolla–Chowilla^	NSW Murray and Lower Darling/ Victorian Murray/ SA River Murray	*			

Environmental asset	Water resource plan area	Total abundance and diversity	Drought refuge	Colonial waterbird breeding	Shorebird abundance
22. Barmah–Millewa^	NSW Murray and Lower Darling/ Victorian Murray	*		*	
23. Kiewa River	Victorian Murray		*		
24. Coroop Wetlands	Northern Victoria	*	*		
25. Winton Wetlands	Northern Victoria		*		
26. Waranga Basin	Northern Victoria		*		
27. Noora evaporation Basin	South Australian Murray Region	*			
28. Pyap Lagoon	South Australian River Murray		*		
29. Hattah Lakes^	Wimmera–Mallee			*	
30. Lake Albacutya^	Wimmera–Mallee	*			
31. Lake Buloke	Wimmera–Mallee	*			
32. Lake Hindmarsh	Wimmera–Mallee	*			
33. Coorong, Lower Lakes and Murray Mouth^	SA River Murray/ SA Murray Region/ Eastern Mount Lofty Ranges	*		*	*

^ *denotes waterbird sites that include Ramsar sites.*

Note: Inclusion of an environmental asset on the list above means that they are important for one or more of the following: maintaining total waterbird abundance and diversity, as a drought refuge, for colonial waterbird breeding, and for shorebirds.

Further information on categories of sites identified in Table 5

Total waterbird abundance and diversity: Environmental assets listed in this category represent a desired conservation target of 80% representation for abundance, of each waterbird species recorded in surveys. The decision on representation target was grounded on accumulated waterbird data suggesting that 80% of waterbird species were present in only about 30 of the wetlands surveyed each year. This analysis was run on the Aerial Waterbird Survey of South Eastern Australia dataset (1983–2012), and separately on The Living Murray survey and the Hydrologic Indicator Site survey (2010–2012). The analysis prioritised each environmental asset by giving them an 'irreplaceability score'. For those environmental assets surveyed by the Aerial Waterbird Survey of South Eastern Australia, the criteria to be included in the list above was an irreplaceability score greater than 0.8 and total waterbird abundance greater than 60,000 individuals. For those environmental assets surveyed by The Living Murray survey and the Hydrologic Indicator Site survey, criteria to be included in the list above was an irreplaceability score greater than 0.8.

Drought refuge: Environmental assets listed in this category are sites that were identified as priorities when setting representation targets during dry times. Some of these sites are wetland complexes (e.g. Lowbidgee floodplain) that can be managed for environmental outcomes. Some storages or water transfer basins that can't be managed for environmental outcomes are nonetheless important refuge for some species during drought—for example, Coolmunda Dam, Split Rock Reservoir and Burrendong Dam. Dry times were defined by examining water availability across the entire Basin over the 30 years and selecting those years in the bottom 25 percentile (2003, 2005–2009). This analysis was run on the Aerial Waterbird Survey of South Eastern Australia dataset.

Colonial waterbird breeding: Environmental assets listed in this category are wetland complexes that have had colonial waterbird breeding events in the historical record. Source data was the Australia Colonial Waterbird Breeding Database, which is a long-term dataset (1899–2012) of colonial waterbird breeding and distribution. It collates records for nine species: Australian pelican (*Pelecanus conspicillatus*), great cormorant (*Phalacrocorax carbo*), pied cormorant (*Phalacrocorax varius*), white-necked heron (*Ardea pacifica*), intermediate egret (*Ardea intermedia*), little egret (*Egretta garzetta*), straw-necked ibis (*Threskiornis spinicollis*), glossy ibis (*Plegadis falcinellus*) and royal spoonbill (*Platalea regia*).

These species breed in single or multi-species colonies of tens to hundreds of thousands of individuals. These species were chosen to be representative of colonial waterbird breeding to analyse the distribution, frequency and diversity of colonial waterbird breeding in the Murray– Darling Basin.

Shorebirds: Environmental assets listed in this category represent a desired conservation target of 80% representation targets for abundance of shorebirds as a functional group. The criteria to be included in the list above was an irreplaceability score greater than 0.8. Analysis was also run for other functional groups but the results are not presented here.

For a fuller account of this work, see: Bino G, Kingsford RT, Brandis K and Porter J, 2014, 'Setting waterbird objectives and priorities for the Basin-wide environmental watering strategy', report to the Murray–Darling Basin Authority, Centre for Ecosystem Science, University of New South Wales.

Appendix 4 – Basin native fish communities

The southern and northern fish communities follow catchment divisions are outlined Figure 8 in the main text (river flows and connectivity). The Lachlan and Paroo catchments are grouped with the northern community, and the Wimmera catchment with the southern community.

The Lachlan catchment has characteristics of both southern and northern fish communities and represents a transition zone between the two systems. For the purposes of this Strategy, the Lachlan is grouped with the northern fish community as it is characterised by semi-arid conditions and flow management arrangements similar to the northern Basin.

Southern Basin community

Most fish in the southern Basin exist in a highly modified environment, particularly in and around the River Murray. Much of this habitat still supports important fish populations, such as iconic riverine specialists Murray cod, trout cod, silver perch and golden perch. The region still has important unregulated systems that support remnant populations of threatened species and are important for overall fish biodiversity. The southern Basin is dominated by naturally high rainfall in winter and spring; however, river regulation has reversed or inverted some of this seasonality. High flows now occur in summer in some locations, with low flows (even drying) in winter.

Fish in the southern Basin are found in a wide variety of habitats. Large-bodied and long-lived species such as Murray cod, trout cod, silver perch and golden perch are all riverine specialists. On the other hand, small-bodied species such as southern purple-spotted gudgeon, southern pygmy perch, flat-headed galaxias, and Murray hardyhead each require access to inundated floodplains to complete their life cycles. Other freshwater habitats such as creeks, wetlands, forest flood-runners, billabongs, and permanent lakes are also important for native fish.

Estuarine fish community

The estuarine fish community supports the highest fish diversity in the Basin as a result of the dynamic nature of the estuary environment. Many species use the estuary including true estuarine species as well as migratory species, marine and freshwater species. The estuarine fish community includes important recreational and commercial fish species such as black bream, greenback flounder, yellow-eye mullet, golden perch, and mulloway. Species like sandy sprat and small-mouthed hardyhead are also essential food sources for predatory fish and waterbirds in the region.

Connectivity, productivity and salinity are the three major factors that regulate fish populations in the estuarine community. Each of these is heavily influenced by freshwater inflows to the Coorong, largely originating from the River Murray. Connectivity between the ocean, the estuary and the river is essential for many species. This connectivity is now restricted and fish must use constructed fishways and the barrages—making flows that operate these structures particularly important.
In addition to connectivity, freshwater inflows also carry nutrients from upstream and contribute to estuarine productivity; and interact with tides to create a salinity gradient (a gradual change from freshwater to hyper-saline water) that influences the distribution and health of fish species.

Northern Basin fish community

The northern Basin is important in maintaining the overall biodiversity of fish in the whole Basin. Its fish community includes 25 resident species, including populations of nationally-listed Murray cod and silver perch. The northern Basin is also a stronghold for many species that are threatened in the south. It has important remnant populations of olive perchlet, southern pygmy perch and freshwater catfish; and unique populations of northern river blackfish in the uplands of the Condamine River. A number of species that are not present in the south, i.e. Rendahl's tandan, Hyrtl's tandan, spangled perch, Darling River hardyhead and desert rainbowfish, exist in the north.

With very variable rainfall, many of the river flows in the northern Basin are highly intermittent. Therefore, natural wetting and drying cycles have a strong influence on fish communities. Survival through drying phases governs the long-term persistence of native fish in this region. Survival heavily depends on quality refuge habitat during dry times and the ability to recolonise habitats when moderate to high flow conditions return.

Appendix 5 – Supporting detail for native fish outcomes

Table 6 gives information for short-lived, moderate- to long-lived and estuarine species targeted by this Strategy. Species-specific recruitment requirements are outlined (see recruitment frequency column) and detail provided on the links between species life history and flow. Some threatened species are not included in the table owing to insufficient information on their flow requirements. This table provides details in relation to expanding distributions of native fish by 2024. Table 7(which follows) provides priorities for increasing the distribution of these species. Both tables are based on the best information currently available. Future application of this information can consider more recent data, if available.

It is important to note that short-lived species have increased vulnerability to successive years of recruitment failure. Therefore, they require frequent recruitment events to sustain populations—annually and biennially depending on their longevity. For moderate to long-lived species, populations are often dominated by a few strong or very strong cohorts (large recruitment events) with fewer individuals from smaller recruitment events in most remaining year classes. For many species, years with strong recruitment coincide with good flow (quantity and quality of flows).

Table 6: Details for short-lived species, moderate to long-lived species, and estuarine species of fish.

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Freshwater species						
Murray hardyhead *(Craterocephalus fluviatilis)*	Short-lived	Annual	Australia NSW, Vic, SA		The main conservation issue is the amount and quality of inflows to riverine and non-riverine wetlands. Regulation and water extraction influences the amount and quality of inflow to the floodplain, riverine and lake habitats. Specifically, off-channel habitats in the lower River Murray dry out due to low river flows and extraction. Reduced connectivity (including secondary connectivity) between the main river channel and floodplain habitat for dispersal.	Southern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
					Associated with aquatic vegetation, possibly for spawning. In particular, this species is associated with stands of Ruppia in saline habitats.	
Olive perchlet *(Ambassis agassizii)*	Short-lived	Annual	SA, NSW (endangered population) (Vic extinct)		Heavily impacted across most of its distribution, although good remnant populations exist in Queensland. Largely a wetland species with heavy dependence on off-channel lagoons and wetlands during the life cycle—therefore heavily impacted by river regulation and infrastructure that disconnects off-channel habitats and the creation of deep pools that drown-out in- channel emergent vegetation. As aquatic vegetation (particularly emergent vegetation) is vital; flows to sustain healthy and diverse aquatic vegetation are important. Artificially prolonged, elevated flows should be avoided as these can kill off aquatic vegetation. Secondary connection events between rivers and lagoons and wetlands are required to enable recruits to enter the river. Suitable refuges are required during summer low flows. Require stable water levels during spawning season.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Southern pygmy perch *(Nannoperca australis)*	Short-lived	Annual	NSW, SA, Vic		Heavily impacted. Largely a wetland species with strong relationships with in-channel submerged macrophytes such as ribbon weed, and with off-channel habitat. Therefore, highly impacted by the loss of macrophytes and off-channel habitats. This species is strongly associated with floodplain environments and most commonly inhabits wetlands and billabongs. Secondary connection events between rivers and lagoons and wetlands are required to enable recruits to enter the river. Increased persistence of drought refuges important.	Southern Basin
Yarra pygmy perch *(Nannoperca obscura)*	Short-lived	Annual	Australia Vic, SA		Heavily impacted. Largely a wetland species. River regulation and water extraction influence the amount and quality of inflow to the floodplain, riverine and lake habitats—specifically, drying out off-channel habitats in the lower River Murray. Aquatic vegetation (particularly emergent vegetation) is important for this species; therefore flows to sustain healthy and diverse aquatic vegetation are important. Artificially prolonged, elevated flows should be avoided as these can kill off aquatic vegetation. Secondary connection events between rivers and lagoons and wetlands are required to enable recruits to enter the river.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Southern purple-spotted gudgeon *(Mogurnda adspersa)*	Short-lived	Biennial	NSW, SA, Vic	Aquarium species	Heavily impacted wetland species. River regulation/extraction have exacerbated water availability—creating habitat loss through drying. Generally found in small, shallow pools or backwaters. High site fidelity to permanent pools in unregulated streams. In NSW, remnant populations often found in small high-order streams and off-stream habitats (particularly wetlands with dense macrophytes) — management of this habitat aspect is critical. Particular habitat requirement for spawning—requires hard substrates or macrophytes. Visual displays are important for breeding. Appear to breed around August in the northern Basin prior to increased summer flows—releasing large amounts of water at this time might reduce the chance of breeding events. Broadscale factors are important—including spring inundation and a summer low-flow period—combining to create suitable local habitat condition and heterogeneity. Spring water rises inundate edge vegetation, allowing fish access to shallow dense habitat and food resources. These benefit the first pulse of larvae as adults come into peak spawning with the return of warmer water temperatures. Secondary connection events between rivers and lagoons and wetlands are required to enable recruits to enter the river.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Silver perch ***(Bidyanus bidyanus)***	Moderate to long-lived	8 years in 10	Australia ACT, NSW, Vic, SA, Qld	Formerly a recreational species but take is now restricted due to threatened status.	Heavily impacted channel specialist. Flow-cued spawning. Flows govern recruitment strength in this species, with spawning and recruitment enhanced by spring/summer flooding and high within-channel flow pulses. Spawn and recruit in flowing habitats. Flows stimulate movement of both adults and juveniles. Large-scale movement requirements that are interrupted by loss of flows and barriers to connectivity: flows (current velocity) disperse early life stages (larval drift) large scale spawning migrations.	Southern & Northern Basin
Golden perch ***(Macquaria ambigua)***	Moderate to long-lived	8 years in 10	No (but a no-take population in Vic)	Key recreational target species. Important economic asset.	Impacted channel specialist. Flow-cued spawning. Flows govern recruitment strength in this species, with spawning and recruitment enhanced with spring/summer flooding and high within-channel flow pulses. Spawn and recruit in flowing habitats. Flows stimulate movement. Flows (current velocity) disperse early life stages. Golden perch have more flexibility in spawning and recruitment than silver perch.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Murray cod ***(Maccullochella peelii peelii)***	Moderate to long-lived	8 years in 10	Australia Vic, SA	Iconic species. Key recreational target species & key economic asset. High importance to Aboriginal peoples. Formerly a commercial species before fishery declined.	Heavily impacted channel specialist. Large-scale movements that are critical in the life-cycle (e.g. spawning migrations and larval drift) are interrupted by loss of flows and barriers to connectivity. Requires access to fast and moderate flowing in-channel habitat of good quality. Spawn and recruit in flowing habitats—loss of these habitats has major impacts on this species. Seasonally appropriate flows (with rising water levels) are required to stimulate migration. Flows also increase productivity and available habitat. Highly impacted by hypoxic blackwater events—flow is important to maintain water quality. Spawning is independent of flooding but recruitment can be enhanced by elevated flows. Nesting species that requires stable water depths for the duration of nesting to ensure adults do not abandon nests. Requires flowing water during this time period to maintain water quality. Flow (current velocity) then disperses larval stages.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Trout cod *(Maccullochella macquariensis)*	Moderate to long-lived	8 years in 10	Australia ACT, NSW, Vic, SA	Formerly a recreational species but take is now restricted due to threatened status.	Heavily impacted channel specialist species. Requires access to fast and moderate flowing in-channel habitat of good quality. Spawns and recruits in flowing habitats—loss of these habitats has major impacts on this species. Seasonally appropriate flows (with rising water levels) are required to stimulate migration. Flows also increase productivity and available habitat. Spawning is independent of flooding but recruitment can be enhanced by elevated flows. Increasing flow is often required to stimulate migration, for productivity and to increase available habitat. Flow is important to maintain water quality—hypoxic blackwater events can have major impacts on this species. Nesting species that requires stable water depths for the duration of nesting to ensure adults do not abandon nests. Requires flowing water during this time period to maintain water quality. Flow (current velocity) then disperses larval stages.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Macquarie perch ***(Macquaria australasica)***	Moderate to long-lived	8 years in 10	Australia ACT, NSW, Vic, SA	Formerly a recreational species but take is now restricted due to threatened status.	Heavily impacted by water extraction, particularly smaller riverine populations. Require flowing water (that retains stable depths) in conjunction with riffle and pool habitats containing cobble and gravel substrates for spawning. Flowing water is also required to disperse eggs and larvae. However, late spring flushes may negatively impact recruitment by disturbing eggs. Macquarie perch spawn in aggregations – barriers may prevent access to suitable spawning habitat or other adult fish. Suitable flows for connectivity are required. Natural freshes are required to scour fine sediment and prepare spawning habitats. Flow is important to maintain water quality. Maintenance of base flows and refuge pools during summer and autumn. They are vulnerable to loss of suitable refuge habitat either through water extraction or flow regulation. This reduces the number and quality of refuge pools during low flow conditions.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Freshwater catfish *(Tandanus tandanus)*	Moderate to long-lived	8 years in 10	SA, Vic, NSW (endangered population)	Important recreational species in Queensland. Formerly a recreational species in the southern Basin but take is now restricted due to threatened status.	Heavily impacted by reduced connectivity, particularly as low and medium flow events have reduced (in frequency and magnitude). In Queensland and northern NSW, catfish are still present in the main channel of rivers and creeks. More abundant in unregulated rivers and often found in deep waterholes. Impacted by reduced opportunities for longitudinal and lateral movement, particularly reduced low and medium flow events. This species is vulnerable to loss of suitable refuge habitat, either through water extraction or flow regulation. This reduces the number and quality of refuge pools during low flow conditions. Flow events enhance recruitment in this species. Secondary connection events between rivers and lagoons and wetlands are required to enable recruits to enter the river. Nesting species that requires stable water depths for the duration of nesting to ensure adults do not abandon nests. Rapidly reducing water levels may cause them to abandon nests. This is an issue in both regulated and unregulated systems. Pumping from pools is an issue.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Hyrtl's tandan *(Neosilurus hyrtlii)*	Moderate to long-lived	8 years in 10	no	Highly restricted localities in the northern basin (Queensland). Rare in Basin context.	Impacted by water extraction in the northern Basin which reduces the number and quality of refuge pools during low-flow conditions. Spawning and adult (upstream) and juvenile (downstream) migration is driven by high flow events in summer. This species requires lateral connectivity between lagoons and tributaries. Adults also migrate into lagoon habitats and tributaries. Drought refugia are important and require protection.	Northern Basin
Rendahl's tandan *(Porochilus rendahli)*	Moderate to long-lived	8 years in 10	no	Highly restricted localities in the northern Basin (Qld). Rare in Basin context.	Migration of adults into lagoons and tributaries is driven by high-flow events in summer. Drought refugia require protection. Probable link with good stands of aquatic vegetation (as it is most abundant in vegetated areas outside the Murray–Darling Basin)—loss of this habitat may restrict its abundance across its Basin-wide range.	Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Northern river blackfish (Qld population) *(Gadopsis marmoratus)*	Moderate to long-lived	8 years in 10	Qld (listed as a no-take species)	Highly restricted localities in the northern Basin (Qld.)	Impacted channel specialist. Requires protection of flows to maintain levels and water quality in drought refuges. Usually occurs in areas of perennial water flows, good physical cover and good water quality. Spawns in response to increasing temperature. Pumping from pools during summer can be an issue, leading to reduction in available habitat and lethal water temperatures.	Northern Basin
River blackfish (Gadopsis marmoratus) and Two-spined blackfish *(Gadopsis bispinosus)*	Moderate to long-lived	8 years in 10	NSW, Vic, SA ACT		These species are vulnerable to loss of suitable refuge habitat either through water extraction or flow regulation. This reduces the number and quality of refuge pools during low-flow conditions. Note: Recent genetic work has potentially identified six candidate species across the current taxa under *Gadopsis marmoratus* and *Gadopsis bispinosus.* This may require adapting outcomes and approaches for management of these species.	Southern & Northern Basin

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Estuarine species						
Mulloway *(Argyrosomus japonicus)*	Moderate to long-lived	5 years in 10	no	Important recreational and commercial target species. Iconic species. Key apex predator in the Coorong estuary.	Impacted marine migrant species. Requires freshwater flows as a cue for spawning as river discharge cues aggregations of adults at the Murray mouth. The estuary is an important nursery habitat for juveniles (0–5 years old), providing high quality protection from predation during years with prolonged seasonal freshwater inflow conditions. Strong recruitment age classes in this species are linked to these years of good freshwater flows, whereas poor recruitment or even recruitment failure is recorded in years of poor inflow. Note: the Coorong estuary likely provides the largest area of protected juvenile habitat for mulloway in southern Australia.	Estuarine

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Black bream *(Acanthopagrus butcheri)*	Moderate to long-lived	8 years in 10	no	Important recreational and commercial target species. Iconic estuarine resident species.	Estuarine-resident species. Distribution within the Coorong is influenced by freshwater flows – this influences the salinity gradient which governs the amount of estuarine habitat available. Spawn during spring/early summer – a suitable salinity gradient is critical for larval survival and development. Variability of freshwater inflows is a key factor influencing recruitment success, with good recruitment occurring during years of intermediate river flows and poor recruitment following periods of very low or high flows.	Estuarine
Greenback flounder *(Rhombosolea tapirina)*	Moderate to long-lived	8 years in 10	no	Important recreational/ commercial target species. Iconic estuarine resident species.	Estuarine-resident species. Distribution within the Coorong is influenced by freshwater flows – this influences the salinity gradient which governs the amount of estuarine habitat available. Spawn during autumn/winter. Freshwater flows to estuaries influence recruitment success through affecting salinities (suitable habitat) and productivity (food availability). Increased freshwater flows are linked to good recruitment and extensive distribution of juvenile fish across the Coorong.	Estuarine

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Sandy sprat *(Hyperlophus vittatus)*	Short-lived	Annual	no	Key food species in the estuary for predatory fish (e.g. Australian salmon, black bream and juvenile mulloway) and waterbirds (e.g. little penguins and little terns).	Freshwater flows, particularly through productivity, drives population abundances of this species. Most abundant during years of high freshwater inflows to the estuary.	Estuarine
Small-mouthed hardyhead *(Atherinosoma microstoma)*	Short-lived	Annual	no	Key food species in the estuary for predatory fish & waterbirds.	Salinity and productivity in the estuary drives population abundances. This is an indicator species for salinity conditions in the estuary.	Estuarine

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Diadromous species						
Congolli *(Pseudaphritis urvilii)*	Moderate to long-lived	8 years in 10 – maintaining stable sex ratios	SA		Heavily impacted by reduced connectivity among habitats in the Coorong. This species must move between freshwater and marine environments to complete its life cycle. To maintain stable sex ratios, segregation of the sexes during breeding seasons must be avoided. Spring–summer upstream movements of juvenile congolli and winter downstream movement of female adult congolli are key requirements for the species. Freshwater discharge and associated connectivity enhance population abundance. Major improvements in population abundance linked to consecutive years of good freshwater flows. Congolli populations are significantly improved by successive years of good freshwater inflows into the estuary.	Estuarine
Common galaxias *(Galaxias maculatus)*	Short-lived	Annual			Heavily impacted by reduced connectivity among habitats in the Coorong. This species must move between freshwater and marine environments to complete its life cycle. Spring–summer upstream movement of juvenile common galaxias is critical. Reduced connectivity can lead to segregation of the sexes of this species, which inhibits breeding.	Estuarine

Species	Longevity	Recruitment frequency	Threatened spp. status	Importance (other)	Links between life history and flow needs	Fish community
Short-headed lamprey *(Mordacia mordax)*	Moderate to long-lived	8 years in 10	SA		Heavily impacted by reduced connectivity among habitats in the Coorong. This species must move between freshwater and marine environments to complete its life-cycle. Large-scale migrations of adults are required to complete the life- cycle. Winter upstream movements of adult lamprey are critical.	Estuarine
Pouched lamprey *(Geotria australis)*	Moderate to long-lived	8 years in 10	SA		Heavily impacted by reduced connectivity among habitats in the Coorong. This species must move between freshwater and marine environments to complete its life-cycle. Winter upstream movements of adult lamprey are critical.	Estuarine

Priorities for increasing the distribution of native fish

Increasing the distribution of native fish relies on expansion of existing populations (see range extension) and/or the establishment of new populations (see additional populations), facilitated by improved water management and flows. Table 7 suggests candidate sites where this outcome can increase distribution of native fish species. Agencies may also consider additional or substitute sites in their planning. In some instances, complementary stocking of threatened species may be needed where flow-mediated range expansion is not feasible. This stocking can provide an initial population that could then be expanded.

For many species, existing distributions are confined to discrete locations (e.g. a river or river reach, specific wetlands). Interpretation of this outcome in relation to the overall distribution of some species is more difficult. These species can be widely distributed, but are highly fragmented, and now absent or no longer common across large parts of their range. For those species (e.g. silver perch), the intent of this outcome is to expand what now constitutes a ‘core range’ of the species. The core range is considered to be where populations are in reasonable condition and abundance. Expansion efforts are directed towards increasing their frequency in areas where they are currently rare (particularly where they used to be common).

Table 7: Detailed species information in relation to outcomes for distributions of native fish by 2024

Species	Priorities for increasing distribution in the Southern Basin	Priorities for increasing distribution in the northern Basin
Macquarie perch	Range extension: Expand at least two current populations (candidate sites include Cotter River, Murrumbidgee above Cooma, Adjungbilly Creek, King Parrot Creek, Hughes Creek, and Hollands Creek). Additional populations: Establish at least four additional riverine populations (candidate sites include. mid-Goulburn River, Ovens River, Kiewa River and Goodradigbee River). Note: Ovens River & Goulburn populations – attempts to re-establish have commenced	Range extension: The distribution of Macquarie perch in the northern Basin is limited to the Lachlan catchment. Range expansion of at least 2 current populations is a priority. Additional populations: Establish 1–3 additional riverine populations within the Lachlan catchment.
Trout cod	Range extension: Expand the range of trout cod up the Murray upstream of Lake Mulwala and into the Kiewa River. For the connected population of the Murrumbidgee–Murray–Edwards: continue downstream expansion. Additional populations: Establish at least two additional populations (candidate sites include the Macquarie River and mid-Goulburn River). Note: Macquarie River and mid-Goulburn populations – attempts to re- establish have commenced	Range extension: The distribution of trout cod in the northern Basin is limited to the Macquarie catchment downstream of Burrendong Dam. Range expansion of the current population is a priority. Additional populations: Establish 1–3 additional populations (candidate sites are primarily within the Macquarie catchment; within the Lachlan, a candidate site is downstream of Wyangala Dam).
Silver perch *** note this is about improving core range of this species (southern & northern)**	Range extension: Expand the core range within the River Murray (Yarrawonga–Euston) and populations within the Edward–Wakool, lower Murrumbidgee and Goulburn Rivers. Expand upstream of Lake Mulwala and into the Ovens River, increase up the lower Goulburn River. Additional populations: Improve core range in at least two additional locations – (candidate sites include Gunbower Creek, Broken Creek, the lower Loddon, lower Darling, Billabong–Yanco system and Campaspe Rivers, ACT reaches of the Murrumbidgee).	Range extension: Expand the core range of at least 2 existing populations (candidate sites include populations in the Namoi, Barwon–Darling and Macquarie catchments) Additional populations: Improve core range (candidate sites are the Warrego, Paroo and Condamine Rivers (including Oakey Creek).

Species	Priorities for increasing distribution in the Southern Basin	Priorities for increasing distribution in the northern Basin
Freshwater catfish * note this is about improving core range of this species (southern & northern)	Range extension: Expand the core range of at least two current populations (candidate sites include Columbo-Billabong Creek and Wakool system and Wimmera River). Additional populations Improve core range in at least three additional locations (candidate sites include the Avoca River, Loddon River upstream Laanecoorie Reserve, Merran Creek area in NSW).	Range extension: Expand the core range of at least 3–5 existing populations (candidate sites include the Gwydir, Namoi, Border Rivers, Macquarie, Warrego and Condamine catchments and the Paroo River)
Southern pygmy perch	Range extension: Expand the range of at least two current populations (candidate sites include Barmah-Millewa and other mid-Murray wetlands). Additional populations: Establish 3–4 additional populations (candidate sites include the lower Murrumbidgee wetlands and Lower Lakes).	Range extension: Expand the range of the Lachlan populations. Additional populations: Establish 1–3 additional populations in the Lachlan catchment.
Olive perchlet * note this is about improving core range of this species in Qld parts of the northern Basin	Olive perchlet are considered extinct in the southern Basin*. Reintroduction using northern populations is the main option for recovery. Candidate sites may result from improved flow that reinstates suitable habitat in River Murray and mid-Murrumbidgee wetlands). * as the Lachlan populations are included in the northern Basin in this document	Range extension: Expand the range (or core range) of at least 3 existing populations (candidate sites include the Border Rivers, Lachlan River and middle Condamine River). Additional populations: Establish or improve the core range of 2–4 additional populations (candidate sites include the Macquarie and Namoi Rivers, Gowrie Creek and Oakey Creek (Condamine tributaries).
Southern purple-spotted gudgeon * note this is about improving core range of this species in Qld parts of the northern Basin	Range extension: Expand the range of at least two current populations (candidate sites include the Jury Swamp populations). Additional populations: Establish 3–4 additional populations (candidate sites include the Murrumbidgee in Adjungbilly and Adelong creeks and Murray wetlands).	Range extension: Expand the range (or core range) of at least 3 existing populations (priority catchments Border Rivers/Gwydir, Macquarie and Condamine). Additional populations: Establish or improve the core range of 2–5 additional populations – (priority catchments Border Rivers/Gwydir, Macquarie, Namoi, Barwon–Darling,

Species	Priorities for increasing distribution in the Southern Basin	Priorities for increasing distribution in the northern Basin
		Lachlan and Condamine in Oakey Creek).
Yarra pygmy perch	Range extension: Expand the range of at least two current populations (candidate sites include the Lower Lakes/Coorong region). Additional populations: Establish 3–4 additional populations.	Not present
Murray hardyhead	Range extension: Expand the range of at least two current populations. Additional populations: Establish 3–4 additional populations, with at least two of these to be within the lower Murray conservation unit, one in the mid-Murray conservation unit and a further population potentially within the Kerang Lakes region.	Not present
River blackfish [21]	Range extension: Expand the range of at least two current populations (candidate sites include the Murrumbidgee River and from the Mulwala canal). Additional populations: Establish 1–3 additional populations (candidate sites include downstream of the Loddon and Campaspe rivers).	Range extension: Expand the range of at least two current populations (candidate sites include tributaries of the Condamine and upland systems of the Border Rivers, Gwydir and Namoi). Additional populations: Establish 1–3 additional populations.
Two-spined blackfish [21]	Range extension: Expand the range of at least two current populations (candidate sites include the Kiewa/Ovens population and upper Goulburn tributaries). Additional populations: Establish 1–3 additional populations.	Not present
Flathead galaxias	Range extension: Expand the core range in the wetlands of the River Murray. Additional populations: Improve core range in 1–2 additional locations (candidate sites include Murrumbidgee, Goulburn, Kiewa and Mitta Mitta rivers and suitable wetlands in these systems).	Flathead galaxias are considered extinct in the northern Basin; therefore the focus for this species is likely to be in the southern Basin. However, reintroduction using southern populations may be an option for recovery in the northern

Species	Priorities for increasing distribution in the Southern Basin	Priorities for increasing distribution in the northern Basin
		Basin in the longer term. Candidate sites may be considered within their former range in the Lachlan and Macquarie catchments.
Diadromous species (Congolli, short- headed and pouched lamprey)	Range extension: Upstream expansion facilitated through flows to operate fishways.	Not present

[21] Recent genetic studies on these two blackfish species has potentially identified six candidate species across river blackfish and two-spined blackfish. For example, Goulburn River system sites are genetically different. This may require adapting outcomes and approaches for management of these species.

Appendix 6 – Important Basin environmental assets for native fish

MDBA's purpose in compiling this list has been to identify broad-scale locations that are of Basin significance for native fish. Outcomes at these locations can be achieved through the use of environmental water in conjunction with natural events and consumptive water. Where active management is not possible, the primary purpose for listing as an environmental asset is to ensure no loss or degradation of their condition. Environmental water managers should use this list as an input into identifying those environmental assets that can be managed with environmental water (termed priority environmental assets by the Basin Plan). Further management of regional and local-scale assets (not explicitly identified in the below table) will also need to be considered in planning and management, particularly to achieve outcomes for threatened species.

Table 8: Important Basin environmental assets for native fish.

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge
Southern Basin						
1. Coorong, Lower Lakes and Murray Mouth	*	*	*		*	*
2. Swamps on the lower Murray channel, between Wellington and Mannum (swamp geomorphic region)		*			*	
3. Kerang Lakes					*	*
4. Katarapko anabranch	*			*		
5. Pike anabranch	*			*		
6. Lower River Murray main channel (from Darling junction downstream)	*	*	*		*	*

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge
7. Murray main channel (from Hume dam to Darling junction)	*	*	*	*	*	*
8. Chowilla anabranch	*	*	*	*	*	*
9. Lindsay–Walpolla–Mularoo Creek	*	*	*	*	*	*
10. Lower Darling main channel	*	*	*	*	*	*
11. Darling anabranch			*			*
12. Hattah Lakes			*			*
13 Euston Lakes (including Washpen and Taila creeks)					*	
14. Lowbidgee Floodplain			*			
15. Murrumbidgee main channel (including upland reaches)	*		*		*	
16. Upland Murrumbidgee main channel	*		*		*	
17. Cotter River			*		*	
18. Koondrook–Perricoota	*	*	*	*	*	
19. Gunbower	*	*	*	*	*	
20. Barmah–Millewa	*	*	*	*	*	*
21. Edward–Wakool system	*		*	*		*
22. Werai Forest			*	*		

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge
23. Billabong–Yanco–Columbo creeks		*	*	*	*	*
24. Lake Mulwala	*		*	*	*	*
25. Ovens River	*	*	*	*	*	*
26. Lower Goulburn River	*	*	*	*	*	*
27. Upper Mitta River			*		*	
28. King River		*		*	*	*
29. Broken River	*	*	*		*	*
30. Broken Creek					*	*
Northern Basin						
31. Warrego (Darling to Ward rivers)	*	*		*	*	*
32. Anabranches laterally connecting the Paroo and Warrego rivers (including Bow, Gumholes and Cuttaburra creeks)	*					
33. Barwon–Darling (Menindee to Mungindi)	*	*		*	*	*
34. Namoi (Gunnedah to Walgett)	*	*	*	*	*	*
35. Culgoa junction to St George (including lateral connectivity to the floodplain)	*	*			*	*
36. Macintyre River – floodplain	*	*	*		*	*

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge
lagoons between Goondiwindi and Boomi						
37. Macquarie River – below Burrendong Dam to Warren	*	*			*	*
38. Macquarie Marshes to Barwon, including lateral connectivity at the marshes	*				*	*
39. Lower Bogan River to junction with the Darling River	*				*	*
40. Talyawalka anabranch	*			*		*
41. Lower Moonie River to Barwon River	*	*		*		*
42. Condamine River – Surat to Oakey Creek, including lower Oakey Creek	*	*		*	*	*
43. Floodplain lagoons between Condamine and Surat	*	*	*		*	*
44. Lachlan River – Condobolin to Booligal	*	*	*	*	*	*
45. Macintyre River – Mungindi to Severn in NSW	*	*		*	*	*

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge
46. Paroo River	*	*			*	*
47. Condamine headwaters and Spring Creek upstream of Killarney				*	*	*
48. Severn River within Sundown National Park		*		*	*	*
49. Peel River downstream of Chaffey Dam		*		*	*	*
50. Namoi River upstream of Keepit Dam		*		*	*	
51. Charley's Creek and tributaries (upstream from Chinchilla)		*	*	*	*	*

Notes:

Sites of significance – includes areas that have high natural abundance of native species and/or are recruitment hotspots.

This table has been compiled using expert opinion and information provided for the assessment of key ecological assets for the development of the Basin Plan.

Office locations
Adelaide
Albury–Wodonga
Canberra
Goondiwindi
Toowoomba

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