Basin-wide environmental watering strategy – Supporting Information

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Acknowledgement of the Traditional Owners of the Murray–Darling Basin
We acknowledge the Traditional Owners and Custodians of Country throughout the Murray–Darling Basin and their continuing connection to land, waters and community. We offer our respects to the people, the cultures and the Elders past and present.

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

Contents

Introduction

The third edition of the Basin-wide environmental watering strategy is delivered as a suite of three products – the Basin-wide environmental watering strategy, a high-level summary product of the Strategy and a detailed supporting information document (this document).

This document aims to capture the supporting technical information upon which the 2024 Basin-wide environmental watering strategy is based. It is a supplementary resource to the Strategy that provides further technical details on each of the four themes (flows and connectivity, native vegetation, waterbirds and native fish), the water management strategies, climate change risks, the influence of other factors and complementary management. As such, this report should be read in conjunction with the Strategy document.

The information within this document was developed in consultation with relevant experts, including Basin State and Territory jurisdictions and respected technical experts through thematic advisory groups. The content builds on the content from the first and second editions whilst continuing to incorporate knowledge from a further 5 years of Basin Plan implementation, advances in environmental water delivery and accounting, and a significantly improved body of Murray–Darling Basin science and knowledge.

The technical content will be updated with future editions of the Strategy, particularly in light of the findings and outcomes from the 2026 Basin Plan Review.

Flows and Connectivity

Context

The natural pattern of river flows, the relationship between flow and in channel hydraulic conditions, and the connection between the river channel, their wetlands and floodplains, and their groundwater systems (see Figure 1) have changed over time through human activities (Walker et al. 1993; Bice et al. 2017; Mallen-Cooper et al. 2018; Mallen-Cooper et al. 2020)

These changes have affected the various features of the natural patterns of river flows in different ways and to different degrees. For example, there has been a decrease in the frequency, magnitude and/or duration of freshes, bank-full and small to medium overbank flows in most systems. In some systems, base flows have increased in their frequency, magnitude and/or duration compared to the natural pattern of river flows. River regulation and the storage of run-off also affects the longitudinal source-to-sea connectivity of flow events and seasonality of flow peaks, resulting in higher summer flows and lower winter-spring flows than would occur naturally (Maheshwari et al. 1995; Mallen-Cooper & Zampatti, 2018; Walker & Thoms, 1993).

Generally, the regulation and extraction of flow has affected the connectivity of rivers:

- longitudinally – by disrupting contiguous flow along their length
- laterally – by altering the frequency, magnitude and/or duration of overbank connection between the river channel and the adjoining floodplain; and
- vertically – by altering connection and recharge between surface water and groundwater.

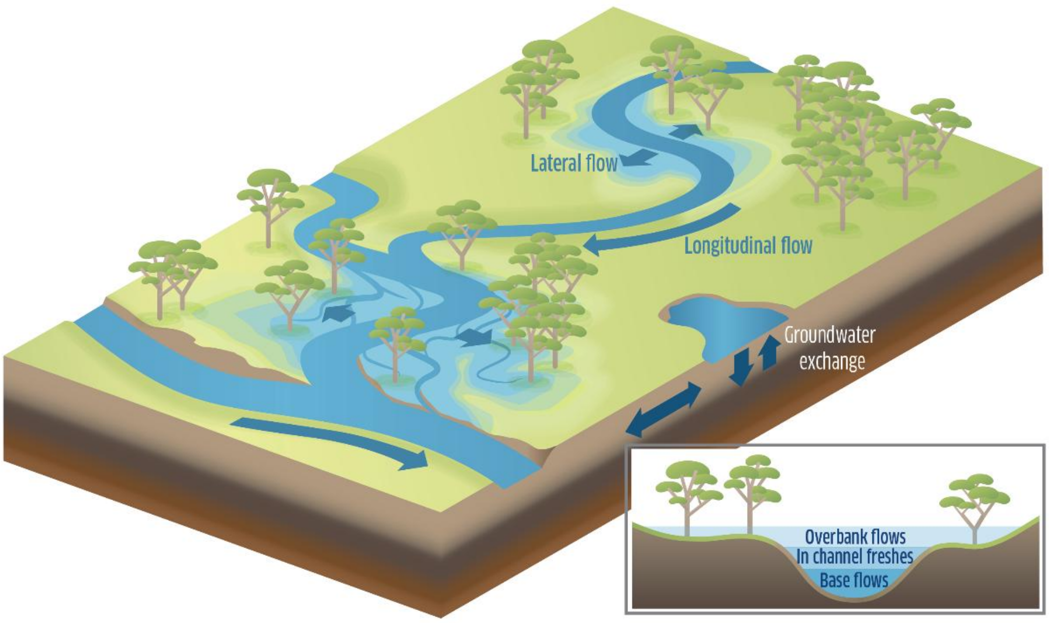

Figure 1: Hydrological connectivity and flows.

The main driver of ecosystem functions is the flow regime. Therefore, changes in the components of the natural flow regimes across the Basin have impacted on the condition, structure and resilience of many water-dependent ecosystems and native species (Arthington et al. 2006; Poff et al. 1997; Walker & Thoms, 1993).

Longitudinal connectivity

The longitudinal connectivity of rivers (either as flows into downstream reaches or terminal wetlands, in the case of fully-connected systems, flows through to the sea) varies across the Basin, both naturally and due to human influences. Connectivity fulfils important environmental functions, including the dispersal of carbon and nutrients, sediment, propagules, eggs and larvae. This allows organisms to disperse and migrate, expanding the range of feeding and breeding opportunities, supporting genetic diversity and flushing sediment and salt out to sea (Bunn & Arthington, 2002; Junk et al. 1989; Kingsford, 2000).

The impacts of river regulation and diversions often increase cumulatively downstream, resulting in reduced hydrodynamic diversity and diminished health and resilience of lowland ecosystems (Bunn & Arthington, 2002; Kingsford & Thomas, 2004; Maheshwari et al. 1995). 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 Great Cumbung Swamp) (Kingsford, 2000).

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 removing salt, sediment, nutrients and pollutants from the Basin and for species that move between fresh and salt water to complete their life cycle (Bourman et al. 2018; Brookes et al. 2018; Mosley et al. 2023).

Figure 2 illustrates longitudinal connectivity between rivers in the Basin (based on modelled scenarios using flow and climatology data from 1895–2009). It shows the proportion of catchment inflows that would have flowed out of the end of each catchment before development; under levels of development before the Basin Plan; and under fully implemented Basin Plan settings[1].

[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 2 may be misleading.

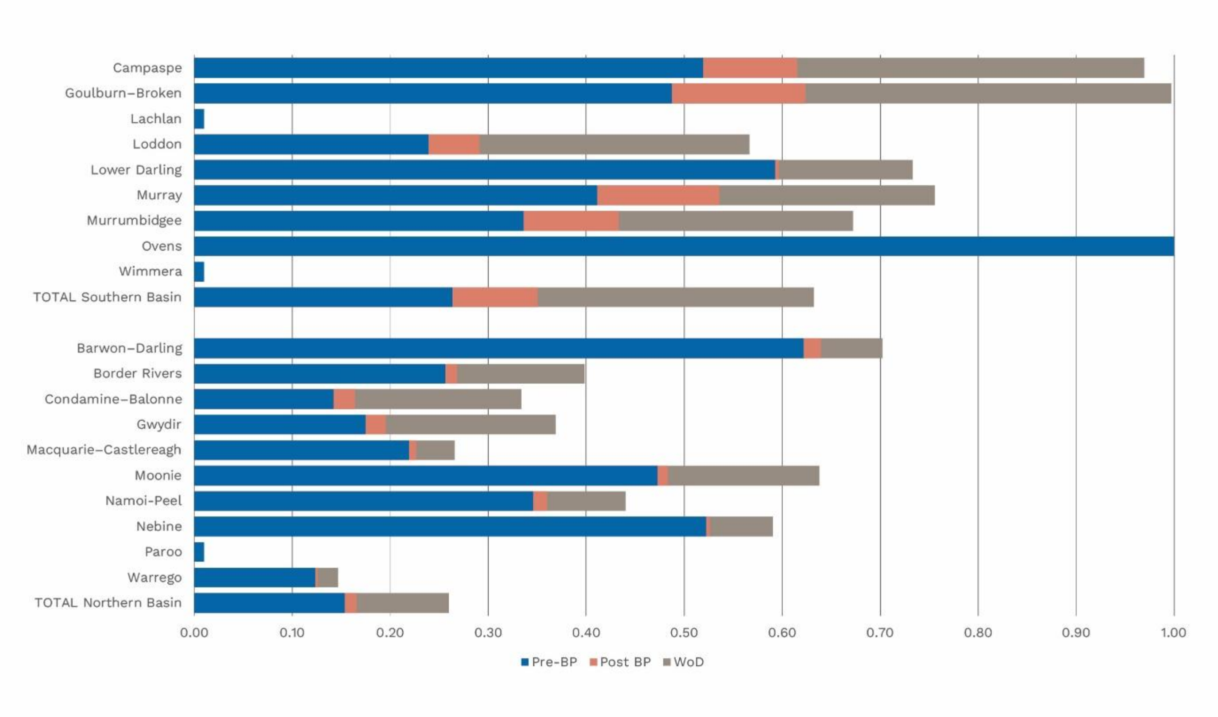

Figure 2: Proportion of catchment inflows flowing out the end of river catchments across the Basin under three modelled scenarios (without development (WoD, grey), without Basin Plan (Pre-BP, blue), and full implementation of the Basin Plan (Post-BP, orange)

Figure 2 shows, as a general trend, that the impact of development on connections between rivers has been greater in the southern Basin than in the northern Basin catchments (i.e. a larger gap between the grey 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 water recovery under the Basin Plan is also greatest in the more developed southern valleys (seen in longer orange 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 20 to 30 years, while floods that follow them have been smaller in magnitude (Murray–Darling Basin Authority 2020d). The Basin Plan has been improving longitudinal connectivity across the northern Basin through water recovery, reducing consumptive water use and increasing river flows, and additional improvements are expected over coming years – many of the northern Basin toolkit measures are aimed towards improving longitudinal connectivity during these dry periods.

In-stream infrastructure that captures and/or re-regulates flow and river stage, such as dams, locks and weirs, limit some of the beneficial effects of longitudinal connectivity. They can also present physical barriers that prevent or reduce the ability of many aquatic species to move longitudinally up and down stream (Bunn & Arthington, 2002). The removal or modification and upgrade of infrastructure (e.g. the construction of fishways), delivery of higher flows that directly link upstream and downstream environments providing alternative unrestricted movement pathway, and improvements to the operation of structures to optimise their function, are expected to enhance connectivity events. Infrastructure can also alter the in-stream hydraulics, creating lentic environments that are less effective at keeping sediment, propagules, fish eggs and larvae in suspension limiting their downstream dispersal (Bunn & Arthington, 2002; Nilsson et al., 2005).

Lateral connectivity

The connection between rivers to their adjacent floodplains and wetlands (lateral connectivity) underpins many ecological processes and functions that are essential for healthy and resilient water-dependent ecosystems (Amoros & Bornette, 2002; Thoms, 2003).

This level of connection naturally varies in frequency, extent and timing across the Basin, and is further affected by extraction, river regulation and diversions. In most valleys across the Basin the frequency, magnitude, timing and duration of flows which connect rivers with their floodplains and wetlands have been substantially impacted as a result of water resource development. In these rivers, the flows delivered from dams have almost always been in-channel—low to medium natural over-bank events have been reduced through the capture and re-regulation of run-off, such that many floodplain ecosystems and the functions they support are at risk. This is illustrated in Figure 3 (for part of the Murray floodplain). The pattern of decline in low to medium natural over-bank events also occurs in the large unregulated valleys without headwater storages, where water plans permit water to be extracted for consumptive use in most medium-sized events. Large over-bank events are less affected as they are often unable to be regulated by storage dams. However, climate variability and changing climate are significant drivers for large over-bank events and, particularly in the southern Basin, the frequency and magnitude of these events are declining long-term.

The Basin Plan aims to protect or restore the connection between rivers and their wetlands and floodplains to the extent possible given the constraints in the system and depending on availability of environmental water held in storages (refer to The managed floodplain section). Valleys with highly altered river flows and large areas of lowland floodplains and wetlands provide the best opportunities to improve lateral connectivity. In the valleys relatively unchanged by development, the Basin Plan and associated water resource plans have the effect of ensuring lateral connectivity is protected. In valleys with either limited or highly elevated floodplains the Basin Plan can maintain small over-bank events and protect longitudinal connectivity through in-channel events, supporting and contributing to larger overbank events in the downstream valleys.

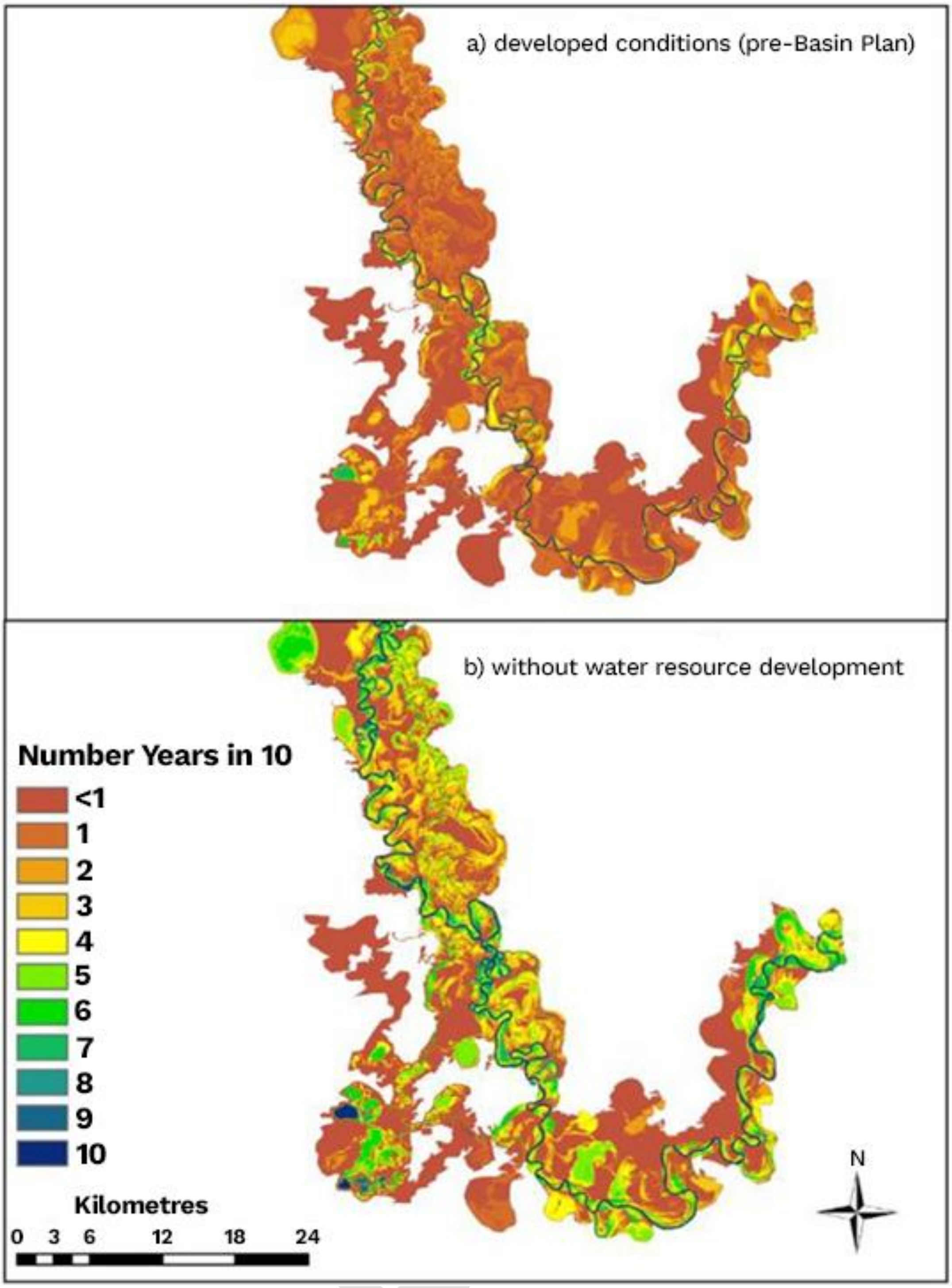

Figure 3: Frequency of inundation between Euston and Lock 10 on the River Murray under a) developed and b) without water resource development.

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 and the watercourse above.

When water infiltrates through a riverbed to the semi-saturated and then saturated zones, the result is a 'losing' stream. Groundwater can also discharge into rivers and wetlands, resulting in a ‘gaining’ stream. Some areas vary over time from ‘losing’ to ‘gaining’ depending on the relative elevation of the connected surface and ground waters and can be driven by factors such as the prevailing climate, natural flooding and 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 leading to a predominately gaining stream becoming a predominately losing stream and water that contributes to the base flow of the river being lost. 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 soil salinisation and increase the salt load added to rivers.

While vertical connectivity is an important element contributing to surface flows and aquifer recharge (and is therefore a driver contributing to some of the Expected Environmental Outcomes within the other themes), there are currently no Expected Environmental Outcomes developed for this component of connectivity within the Strategy.

Ecosystem functions

The four existing themes of the Strategy[2] are a subset of all themes that constitute a water-dependent ecosystem. Ecosystem functions are embedded within both the *Water Act 2007* and Basin Plan legislation as an important part of a healthy water-dependent ecosystem. Flows and connectivity are the ‘maestro’ that drives a range of water-dependent ecosystem functions.

Accordingly, ecosystem structural outcomes are dependent on a range of ecosystem functions being maintained and restored. 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. Figure 4 illustrates the numerous interactions between a suite of abiotic and biotic ecosystem functions that are important for the health and condition of native vegetation, fish and waterbirds.

Ecosystem functions are a broad suite of processes and activities that are essential for maintaining health, structure, and integrity of an ecosystem. Ecosystem structure and functions are intrinsically linked, with both being essential to an ecosystem (see Figure 4). 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.

[2] Flows and connectivity, native vegetation, waterbirds and native fish.

Leading conceptual models of ecosystem functions in the literature (Humphries et al. 2014; Thorp & Delong 1994; Vannote et al. 1980) demonstrate that connectivity (hydrological, habitat and biological) is essential to a healthy functioning river system. Application of management approaches that focus on ecosystem functions and processes including connectivity are gaining momentum (e.g. Baldwin et al. 2016; Wohl 2017; Yarnell et al. 2020; Sengupta et al. 2023), particularly in an uncertain future (Tonkin et al. 2019a).

The Expected Environmental Outcomes for the river flows and connectivity theme are an important subset of ecosystem functions that will contribute to a healthy water-dependent ecosystem. There are also a range of ecosystem functions that are unique to each ecological theme such as habitat provision and life cycle requirements for reproduction, movement and dispersal that are fundamental to achievement of Expected Environmental Outcomes for the native vegetation, fish and waterbirds ecological themes. Ecological theme-specific outcomes already explicitly and implicitly incorporate a suite of ecosystem functions that relate to life-cycle processes.

There remain key challenges for incorporating ecosystem functions into environmental water planning, delivery and monitoring. These include that there are an almost infinite number of ecosystem processes and interactions within freshwater and estuarine ecosystems. Our knowledge of the role and importance of ecosystem functions in supporting a healthy ecosystem is evolving. Basin-scale research undertaken as part of the CSIRO Ecosystem Functions research project (Ecosystem functions in the Murray–Darling Basin - CSIRO; see Sengupta et al. (2023) for a synthesis of this research) across four themes has advanced our knowledge of ecosystem functions for a subset of the vast number of ecosystem functions within the Murray–Darling Basin. Similarly, other research programs such as the Commonwealth Flow-MER - Environmental Water Monitoring, Evaluation and Research and the Murray–Darling Water and Environment Research Program are advancing our understanding of ecosystem functions in the Basin. Nonetheless, there remain critical gaps in our understanding of causal relationships between ecosystem functions and flow/connectivity or there are critical information and data gaps.

Notwithstanding these challenges, water holders across the Basin are already considering ecosystem functions in environmental water planning and delivery at different spatial and temporal scales. This includes objectives, targets and water requirements specified for a range of different ecosystem functions in long-term environmental watering plans. At finer spatial and temporal scales, environmental water managers are actively planning and delivering water for the environment to achieve a range of ecosystem function outcomes such as longitudinal and lateral connectivity, habitat provision, biological movement, water quality maintenance and enhanced productivity and food resources.

Environmental water holders are encouraged to further embed ecosystem functions into environmental water management, particularly as our knowledge improves over time. The water management strategies for maximising environmental outcomes include strategies for enhancing ecosystem functions outcomes and the Strategy will continue to build on these over time.

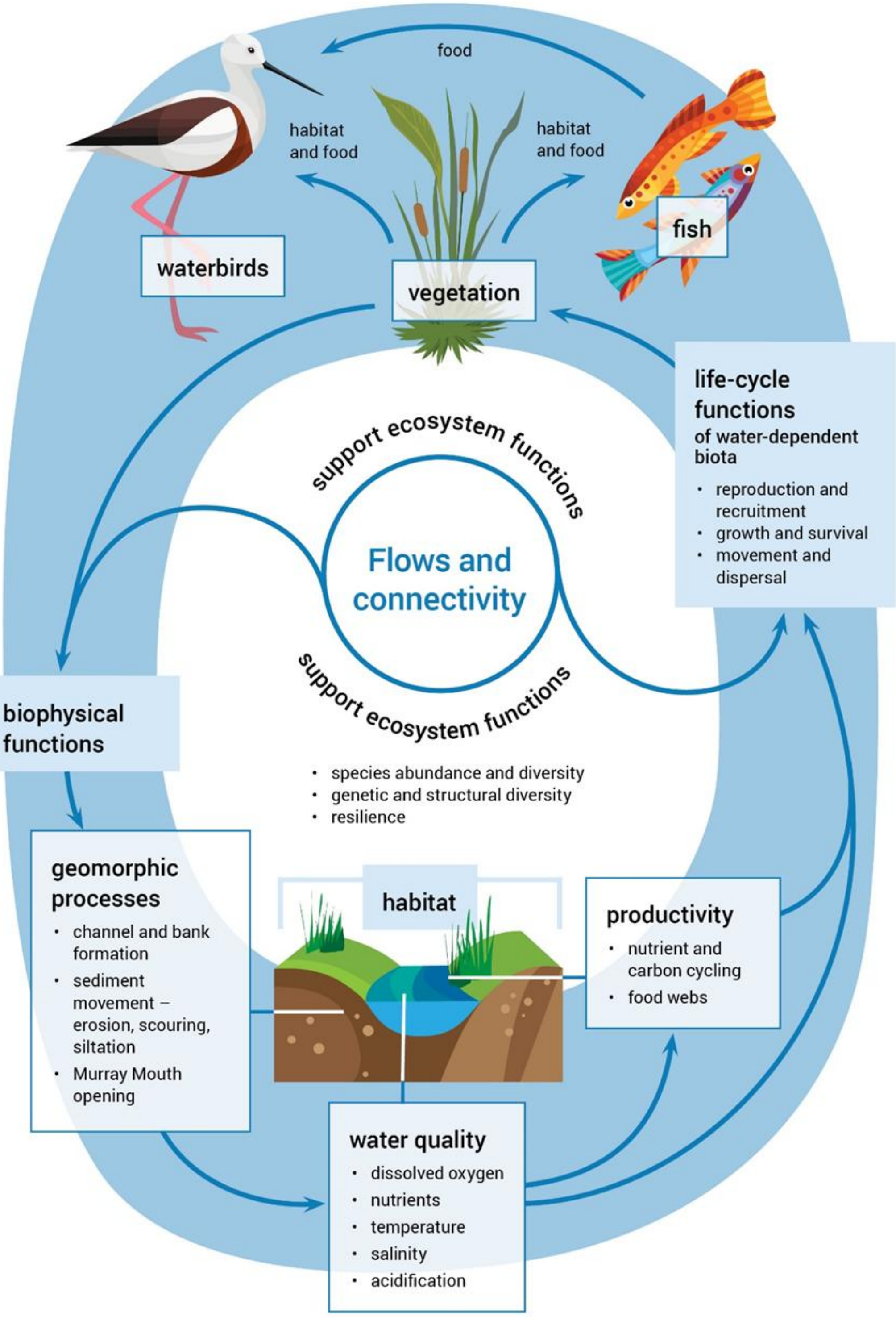

Figure 4: Conceptual illustration of the central role of flows and connectivity supporting a range of flow-related ecosystem functions and the role of ecosystem functions in supporting ecological outcomes for waterbirds, vegetation and fish.

Flow regimes

Ecosystems in the Basin are well adapted to natural variability in flow and river stage. These can be: Smaller (e.g. centimeter) fluctuations occurring over shorter time scales (e.g. days to weeks) that create a dynamic wetting front along the riverbank, or; Longer (e.g. months) and larger (e.g. meters) such as the variation in summer versus winter flows driven by seasonal climates. Variability over multiple years (e.g. decades) with wetter periods and dryer periods are also a feature of the Basin's climate variability (Stewardson et al., 2021).

Patterns of agricultural and urban water use can change 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 (CSIRO, 2008). 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 volume 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 can 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. This same seasonality does not necessarily apply in the northern Basin, where flows are extremely variable year to year and summer can be dominated with large flows connected to the monsoonal season (CSIRO, 2008).

Following inundation, periodic drying, that disconnects wetlands and billabongs from the main stem of rivers and allows floodplains to shed water back to the river channel is an equally important element in the flow regime for many parts of the Basin. In some cases, drying phases have been lost due to the regulation of rivers (Walker, 2006). In these systems, reinstating a complex water regime that features drying phases at frequencies characteristic of the waterway under natural conditions, can contribute to improved ecosystem health. This includes creating wide and diverse littoral and riparian floodplain zones and interconnected mosaics of complex wetland habitats that can support an increased diversity and abundance of native species.

Variability in river flow and river stage also creates hydraulic diversity within the river channel. This hydraulic diversity is a result of the interaction between flows and the physical structure of the river channel (e.g. bank geomorphology and other structure such as snags). Hydraulic diversity is critical for providing habitat and supporting life history stages of native aquatic biota and driving natural geomorphic processes (e.g. sediment erosion and deposition) (Mallen-Cooper & Zampatti, 2018; Walker, 2006). In upland and mid-slope rivers, this variability is provided by the presence of features including pools, runs and riffles along the river channel, as well as variability across the channel with slower-flowing edges and faster-flowing mid-sections. In lowland rivers, hydraulic diversity includes pools, inside and outside bends, anabranches and slackwaters.

Hydraulic diversity has been significantly affected across the Basin by a range of factors including the construction of weirs, which have created a series of semi-disconnected lentic 'pool' habitats that have reduced the extent of fast-flowing lotic habitats that existed historically. The lower 800 km of the River Murray has been most affected by development—it has closely spaced, continuous weir pools that maintain consistent water levels at near bank full levels under most flow conditions

(Mallen-Cooper & Zampatti, 2018). Lotic conditions and hydraulic diversity can be restored by delivering varying flows, by changing how weirs are operated (e.g. weir pool manipulation for ecological benefit) 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.

The use of water for the environment aims to restore ecologically significant components of the flow regime to a more natural pattern. This is achieved by adding water to existing flows, by releasing water for the environment held in dams at ecologically appropriate times and rates, or by protecting a proportion of a flow event as water for environment. When delivered as flow, water for the environment will contribute to longitudinal, lateral, and vertical connectivity on a continuum depending on the magnitude of the event. Infrastructure can also be used to deliver volumes of environmental water, such as managed floodplain inundation, weir pool manipulation and wetland pumping. This infrastructure can deliver volumes of environmental water and are key management tools to restore components of the natural hydrograph that would otherwise be difficult using flow alone. For example, using environmental regulators to increase water levels equivalent to medium overbank flows where there are flow delivery constraints or there is insufficient availability of water for the environment to create flows of this magnitude. Unlike flow, these managed actions can only restore components of a flow regime for a discrete area or asset (i.e. the maximum inundation extent or area of influence of the environmental regulator). These managed actions often cannot contribute equally to longitudinal, lateral, and vertical connectivity outcomes, and are therefore less likely to contribute to ecosystem functions or system-scale outcomes (Bond et al. 2014; Wallace et al. 2011). The improvements in flow and connectivity from these combined actions over time are expected to support ecosystem functions across the Basin and generate positive environmental outcomes for native vegetation, waterbirds, native fish, and other water-dependent biota.

Flow categories

The different magnitudes of river flows that comprise a flow regime can be divided into categories (refer to Figure 5). Each flow category contributes to overall connectivity and ecosystem function uniquely. The extent to which these categories can be managed though the Basin Plan, and in turn their associated environmental outcomes differ.

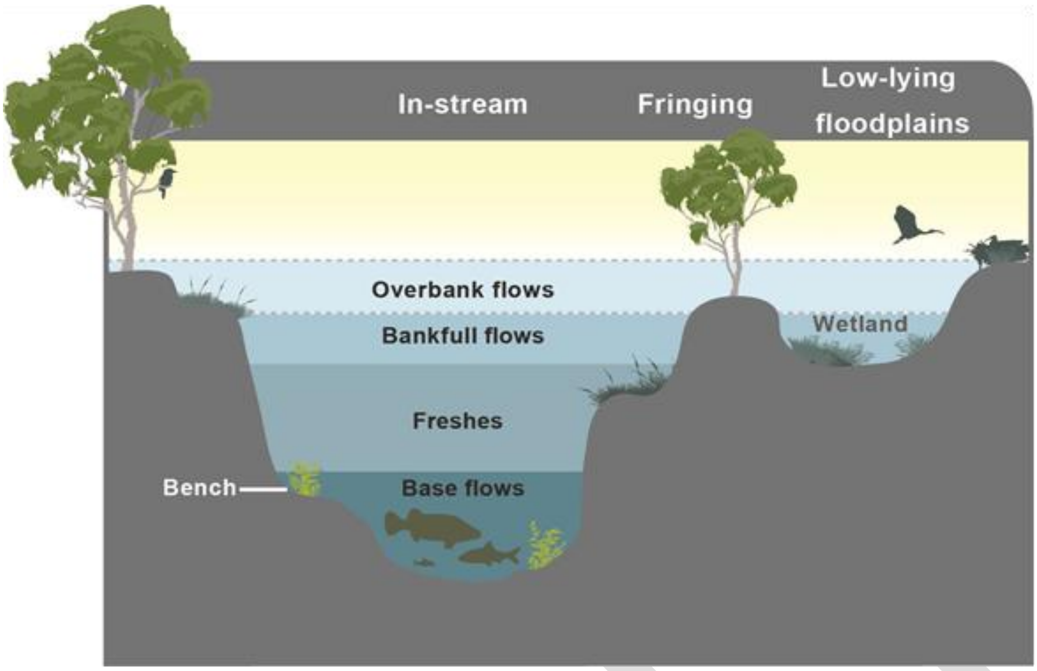

Figure 5: An illustrative river cross section showing components of a flow regime.

Base flows (or low, in-channel flows[3]) 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 in gaining streams and/or small inflow events that generate surface water 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. 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 fringing the channel, comprising various aquatic and semi-aquatic species, and vegetation communities such as river red gum, black box, coolabah (sometimes spelled 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.

Low and medium over-bank flows are substantial flow events that spill onto the low-level 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

[3] The lowest 20% of flows.

communities such as river red gum, black box, coolabah, and lignum as well as non-woody understory floodplain vegetation communities. 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 environmental water, with further gains possible once physical and operational constraints in the system are addressed.

Large over-bank flows are events with high volumes of water which inundate substantial parts of the floodplain including areas at higher elevations. These occur infrequently and are driven by significant climate events. They cannot be actively contributed to or delivered with water recovered under the Basin Plan but remain a critical component of the flow regime that contribute significantly to the condition of ecosystems on the continuum from riverbank to high elevation floodplain area and to vertical connectivity with groundwater systems.

The managed floodplain

In the context of a healthy, working river system, it is useful to think about the degree of influence actively managed flows can have. It is not possible to have a consistent or in some cases any influence over all areas of floodplain area in the Murray–Darling Basin. Achieving lateral connections with most medium and almost all higher-level floodplain environments is out of the scope of most active flow management, due to several factors. These include the physical or operational limits to the capacity to augment flows (e.g. restricted dam outlet capacity), the need to protect towns and high-value agriculture or infrastructure and the finite availability of environmental water to create or contribute to the size of flow events. Therefore, these higher parts of the floodplain are only inundated through passive management, such as occurs from large, natural flood events.

This idea is captured in the concept of the managed floodplain, which differentiates those parts of the floodplain which can receive water through actively managed flows versus those that cannot and are reliant on natural flooding events.

Active management of flows occurs when decisions are made in the course of running a river. It includes decisions to release held environmental water (HEW) from dams, use of the relatively small discretionary component of PEW (e.g. an environmental water allocation (EWA) 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 sharing or resource plans which provide for water for the environment and unregulated flows to pass through the system (i.e. the majority of PEW), rules which limit the amount of water extracted for consumptive use, and rules which restrict the size of flows (i.e. rules that recognise operational and physical constraints in the system). Passive management does not use licensed environmental water (HEW) and so is outside the scope of influence of operational decision making for environmental water managers.

Examples of passive management include:

- ‘Transparent and Translucent flows’ – Under certain conditions all (i.e. transparent) or a portion (i.e. translucent) of inflows can be passed through a regulating structure (normally a dam) resulting in a near-natural flow pulse response to be passed downstream from the

inflow event. These passive management rule exist in some NSW valleys (e.g. NSW Border Rivers (Dumeresq River, MacIntyre River), Macquarie (excluding Cudgegong), Lachlan and Murrumbidgee valleys).
- 'Resumption of flows rule' – After an extended dry period the pumping of water flowing through the Barwon – Darling system is restricted so that the first flows can provide for critical environmental and social needs by achieving connectivity from the Queensland border to Menindee Lakes.
- 'Active Environmental Water (AEW) Protection Management rule' – Protects HEW and some EWA from extraction as it flows downstream (i.e. shepherding) in some unregulated reaches (e.g. Barwon – Darling, lower Macquarie and lower Gwydir).
- Floodplain harvesting regulation and compliance – to reduce the capture of water that flows across the floodplain to ensure the take of water is within sustainable limits.
- Individual Daily Extraction Components in the unregulated Barwon – Darling – that limit total daily extraction to restrict the impact of rapid water removal during peak irrigation periods on river flows.

Both active and passive management of flows contribute towards water remaining in the rivers to provide environmental outcomes.

Actively managed flows of HEW are most effective at creating or contributing to in-channel freshes, or depending on prevailing conditions bank-full or low to medium overbank flows that connect 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 existing flows in the river, or infrastructure is used to raise water levels for a specific area.

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 as 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 varies depending on prevailing river flows and climatic conditions and the amount and location of environmental water in storages.

- Areas that can be inundated using environmental infrastructure. This includes work by the Basin governments and the Murray–Darling Basin Authority 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 are expected to increase as some of the SDLAM environmental works projects are progressively implemented.

The **passively managed floodplain** includes:

- Areas where inundation relies on natural processes of uncontrolled flooding (e.g. unregulated systems) 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).

Valleys with highly altered river flows and large areas of lowland floodplains and wetlands 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 overbank 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.

Figure 6 shows catchments where the Basin Plan should result in connectivity improvements for different parts of the flow regime. Refer to Figure 2 and the section on flow regimes for further explanation.

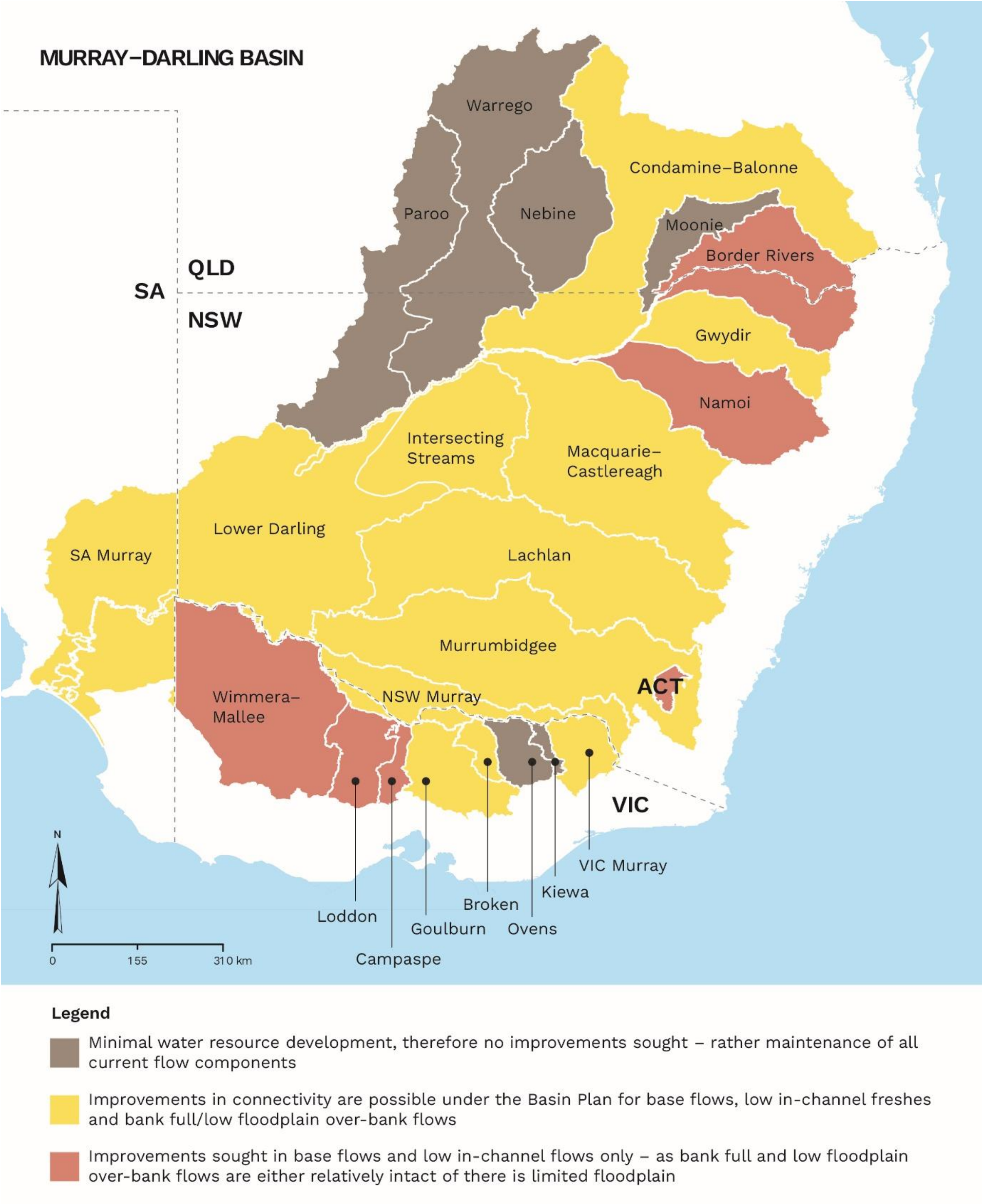

Figure 6: Level of flow component improvement expected under the Basin Plan.

Expected environmental outcomes for river flows and connectivity

The Expected Environmental Outcomes for river flows and connectivity are provided in the Basin-wide Environmental Watering Strategy. These are focused on metrics of longitudinal connectivity, lateral connectivity and end-of-basin flows and are summarised below in Table 1.

Table 1: Summary of flows and connectivity expected environmental outcomes for flows and connectivity (refer to Basin-wide environmental watering strategy for full expected environmental outcome descriptions).

Improve connections along rivers and between rivers and their floodplains
Maintain base flows
• at least 60% of natural levels
Improve overall flow
• 10% more into the Barwon–Darling [1]
• 30% more into the River Murray[2]
• 30–40% more to the Murray Mouth
Maintain connectivity in areas where it is relatively unaffected
• between rivers and floodplains in the Paroo, Moonie, Nebine, Warrego and Ovens
Improve connectivity with bankfull and/or low floodplain flows
• by 30–60% in the Murray, Murrumbidgee, Goulburn and Condamine–Balonne
• by 10–20% in remaining catchments[3]
End-of-Basin flows
• Maintain lake levels and salinity
• Maintain barrage flows

Note 1: Comprising tributary contributions from: Condamine–Balonne, Border Rivers, Gwydir, Namoi and Macquarie–Castlereagh catchments.
Note 2: Comprising tributary contributions from: Murrumbidgee, Goulburn–Broken, Campaspe, Loddon and Lower Darling catchments.
Note 3: Border Rivers, Gwydir, Namoi, Macquarie–Castlereagh, Barwon–Darling, Lachlan, Campaspe, Loddon and Wimmera catchments.

Context

The use of water for the environment aims to restore ecologically significant components of the flow regime to a more natural pattern. This is achieved by adding water to existing flows, by releasing water for the environment held in dams at ecologically appropriate times and rates, or by protecting a proportion of a flow event as water for environment.

The improvements in flow and connectivity from these actions are expected to support ecosystem functions across the Basin and generate positive environmental outcomes for native vegetation, waterbirds, native fish, and other water-dependent biota. When delivered as flow, water for the environment will contribute to longitudinal, lateral, and vertical connectivity on a continuum depending on the magnitude of the event.

Basis for expected outcomes

The Murray–Darling Basin Authority used flow models developed for the Basin Plan to predict how flow and connectivity would respond to environmental water (Murray–Darling Basin Authority, 2012; Parsons et al. 2008). 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
- a baseline scenario, which represents the Basin with the consumptive use and the rules and sharing arrangements as at June 2009
- 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 Murray–Darling Basin Authority 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.

Native Vegetation

Context

The high diversity of habitats within the Murray–Darling Basin supports thousands of native plant species, including more than 200 nationally threatened plants and 28 nationally threatened ecological communities. Riverine, wetland and floodplain environments within the Basin support a diversity of plants including ferns, forbs, grasses, sedges, rushes, shrubs and trees. These plants form communities that occupy permanently, seasonally, and intermittently inundated habitats.

Diverse vegetation in and around rivers, wetlands and floodplains provides food and habitat for a variety of wildlife including waterbirds, woodland birds, frogs, turtles, fish, bats, mammals, reptiles, and macroinvertebrates (Stewart et al. 2010; Blakey et al. 2017; Reid et al. 2022). Riverine, wetland and floodplain environments provide important refuge and habitat corridors during drought and under climate change (Capon et al. 2013). Provision of habitat and food resources by vegetation also contributes to the protection of threatened fauna, such as migratory bird species.

The importance of vegetation extends to all rivers, wetlands and floodplains. Vegetation influences nutrient and carbon dynamics and contributes organic matter to rivers which is important for food webs (Baldwin et al. 2013). Plants are a direct source of food for fauna such as fish and waterbirds. Vegetation helps maintain water quality by filtering pollutants and sediments from run-off, contributes to instream processes such as substrate for biofilms, and helps maintain soil and bank stability (Brix 1997; Wijewardene et al. 2022; Treadwell et al. 2023). Vegetation is also important for micro-climatic regulation, such as shading and cooling of instream waters and floodplain soils (Riis et al. 2020), and for facilitating the growth of other plants (James et al. 2015).

People value the Basin's native vegetation. Native vegetation holds cultural significance for First Nations people for medicine, fibre, food resources, shelter, messages or boundaries, ceremonial or dreaming/storytelling, hunting or fishing, basket weaving, and many other uses or values[4].

Native vegetation is connected to health and wellbeing, has aesthetic appeal, and contributes to recreational enjoyment (e.g. Campbell et al. 2023a). It is also important for tourism, along with industries such as grazing, and (in some places) forestry. Depicted in Australian art and literature, river red gum, black box and coolabah are valued as part of Australian cultural identity.

Typology

Figure 7 depicts a simplified representation of how different structural vegetation groups are commonly positioned on floodplains of the Basin. This depiction is indicative only and vegetation responses to watering regimes will vary spatially in relation to a wide range of factors. These factors may include soil type, groundwater depth and salt content, climate and weather, land use, condition of the vegetation, recent and historic water regimes, and predicted climatic and water availability scenarios.

[4] See table and multiple references within Campbell et al. 2023b, p. 107.

For the purpose of the Strategy, native vegetation has been categorised into three broad 'structural groups' to represent different broad habitat types: i) forests and woodlands, ii) shrublands, and iii) non-woody vegetation.

These broad structural groups are defined in terms of the dominant life-forms. Within these broad structural groups, the Expected Environmental Outcomes and watering strategies to achieve these outcomes, are expected to target and provide benefit to plant communities (including the understory of forests and woodlands), not just those of a dominant species.

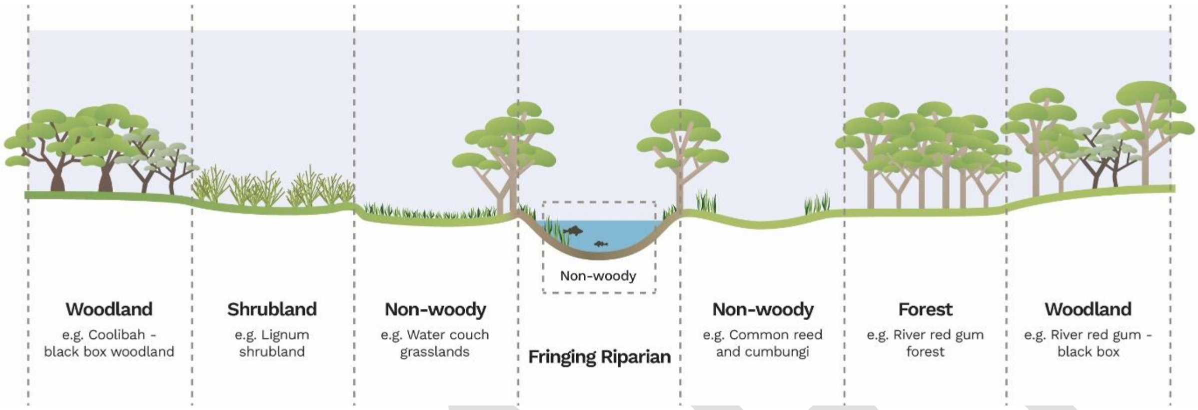

Figure 7: A conceptual view of structural groups of Basin river, wetland and floodplain vegetation.

Forests and woodlands

River red gum (*Eucalyptus camaldulensis*), black box (*Eucalyptus largiflorens*) and coolabah (*Eucalyptus coolabah)* are three iconic tree species that dominate many of the forests and woodlands associated with the rivers, wetlands and floodplains of the Basin. These forests and woodlands line rivers and creeklines, fringe wetlands, and form extensive forests and woodlands across floodplain areas.

River red gum typically dominates lower-lying temperate floodplains in the southern and central-eastern Basin including Barmah – Millewa Forest, Gunbower-Koondrook-Pericoota Forest, and the Macquarie Marshes. Black box, where it occurs with river red gum or coolabah, typically occupies higher elevation floodplain. Black box extends into semi-arid and arid parts of the Basin such as the floodplains of the Lower Darling, Lachlan River, and Chowilla-Lindsay-Mulcra-Wallpolla Islands. Coolabah typically dominates the rivers and floodplains of the northern Basin, such as the Condamine-Balonne, Paroo, Warrego, and Namoi Rivers. The *Coolibah – Black Box woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions* are listed as an Endangered ecological community under the *Environment Protection Biodiversity Conservation Act 1999*.

Shrublands

Shrublands are plant communities dominated by shrubs with scattered or no tree cover. An important shrub species associated with the wetlands and floodplains of the Basin is Tangled Lignum (*Duma florulenta*) (hereafter referred to as 'lignum'). Lignum forms vast shrublands, such as along the Booligal Wetlands in the Lachlan catchment, Narran Lakes in the Condamine-Balonne catchment, and wetlands and floodplains associated with the Macquarie Marshes, Gwydir River and Lower Murrumbidgee River floodplains. Lignum shrublands can facilitate higher levels of non-woody plant diversity in their understorey (James et al. 2015) and provide significant habitat and nesting areas (rookeries) for waterbirds (Butcher et al. 2011, NSW DPIE 2020a, b). Lignum shrublands are commonly used by large waders such as ibis, spoonbills, herons and egrets, along with cryptic species such as Australasian bittern, Australian painted snipe, Australian spotted crake and Ballion’s crake (Brandis et al. 2022; McGinness et al. 2023). Extensive areas of lignum shrubland have been cleared and drained across the Basin since European settlement. Areas of lignum have also been lost or structurally modified (reduced height, width, density, cover) because of reduced inundation frequency (Campbell et al. 2019).

Non-woody vegetation

The broad structural group ‘non-woody vegetation’ refers to areas of herbaceous habitat dominated by non-woody plants, such as charophytes, forbs, grasses, sedges, reeds and rushes. In wetland and instream settings these plants may collectively be referred to as macrophytes. In the context of this Strategy, non-woody vegetation refers to areas of herbaceous plant communities that fringe water courses, grow instream, and occur within wetlands and across floodplains. Examples of herbaceous plant communities include the semi-aquatic grasslands dominated by Moira grass (*Pseudoraphis spinescens*) in the Barmah – Millewa Forest; water couch (*Paspalum distichum)* meadows in the Gwydir Wetlands and Macquarie Marshes; large areas of marsh club rush (*Bolboschoenus fluviatilis*) that occur across the Gwydir Wetlands; the expansive areas of common reed (*Phragmites australis*) and cumbungi (*Typha* spp.) that characterise the Great Cumbung Swamp and Macquarie Marshes; along with many other areas identified in long-term watering plans.

Areas of non-woody vegetation across the Basin provide diverse and vital habitat for different species. The mid and lower Murrumbidgee support diverse aquatic meadows that provide habitat for a range of fauna, including the threatened growling grass frog (*Litoria raniformis*) (Wassens et al. 2023). Freshwater wetlands with dense, emergent vegetation support the threatened Australasian Bittern (TSSC 2019). In semi-arid to arid regions such as the Lower Balonne, Chowilla Floodplain, and along the Murray-Lower Darling Rivers, ephemeral wetlands support dynamic communities of amphibious herbs that germinate and grow as water recedes (NSW DPIE 2020a, c).

In the Lower Lakes and Coorong, beds of *Ruppia tuberosa* and other species (referred to as the ruppia community) provide food and habitat for macroinvertebrates and fish, including the small-mouth hardyhead (*Atherinosoma microstoma*) and protected migratory waterbirds (i.e. those listed under JAMBA, ROKAMBA, and the Bonn Convention) (Nicol 2005; Waycott and Lewis 2022). Many of these examples of non-woody plant communities contribute to the ecological character of Ramsar wetland sites or to sites listed on the Directory of Important Wetlands in Australia. Basin state government long-term watering plans identify additional areas of non-woody vegetation that are important in their regional areas and contribute to the diversity of the Basin.

Condition

The status of vegetation across the Basin is variable and can fluctuate through time. There are examples of improvements, maintenance, and declines in vegetation condition.

The 2020 Basin Evaluation assessed the proportion of tree stands in moderate or better condition for river red gum, black box and coolabah trees pre (1987 – 2011) and post (2014 – 2019) the Basin

Plan using the Stand Condition Tool (SCT) (see Cunningham et al. 2014; Murray–Darling Basin Authority 2020b). The proportion of trees in moderate or better condition (using the SCT) varies considerably across the Basin and between the three species; it ranged from 60 % to 90 % for river red gum, from < 20 % to just over 50 % for black box, and from 25 % to 70 % for coolabah (Murray–Darling Basin Authority 2020b). The 2020 Basin Evaluation found that the proportion of trees in moderate or better condition was similar pre and post Basin Plan for the majority of the 20 BWS regions (as relevant) for black box and coolabah and to a lesser extent for river red gum. The analysis showed that the proportion of river red gum trees in moderate or better condition had declined in six regions, with an increase noted for one region (Murray–Darling Basin Authority 2020b).

Monitoring and reporting of vegetation responses through The Living Murray program (TLM) report cards indicates that outcomes for wetland and floodplain vegetation have incrementally improved over time at some icon sites such as Barmah – Millewa Forest, Gunbower Forest and Hattah Lakes[5]. Other icon sites have not observed wide-spread improvements in vegetation and predominantly report[6] the maintenance of vegetation that is fair (e.g. Chowilla) or needs attention (e.g. Koondrook-Perricoota). Monitoring conducted under the Commonwealth Environmental Water Holder's Flow-MER program indicates that environmental water actions over the last 8 years have inundated a representative range of ecosystem types across the Basin (Brooks 2023) and contributed to the maintenance of water-dependent plant species (Campbell et al. 2023b). In the absence of environmental water delivery during this period, the distribution and abundance of certain types of non-woody vegetation, such as submerged and amphibious species, is likely to have been reduced because of reduced inundation frequency and increased duration of inter-flood dry periods (Campbell et al. 2023b). For example, wetlands in the mid and lower Murrumbidgee contain aquatic plants that require seasonal inundation. The regular delivery of water for the environment to some wetlands in this region contributes to the maintenance of diverse aquatic meadows (Wassens et al. 2023). Monitoring of waterways through programs such as Flow-MER and VEFMAP has also shown that environmental flows can successfully be used to promote growth and recruitment of aquatic plants both instream and on riverbanks.

Environmental water management has led to responses in a range of vegetation types across the Basin. For example, there have been improvements in the cover and biomass of tall reed beds in parts of the Great Cumbung Swamp (Higgisson et al. 2022, 2024; James 2022) and increases in lignum and tree condition scores in parts of the mid to lower Murray (Wallace et al. 2020; Campbell et al. 2021a; Higgisson et al. 2023). In addition, environmental water management has contributed to the maintenance of wet-dry transitions in vegetation communities such as river cooba and lignum shrubland in the Gwydir, and water couch and river red gum communities in the Macquarie Marshes, contributing to improved plant diversity, cover and composition (Gwydir Flow-MER 2022; Mason et al. 2022). Improved cover of bank vegetation in the Goulburn/Kaiela River, from changes in water management, also contributes to bank stabilisation and improvements in sedimentation and erosion processes (Treadwell et al. 2023).

[5] Follow links for report cards and access to additional reports and references.

[6] Noting that reporting is a grading system that is based on the percentage of ecological objectives, relating to a specific component such as vegetation, that have been met.

The Living Murray program monitors the response of the *Ruppia tuberosa* community (referred to as ruppia) in the South Lagoon of the Coorong. The 2020 Basin Evaluation reported that there had been significant improvements in ruppia extent since the implementation of the Basin Plan with extent targets being achieved in both 2017 and 2018 for the first time since the Millennium Drought (Murray–Darling Basin Authority 2020a). Shoot density had also shown improvement since the Millennium Drought, noting shoot density is variable between years (Figure 8). The seedbank of ruppia, however, remained very low at the time of the 2020 Evaluation (Murray–Darling Basin Authority 2020a) (~200 seeds/m^2 in summer surveys and < 400 seeds/m^2 in winter surveys) and has continued to remain low in recent years (Figure 8). As ruppia is an annual plant it must produce seeds and turions to secure its future viability (Nicol 2005). Recent summer monitoring (January 2024; Paton and Paton 2024) indicates a reduction in ruppia extent with a sharp decline in the number of sites with live plant material. Persistently low seedbank abundance coupled with a recent decline in extent of live plant material has raised concerns regarding the viability of ruppia in the South Lagoon of the Coorong (Paton & Paton 2024).

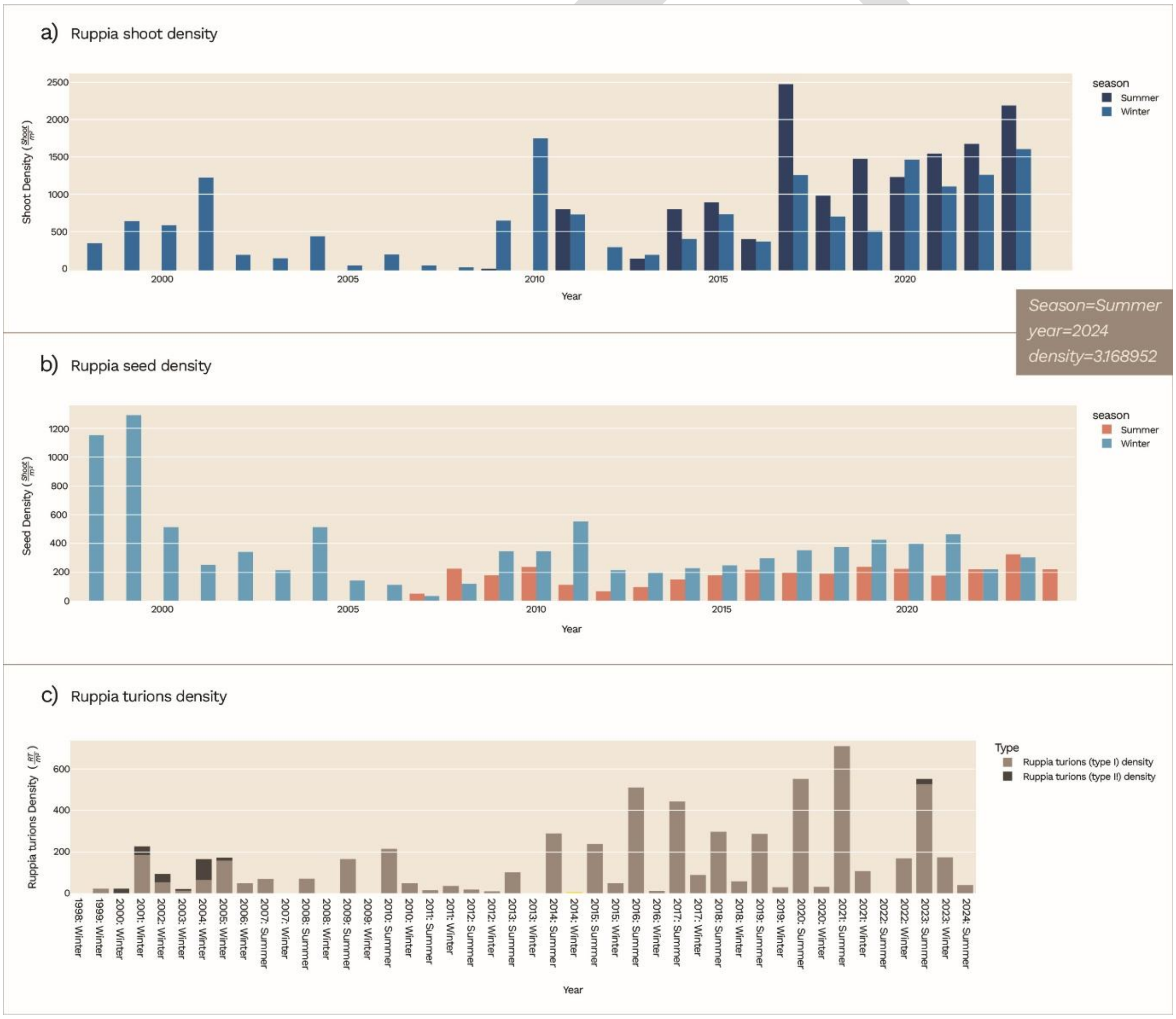

Figure 8: Density of Ruppia tuberosa a) shoots, b) seeds and c) turions from winter and summer monitoring in the South Lagoon of the Coorong, winter 1998 to summer 2024. Note that summer monitoring in 2024 detected very low shoot density that is not visible as a bar on the graph.

Threatened species

Many of Australia's plants are unique and occur nowhere else in the world. Australia hosts the highest proportion (88%) of endemic plants of any country (Gallagher et al. 2023, State of the World's Plants and Fungi). The extent to which Australia has assessed the extinction threat facing its endemic plant species is considered low by global standards with more than 60% of plant species awaiting rigorous threat assessment (Gallagher et al. 2023). This means there may be more plant species threatened with extinction than currently known.

Within the Basin, across river, wetland and floodplain habitats[7], there are 214 *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act) listed plant species and 28 ecological communities that are likely to occur[8]. Table 6 and Table 7 identifies 25 EPBC Act listed plant species and 15 ecological communities considered likely to have life cycle or habitat requirements associated with water-dependent ecosystems that depend on Basin water resources. This Strategy has considered plant species and ecological communities listed under the EPBC Act with state-listed plant species and ecological communities to be reviewed in the future. Identified threatened plants and ecological communities will need to be periodically updated.

Interactions between native vegetation and flows

Vegetation responds to changes in hydrologic conditions through shifts in attributes such as composition, cover, height and extent along with other physiological and phenological responses such as photosynthetic capacity, water use, growth rates, biomass accumulation, and reproduction.

Plant communities in rivers, wetlands and floodplains rely on varying combinations of water sources including river flows, groundwater, and rainfall, with complex relationships and interactions among water sources (e.g. Thorburn & Walker 1994; Holland et al. 2006; DSITI 2017). The use of water sources will vary between specific plant species and communities, including for different life-history stages (e.g. seedlings or adults). For certain species, such as coolabah, there is some uncertainty regarding the requirement for particular water sources to support different life-history stages (DSITI 2017). The use of water sources will vary spatially in relation to multiple factors, such as climate, soil type, depth to groundwater and groundwater salinity. The Basin Plan is unable to influence all water sources (e.g. rainfall) and is constrained in the ability to influence river flows and groundwater in certain spatial locations.

River flows are a critical and integral part of river, wetland and floodplain ecosystems. For example, river flow influences soil moisture and groundwater levels (Stewardson et al. 2021; Bennetts et al. 2022), are important for the transport of organic material and propagules, and contribute to carbon and nutrient dynamics that influence soil microbial processes and soil health (Baldwin et al. 2013). Appropriate flow regimes, influencing the availability of nutrients and water (surface, soil and /or groundwater), are fundamental to the growth and survival of plants in rivers, wetlands and floodplains.

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[7] As defined by spatial layers that designate Australian National Aquatic Ecosystem (ANAE) types, actively managed areas of the floodplain under both current and relaxed constraints, and passively managed areas of the floodplain.
[8] Based on the intersection of distributions of 'habitat likely to occur' (part of the SPRAT database and available here) with the Murray–Darling Basin floodplain layers in the footnote above.

Expected environmental outcomes for water-dependent vegetation

The Expected Environmental Outcomes for water dependent vegetation are provided in the Basin-wide Environmental Watering Strategy. These are focused on metrics such as extent, condition, age structure, opportunities for growth, and sustained and adequate populations and are summarised below in Table 2.

Table 2: Metrics used to describe Expected Environmental Outcomes for broad structural groups of native vegetation. Refer to Basin-wide environmental watering strategy for full expected environmental outcomes for native vegetation.

	Forests and woodlands	Shrublands	Non-woody vegetation
Extent	Maintain	Maintain	Maintain
Condition	No decline Improve (specific context)	Improve	
Age structure	Improve		
Periods of growth			Increase
Sustained and adequate populations			Specific to *Ruppia tuberosa*

Context

Environmental water management is an important aspect in the conservation and protection of native vegetation. The Expected Environmental Outcomes described in the Strategy are focused on riverine, wetland and floodplain native vegetation which rely on the Basin's water-dependent ecosystems. Environmental water management to support native vegetation includes surface flows, such as in-stream fluctuations and water level variability, permanent, seasonal or intermittent inundation from riverine connections, as well as interactions with groundwater.

To maximise the likely benefits, environmental water management for native vegetation outcomes needs to be undertaken in conjunction with integrated land management and continued efforts to optimise the spatial extent that can be influenced by water management[9].

Within the broad structural groups, the Expected Environmental Outcomes and watering strategies to achieve these outcomes, are expected to target and provide benefit to plant communities, not just those of a dominant species. For example, Expected Environmental Outcomes for forests and woodlands are expected for the dominant canopy species as well as associated understory species. Similarly, Expected Environmental Outcomes for non-woody vegetation are expected for plant communities, for example water couch meadows, which may include one or more plant species.

Basis for expected outcomes

The vegetation outcomes expected under the Strategy are described for areas that can be influenced with environmental water. Outcomes are predominantly described at a Basin-scale with additional details provided for specific assets or Basin regions. This section includes key c

[9] Noting that water management encompasses the delivery of environmental water along with operational guidelines and other policy decisions that influence disruptions, barriers, or alterations to water flows, or groundwater levels.

onsiderations and definitions for the Expected Environmental Outcomes for water-dependent vegetation.

Forests and woodlands

Forests and woodlands include wooded communities fringing riverbanks or wetlands, occurring in wetlands (e.g. river red gum swamps or coolabah woodland wetlands) and on floodplains (e.g. forests or woodlands). Where herbaceous (non-wooded) habitat characteristics are valued (e.g. non-woody wetlands or grasslands) woody encroachment is not an expected outcome and interventions may be required to manage encroachment and maintain herbaceous (non-wooded) habitat values.

Forests and woodlands extent (V1) (see section below - Supporting information for expected outcomes), is based on Cunningham et al. 2013 modelling. Work is ongoing to update how extent is derived and to calculate changes in extent overtime. Improvements in mapping technology and development of new mapping tools will enhance the accuracy of forest and woodland extent outcomes over time. Once mapping tools are fully developed, updated areas of vegetation extent will be incorporated into vegetation Expected Environmental Outcomes.

Forests and woodlands condition (V2) was calculated using the Stand Condition Tool (Cunningham et al. 2007, 2014) in 2014 for the first edition of the Strategy. These condition scores were used to develop Expected Environmental Outcomes to maintain or improve condition (see section below - Supporting information for expected outcomes). An assessment of the SCT in 2019 found opportunities for improvement that will be investigated (Murray–Darling Basin Authority 2020c; The Murray–Darling Basin Tree Stand Condition Tool Hindcast Report (mdba.gov.au).

Expected Environmental Outcomes for **forest and woodland age class structure (V3)**, to support viable population demographics (defined below) applies in forest and woodland communities and/or in areas where tree population demographics has been identified as a management objective in regional plans. Expected Environmental Outcomes for forest and woodland age class structure across the Basin are informed by expert scientific advice along with work jointly undertaken by the Basin states and Murray–Darling Basin Authority (e.g. VTAG 2021). Age class structure relates to all tree stages (e.g. seedling, sapling, adult trees, hollow-bearing trees). Regionally specific objectives for age class structure may refer to increased opportunities for germination, facilitating survival from seedling to sapling (e.g. managing the effect of grazing pressure), or management actions that aim to protect or promote large hollow-bearing trees. **Viable population demographics (V3)** represents appropriate germination and establishment through tree stages (e.g. seedling, sapling, adult trees, hollow-bearing trees) to maintain characteristics of the population, such as habitat value.

Shrublands

Tangled lignum (*Duma florulenta*) is recognised as a wide-spread, structurally dominant shrub in wetland and floodplain habitats across the Basin. **Lignum shrublands** are the primary shrubland type targeted by these Expected Environmental Outcomes. Shrublands characterised by other structurally dominant shrub species may be important in specific locations across the Basin and may be addressed in regional plans.

Updates to BWS regions where Expected Environmental Outcomes for lignum are expected (see section below - Supporting information for expected outcomes) were informed by Long-Term Water Plans (LTWPs). Expected Environmental Outcomes for the **extent of lignum shrubland (V4)** across the Basin are not yet expressed quantitatively, with work ongoing to make that possible. Outcomes apply to wetland or floodplain areas where lignum is structurally dominant, for example (but not limited to) the ANAE mapping units Pt1.7.2: Temporary lignum swamp and F2.2: Lignum shrubland riparian zone or floodplain, or areas identified in LTWPs.

Currently there is no Basin-scale approach to calculate the **condition of lignum (V5)**. Regional approaches exist including both field and drone-based approaches. Opportunities to aggregate outcomes from regional scales or develop Basin-scale approaches will be investigated. Outcomes for lignum shrubland apply across most Basin regions.

Non-woody vegetation

Non-woody vegetation refers to areas of herbaceous (non-wooded) habitat dominated by herbaceous (non-woody) plants, such as forbs, grasses, sedges, reeds and rushes. In the context of this Strategy, non-woody vegetation refers to areas of herbaceous plant communities that fringe water courses, grow instream, and occur within wetlands and across floodplains. It refers specifically to herbaceous (non-wooded) plants and communities which occur in water-dependent ecosystems such as rivers, wetlands and floodplains. Expected Environmental Outcomes for non-woody vegetation were drawn from expert scientific advice and in multiple instances were developed to reflect the ecological character of Ramsar sites. Updates to BWS regions where Expected Environmental Outcomes for non-woody vegetation are expected (see section below - Supporting information for expected outcomes) were informed by Long-Term Water Plans (LTWPs).

Expected Environmental Outcomes for the **extent of non-woody vegetation (V6)** across the Basin are not yet expressed quantitatively. It may be possible to make use of best available local information.

Increased periods of growth (V7) recognises the requirement for appropriate flow regimes for different non-woody plants and vegetation communities. For example, hydrological variability, including increases and decreases in water level (e.g. for vegetation on riverbanks or closely fringing river corridors), periodic inundation and in some instances drying (e.g. extensive stands within wetlands and floodplains), along with other hydrological variables such as season, frequency, depth, duration, etc. The intent is to provide (via flow regimes) and observe (via monitoring) increased periods of growth, compared to the scenario without Basin Plan implementation, for non-woody vegetation in water-dependent ecosystems. Providing increased periods of growth aims to enable (all or some) life-cycle components to occur, such as germination, growth, reproduction / regeneration, and dispersal to maintain the viability of communities. Evaluation of increased periods of growth should consider hydrological conditions and vegetation responses across multiple years. Appropriate periods of growth, to maintain the characteristics and values of target communities, will vary for different types of non-woody plant communities. LTWPs are well placed to identify quantified objectives, targets and/or water regimes for specific types of non-woody plant communities at regional and local scales.

Advice suggests for the seed bank to be sufficient for the ***Ruppia tuberosa*** **(V8)** population to be resilient to major disturbances would require at least 10,000 seeds/m^2 within the bed of the core population of *R. tuberosa* (Waycott & Lewis, 2022).

Supporting information for expected outcomes

Five tables are provided to support the explanation of the native vegetation Expected Environmental Outcomes:

- Table 3: Expected extent and condition outcomes for communities of water-dependent vegetation as a result of the Basin Plan.
- Table 4: Table 4: Condition of black box trees in the Lachlan, Murrumbidgee, Lower Darling, Murray, Wimmera–Avoca and Goulburn–Broken.
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- Table 5: Condition of river red gum trees in the Lachlan, Murrumbidgee, Lower Darling, Murray, Wimmera–Avoca and Goulburn–Broken.
- Table 6: EPBC-listed plant species with a likely link to water-dependent ecosystems reliant on Basin water resources.
- Table 7: EPBC-listed ecological communities with a likely link to water-dependent ecosystems reliant on Basin water resources.

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

Outcomes for native vegetation have been considered for 20 regions across the Basin (Basin environmental watering strategy (BWS) regions; Figure 9). Table 3 estimates outcomes that are expected within current constraints and operational works and measures – i.e. in areas that can be influenced by environmental water management. It should be noted that the outcomes listed below will be influenced by a combination of water management under the Basin Plan, unregulated high flows, climatic and weather condition, land use decisions, fire, and constraints to flow. The relaxation of constraints would result in greater outcomes because the areas of floodplain vegetation receiving flows would increase.

Environmental assets and outcomes listed below must be considered in regional long-term environmental watering plans (LTWPs) (in addition to regionally significant sites). They may be considered explicitly via specific objectives and targets (e.g. objectives that relate to river red gum) and/or they may be considered as part of the delivery of flow components (e.g. overbank flows) to support ecological functions (e.g. dispersal or recruitment of water-dependent biota). Relevant LTWPs are indicated for each BWS region. Additional detail on regional extent and expected outcomes are available within LTWPs. The number of hectares stated is based on vegetation extent using Cunningham et al. 2013 mapping cropped to the managed floodplain. Areas may change as updated information and knowledge is received.

Data source: Geoscience Australia Topo250k, Bureau of Meteorology

Figure 9: Basin environmental watering strategy (BWS) regions used to define expected extent and condition outcomes for communities of water-dependent vegetation.

Table 3: Expected extent and condition outcomes for communities of water-dependent vegetation as a result of the Basin Plan.

BWS region	Outcomes for water-dependent vegetation	Area of river red gum (ha)*	Area of black box (ha)*	Area of coolabah (ha)*	Shrublands	Non–woody water-dependent vegetation	Relevant LTWPs
Paroo	Maintain extent and condition** of water-dependent vegetation near river channels and on the floodplain Where feasible maintain or improve vegetation that contributes to the ecological character of the Paroo River Wetlands[ii] and Currawinya Lakes[ii] Ramsar sites	2,300	38,300	22,800	Lignum in the Paroo River region	Closely fringing or occurring within the Paroo River and associated wetlands	• QLD Warrego, Paroo, Bulloo, Nebine LTWP • NSW intersecting streams LTWP (i.e. Paroo River planning unit)
Warrego	Maintain extent and condition** of water-dependent vegetation near river channels and on the floodplain	7,300	80,400	121,400	Lignum in the Warrego River and Toorale region	Closely fringing or occurring within the Warrego, Langlo, Ward & Nive rivers	• QLD Warrego, Paroo, Bulloo, Nebine LTWP • NSW intersecting streams LTWP (i.e. Warrego River and Toorale planning units)
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	• QLD Warrego, Paroo, Bulloo, Nebine LTWP
Condamine–Balonne	Maintain extent and condition** of water-dependent vegetation near river channels and on areas of the floodplain Where feasible maintain or improve vegetation that contributes to the ecological	11,500#	36,100#	62,900#	Lignum in Narran Lakes, the Lower Balonne and Culgoa river regions	Closely fringing or occurring within the Condamine, Balonne, Birrie, Bokhara, Culgoa, Maranoa, Merivale & Narran rivers	• QLD Condamine-Balonne LTWP • NSW intersecting streams LTWP (i.e. Culgoa, Narran planning units)

BWS region	Outcomes for water-dependent vegetation	Area of river red gum (ha)*	Area of black box (ha)*	Area of coolabah (ha)*	Shrublands	Non–woody water-dependent vegetation	Relevant LTWPs
	character of the Narran Lake Nature Reserve Ramsar site					Forming extensive stands such as lakebed herbfields in Narran Lakes	
Moonie	Maintain extent and condition** of water-dependent vegetation near river channels and on the floodplain	2,200	2,500	7,900	Lignum in the Moonie river region	Closely fringing or occurring within the Moonie River	• QLD Border Rivers and Moonie LTWP • NSW intersecting streams LTWP (i.e. Moonie River planning unit)
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, including Macintyre and Boomi Rivers (downstream of the confluence with Dumaresq), Whalan and Croppa Creeks	Closely fringing or occurring within the Barwon, Dumaresq, Macintyre rivers & Macintyre Brook	• QLD Border Rivers and Moonie LTWP • NSW Border Rivers LTWP
Gwydir	Maintain extent and condition** of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Where feasible maintain or improve vegetation that contributes to the ecological character of the Gwydir Wetlands Ramsar site	4,500#	600#	6,500#	Lignum in the lower Gwydir	Closely fringing or occurring within the Gwydir River Forming extensive stands such as marsh club-rush and water couch in the Gwydir Wetlands	• NSW Gwydir LTWP

BWS region	Outcomes for water-dependent vegetation	Area of river red gum (ha)*	Area of black box (ha)*	Area of coolabah (ha)*	Shrublands	Non–woody water-dependent vegetation	Relevant LTWPs
Namoi	Maintain extent and condition** of water-dependent vegetation near river channels.	6,100	800	4,200	Lignum in the Namoi catchment region	Closely fringing or occurring within the Namoi River	• NSW Namoi LTWP
Macquarie–Castlereagh	Maintain extent and condition** of water-dependent vegetation near river channels and on low-lying areas of the floodplain Where feasible maintain or improve vegetation that contributes to the ecological character of the Macquarie Marshes Ramsar site	58,200	57,100	32,000	Lignum in parts of the Macquarie-Castlereagh region including the Macquarie Marshes	Closely fringing or occurring within the Bogan, Castlereagh, Macquarie and Talbragar rivers Forming extensive stands such as common reed, cumbungi and water couch in the Macquarie Marshes	• NSW Macquarie-Castlereagh LTWP
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#	Lignum in the Barwon – Darling region	Closely fringing or occurring within the Darling River	• NSW Barwon – Darling LTWP
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 Forming extensive stands such as common reed and	• NSW Lachlan LTWP

BWS region	Outcomes for water-dependent vegetation	Area of river red gum (ha)*	Area of black box (ha)*	Area of coolabah (ha)*	Shrublands	Non–woody water-dependent vegetation	Relevant LTWPs
						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 Where feasible maintain or improve vegetation that contributes to the ecological character of Ramsar sites in the Murrumbidgee region: Fivebough and Tuckerbil Swamps and Ginini Flats[ii] wetlands	68,300	38,900		Lignum in the lower Murrumbidgee	Closely fringing or occurring within the Murrumbidgee River, Billabong and Yanco creeks Forming extensive stands such as aquatic herbfields in the Lowbidgee	• NSW Murrumbidgee LTWP • ACT LTWP (in prep)
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 in the lower Darling region	Closely fringing or occurring within the Darling River, Great Darling Anabranch and Talywalka Anabranch	• NSW Murray-Lower Darling LTWP
Ovens	Maintain extent and condition** of water-dependent vegetation near river channels and on the floodplain	10,200	<100			Closely fringing or occurring within the Ovens River	• Northern Victoria LTWP
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	• Northern Victoria LTWP

BWS region	Outcomes for water-dependent vegetation	Area of river red gum (ha)*	Area of black box (ha)*	Area of coolabah (ha)*	Shrublands	Non–woody water-dependent vegetation	Relevant LTWPs
Campaspe	Maintain extent and condition** of water-dependent vegetation near river channels	1,900	<100		Lignum in the Campaspe region	Closely fringing or occurring within the Campaspe River	• Northern Victoria LTWP
Loddon	Maintain extent and condition** of water-dependent vegetation near river channels Where feasible maintain or improve vegetation that contributes to the ecological character of the Kerang Lakes Ramsar site (within the Loddon region)	2,200	700		Lignum in the Loddon region	Closely fringing or occurring within the Loddon River	• Northern Victoria LTWP
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. Where feasible maintain or improve vegetation that contributes to the ecological character of Ramsar sites along the Murray River corridor including Barmah Forest, NSW Central Murray State Forests, Gunbower Forest, Hattah-Kulkyne Lakes, the South Australian Riverland, and the Coorong and Lakes Alexandrina and Albert sites.	90,600	41,700		Lignum along the Murray River from the junction with the Wakool River to downstream of Lock 3, including Chowilla and Hattah Lakes	Closely fringing or occurring within rivers and creeks in the Murray region from Hume Dam to the Murray Mouth Forming extensive stands such as *Ruppia tuberosa* in the Coorong and Moira grasslands in the Barmah–Millewa Forest	• NSW Murray-Lower Darling LTWP • Victorian Murray LTWP • Victorian Wimmera-Mallee LTWP • SA River Murray LTWP • SA Murray Region LTWP
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		Lignum in wetlands in the Wimmera-Avoca region	Closely fringing or occurring within the Avoca, Avon, Richardson and Wimmera rivers	• VIC Wimmera-Mallee LTWP

BWS region	Outcomes for water-dependent vegetation	Area of river red gum (ha)*	Area of black box (ha)*	Area of coolabah (ha)*	Shrublands	Non–woody water-dependent vegetation	Relevant LTWPs
	Where feasible maintain or improve vegetation that contributes to the ecological character of the Kerang Lakes Ramsar site (within the Avoca region) and Lake Albacatya[ii] Ramsar site						
Eastern Mt Lofty Ranges	Maintain extent and condition of water-dependent vegetation near river channels	<100	<100			Closely fringing or occurring within river channels Important wetland areas such as the Fleurieu swamps	• SA Eastern Mt Lofty Ranges LTWP

*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 are 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. See also Cunningham SC, Griffioen P, White M and Mac Nally R, (2014) A Tool for Mapping Stand Condition across the Floodplain Forests of The Living Murray Icon Sites. Murray–Darling Basin Authority, Canberra.

#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 technical limitations in determining the lateral extent achieved through implementation of the Basin Plan.

i Condition, from which improvement is expected, is scored from 0–10, using the Stand Condition Tool (Cunningham et al 2014), 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 (see also Table 4 and Table 5).

[ii]We acknowledge that some Ramsar wetlands sites in the Basin, such as Currawinya Lakes, Paroo River Wetlands, Lake Albacutya, and Ginini Flats, have very limited capacity to be influenced by Murray–Darling Basin water management.

Condition of black box and river red gum trees in the Lachlan, Murrumbidgee, Lower Darling, Murray, Wimmera–Avoca and Goulburn–Broken

Outcomes for tree condition are based on work undertaken through the Stand Condition Tool (Cunningham et al 2007, 2014) and provided for six Basin regions (Table 4, Table 5). The area of tree communities in different condition categories is taken from the 2014 version of the Strategy and is based on data prior to 2013. Forest and woodland Expected Environmental Outcomes and the assessment of tree condition, across all Basin regions and all priority tree species, will be revised following the 2026 Basin Plan Review.

Table 4: 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)[ii]
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 5: 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)[ii]
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, using the Stand Condition Tool (Cunningham et al. 2014), 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.

[ii] The area of vegetation where condition has been assessed is based on the extent of RapidEye™ imagery purchased for this assessment because Landsat 7 data were corrupted (purchased for the 2014 version of the Strategy).

Environment Protection and Biodiversity Conservation (EPBC) _Act 1999_-listed plant species and ecological communities with a likely link to water-dependent ecosystems reliant on Basin water resources

The Basin Plan established provisions for threatened species and communities via objectives in Chapter 8, particularly 8.05(3) An objective is to protect and restore biodiversity that is dependent on Basin water resources by ensuring that:

(a) 'water-dependent ecosystems that support the life cycles of a listed threatened species or listed threatened ecological community, or species treated as threatened or endangered (however described) in State law, are protected and, if necessary, restored so that they continue to support those life cycles;

Within the Murray–Darling Basin, across river, wetland and floodplain habitat[10], there are 214 EPBC Act listed plant species and 28 ecological communities that are likely to occur[11]. Table 6 and Table 7 provide additional information for 25 EPBC Act listed plant species and 15 ecological communities that are likely to have life-cycle or habitat requirements associated with water-dependent ecosystems reliant on Basin water resources[12]. A decision trees along with available ecological information associated with each EPBC listing was used to inform the short-listing of plant species and ecological communities in Table 6 and Table 7[13]. For this version of the Strategy, plant species and communities listed under the EPBC Act have been considered with state-listed plant species and communities to be reviewed in the future. Identified threatened plants and communities will need to be periodically updated.

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[10] As defined by spatial layers that designate Australian National Aquatic Ecosystem (ANAE) types, actively managed areas of the floodplain under both current and relaxed constraints, and passively managed areas of the floodplain.
[11] Based on the intersection of distributions of 'habitat likely to occur' (part of the SPRAT database and available here) with the defined Murray–Darling Basin floodplain layers.
[12] Where 'water-dependent ecosystems' and 'Basin water resources' are defined under the _Water Act 2007_
[13] This information is available on request.

Table 6: *Environment Protection and Biodiversity Conservation* (EPBC) *Act 1999*-listed plant species with a likely link to water-dependent ecosystems reliant on Basin water resources.

Name	EPBC Act threatened status	Brief description	Indicative Basin distribution and habitat[14]	Links between life history, habitat and Basin water resources
Plant species				
***Amphibromus fluitans* Kirk**	Vulnerable	Perennial aquatic (amphibious) grass	NSW, VIC; permanent swamps to wetlands with seasonally fluctuating water levels, moderately fertile wetlands (also occurs in TAS and NZ).	Limited available information on flow-dependencies in life-cycle processes. It is an aquatic (amphibious) grass so flow-related dependencies for germination, growth, reproduction and/or dispersal are assumed but require further investigation. Requires periodic flooding of habitat to maintain wet conditions. Species may be influenced by delivery of water for the environment and/or policy decisions related to disruptions, barriers, or alterations to water flows.
***Brachyscome muelleroides* G.L.Davis**	Vulnerable	Small annual forb (herb, daisy)	NSW, VIC; thought to be restricted to the floodplains of the Murray and Murrumbidgee Rivers and their tributaries. Occurs in seasonally wet depressions and around the margins of swamps, lagoons and claypans.	Limited available information on flow-dependencies in life-cycle processes. Localised soil water logging or periodic flooding appears to be required to initiate seed germination and plant growth. Species will be influenced by delivery of water for the environment.
***Callistemon wimmerensis* Marriot & G.W.Carr**	Critically Endangered	Riparian shrub or small tree	VIC; known only from the McKenzie River in western Victoria; grows on the immediate stream banks and alluvial terraces.	Limited available information on flow-dependencies in life-cycle processes. Recruitment was reported following delivery of an environmental flow in 2005. Species will be influenced by delivery of water for the environment and/or policy decisions related to disruptions, barriers, or alterations to water flows.
***Eleocharis obicis* L.A.S.Johnson & O.D.Evans**	Vulnerable	Small, tufted, perennial sedge	NSW, VIC; grows in ephemerally wet situations, usually in low-lying grassland including on the Lachlan River floodplain and seasonally wet gilgai in VIC.	Limited available information on flow-dependencies in life-cycle processes. It is only known to occur in ephemeral or seasonally wet habitats so a reliance on flow or flow-related processes is assumed. Species may be influenced by delivery of water for the environment and/or policy decisions related to disruptions, barriers, or alterations to water flows.
***Eriocaulon australasicum* (F.Muell.) Körn.**	Endangered	Small, semi-aquatic, annual forb (herb)	NSW, VIC; grows in shallow, seasonally inundated depressions and swamp margins on clay plains, in a disused quarry, in shallow	Species requires inundation to enable germination and plants start to grow in shallow water (up to 20cm). Dispersal by flood water is considered possible but unknown. Seeds are assumed to persist in seed banks as the species does not appear every year, but seed bank longevity is unknown.

[14] Indicative distribution is based on spatial distribution layers from the SPRAT database and information in associated listing advice (e.g. listing and conservation advice, and/or recovery plans where available). Species may occur within other Basin states or may have limited distributions in river, wetland and floodplain habitats within specified states. Regional plans are well placed to identify the relevance of threatened species at smaller spatial scales.

Name	EPBC Act threatened status	Brief description	Indicative Basin distribution and habitat[14]	Links between life history, habitat and Basin water resources
			sedge swamps and on ephemeral clay outwash pools.	Species may be influenced by policy decisions related to groundwater extraction, along with disruptions or barriers to water flows.
***Eucalyptus cadens* J.D.Briggs & Crisp**	Vulnerable	Tree	VIC; restricted to north-east Victoria, occurs in woodlands in or around the peripheries of springs, soaks and waterbodies.	This species only grows in seasonally waterlogged and permanently moist sites; it is believed these conditions are required for germination and growth. Species may be influenced by policy decisions related to groundwater extraction, or development that impacts groundwater or surface flows to known habitat.
***Grevillea wilkinsonii* Makinson**	Critically Endangered	Riparian shrub	NSW; largely restricted to riparian vegetation along the Goobarragandra River.	Limited available information on flow-dependencies in life-cycle processes. It is only known to occur in riparian habitats so a reliance on flow or flow-related processes is assumed. Germination and recruitment occurs best on bare soil. Species may be influenced by policy decisions related to disruptions or barriers to water flows.
***Lepidium aschersonii* Thell.**	Vulnerable	Small, short-lived, perennial forb (herb)	VIC, NSW; occurs in periodically wet sites such as gilgai depressions and the margins of freshwater and saline marshes and shallow lakes, some sites can remain wet for a few months (also occurs in WA).	Occurs at some locations that are occasionally flooded and shows some adaptation to the seasonal filling and drying of wetlands, e.g. seed is stored in the lake bed of Lake Omeo and germinates when the lake dries out. Established plants can also withstand some period of submergence. Species may be influenced by policy decisions related to disruptions or barriers to water flows. Species may also be influenced by delivery of water for the environment.
***Lepidium hyssopifolium* Desv.**	Endangered	Perennial forb (herb)	VIC, NSW, ACT; widely but patchily distributed across a range of habitats that are mostly heavily modified; also known from the floodplains of the Lachlan, Gwydir, and Warrego-Darling (also occurs in TAS).	Habitat requirements and flow-dependencies in life-cycle processes are not well understood. The species is thought to require disturbance and open conditions for seed to germinate. More information is needed about its potential response to flow. It is included here because of the known distribution in floodplain habitats.
***Lepidium monoplocoides* F.Muell.**	Endangered	Small, annual to biennial, forb (herb)	VIC, NSW (old record from SA); widely distributed on the inland plains of south-eastern Australia in arid to semi-arid regions, occurs on heavy clay or clay-loam soils prone to waterlogging or seasonally flooded, including the floodplains of Hattah Lakes, Barmah and Gunbower Forests.	Limited available information on flow-dependencies in life-cycle processes. Largely occurs on ephemeral floodplains so a reliance on flow or flow-related processes is assumed. Species may be influenced by delivery of water for the environment.

Name	EPBC Act threatened status	Brief description	Indicative Basin distribution and habitat[14]	Links between life history, habitat and Basin water resources
***Muehlenbeckia tuggeranong* Mallinson**	Endangered	Riparian shrub	ACT; only known from flood terraces on the east bank of the Murrumbidgee River, south of Canberra.	Limited available information on flow-dependencies in life-cycle processes. Only known from flood terraces on the Murrumbidgee River so a reliance on flow or flow-related processes is assumed. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Myriophyllum porcatum* Orchard**	Vulnerable	Annual aquatic forb (herb)	VIC; aquatic herb of shallow, ephemeral, seasonal wetlands and lakes in north and north-west VIC.	Limited available information on flow-dependencies in life-cycle processes. As this species occupies ephemeral wetlands it is assumed that seed persists in soil seedbanks and germinates following inundation. This is an aquatic species that only persists when surface water is present and on damp mud following drawdown. Species may be influenced by delivery of water for the environment and/or policy decisions related to disruptions, barriers, or alterations to water flows.
***Nitella parooensis* M.T.Casanova & J.L.Porter**	Critically Endangered	Annual, submerged, charophyte (macro-algae)	NSW; known from ephemeral claypan wetlands on the Paroo River floodplain.	This species is an aquatic charophyte that requires inundation for germination and growth. The tiny sexual propagules (oospores) can survive prolonged desiccation remaining dormant in the soil. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Prasophyllum frenchii* F.Muell.**	Endangered	Terrestrial orchid (i.e. grows in the ground) that emerges annually from an underground tuber	VIC, SA; occurs in grassland/grassy woodlands on sandy to black clay loams that are generally damp but well drained, though some sites are seasonally waterlogged including the margins of shallow freshwater marshlands.	Habitat requirements and flow-dependencies in life-cycle processes are not well understood. The species appears to occupy the narrow margins of marshy sites, but are absent from adjacent higher, drier ground. More information is needed about potential requirements for inundation or damp/waterlogged soil. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Prasophyllum murfetii* D.L.Jones**	Critically Endangered	Terrestrial orchid (i.e. grows in the ground)	SA; occurs in swampy sites in low-lying areas around the margins of permanent water bodies and lakes on the Fleurieu peninsula, including records from Lake Alexandrina.	Habitat requirements and flow-dependencies in life-cycle processes are not well understood. The species occurs in swampy sites around the margins of permanent water bodies and lakes so a reliance on inundation-related processes / waterlogged soil is assumed. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Pterostylis cheraphila* D.L.Jones & M.A.Clem.**	Vulnerable	Terrestrial orchid (i.e. grows in the ground) that emerges annually from an underground tuber	VIC; grows in *Eucalyptus largiflorens/Eucalyptus leucoxylon* woodlands on seasonally inundated heavy clay soil, known from the floodplain of the Wimmera River.	Habitat requirements and flow-dependencies in life-cycle processes are not well understood. The species is known from seasonally inundated heavy clay soil locations or from intermittently inundated floodplains so a reliance on flow or flow-related processes is assumed. Species may be influenced by policy decisions related to disruptions, barriers, or

Name	EPBC Act threatened status	Brief description	Indicative Basin distribution and habitat[14]	Links between life history, habitat and Basin water resources
				alterations to water flows. Species may also be influenced by delivery of water for the environment.
***Sclerolaena napiformis* Paul G.Wilson**	Endangered	Small, perennial, chenopod shrub	VIC, NSW; grows on clay-loam soils and appears to tolerate waterlogging with all remaining populations occurring in close vicinity to a watercourse or swamp.	Habitat requirements and flow-dependencies in life-cycle processes are not well understood. All remaining populations occur in close vicinity to a watercourse or swamp. More information is needed about potential requirements for flow or flow-related processes. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Senecio behrianus* Sond. & F.Muell.**	Endangered	Small perennial shrub	VIC (SA, NSW-presumed extinct in both); grows on floodplains; considered to have once been widespread on floodplains of the Murray–Darling river system; herbarium records indicates plants grew in 'swampy soil' and 'sandy clay' in seasonally inundated areas on flats or banks close to rivers.	Hydrological regime is probably an important aspect of habitat, although the optimal timing and extent of flooding are unknown. Plant growth is apparently more prolific in areas that are flooded to a depth of 30 cm or more, perhaps due to lack of competition. A poor understanding of the species' biology and ecology, especially habitat requirements and ecological conditions for germination, are noted in the recovery plan as making it difficult to develop management strategies. Species may be influenced by delivery of water for the environment and/or policy decisions related to disruptions, barriers, or alterations to water flows.
***Senecio psilocarpus* Belcher & Albr.**	Vulnerable	Erect herb that arises annually from a perennial rootstock	VIC, SA; occurs in herb-rich wetlands on open plains or rarely with *Eucalyptus camaldulensis* in woodlands (also occurs in TAS).	Limited available information on flow-dependencies in life-cycle processes. Wetlands where the species occurs can be inundated with up to 60cm or more of water during winter but are almost dry in summer. Distribution is restricted to wetland / swampy areas so a reliance on inundation or inundation-related processes is assumed. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Solanum karsense* Symon**	Vulnerable	Grey-green hairy forb (herb) or sub-shrub	NSW, SA; known from lakebeds and floodplains around Menindee and between the Darling and Lachlan Rivers.	This species is clonal with an extensive root system. It is ephemeral in nature appearing following rainfall, flooding or disturbance such as grading or ploughing. It is considered common to locally abundant in known populations. There is limited available information on flow-dependencies in life-cycle processes. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Swainsona murrayana* Wawra**	Vulnerable	Perennial forb (herb)	SA, VIC, NSW, QLD; found in a variety of habitats including grassland, herbland and open *Eucalyptus largiflorens* woodlands, often in depressions.	Habitat requirements and flow-dependencies in life-cycle processes are not well understood. The species occurs in depressions on clay soil that may pond water following rainfall or flooding (does occur on ephemeral floodplains). More information is needed about its potential requirements for inundation. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.

Name	EPBC Act threatened status	Brief description	Indicative Basin distribution and habitat[14]	Links between life history, habitat and Basin water resources
***Swainsona plagiotropis* F.Muell.**	Vulnerable	Small, prostrate, perennial forb (herb)	VIC, NSW; habitat described as inland riverine grassy plains that are seasonally waterlogged on red-brown clay and clay loam soils.	Limited available information on flow-dependencies in life-cycle processes. Considered to be highly responsive to seasonal moisture conditions with large numbers of plants appearing in years with higher rainfall and habitat described as seasonally waterlogged. More information is needed about its potential requirements for inundation. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Thelymitra hygrophila* R.J.Bates**	Critically Endangered	Clumping, terrestrial orchid (i.e. grows in the ground) that emerges annually from an underground tuber (that is replaced annually)	SA; found in seasonally wet habitats such as the margins of vernal pools, ephemeral ponds and seepage areas in the Mt Lofty ranges.	Limited available information on flow-dependencies in life-cycle processes. As the only known habitat is at the margins of seasonally wet habitats a reliance on inundation or inundation-related processes (soil waterlogging) is assumed. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Veronica derwentiana* subsp. *homalodonta* (B.G.Briggs & Ehrend.) B.G.Briggs**	Critically Endangered	Large forb (herb) that emerges annually from a long-lived rootstock	SA; found in the Mt Lofty ranges where it occurs in higher, wetter regions, found in moist gullies and creek lines often in the gap between the waterline and the tree canopy; also known from Kangaroo Island.	Limited available information on flow-dependencies in life-cycle processes. Habitat is described as moist gullies and creek lines often in the gap between the waterline and the tree canopy, therefore a reliance on flow or flow-related processes (soil waterlogging) is assumed. Species may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
***Xerochrysum palustre* (Flann) R.J.Bayer**	Vulnerable	Perennial, erect forb (herb)	NSW, VIC (TAS); swamp, wetland plant of ephemeral freshwater wetlands; has a relatively wide distribution (including coastal and/or montane); habitat described as seasonal or permanent wetlands including sedge-swamps and shallow freshwater marshes often on heavy black clay soils.	Limited available information on flow-dependencies in life-cycle processes. Plants are known to grow in 1m depth of water in seasonally wet grassland. As its habitat is described as seasonal or permanent wetlands a reliance on inundation or inundation-related processes is assumed. Species may be influenced by policy decisions related to groundwater extraction, or development that impacts groundwater or surface flows to known habitats

Notes: Plant species (deemed to have a likely link to water-dependent ecosystems reliant on Basin water resources) that have only a small, limited proportion of their total distribution within the Basin have not been included in this table, e.g.: *Commersonia prostrata* (Maiden & Betche) C.F.Wilkins & Whitlock, *Correa calycina* J.M.Black, *Eucalyptus crenulata* Blakely & Beuzev., *Eucalyptus paludicola* D.Nicolle, *Lachnagrostis limitanea* (J.M.Black) S.W.L.Jacobs. The inclusion/exclusion of *Environment Protection and Biodiversity Conservation Act 1999* listed plant species from this table will be periodically reviewed. More information is available on request.

Table 7: *Environment Protection and Biodiversity Conservation* (EPBC) *Act 1999*-listed ecological communities with a likely link to water-dependent ecosystems reliant on Basin water resources.

Name	EPBC Act threatened status	Brief description	Basin distribution and habitat	Links between life history, habitat and Basin water resources
Ecological communities				
Natural Grasslands of the Murray Valley Plains	Critically Endangered	Open grassland to forbland in which trees and tall shrubs are sparse to absent	VIC, NSW; distributed across the southern parts of the Riverina Bioregion in NSW and VIC and the Wimmera plains of VIC. Occurs predominantly on flat, alluvial lowland plains with heavy-textured grey, brown and red clays.	The community is associated with alluvial lowland plains on heavy-textured soils. The Riverina bioregion is described as comprising multiple rivers and major tributaries (e.g. Murray, Murrumbidgee, Lachlan and Goulburn) with a landscape that consists of a mosaic of woodlands interspersed with grasslands wherever soil textures are heavier and less well-drained, and ephemeral or seasonal wetlands on depressions and drainage lines. Characteristic species of the EEC include EPBC Act listed plant species considered as having a 'likely link with water-dependent ecosystems' (e.g. *Swainsona murrayana, Swainsona plagiotropis, Sclerolaena napiformis*). Little is known about specific flow-dependencies in community dynamics. Potential links with hydrology should be further investigated to better determine links to floodplain systems. Ecological community may be influenced by policy decisions related to disruptions, barriers, or alterations to water flows.
Subtropical and Temperate Coastal Saltmarsh	Vulnerable	The EEC consists of organisms including and associated with saltmarsh in coastal regions of sub-tropical and temperate Australia; salt-tolerant vegetation includes grasses, herbs, sedges, rushes and shrubs; tree canopy cover is ≤50% and seagrass cover is ≤50%	QLD, NSW, VIC, SA; occurs within a relatively narrow margin of the Australian coastline within subtropical and temperate climatic zones. Of relevance to the Murray–Darling Basin is its distribution in the Coorong, Lower Lakes and Murray Mouth (CLLMM) in SA. EEC occurs on places with at least some tidal connection, including rarely-inundated supratidal areas, intermittently opened or closed lagoons, and groundwater tidal influences (but not areas receiving only aerosol spray) (also occurs in WA and TAS).	Coastal Saltmarsh, such as parts of the CLLMM, may have complex surface water-groundwater-tidal interactions. One of the research priorities for this EEC is to undertake or support analysis of the hydrological needs of the EEC, including: interactions between saltmarsh and groundwater; and modelling altered hydrological regimes. In addition, there are four priority conservation actions that relate to altered hydrology. EEC may be influenced by policy and / or management of water that influences surface and / or groundwater interactions with tidal saltmarsh.

Name	EPBC Act threatened status	Brief description	Basin distribution and habitat	Links between life history, habitat and Basin water resources
Poplar Box Grassy Woodland on Alluvial Plains	Endangered	Woodland with a canopy dominated by *Eucalyptus populnea* (tree crown cover of 10% or more) and understorey mostly of grasses and other herbs	QLD, NSW; located west of the Great Dividing Range, typically at less than 300m above sea level and between latitudes 20°S to 34°S. Occurs on a wide range of soil types of alluvial and depositional origin. The EEC occurs occasionally along watercourses and is sometimes found in close proximity to ephemeral watercourses and depressions. Parts of the EEC occur on elevated floodplains or in areas prone to inundation and includes species such as *Carex inversa, Eleocharis plana, Juncus* spp. and *Marseilea drummondii.*	Hydrology and flooding are included as determinants of the structure and composition of the EEC. The EEC is described as experiencing occasional inundation and cyclic changes in vegetation. Ecological community may be influenced by policy decisions or development that impacts groundwater or surface flows to known habitats, including further development of water storages.
Plains mallee box woodlands of the Murray Darling Depression, Riverina and Naracoorte Coastal Plain Bioregions	Critically Endangered	A medium to tall open mallee eucalypt woodland with a canopy typically dominated by 'mallee box' *Eucalyptus* species (box-barked species with a mallee growth form)	SA, VIC, NSW; Occurs in semi-arid to arid regions in the Murray Darling Depression Bioregion, Riverina Bioregion and Naracoorte Coastal Plain Bioregion. Occurs on medium-textured soils (heavier than for other mallee communities but lighter than the communities that support saltbush shrublands and *Eucalyptus largiflorens* woodlands); occasionally within run-on landscape depressions.	Changes in water availability is listed as a threatening process including mention of the development of water storages and river regulation with flow on effects to woodland biodiversity and ecological processes; changes to groundwater and higher water tables and altered flooding regimes impacting on biodiversity in the mallee region (e.g. less recruitment) is also mentioned. Potential links with hydrology should be further investigated to better understand the impact of changes in water availability and links to floodplain or groundwater systems. Ecological community may be influenced by policy decisions or development that impacts groundwater or surface flows to known habitats, including further development of water storages.
Natural Temperate Grassland of the South Eastern Highlands	Critically Endangered	Grassland community (naturally treeless or sparsely treed) dominated by native perennial tussock grasses up to 1 m in height.	VIC, ACT, NSW; in and around the South Eastern Highlands up to ~1200 m (and down as low as 250 m). EEC occurs on a wide range of topographic positions and soil types including granites, basalts, sediments, colluvium and alluvium	Some areas of the EEC occur on low-lying flats and drainage depressions; a subtype of the EEC develops on ephemeral wetlands on Lake George, Lake Bathurst and Rowes Lagoon; sedges and rushes may occur in seasonally wet areas; drainage patterns and periodic water-logging are mentioned as affecting composition, structure and vegetation dynamics; avoiding disturbances that detrimentally alter the hydrology is listed as a research / management priority (though potentially in terms of preventing additional inundation). Potential links with hydrology should be further investigated

Name	EPBC Act threatened status	Brief description	Basin distribution and habitat	Links between life history, habitat and Basin water resources
				to determine if seasonally wet variants of the EEC are restricted to rainfed systems or are linked to floodplain systems. Ecological community may be influenced by policy decisions or development that impacts surface flows to known habitats.
Dunn's white gum (*Eucalyptus dunnii*) moist forest in north-east New South Wales and south-east Queensland	Endangered	Wet sclerophyll forest with a tall canopy of *Eucalyptus dunnii* and a structurally complex understorey of rainforest trees, shrubs, palms, vines, ferns, herbs and shade-tolerant graminoids	NE NSW, SE QLD; found at the margins of rainforests in areas with an average rainfall of 1000-1500 mm. EEC occurs on deep, fertile soils, largely confined to fertile basaltic derived soils, or fine-grained sediments of colluvium or alluvium.	Reduced river runoff, water availability and regional flooding are mentioned as threats in association with climate change. In addition, floods are mentioned in relation to climate and weather as influencing species presence and abundance. Potential links with hydrology should be further investigated to better understand the impact of changes in hydrology and any links to floodplain or groundwater systems. Ecological community may be influenced by policy decisions or development that impacts runoff and surface flows to known habitats.
Brigalow (*Acacia harpophylla* dominant and co-dominant)	Endangered	Open forests and woodlands dominated or co-dominated by *Acacia harpophylla*	QLD, northern NSW; semi-arid eastern Australia, mostly west of the Great Dividing Range. EEC occurs on acidic and salty clay soils; mostly on deep cracking clay soils with a microrelief pattern referred to as gilgai which intermittently fill will water; some areas of the EEC are associated with river and creek flats.	As the EEC occurs on gilgai that intermittently fill with water as well as on river and creek flats, a relationship with periodic inundation is assumed; one of the priority recovery and threat abatement actions is to devise and implement water management, sediment erosion and pollution control and monitoring plans. Potential links with hydrology should be further investigated to better understand the impact of changes in hydrology and associations with floodplain or groundwater systems. Ecological community may be influenced by policy decisions or development that impacts runoff and surface flows to known habitats.
Buloke Woodlands of the Riverina and Murray–Darling Depression Bioregions	Endangered	Woodland dominated or co-dominated by Buloke (*Allocasuarina luehmannii*) usually with a grassy understorey though may include shrubs and herbs	SA, VIC, NSW; across the Riverina and Murray–Darling Depression Bioregions. Occurs on clayey and/or alkaline sub-soils; in part of its distribution this EEC is restricted to near freshwater river systems (Murray and Wimmera Rivers) or adjacent to sites of groundwater discharge; EEC occurs on heavy loams or clay loams frequently waterlogged in winter (but not closely associated with rivers or streams) or on sands (adjacent to	Hydrology appears to be an important part of the ecology of this EEC either via waterlogging from rainfall or associations with freshwater systems or groundwater. Ecological community may be influenced by policy decisions or development that impacts surface flows or groundwater to known habitats.

Name	EPBC Act threatened status	Brief description	Basin distribution and habitat	Links between life history, habitat and Basin water resources
			freshwater systems or groundwater discharge sites).	
Swamps of the Fleurieu Peninsula	Critically Endangered	Semi-permanent to permanent swamps or wetlands of the Fleurieu Peninsula	SA; Fleurieu Peninsula. The swamps are associated with some streams that are part of the Murray–Darling Basin (e.g. Currency and Tookayerta Creeks, Finniss River), however most swamps within this EEC are not considered to be part of the Lower Murray System. The EEC occurs as densely vegetated patches on peat, silt, or black clay soils, in and adjacent to waterlogged areas near low-lying creeks and flats.	The EEC relies on soils that are seasonally or permanently saturated and generally have a permanently wet core. The swamps may be inundated via surface and subsurface water flow and/or rely on connection to the water table. Research priorities and priority actions include to determine environmental flow requirements and adequacy of current and projected water regimes to maintain swamps into the future, changes in composition, hydrology and resilience in response to variations in climate and a changing climate, investigate the impact of disturbances such as water extraction and to prevent or manage changes to hydrology that impact natural patterns of inundation, water table levels or water quality. Ecological community may be influenced by policy decisions or development that impacts surface flows or groundwater to known habitats.
White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland	Critically Endangered	Woodland dominated (or formerly dominated) by a range of eucalypt species including *Eucalyptus albens* (white box), *E. melliodora* (yellow box) and/or *E. blakelyi* (Blakely's red gum), and in some areas the grey box species *E. microcarpa* and/or *E. moluccana*. The EEC also includes derived grasslands that have resulted from the loss of the characteristic tree layer but retain an intact ground layer.	VIC, NSW, ACT, QLD (and maybe formerly SA); broadly distributed along the western slopes and tablelands of the Great Dividing Range. EEC occurs on hilly to undulating landscapes in areas with soils of moderate fertility.	There is limited information regarding direct links to hydrology, however salinity and rising groundwater levels threaten many of the remaining patches of the EEC. Threats also refer to hydrological changes and erosion within sites or the local catchment affecting the amount of water, timing of flows, water quality and nutrient levels in patches of the EEC. Ecological community may be influenced by policy decisions or development that impacts surface flows or groundwater to known habitats.
Coolabah - Black Box Woodlands of the Darling Riverine Plains	Endangered	Woodland dominated by *Eucalyptus coolabah subsp. coolabah* and/or *Eucalyptus largiflorens*	NSW, QLD; associated with the floodplains and drainage areas of the Darling Riverine Plains and the Brigalow Belt South Bioregions. EEC	This EEC is a floodplain ecological community that relies on periodic inundation and/or access to groundwater. Potential threats include changes to water flows and patterns associated with river regulation infrastructure and water storage for irrigation. Multiple priority actions

Name	EPBC Act threatened status	Brief description	Basin distribution and habitat	Links between life history, habitat and Basin water resources
and the Brigalow Belt South Bioregions		typically with a grassy understorey.	occurs on grey, self-mulching clays of periodically waterlogged floodplains, swamp margins, ephemeral wetlands, and stream levees.	relate to minimising and managing distributions to water flows including changes to water table levels. Ecological community may be influenced by policy decisions or development that impacts surface flows or groundwater to known habitats; some locations may be influenced by the delivery of environmental flows.
New England Peppermint (*Eucalyptus nova-anglica*) Grassy Woodlands	Critically Endangered	Temperate grassy woodland to open forest with a tree canopy dominated or co-dominated by *Eucalyptus nova-anglica* (New England Peppermint).	North NSW, south QLD; mainly on the New England or Northern tablelands. EEC occurs in valley bottoms, flats or lower slopes, often in areas subject to cold air drainage, on basaltic, granitic or sedimentary substrates.	There is limited information regarding direct links to hydrology, however managing changes to hydrology that may result in changes to water table levels is listed as a priority action, though it may relate more to the prevention of waterlogging. Ecological community may be influenced by policy decisions or development that impacts surface flows or groundwater to known habitats.
Grey Box (*Eucalyptus microcarpa*) Grassy Woodlands and Derived Native Grasslands of South-eastern Australia	Endangered	Woodland to open forest with a canopy dominated or co-dominated by *Eucalyptus microcarpa* with a moderately dense to sparse shrub layer and a groundlayer of grasses and herbs. The EEC also includes derived grasslands that have resulted from the loss of the characteristic tree layer but retain an intact ground layer.	SA, VIC, NSW; from central-western NSW, through northern and central Victoria into South Australia. EEC typically occurs in landscapes of low-relief on productive soils derived from alluvial or colluvial materials.	There is limited information regarding direct links to hydrology, however, State vegetation community descriptions included in the EEC include communities which are floodplain transition woodlands, communities which occur on alluvial plains or terraces or in a mosaic with gilgai wetlands, and communities described as riverine that contain a significant sedge and rush component. Threats include salinity and impacts from disruptions to groundwater hydrology such as rising water tables, while threats from climate change refer to altered hydrological regimes. Ecological community may be influenced by policy decisions or development that impacts groundwater levels at known habitats.
Natural grasslands on basalt and fine-textured alluvial plains of northern New South Wales and southern Queensland	Critically Endangered	Native grasslands typically composed of perennial native grasses; a tree canopy is usually absent or sparse (≤10% foliage cover).	Northern NSW, southern QLD; occurs from the Darling Downs in QLD to Dubbo in NSW and incorporates the Liverpool and Moree Plains. ECC occurs on soils that are fine textured (often cracking clays) derived from either basalt or alluvium on flat to low slopes.	There is limited information regarding direct links to hydrology, however, associated state-based community descriptions include grasslands on alluvial plains and a semi-arid floodplain grassland. Changes to flooding patterns due to development of extensive flood irrigation farming and associated overland water flow diversionary earthworks are mentioned as causing compositional differences. In addition, waterlogging is mentioned as a factor which determines the distribution of certain taxa of grasslands. Managing disruptions to water flows and changes to water table levels are listed as a priority action. Potential links with hydrology should be further investigated to better understand the impact of changes in hydrology and

Name	EPBC Act threatened status	Brief description	Basin distribution and habitat	Links between life history, habitat and Basin water resources
				associations with floodplain or groundwater systems. Ecological community may be influenced by policy decisions or development that impacts surface flows or groundwater to known habitats.
Weeping Myall Woodlands	Endangered	Woodland (4-12 m high) in which Weeping Myall (*Acacia pendula*) trees are the sole or dominant overstorey species with either a shrubby or grassy understorey. In higher rainfall areas it typically forms an open woodland. As rainfall decreases the EEC becomes restricted, occurring as bands that fringe 'better-watered' country including on the margins of floodplain woodland.	NSW, QLD; occurs on the inland alluvial plains west of the Great Dividing Range. The EEC occurs on flat areas, shallow depressions or gilgais on raised (relic) alluvial plains, on black, brown, red-brown or grey clay or clay loam soils.	There is limited information regarding direct links to hydrology. The listing advice states that the areas where the EEC occurs 'are not associated with active drainage channels and are rarely if ever flooded.' However, the listing advice also mentions distribution on the margins of floodplain woodland particularly in lower rainfall areas and refers to 'Riparian/Floodplain remnants.' The EEC is treated here as having potential associations with floodplains however potential links with hydrology (surface water and/or groundwater) should be further investigated. Ecological community may be influenced by policy decisions or development that impact potential groundwater interactions at known habitats.

Notes:
Ecological communities (deemed to have a likely link to water-dependent ecosystems reliant on Basin water resources) that have only a small, limited proportion of their total distribution within the Basin have not been included in this table, e.g.: '*Lowland Rainforest of Subtropical Australia*'. The inclusion/exclusion of EPBC Act listed ecological communities from this table will be periodically reviewed. More information is available on request.

Waterbirds

Context

Waterbirds are birds that depend on wetlands, waterways or shorelines for foraging, roosting or breeding habitat (Clemens et al. 2019). More than 100 waterbird species regularly use the Basin (Table 9) with over 120 species (including vagrants) recorded in total. Waterbirds are a highly diverse and mobile component of the Murray–Darling Basin's aquatic ecosystem. They cover multiple feeding and habitat guilds, with each species having specific requirements for diet, foraging, roosting and breeding. Waterbirds can be found in every aquatic environment in the Basin including artificial, natural, saline and freshwater systems ranging from permanent to ephemeral hydrology. Each habitat type supports a different combination of species and fulfills different life history needs over time. Many Australian waterbirds move within the Basin and beyond to exploit suitable habitat when it becomes available (Kingsford et al. 2010).

Waterbirds perform an important ecological function across the landscape through their widespread transport and distribution of seeds from wetland, floodplain and terrestrial plants, and eggs from invertebrates and some fish (Green et al. 2023). The movement and replenishment of genetic material, likely improves the resilience of the Basin's wetland ecosystems to recover from disturbances, such as prolonged drought. Waterbirds perform an important functional role in the aquatic food web through consuming a diversity of food resources including aquatic plants, invertebrates, crustaceans, frogs and fish (Green & Elmberg 2014). Waterbirds also provide food resources (particularly chicks and eggs) for reptiles and predatory birds.

At a local scale, waterbirds perform an important role in the creation of microhabitats through feeding and nest construction. For example, openings in dense reed beds created during nest building are important for aquatic invertebrates, aquatic plant diversity, fish and other waterbirds (Green & Elmberg 2014). Waterbirds also perform a role in nutrient cycling, where large nesting groups contribute subsidies of nutrients at nesting sites and can transfer nutrients between aquatic and terrestrial environments (Green & Elmberg 2014).

Outside their ecological importance, waterbirds are culturally significant to many First Nation groups. Certain species such as the brolga (*Grus rubicunda*) hold spiritual meaning, while other species such as Australasian bittern (*Botaurus poiciloptilus*) are important for storytelling. Several waterbirds such as ducks and black swans (*Cygnus atratus*) provide resources in the form of meat, eggs, feathers and down. The strong cultural connection between many First Nations groups and waterbirds continues in the Basin today.

Waterbirds have recreational value for Basin communities in the form of bird watching, photography and harvesting (in some areas). This can contribute to local economies by attracting visitors to those towns near inundated wetlands and floodplains. The consumption of terrestrial insects (e.g. locusts) by waterbirds such as ibis can also provide a degree of natural pest control for some crops (Natural Capital Economics 2019; Green & Elmberg 2014).

The Murray–Darling Basin is an important location for Australia's waterbird community. Approximately 17% of Australia's wetlands are in the Basin, providing over 6.5 million hectares of diverse waterbird habitat (Bino et al. 2016). Almost half of all Australian waterbird species spend time in the Basin, with more than half of these listed as threatened species or recognised under international agreements. The Basin contains 46% of Australia's wetlands where group-nesting waterbirds breed (Bino et al. 2014). Analysis of feathers from across the Australian continent has shown the Murray–Darling Basin is a key location for which many mobile waterbirds spend time before dispersing to other wetlands. 10 of the 13 Australian river basins had been visited by waterbirds that had spent time (and grown feathers) in the Murray–Darling Basin (Brandis et al. 2021).

The importance of the Basin's waterbird community is reflected in Australia's obligations under international agreements and in Commonwealth and various state/territory legislation to protect and manage various waterbird species. This includes the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention), China – Australia Migratory Bird Agreement (CAMBA), Japan – Australia Migratory Bird Agreement (JAMBA) and the Republic of Korea – Australia Migratory Bird Agreement (ROKAMBA).

Within the Basin, certain wetlands are particularly important for supporting waterbird diversity, abundance and breeding. A total of 28 sites of Basin significance for waterbirds have been identified (Figure 10). These include a combination of individual natural wetlands, large wetland complexes and waterways. A wide diversity of habitats occurs across these sites, providing conditions suitable for meeting multiple waterbird dietary preferences, feeding habitats, nesting and roosting sites. The 28 sites of significance include those locations identified as:

- Collectively supporting 80% of the abundance of each species' population (under overall, dry and wet conditions), for the 52 waterbird species recorded in the Basin during the Eastern Australian Waterbird Aerial Survey (EAWS) (from 1983-2012) (Bino et al. 2015).
- Breeding areas for group-nesting waterbirds including those sites identified as frequent and/or larger group-nesting sites (Brandis et al. 2022).

Of these 28 sites, 18 can receive water for the environment[15], meaning most are currently within the scope of influence of active hydrological management. The remaining sites are reliant upon natural rainfall and runoff. Many other waterbird sites (including those of local or regional significance) occur across the Basin. These are identified in various state government documents including long-term environmental watering plans. In any year, most Basin waterbirds (80% of total abundance) can generally be found in 20 wetland complexes, however, the locations used can vary from year to year depending on where water is prevalent (Kingsford et al. 2013).

[15] Includes Planned Environmental Water and Held Environmental Water.

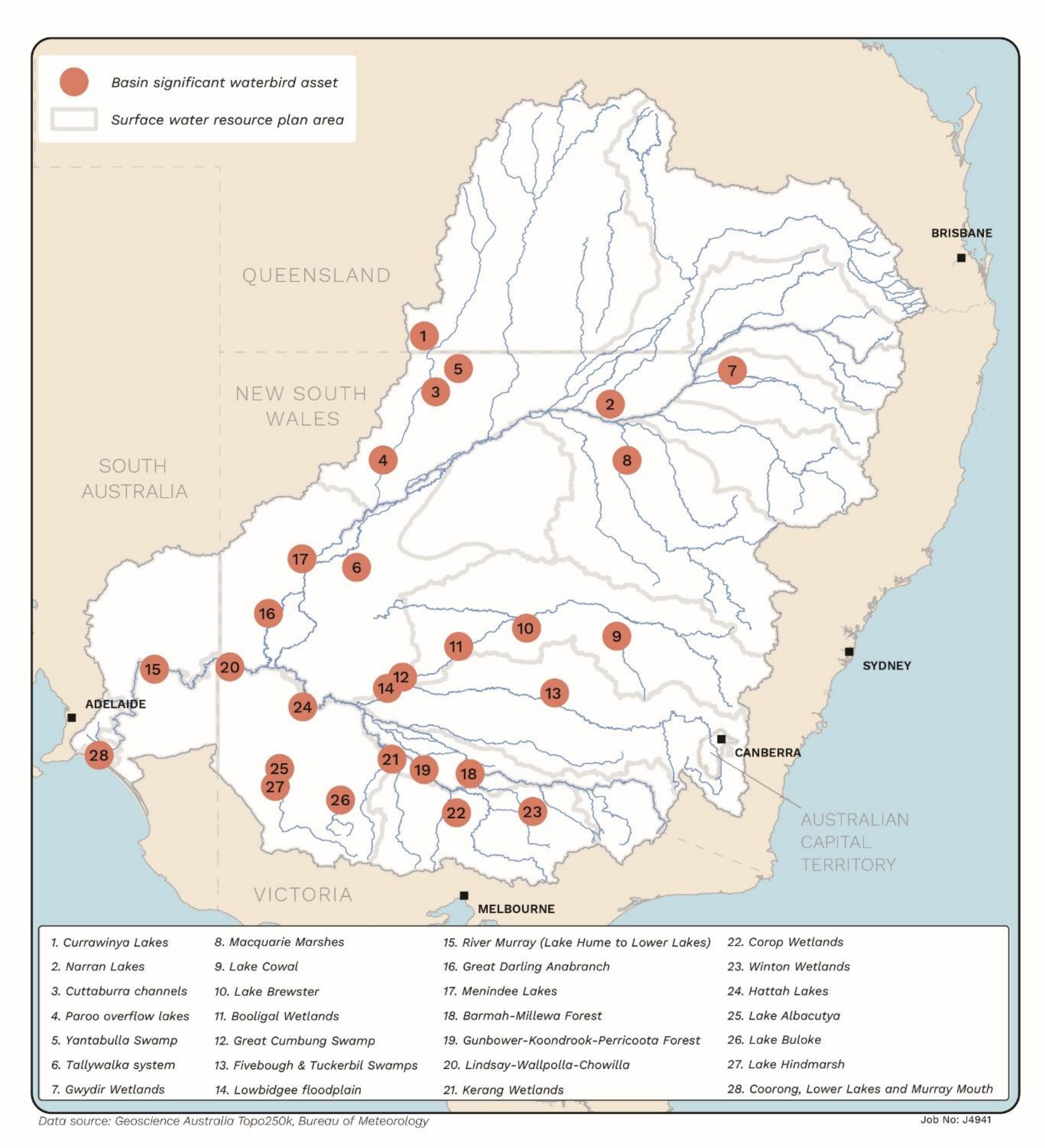

Figure 10: Significant assets for waterbirds in the Murray–Darling Basin.

The Basin's waterbird community is strongly influenced by available surface water conditions. The Murray–Darling Basin waterbird community relies heavily on water being in the right place, to an adequate degree (extent, depth, duration), at the right time to support roosting, foraging and (in most cases) breeding requirements (Figure 11). Given the mobile nature of many Basin waterbirds, multiple wetlands may be needed to meet an individual bird's requirements throughout its lifecycle.

The strong association between waterbirds and surface water availability, along with their relative ease of monitoring, makes waterbirds a key indicator of aquatic ecosystem health across the Murray–Darling Basin.

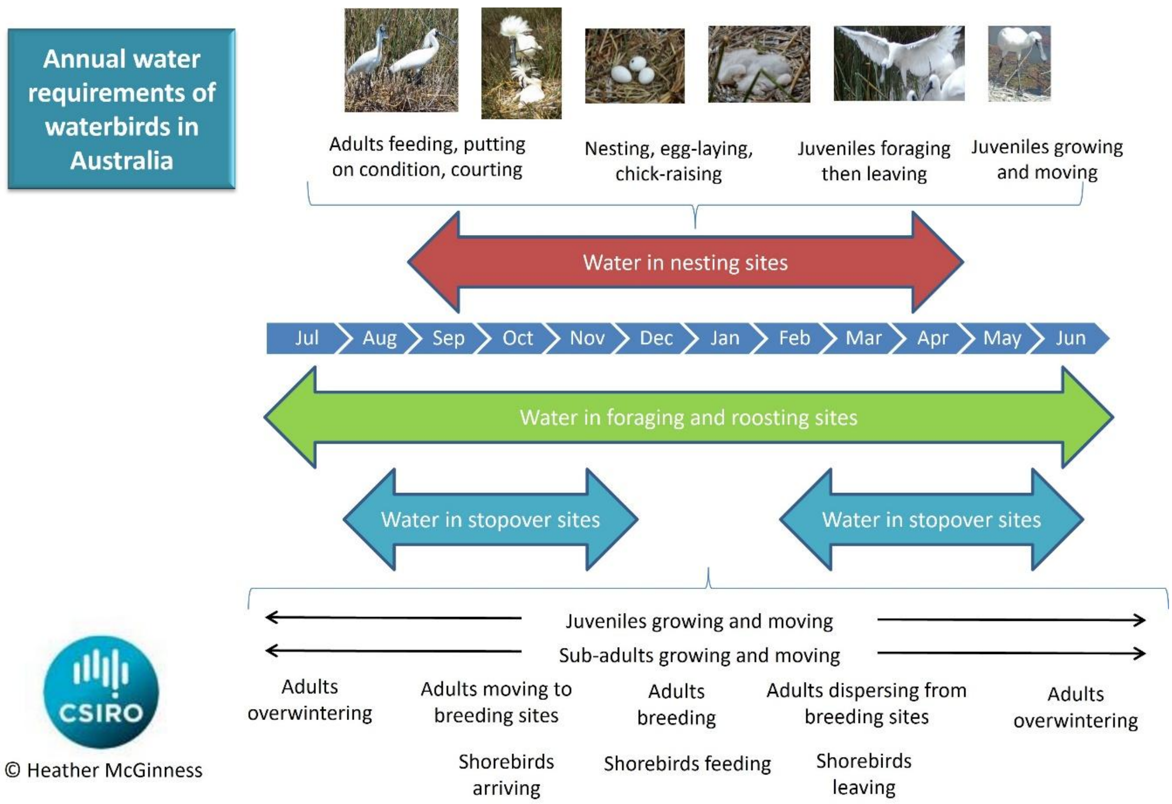

Figure 11: Annual water requirements of Australian waterbirds.

Typology

Waterbirds include herbivores, invertebrate feeders, piscivores or omnivores that feed on both plant and animal material (Kingsford & Norman 2002). Foraging behaviours can range from grazing, filter-feeding, dabbling, diving, wading and shoreline foraging (Roshier et al. 2002; Taft et al. 2002). Waterbirds can roost in trees (including fallen timber), aquatic vegetation/shrubs, in open water or on the ground (Jaensch 2002). Breeding habitat is also variable including ground-nesting, aquatic vegetation/shrub-nesting and tree-nesting (hollows or nest platforms), with some waterbirds nesting individually and others nesting in large groups (Brandis et al. 2022).

Movement patterns can vary between species, within populations of species and across seasons. For example, satellite tracking of straw-necked ibis (*Threskiornis spinicollis*) found some individuals remained relatively resident (or sedentary) in one area, while others moved nomadically across a region or sub-catchment, and others moved thousands of kilometres up and down the Murray–Darling Basin (McGinness et al. 2019). In addition, 30 migratory species forage in the Basin over the warmer months, prior to returning to other countries via the East Asian-Australasian Flyway[16] to breed (Table 9).

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[16] The East Asian-Australasian Flyway extends from the Russian Far East and Alaska, southwards through East Asia and South-east Asia, to Australia and New Zealand. It includes 22 countries. The Australian continent lies entirely within the Flyway (The Flyway - Eaaflyway).

Condition

Waterbird condition refers to the health of the Basin's waterbird community. This report assesses waterbird condition using indicators for waterbird habitat, waterbird abundance, diversity and the number of species breeding.

Waterbird abundance and breeding are best gauged through long-term trends and comparing survey results to previous results under similar surface water conditions. In contrast, the diversity of waterbirds in the Basin has remained relatively constant over time (Bino et al. 2023).

The latest evidence from over 40 years of spring aerial surveys in eastern Australia (Porter et al. 2023) suggests that three major indices for waterbirds continue to show significant long-term declines (1984 to 2023). This includes wetland area (i.e. waterbird habitat), total waterbird abundance and the diversity of species breeding (Figure 12).

Availability of wetland habitat is a major driver of waterbird abundance (Figure 13) and breeding diversity. Reductions in habitat area and persistence have contributed to the measured declines in the Basin's waterbirds (Porter et al. 2023). In recent years (particularly since 1998), the response of waterbirds to increased water availability has been subdued compared to the past, indicating a potential long-term decline in population condition and resilience (Bino et al. 2021a).

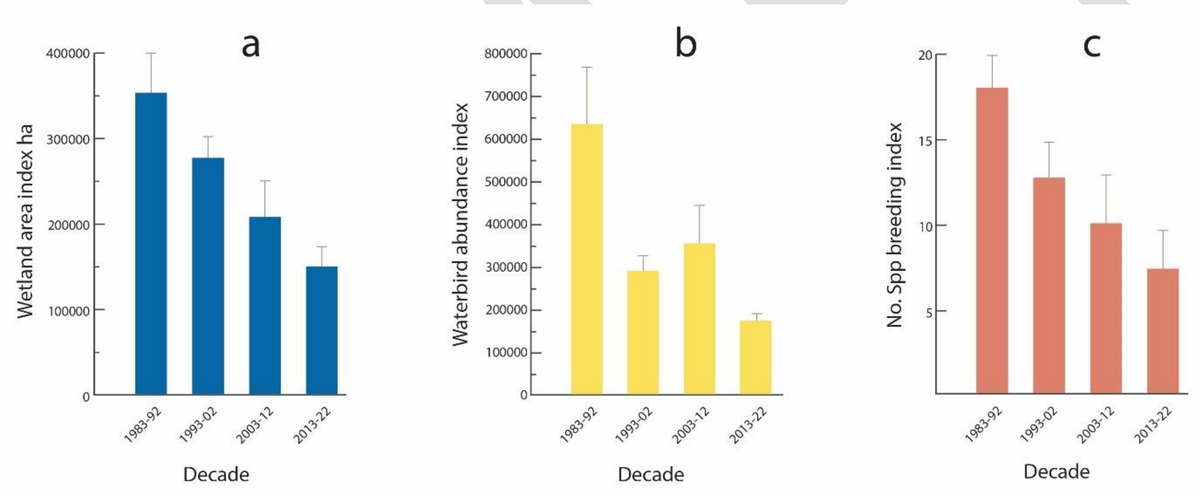

Figure 12: Decadal averages of a) wetland area index, b) total abundance index and c) number of breeding species in the spring Eastern Australian Waterbird Aerial Survey (1983-2023) (Porter et al. 2023). Error bars are Standard Error. Results reflect the entire dataset for the Eastern Australian Waterbird Aerial Survey, including those areas outside of the Murray–Darling Basin.

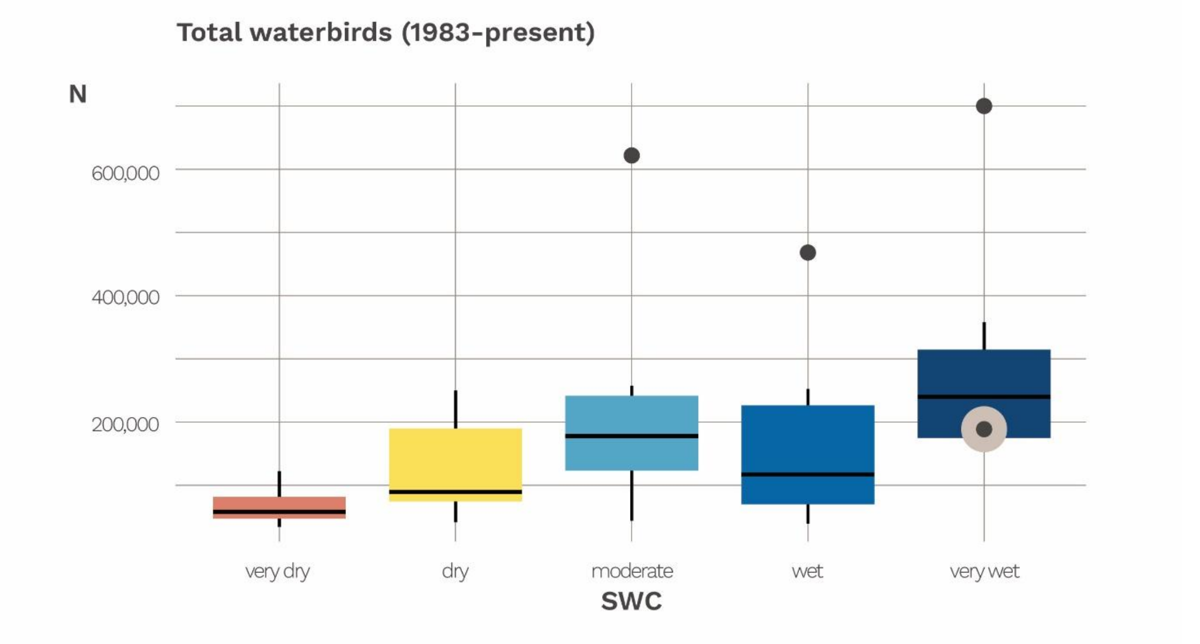

Figure 13: Boxplot showing the spring Eastern Australian Waterbird Aerial Survey waterbird abundance across the Murray—Darling Basin (1983-2023) under different Surface Water Conditions (SWCs) (Bino et al. 2023; Bino et al. 2021b). The centre line of each boxplot represents the median annual abundance of waterbirds in each SWC, the bottom and top lines represent the 25th percentile and 75th percentile, respectively. The large black/grey circle represents 2023 waterbird abundance.

Shorebirds in the Basin, particularly the Coorong and Lower Lakes (including Lake Albert and Lake Alexandrina) have also shown a decline over time. While the presence of shorebirds is highly dependent on water levels being adequately shallow for foraging, the abundance of three previously common migratory shorebirds—the sharp-tailed sandpiper (*Calidris acuminata*), red-necked stint (*Calidris ruficollis*) and curlew sandpiper (*Calidris ferruginea*) —declined significantly in the Coorong between 1984 and 2007 (East Asian-Australasian Flyway Partnership 2013). Ongoing monitoring in the Coorong (2000-2023) suggests some shorebirds continue to experience a long-term decline including eastern curlew (*Numenius madagascariensis*), common greenshank (*Tringa nebularia*), curlew sandpiper and sharp-tailed sandpiper (Figure 14; Paton et al. 2023). Each of these species is migratory, recognised under international bird agreements and is a listed threatened species.

Water for the environment delivery to support waterbird breeding or habitat retention in the Basin has provided some offset to declines (Porter et al. 2023). However, further research is needed into how to optimise delivery of water across the Basin landscape to best support waterbirds.

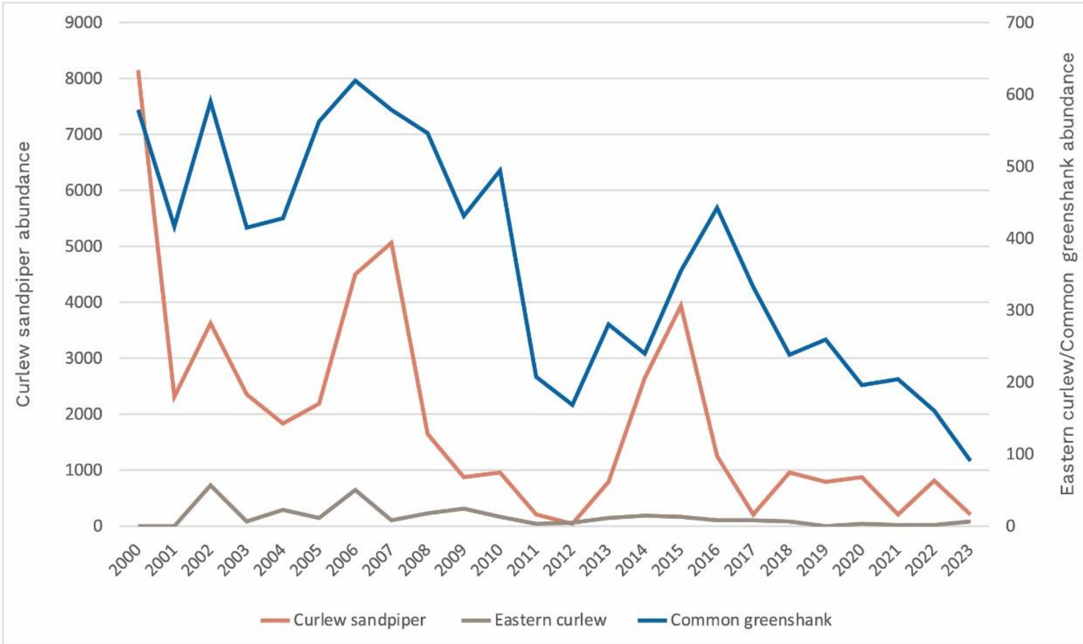

Figure 14: Examples of threatened migratory shorebird species decline in the Coorong. Data source: Paton et al. 2023.

Threatened Species

More than half (58) of the Basin's regular waterbird species were listed under national and/or state/territory legislation in 2024 (Table 9). Threatened species are spread across every waterbird feeding and habitat guild and include resident native waterbirds and migratory species.

A significant area of wetlands has been lost from the Murray–Darling Basin since European settlement, with the greatest reductions occurring across New South Wales, Victoria and South Australia. Over 200,000 hectares (26%) of wetland area has been estimated as lost from Victoria (Papas & Moloney 2012), while New South Wales and South Australia have estimated losses of at least 40% and 70% of their original wetland area, respectively (Kingsford et al. 2003; Department for Environment and Heritage & Department of Water, Land and Biodiversity Conservation, 2003). Additional threats, such as predation and habitat disturbance from invasive species, adds further pressure to the viability of waterbird populations.

The high threat status of the Basin's waterbird community and its continuing long-term decline, reinforces the importance of delivering water for the environment to provide adequate wetland habitat across the Basin to meet waterbird needs.

Expected environmental outcomes for waterbirds

The Expected Environmental Outcomes for waterbirds are provided in the Basin-wide Environmental Watering Strategy. These are focused on metrics of abundance, species richness, breeding abundance, and migratory shorebird abundance and are summarised below in Table 8.

Table 8: Waterbird expected environmental outcomes (refer to Basin-wide environmental watering strategy for full expected environmental outcome descriptions).

Scale	Expected environmental outcomes
Basin-wide	**B1**: The number and type of waterbird species present in the Basin will not fall below current observations.
	B2: A significant improvement in waterbird populations in the order of 20-25% over the baseline scenario, with increases in all waterbird functional groups.
	B3: Breeding events (the opportunities to breed rather than the magnitude of breeding per se) of group-nesting waterbirds to increase by up to 50% compared to the baseline scenario.
	B4: Breeding abundance (nests and broods) for all of the other functional groups to increase by 30-40% compared to the baseline scenario, especially locations where the Basin Plan improves over-bank flows.
Lower Lakes, Coorong & Murray Mouth	**B5**: 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.

Context

The expected outcomes for waterbirds include Basin-wide outcomes and those specific to the migratory shorebirds of the Coorong and Lower Lakes. Achieving these outcomes would result in waterbird populations similar to those in the early 1990s, which is necessary for a resilient Basin waterbird community.

Delivery of water for the environment can contribute to a diverse mosaic of waterbird habitats across the Basin that support the various life-history stages of multiple species, depending on the location and timing of deliveries. This includes providing locations suitable for roosting, foraging and breeding, while also supporting the movement of waterbirds throughout the Basin by providing stop-over sites (McGinness et al. 2019). Importantly, water for the environment contributes to the availability of adequate foraging habitat following large waterbird breeding events (McGinness et al. 2019; McGinness et al. 2023), supporting the recruitment of juvenile waterbirds into the adult breeding population (O'Brien & McGinness 2019).

During very dry periods, delivering water for the environment can secure roosting and foraging habitat within drought refuge areas, while also supporting small-scale breeding events where suitable breeding habitat exists. The provision of habitat during dry times helps support the survival of waterbirds until seasonal conditions improve.

Under moderate seasonal conditions, water for the environment can play a key role in the inundation of waterbird habitat across the Basin, particularly where adequate environmental water is available but unregulated inundation is lacking or limited. This includes delivering to targeted wetland sites/complexes and inundating low-lying floodplain wetlands adjacent to waterway channels, through the delivery of higher river and creek flows. The increased extent of wetland inundation improves the availability of waterbird foraging habitat, which can encourage waterbird breeding and support the recruitment of juvenile birds.

During wetter periods, water for the environment can enhance natural unregulated flows to improve the extent and duration of wetland and floodplain inundation, promoting aquatic food production and larger waterbird breeding events.

By managing environmental water to meet the water regime requirements of different wetland habitats, deliveries can improve the quality and productivity of available waterbird habitat. This in turn contributes to improving the carrying capacity of each site so that a larger number of waterbirds can be supported, and juvenile waterbirds have ample food to successfully reach adulthood.

Basis for expected outcomes

There is a strong relationship between flow, flooding and waterbird outcomes, particularly abundance and opportunities to breed (Bino et al. 2014). These relationships enabled the Murray–Darling Basin Authority to predict how waterbirds would respond to water for the environment using modelling scenarios developed for the Basin Plan.

Based on historic correlations between spring aerial waterbird survey results and flow in the Basin, waterbird populations were modelled under different flow scenarios, including (Bino et al. 2014):

- 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
- the Environmentally Sustainable Level of Take (ESLT) which represents reductions in take of 2,400 GL, 2,800 GL and 3,200 GL per year.

To calculate the Expected Environmental Outcomes, the Murray–Darling Basin Authority compared the modelling predictions for baseline with the predictions for the various level of take scenarios (2,400 GL, 2,800 GL and 3,200 GL water recovery). For example, under the baseline scenario, waterbird abundance in the spring aerial survey area was predicted to be 168,000 individuals on average; compared to the ESLT scenarios of between 202,000 and 214,000 individuals (Bino et al. 2014). This equates to a 20–25% increase.

The outcome for an expected increase in waterbird breeding events was also based on the modelled scenarios. In particular, the flow conditions conducive to waterbird breeding (e.g. flow that inundates waterbird habitat for more than three months to allow for a breeding event) can be identified in the modelled flow sequences. The change in breeding events from the baseline scenario to what happens under the Basin Plan can then be quantified as an increase in opportunity. For example, under the baseline scenario, waterbird breeding abundance in the spring aerial survey area was predicted to be 495 on average, compared to the ESLT scenarios of between 634 and 695 (Bino et al. 2014). This equates to a 30-40% increase.

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. Indicative species were chosen (migratory species listed under international agreements) and a baseline established, which represents the time period prior to the first (2014) Basin-wide Environmental Watering Strategy where waterbird survey data was collected.

Regular waterbird species of the Murray–Darling Basin

Table 9: Regular waterbird species of the Murray–Darling Basin.

Species breeding outside the Murray–Darling Basin – highlighted grey. Group-nesting species – (g).

* International agreements – B (Bonn Convention), C (China-Australia Migratory Bird Agreement), J (Japan-Australia Migratory Bird Agreement), R (Republic of Korea Migratory Bird Agreement).

^ Listed threatened fauna under the Commonwealth Environment Protection and Biodiversity Conservation Act (1999) in February 2024.

~ State/territory listings (as of December 2023) – Vic Flora and Fauna Guarantee Act (1988) - September 2022 list, NSW Biodiversity Conservation Act (2016), SA National Parks and Wildlife Act (1972), Qld Nature Conservation Act (1992), ACT Nature Conservation Act (2014).

Common name	Scientific name	Australian IUCN Red List Status (2020)	Listed under international agreement(s)*	Nationally listed as threatened^	State/territory listed~
Australasian bittern	*Botaurus poiciloptilus*	Endangered	-	Yes	Vic, NSW, SA, Qld, ACT
Australasian darter	*Anhinga novaehollandiae*	-	-	-	SA
Australasian grebe	*Tachybaptus novaehollandiae*	-	-	-	-
Australasian shoveler	*Spatula rhynchotis*	Least concern	-	-	Vic, SA
Australian gull-billed tern (g)	*Gelochelidon macrotarsa*	Least concern	C	-	Vic
Australian little bittern	*Ixobrychus dubius*	Least concern	-	-	Vic, SA
Australian painted-snipe	*Rostratula australis*	Endangered	-	Yes	Vic, NSW, SA, Qld, ACT
Australian pelican (g)	*Pelecanus conspicillatus*	Least concern	-	-	-
Australian pied oystercatcher	*Haematopus longirostris*	Least concern	-	-	SA
Australian pratincole	*Stiltia isabella*	Least concern	-	-	-
Australian shelduck	*Tadorna tadornoides*	Least concern	-	-	-
Australian spotted crake	*Porzana fluminea*	Least concern	-	-	-

Common name	Scientific name	Australian IUCN Red List Status (2020)	Listed under international agreement(s)*	Nationally listed as threatened^	State/territory listed~
Australian white ibis (g)	*Threskiornis moluccus*	-	-	-	-
Australian wood duck	*Chenonetta jubata*	Least concern	-	-	-
Baillon's crake	*Zapornia pusilla*	-	B	-	-
Banded stilt (g)	*Cladorhynchus leucocephalus*	Least concern	-	-	SA
Bar-tailed godwit	*Limosa lapponica*	-	B, J, C, R	Yes	Vic, SA, Qld
Black swan	*Cygnus atratus*	Least concern	-	-	-
Black-faced cormorant (g)	*Phalacrocorax fuscescens*	Least concern	-	-	-
Black-fronted dotterel	*Elseyornis melanops*	Least concern	-	-	-
Black-necked stork	*Ephippiorhynchus asiaticus*	-	-	-	-
Black-tailed godwit	*Limosa limosa*	-	B, J, C, R	Yes	Vic, NSW, SA
Black-tailed native-hen	*Tribonyx ventralis*	Least concern	-	-	-
Blue-billed duck	*Oxyura australis*	Least concern	-	-	Vic, NSW, SA
Broad-billed sandpiper	*Calidris falcinellus*	-	B, J, C, R	-	NSW
Brolga	*Grus rubicunda*	Least concern	-	-	Vic, NSW, SA
Buff-banded rail	*Hypotaenidia philippensis*	-	-	-	-
Cape barren goose (g)	*Cereopsis novaehollandiae*	-	-	-	SA
Caspian tern (g)	*Hydroprogne caspia*	Least concern	J	-	Vic
Cattle egret (g)	*Bubulcus ibis*	-	J, C	-	SA
Chestnut teal	*Anas castanea*	Least concern	-	-	-
Common greenshank	*Tringa nebularia*	Vulnerable	J, C	Yes	Vic, SA
Common gull-billed tern	*Gelochelidon nilotica*	-	C	-	Vic

Common name	Scientific name	Australian IUCN Red List Status (2020)	Listed under international agreement(s)*	Nationally listed as threatened^	State/territory listed~
Common sandpiper	*Actitis hypoleucos*	Least concern	B, J, C, R	-	Vic
Common tern	*Sterna hirundo*	-	C, J, R	-	SA
Curlew sandpiper	*Calidris ferruginea*	Endangered	C, J, R	Yes	Vic, NSW, SA, Qld
Double-banded plover	*Charadrius bicinctus*	-	B	-	-
Dusky moorhen	*Gallinula tenebrosa*	-	-	-	-
Eurasian coot	*Fulica atra*	-	-	-	-
Fairy tern (g)	*Sternula nereis*	-	-	-	Vic, SA, Qld
Far eastern curlew	*Numenius madagascariensis*	Endangered	B, J, C, R	Yes	Vic, SA, Qld
Freckled duck	*Stictonetta naevosa*	Least concern	-	-	Vic, NSW, SA
Glossy ibis (g)	*Plegadis falcinellus*	Least concern	B, C	-	SA
Great cormorant (g)	*Phalacrocorax carbo*	-	-	-	-
Great crested grebe	*Podiceps cristatus*	-	-	-	SA
Great egret (g)	*Ardea alba*	-	B, J, C	-	Vic
Great knot	*Calidris tenuirostris*	Near threatened	B, J, C, R	Yes	Vic, NSW, SA, Qld
Great pied cormorant (g)	*Phalacrocorax varius*	-	-	-	-
Greater crested tern (g)	*Thalasseus bergii*	-	B, J	-	SA
Greater sand plover	*Charadrius leschenaultii*	-	B, J, C, R	Yes	Vic, NSW, SA, Qld
Grey plover	*Pluvialis squatarola*	-	B, J, C, R	Yes	Vic, SA
Grey teal	*Anas gracilis*	Least concern	-	-	-
Grey-tailed tattler	*Tringa brevipes*	Least concern	J, C, R	-	Vic, SA
Hardhead	*Aythya australis*	Least concern	-	-	Vic

Common name	Scientific name	Australian IUCN Red List Status (2020)	Listed under international agreement(s)*	Nationally listed as threatened^	State/territory listed~
Hoary-headed grebe	*Poliocephalus poliocephalus*	Least concern	-	-	-
Hooded plover	*Thinornis cucullatus*	-	-	-	Vic, SA
Latham's snipe	*Gallinago hardwickii*	Vulnerable	J, C, R	Yes	SA
Lesser sand plover	*Charadrius mongolus*	-	R	Yes	Vic, NSW, SA, Qld
Lewin's rail	*Lewinia pectoralis*	-	-	-	Vic, SA
Little black cormorant (g)	*Phalacrocorax sulcirostris*	Least concern	-	-	-
Little egret (g)	*Egretta garzetta*	-	-	-	Vic, SA
Little pied cormorant (g)	*Microcarbo melanoleucos*	-	-	-	-
Little tern (g)	*Sternula albifrons*	-	B, J, C, R	-	Vic, NSW, SA
Long-toed stint	*Calidris subminuta*	Least concern	J, C, R	-	SA
Magpie goose (g)	*Anseranas semipalmata*	Least concern	-	-	Vic, NSW, SA
Marsh sandpiper	*Tringa stagnatilis*	Least concern	B, C, R	-	Vic, SA
Musk duck	*Biziura lobata*	-	-	-	Vic, SA
Nankeen night-heron (g)	*Nycticorax caledonicus*	-	-	-	-
Oriental pratincole	*Glareola maldivarum*	Least concern	J, C, R	-	-
Pacific black duck	*Anas superciliosa*	Least concern	-	-	-
Pacific golden plover	*Pluvialis fulva*	Least concern	R	-	Vic, SA
Pacific gull	*Larus pacificus*	-	-	-	-
Pectoral sandpiper	*Calidris melanotos*	Least concern	B, J, R	-	SA
Pied stilt (g)	*Himantopus leucocephalus*	Least concern	B	-	-

Common name	Scientific name	Australian IUCN Red List Status (2020)	Listed under international agreement(s)*	Nationally listed as threatened^	State/territory listed~
Pink-eared duck	*Malacorhynchus membranaceus*	Least concern	-	-	-
Plumed egret (g)	*Ardea plumifera*	Least concern	-	-	Vic, SA
Plumed whistling-duck	*Dendrocygna eytoni*	Least concern	-	-	-
Purple swamphen	*Porphyrio porphyrio*	-	-	-	-
Red knot	*Calidris canutus*	-	B, J, C, R	Yes	Vic, SA, Qld
Red-capped plover	*Charadrius ruficapillus*	Least concern	-	-	-
Red-kneed dotterel	*Erythrogonys cinctus*	Least concern	-	-	-
Red-necked avocet (g)	*Recurvirostra novaehollandiae*	Least concern	-	-	-
Red-necked stint	*Calidris ruficollis*	Near threatened	J, C, R	-	SA
Royal spoonbill (g)	*Platalea regia*	Least concern	-	-	-
Ruddy turnstone	*Arenaria interpres*	-	B, J, C, R	Yes	Vic, SA
Sanderling	*Calidris alba*	-	B, J, C, R	-	NSW, SA
Sharp-tailed sandpiper	*Calidris acuminata*	Vulnerable	B, J, C, R	Yes	SA
Silver gull (g)	*Larus novaehollandiae*	-	-	-	SA
Sooty oystercatcher (g)	*Haematopus fuliginosus*	-	-	-	SA
Spotless crake	*Zapornia tabuensis*	-	-	-	SA
Straw-necked ibis (g)	*Threskiornis spinicollis*	Least concern	-	-	-
Terek sandpiper	*Xenus cinereus*	Vulnerable	B, J, C, R	Yes	Vic, NSW, SA
Wandering whistling-duck	*Dendrocygna arcuata*	-	-	-	-
Whimbrel	*Numenius phaeopus*	-	B, J, C, R	-	Vic, SA

Common name	Scientific name	Australian IUCN Red List Status (2020)	Listed under international agreement(s)*	Nationally listed as threatened^	State/territory listed~
Whiskered tern (g)	*Chlidonias hybrida*	-	-	-	-
White tern (g)	*Gygis alba*	-	-	-	NSW
White-faced heron (g)	*Egretta novaehollandiae*	-	-	-	-
White-fronted tern (g)	*Sterna striata*	-	-	-	
White-necked heron (g)	*Ardea pacifica*	Least concern	-	-	-
White-winged black tern	*Chlidonias leucopterus*	Least concern	B, J, C, R	-	-
Wood sandpiper	*Tringa glareola*	Least concern	B, J, C, R	-	Vic, SA
Yellow-billed spoonbill (g)	*Platalea flavipes*	Least concern	-	-	-

Important Basin assets for waterbirds

Within the Basin, certain locations provide significant waterbird habitat. The below list of assets has been identified as critical to achieving a sustainable Basin waterbird community. Outcomes at these locations will be achieved through a combination of water for the environment, unregulated flows and consumptive deliveries. Sites that can receive water for the environment are termed Priority Environmental Assets in the Basin Plan. Further detail on the assets and the criteria for their inclusion on this list is provided below.

Table 10: Important Basin assets for waterbirds.

Grey assets can receive water for the environment; ^ Includes Ramsar site(s)

Asset		Total abundance and diversity	Shorebird abundance	Group-nesting	Drought refuge
1	Currawinya Lakes (Qld)^	*	*	*	*
2	Narran Lakes (NSW)^	*	*	*	
3	Cuttaburra channels (NSW)	*	*	*	
4	Paroo overflow lakes (NSW)^	*	*	*	
5	Yantabulla Swamp (NSW)	*	*		
6	Tallywalka system (NSW)	*			
7	Gwydir Wetlands (NSW)^	*		*	
8	Macquarie Marshes (NSW)^	*	*	*	
9	Lake Cowal (NSW)	*	*	*	*
10	Lake Brewster (NSW)	*		*	*
11	Booligal Wetlands (NSW)	*		*	
12	Great Cumbung Swamp (NSW)	*		*	*
13	Fivebough & Tuckerbil Swamps (NSW)^	*	*		*
14	Lowbidgee floodplain (NSW)	*	*	*	*
15	River Murray (NSW/Vic/SA)				*
16	Great Darling Anabranch (NSW)	*			
17	Menindee Lakes (NSW)	*	*	*	

Asset		Total abundance and diversity	Shorebird abundance	Group-nesting	Drought refuge
18	Barmah – Millewa Forest (NSW/Vic)^	*		*	
19	Gunbower-Koondrook-Perricoota Forest (NSW/Vic)^			*	
20	Lindsay-Wallpolla-Chowilla (Vic/SA)^	*		*	*
21	Kerang Wetlands (Vic)^	*	*	*	
22	Corop Wetlands (Vic)	*			*
23	Winton Wetlands (Vic)				*
24	Hattah Lakes (Vic)^			*	
25	Lake Albacutya (Vic)^	*			
26	Lake Buloke (Vic)	*			
27	Lake Hindmarsh (Vic)	*			
28	Coorong, Lower Lakes and Murray Mouth (SA)^	*	*	*	*

Further information on the four categories identified in Table 10 is provided below. For additional detail, refer to Bino et al. (2014).

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 spring aerial surveys. The representation target was based on accumulated waterbird data that suggested 80% of waterbird species were present in about 20 of the wetlands surveyed each year (Kingsford et al. 2013). The analysis was run on the Aerial Waterbird Survey of South Eastern Australia dataset (1983–2012), 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 (Bino et al. 2014). 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. The sites meeting this criterion include those that collectively support 80% of the abundance of each waterbird species' population over 1983-2012, for the 52 waterbird species recorded in the Basin during the Eastern Australian Waterbird Aerial Survey (Bino et al. 2015).

Shorebirds: Environmental assets listed in this category represent a desired conservation target of 80% representation for abundance of shorebirds as a functional group. The criteria included in the list above was an irreplaceability score greater than 0.8 (Bino et al. 2014). Outside of this analysis, any sites recorded as supporting over 5,000 shorebirds at a time were also noted as being significant. This is based on the criteria for a site to be considered internationally important and included in the Flyway Site Network (East Asian-Australasian Flyway Partnership 2013). A limitation to this approach is the spring timing of aerial surveys, which do not align with the period of peak shorebird abundance in summer. Additional knowledge on sites supporting large numbers of shorebirds was provided through the Waterbird Advisory Panel for the Strategy's 2024 update.

Group-nesting: Environmental assets listed in this category are wetland complexes that have had more than one group-nesting waterbird breeding event in the historical record. Nine species were chosen to be representative of group-nesting waterbird breeding to analyse the distribution, frequency and diversity of group-nesting waterbird breeding in the Murray– Darling Basin: Australian pelican, great cormorant, pied cormorant (*Phalacrocorax varius*), white necked heron, plumed egret, little egret (*Egretta garzetta*), straw-necked ibis, glossy ibis and royal spoonbill. These species breed in single or multi-species groups of tens of thousands to hundreds of thousands of individuals. Additional knowledge on group-nesting sites was provided through the Waterbird Advisory Panel for the Strategy's 2024 update.

Drought refuge: Environmental assets listed in this category are sites that were identified as priorities when setting representation targets during dry times. Dry times were defined by examining water availability across the entire Basin over 30 years (1983 –2012) and selecting those years in the bottom 25 percentile (2003, 2005–2009). It includes those locations that provide refuge habitat in dry years, but may not hold water in extreme drought years. Some drought refuge sites can receive water for the environment to help maintain refuge habitat. The analysis was run on the Aerial Waterbird Survey of South Eastern Australia dataset. A limitation to this approach is the spring timing of aerial surveys, which does not enable identification of important refuge areas during summer and autumn. Additional drought refuge areas were identified through the Waterbird Advisory Panel for the Strategy's 2024 update.

As part of the 2024 update of the BWS, the Waterbird Advisory Panel reviewed the 2019 list of important Basin assets for waterbirds. This resulted in several changes as follows:

- Removal of some assets no longer deemed significant at the Basin scale based on survey results and in the case of Noora Evaporation Basin, changes in hydrological management. Assets removed included the upper Darling River, Euston Lakes (which were originally combined with the River Murray asset), Waranga Basin, Noora Evaporation Basin and Kiewa River.
- Improved clarity that the River Murray asset includes the entire waterway from Hume Dam to the Murray Mouth, including the pool-connected wetlands. Pyap Lagoon (a pool-connected wetland) was originally listed as a separate asset but is now included as part of the River Murray asset.

Further information on important Basin assets for waterbirds

The tables below provide further information on the important Basin assets for waterbirds.

Waterbird abundance and diversity figures are from the spring Murray–Darling Aerial Waterbird Survey dataset (2007 –2020) collected by the University of New South Wales on Murray–Darling Basin Authority's behalf (Bino et al. 2021), unless otherwise specified. Figures represent years where waterbirds were present i.e. years where assets were dry and waterbirds were absent have not been included in the analysis.

Group-nesting figures are from 2007 –2023. This includes an analysis by Brandis et al. (2022) from 2007 –2020, with the addition of spring aerial survey data up to and including 2023, unless otherwise specified. The Brandis et al. (2022) analysis used three primary data sources: 1) NSW DCCEEW waterbird ground surveys, 2) Eastern Australian Waterbird Survey and 3) UNSW group-nesting waterbird site monitoring. Group-nesting figures from NSW waterbird surveys over 2021 – 2023 were not available at the time of reporting. Functional group species lists can be viewed in Bino et al. (2014).

Asset name	1) Currawinya Lakes
Site details	
Location	South-west Queensland (-28.738163, 144.317383)
Area	151,300 ha (Ramsar site area)
Recognition/protection	Ramsar Currawinya National Park
Key sub-sites within asset	Lake Numalla and Lake Wyara
Hydrology	Supplied from Paroo River Permanent (Lake Numalla) and semi-permanent areas Freshwater and saline
Water management	Unregulated Unable to receive water for the environment
Waterbird community	
Abundance	Maximum– 172,469 (2011 survey) (Kingsford et al. 2013) 75th percentile – 34,761 50th percentile – 15,007 25th percentile – 1,614
Diversity	Maximum – 41 (East Asian-Australasian Flyway Partnership 2013) Average - 27
Dominant functional groups (≥25% of abundance composition)	Ducks and herbivores Note: Herbivores include herbivorous ducks
Shorebird abundance	Maximum – 13,768 (2015 survey) Average – 2,676
Group-nesting	Frequency - 24% of survey years (4 in 17 years) Maximum nest abundance – 7,754 (2022 survey) Average nest abundance – 2,018
Other notes	• The site contains one of the most diverse collections of wetlands in inland Australia, including freshwater and saline lakes, clay pans, salt pans, swamps, springs and the waterholes of the Paroo River (Queensland Government 2014). • One of only two locations in the Basin recognised as internationally important to migratory waterbirds along the East Asian-Australasian Flyway. Can support >1% of the sharp-tailed sandpiper population (East Asian-Australasian Flyway Partnership 2013). • One of only a small number of known breeding sites in the Basin for Australian pelican.

Asset name	2) Narran Lakes
Site details	
Location	Western New South Wales (-29.844251, 147.334705)
Area	13,100 ha (four main lakes)
Recognition/protection	Ramsar (part of asset) Directory of Important Wetlands in Australia Narran Lake Nature Reserve
Key sub-sites within asset	Narran Lake (the largest of the lakes), Clear Lake, Back Lake and Long Arm
Hydrology	Supplied from the Narran River. Semi-permanent. Narran Lake can retain water for >12 months post filling. Freshwater
Water management	Unregulated Can receive water for the environment (Commonwealth Environmental Water Holder)
Waterbird community	
Abundance	Maximum– 85,217 (2010 survey) 75^{th} percentile – 30,810 50^{th} percentile – 17,134 25^{th} percentile – 3,915
Diversity	Maximum – 40 (NSW Government 2023) Average - 27
Dominant functional groups (≥25% of abundance composition)	Ducks and piscivores
Shorebird abundance	Maximum – 9,462 (2010 survey) Average – 1,922
Group-nesting	Frequency - 47% of survey years (8 in 17 years) Maximum nest abundance – 131,442 (2011 survey) Average nest abundance – 33,032
Other notes	• The site contains a diversity of habitats including some of the largest areas of lignum in New South Wales (NSW Government 2023). • One of only a small number of known breeding sites in the Basin for Australian pelican. • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (particularly for obligate wetland-feeding large waders such as spoonbills, herons and egrets) (McGinness et al. 2023).

Asset name	3) Cuttaburra Channels
Site details	
Location	Western New South Wales (-29.644134, 144.501352)
Area	Undefined
Recognition/protection	-
Key sub-sites within asset	None identified
Hydrology	Supplied from Warrego River (via Cuttaburra Creek and Yantabulla Swamp). Flow continues into the Paroo River under high flows. Ephemeral, freshwater.
Water management	Unregulated Unable to receive water for the environment
Waterbird community	
Abundance	Maximum– 177,535 (1983 survey) Average – 17,835 (Kingsford et al. 2013)
Diversity	Maximum – 32 (Kingsford et al. 2013) Average – 13 (Kingsford et al. 2013)
Dominant functional groups (≥25% of abundance composition)	Ducks
Shorebird abundance	Maximum – 6,202 (Kingsford et al. 2013) Average – 1,100 (Kingsford et al. 2013)
Group-nesting	No records
Other notes	-

Asset name	**4) Paroo Overflow Lakes**
Site details	
Location	Western New South Wales (-30.751253, 143.649770)
Area	Undefined
Recognition/protection	Ramsar Directory of Important Wetlands in Australia
Key sub-sites within asset	Mullawoolka Basin, Blue Lake, Gilpoko Lake, Poloko Lake, Peery Lake, Tongo Lake and Yantabangee
Hydrology	Supplied from Paroo River Ephemeral, freshwater Parts can retain water for >12 months post filling
Water management	Unregulated Unable to receive water for the environment
Waterbird community	
Abundance	Maximum– 71,993 (1994 survey) (Kingsford et al. 2013) 75th percentile – 8,024 50th percentile – 3,821 25th percentile – 2,159
Diversity	Maximum – 42 (Kingsford and Lee 2010) Average – 21
Dominant functional groups (≥25% of abundance composition)	Ducks
Shorebird abundance	Maximum – 14,780 (Kingsford et al. 2013) Average – 2,107
Group-nesting	Frequency - 29% of survey years (5 in 17 years) Maximum nest abundance – 1,905 (2010 survey) Average nest abundance – 443
Other notes	• Extensive area of freshwater lakes and lignum. • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (particularly for non-obligate wetland-feeding large waders such as ibis) (McGinness et al. 2023).

Asset name	**5) Yantabulla Swamp**
Site details	
Location	Western New South Wales (-29.266269, 144.870768)
Area	9,660 ha
Recognition/protection	Directory of Important Wetlands in Australia NSW National Park
Key sub-sites within asset	None identified
Hydrology	Supplied from Cuttaburra Creek (a distributary of the Warrego River) and the Paroo River during floods. Semi-permanent, freshwater
Water management	Unregulated Unable to receive water for the environment
Waterbird community	
Abundance	Maximum– 83,008 (2010 survey) 75th percentile – 26,631 50th percentile – 4,870 25th percentile – 1,426
Diversity	Maximum – 28 Average – 16
Dominant functional groups (≥25% of abundance composition)	Large waders
Shorebird abundance	Maximum – 15,281 (2010 survey) Average – 4,107
Group-nesting	Frequency - 6% of survey years (1 in 17 years) Maximum nest abundance – 109 (2019 survey)
Other notes	-

Asset name	6) Tallywalka System
Site details	
Location	Western New South Wales (-32.493177, 143.218302)
Area	Undefined
Recognition/protection	Directory of Important Wetlands in Australia
Key sub-sites within asset	Victoria Lake, Dennys Lake, Brummeys Lake, Waterloo Lake, Ratcatchers Lake and Teryaweynya Lake
Hydrology	Supplied from the Darling River during floods via the Talyawalka Creek. Ephemeral, freshwater.
Water management	Unregulated Unable to receive water for the environment
Waterbird community	
Abundance	Maximum– 66,826 (1990 survey) (Kingsford et al. 2013) 75th percentile – 1,524 50th percentile – 1,060 25th percentile – 596
Diversity	Maximum – 31 (1991 survey) (Kingsford et al. 2013) Average – 14
Dominant functional groups (≥25% of abundance composition)	Piscivores
Shorebird abundance	Maximum – 494 (Kingsford et al. 2013) Average – 189
Group-nesting	No records
Other notes	-

Asset name	7) Gwydir Wetlands
Site details	
Location	North west New South Wales (-29.298905, 149.315255)
Area	102,120 ha
Recognition/protection	Ramsar (823 ha) Directory of Important Wetlands in Australia Gwydir Wetlands State Conservation Area
Key sub-sites within asset	Two main watercourses – Lower Gwydir Watercourse and Gingham Watercourse Four separate Ramsar areas – Crinolyn, Goddard's Lease, Old Dromana and Windella
Hydrology	Supplied from the Gwydir River Semi-permanent, freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 13,555(2011 survey) 75th percentile – 9,673 50th percentile – 3,678 25th percentile – 2,018
Diversity	Maximum – 34 (2018 survey) Average – 27
Dominant functional groups (≥25% of abundance composition)	Herbivores, ducks and large waders
Shorebird abundance	Maximum – 1,154 (2021 survey) (NSW DCCEEW 2023) Average – 521 (NSW DCCEEW 2023)
Group-nesting	Frequency - 65% of survey years (11 in 17 years) Maximum nest abundance – 150,000 (1998) (Waterbird Tracker 2024) Average nest abundance – 8,531
Other notes	• Supports breeding across a high diversity of group-nesting species (14 species recorded breeding from 2007-2020) (Brandis et al. 2022). • One of a small number of locations in the Basin where group-nesting occurs frequently (50 percent or more of years) (Brandis et al. 2022). • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (for both obligate and non-obligate wetland-feeding large waders) (McGinness et al. 2023). • Satellite tracking data suggests the wetlands are a staging area for Latham's snipe (prior to their autumn migration) (H. McGinness, pers. comm. 30 April 2024).

Asset name	**8) Macquarie Marshes**
Site details	
Location	Central west New South Wales (-30.755414, 147.604967)
Area	200,000 ha
Recognition/protection	Ramsar (19,850 ha) Directory of Important Wetlands in Australia Macquarie Marshes Nature Reserve
Key sub-sites within asset	None identified
Hydrology	Supplied from the Macquarie River Semi-permanent, freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 305,373 (2022 survey) 75th percentile – 82,041 50th percentile – 79,660 25th percentile – 73,884
Diversity	Maximum – 35 (2022 survey) Average – 18
Dominant functional groups (≥25% of abundance composition)	Ducks and large waders
Shorebird abundance	Maximum – 10,120 (2010 survey) Average – 2,531
Group-nesting	Frequency - 82% of survey years (14 in 17 years) Maximum nest abundance – 125,422 (2010 survey) Average nest abundance – 16,893
Other notes	• Includes a high diversity of wetland types including freshwater waterways, with semi-permanent and ephemeral swamps and floodplains. • One of a small number of locations in the Basin where group-nesting occurs frequently (50 percent or more of years) (Brandis et al. 2022). • Supports breeding across a high diversity of group-nesting species (13 species recorded breeding from 2007-2020) (Brandis et al. 2022). • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (for both obligate and non-obligate wetland-feeding large waders) (McGinness et al. 2023).

Asset name	9) Lake Cowal
Site details	
Location	Central west New South Wales (-33.610122, 147.439253)
Area	16,150 ha
Recognition/protection	Directory of Important Wetlands in Australia
Key sub-sites within asset	None identified
Hydrology	Supplied from the Bland Creek. Receives inflows from the Lachlan River during floods. Ephemeral, freshwater. Can retain water for about 3 years post filling.
Water management	Unregulated Can receive water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 57,513 (2020 survey) 75th percentile – 20,433 50th percentile – 15,828 25th percentile – 8,317
Diversity	Maximum – 38 (2011 survey) Average – 30
Dominant functional groups (≥25% of abundance composition)	Ducks
Shorebird abundance	Maximum – 6,835 (2015 survey) Average – 2,204
Group-nesting	Frequency - 29% of survey years (5 in 17 years) Maximum nest abundance – 12,100 (2022 survey) Average nest abundance – 3,715
Other notes	• Largest natural inland lake in NSW. • Supports breeding across a high diversity of group-nesting species (14 species recorded breeding from 2007-2020) (Brandis et al. 2022).

Asset name	10) Lake Brewster
Site details	
Location	Riverina, New South Wales (-33.479781, 145.975894)
Area	6,140 ha
Recognition/protection	Directory of Important Wetlands in Australia
Key sub-sites within asset	None identified
Hydrology	Supplied from the Lachlan River. Artificially permanent (water storage), freshwater.
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum – 35,251 (2011 survey) 75th percentile – 22,515 50th percentile – 9,306 25th percentile – 4,844
Diversity	Maximum – 32 (Multiple surveys) Average – 27
Dominant functional groups (≥25% of abundance composition)	Ducks, herbivores and piscivores
Shorebird abundance	Maximum – 1,641 (2020 survey) Average – 427
Group-nesting	Frequency - 47% of survey years (8 in 17 years) Maximum nest abundance – 49,500 (2022 survey) Average nest abundance – 8,353
Other notes	• Also known as Lake Ballyrogan. • Used in conjunction with Wyangala Dam and Lake Cargelligo to regulate the Lachlan River. • Supports breeding across a high diversity of group-nesting species (8 species recorded breeding from 2007-2020) (Brandis et al. 2022). • One of only a small number of known breeding sites in the Basin for Australian pelican.

Asset name	11) Booligal Wetlands
Site details	
Location	Riverina, New South Wales (-33.775534, 144.874677)
Area	5,000 ha
Recognition/protection	Directory of Important Wetlands in Australia
Key sub-sites within asset	The swamps of the Merrowie, Merrimajeel and Muggabah Creeks, including Booligal Swamp, Upper Gum Swamp, Lower Gum Swamp, Merrimajeel Swamp and Murrumbidgil Swamp.
Hydrology	Supplied from the Lachlan River. Semi-permanent, freshwater.
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 220,626 (2010 survey) (Kingsford et al. 2013) 75^{th} percentile – 21,494 50^{th} percentile – 5,943 25^{th} percentile – 2,870
Diversity	Maximum – 34 (2012 and 2020 surveys) Average – 25
Dominant functional groups (≥25% of abundance composition)	Large waders and ducks
Shorebird abundance	Maximum – 2,207 (2020 survey) Average – 416
Group-nesting*	Frequency - 65% of survey years (11 in 17 years) Maximum nest abundance – 109,960 (2016 survey) Average nest abundance – 24,148
Other notes	• One of a small number of locations in the Basin where group-nesting occurs frequently (50 percent or more of years) (Brandis et al. 2022).

* 'Lower Lachlan' data from Brandis et al. (2022) plus 2020 –2023 Booligal wetland spring aerial survey results.

Asset name	12) Great Cumbung Swamp
Site details	
Location	Riverina, New South Wales (-34.273761, 143.965589)
Area	16,000 ha
Recognition/protection	Directory of Important Wetlands in Australia
Key sub-sites within asset	None identified
Hydrology	Supplied from the Lachlan River. Semi-permanent, freshwater.
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 31,621 (2012 survey) 75th percentile – 7,196 50th percentile – 3,811 25th percentile – 1,780
Diversity	Maximum – 36 (2011 survey) Average – 25
Dominant functional groups (≥25% of abundance composition)	Ducks and herbivores
Shorebird abundance	Maximum – 1,189 (2011 survey) Average – 337
Group-nesting	Frequency - 18% of survey years (3 in 17 years) Maximum nest abundance – 235 (2016 survey) Average nest abundance – 86
Other notes	• Includes areas of deep, open water lake and shallow marsh mudflats, as well as large areas of reed bed. • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (for both obligate and non-obligate wetland-feeding large waders) (McGinness et al. 2023).

Asset name	**13) Fivebough and Tuckerbil Swamps**
Site details	
Location	Riverina, New South Wales (-34.530529, 146.431459 and -34.486286, 146.349306)
Area	400 ha (Fivebough Swamp) 280 ha (Tuckerbil Swamp)
Recognition/protection	Ramsar Directory of Important Wetlands in Australia
Key sub-sites within asset	Fivebough Swamp, Tuckerbil Swamp
Hydrology	Supplied from catchment runoff (and irrigation channels sourced from the Murrumbidgee River). Permanent, semi-permanent and ephemeral areas. Fresh-brackish-saline
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 15,869 (1995 survey) (Kingsford et al. 2013) 75th percentile – 2,710 50th percentile – 1,126 25th percentile – 525
Diversity	Maximum – 25 (Kingsford et al. 2013) Average – 13
Dominant functional groups (≥25% of abundance composition)	Ducks
Shorebird abundance	Maximum – 2,476 (Kingsford et al. 2013) Average – 297
Group-nesting	Frequency - 47% of survey years (8 in 17 years) Maximum nest abundance – 690 (2016 survey) Average nest abundance – 235
Other notes	• Glossy ibis, sharp-tailed sandpiper, whiskered tern, Australasian bittern and brolga have all been recorded at the site in numbers estimated to be greater than 1% of their populations (NSW Government 2018). • Provide valuable shorebird habitat, with 19 shorebird species recorded at the site (White 2014).

Asset name	14) Lowbidgee floodplain
Site details	
Location	Riverina, New South Wales (-34.455694, 143.720029)
Area	217,000 ha
Recognition/protection	Directory of Important Wetlands in Australia Yanga National Park (part of asset)
Key sub-sites within asset	Gayini Nimmie-Caira, Redbank and Western Lakes systems
Hydrology	Supplied from the Murrumbidgee River Semi-permanent, freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 178,947 (1984 survey) (Kingsford et al. 2013) 75th percentile – 54,353 50th percentile – 11,158 25th percentile – 6,159
Diversity	Maximum – 39 (Kingsford et al. 2013) Average – 26
Dominant functional groups (≥25% of abundance composition)	Large waders
Shorebird abundance	Maximum – 44,368 (Kingsford et al. 2013) Average – 431
Group-nesting	Frequency - 94% of survey years (16 in 17 years) Maximum nest abundance – 78,810 (2010 survey) Average nest abundance – 12,619
Other notes	• Includes the third largest (45,000 ha) contiguous river red gum forest/woodland in Australia, plus black box, lignum and 15,000 ha of reed beds (Rogers et al. 2013). • One of a small number of locations in the Basin where group-nesting occurs frequently (50 percent or more of years) (Brandis et al. 2022). • Supports breeding across a high diversity of group-nesting species (13 species recorded breeding from 2007 –2020) (Brandis et al. 2022). • One of only a small number of known breeding sites in the Basin for Australian pelican (i.e. Kieeta Lake in the Lowbidgee). • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (for both obligate and non-obligate wetland-feeding large waders) (McGinness et al. 2023).

Asset name	**15) River Murray**
Site details	
Location	Lake Hume (Vic/NSW) to Lower Lakes (SA) Approximate mid-point (-35.255070, 143.573207)
Length	2,200 km
Recognition/protection	Icon Site – The Living Murray program Bordered by multiple National Parks, reserves and other protected areas at various locations.
Key sub-sites within asset	Main river body. Adjacent wetlands that are hydrologically connected under in-stream flows e.g. pool-connected wetlands in South Australia.
Hydrology	Supplied from the Murray River (upstream of Lake Hume) and multiple tributaries. Permanent, freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder plus environmental water entering from various tributaries)
Waterbird community	
Abundance	Maximum– 459 (2011 survey) 75^{th} percentile – 411 50^{th} percentile – 340 25^{th} percentile – 257
Diversity	Maximum – 22 Average – 15
Dominant functional groups (≥25% of abundance composition)	Piscivores and herbivores
Shorebird abundance	Maximum – 9 (2014 survey) Average – 1
Group-nesting	No records
Other notes	-

Asset name	16) Great Darling Anabranch
Site details	
Location	Western New South Wales Approximate mid-point (-33.239531, 141.789412)
Area	269,000 ha (Darling Anabranch Lakes)
Recognition/protection	Directory of Important Wetlands in Australia Nearie Lake Nature Reserve
Key sub-sites within asset	Mindona Lake, Little Lake, Travellers Lake, Popio Lake, Popiltah Lake, Yelta Lake, Binjie Lake, Nialia Lake, Pine Lake, Rotten Lake, Warrawenia Lake, Nitchie Lake, Nearie Lake and Milkengay Lake.
Hydrology	Supplied from the Darling River. Can also receive flow from the Menindee Lakes system through Tandou Creek and several other minor creeks. Ephemeral and semi-permanent areas. Some lakes retain water for up to 5 years post filling. Freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder)
Waterbird community	
Abundance	Maximum– 14,955 (2013 survey) 75th percentile – 4,313 50th percentile – 2,876 25th percentile – 1,438
Diversity	Maximum – 27 (2013 survey) Average – 24
Dominant functional groups (≥25% of abundance composition)	Piscivores and ducks
Shorebird abundance	Maximum – 944 (2013 survey) Average – 508
Group-nesting	Frequency - 6% of survey years (1 in 17 years) Maximum nest abundance – 473 (2023 survey)
Other notes	Flows from the Darling River (downstream of Menindee Lakes) to the River Murray (downstream of Wentworth).

Asset name	17) Menindee Lakes
Site details	
Location	Western New South Wales (-32.353692, 142.334722)
Area	45,700 ha
Recognition/protection	Directory of Important Wetlands in Australia Kinchega National Park (part of asset)
Key sub-sites within asset	Lake Cawndilla, Lake Menindee, Emu Lake, Kangaroo Lake, Lake Pamamaroo, Lake Bijiji, Lake Malta, Tandure Lake, Lake Balaka and Lake Wetherell.
Hydrology	Supplied from the Darling River. Artificially permanent (water storage) - Lakes Pamamaroo, Menindee, Cawndilla and Wetherell. Ephemeral elsewhere. Freshwater
Water management	Regulated Stores water for the environment (Commonwealth Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 137,940 (1985 survey) 75th percentile – 24,574 50th percentile – 12,052 25th percentile – 2,196
Diversity	Maximum – 33 (Multiple surveys) Average – 28
Dominant functional groups (≥25% of abundance composition)	Ducks and piscivores
Shorebird abundance	Maximum – 9,023 (Kingsford et al. 2013) Average – 1,357
Group-nesting	Frequency - 24% of survey years (4 in 17 years) Maximum nest abundance – 2,574 (2023 survey) Average nest abundance – 1,020
Other notes	-

Asset name	18) Barmah – Millewa Forest
Site details	
Location	Central Murray, Vic/NSW (-35.839531, 145.060560)
Area	66,000 ha
Recognition/protection	Ramsar Directory of Important Wetlands in Australia Murray Valley National Park and Barmah National Park River Murray Reserve Icon Site – The Living Murray program
Key sub-sites within asset	None identified
Hydrology	Supplied from the Murray River. Semi-permanent, freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, The Living Murray program, Victorian Environmental Water Holder)
Waterbird community	
Abundance	Maximum– 50,000 (2005 survey) (Hale & Butcher 2011) 75th percentile – 2,032 50th percentile – 1,758 25th percentile – 978
Diversity	Maximum – 24 (2019 survey) Average – 19
Dominant functional groups (≥25% of abundance composition)	Large waders and piscivores
Shorebird abundance	Maximum – 120 (Kingsford et al. 2013) Average – 10
Group-nesting	Frequency - 76% of survey years (13 in 17 years) Maximum nest abundance – 3,183 (2016 survey) Average nest abundance – 553
Other notes	• Largest river red gum forest in Australia. • One of a small number of locations in the Basin where group-nesting occurs frequently (50 percent or more of years) (Brandis et al. 2022). • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (for both obligate and non-obligate wetland-feeding large waders) (McGinness et al. 2023). • Important site for Australasian bittern (N. Khwaja, Arthur Rylah Institute, pers. com, April 2024).

Asset name	19) Gunbower-Koondrook-Perricoota Forest
Site details	
Location	Central Murray, Vic/NSW (-35.773818, 144.312987)
Area	31,150 ha
Recognition/protection	Ramsar Directory of Important Wetlands in Australia Gunbower National Park River Murray Reserve Icon Site – The Living Murray program
Key sub-sites within asset	None identified
Hydrology	Supplied from the Murray River. Semi-permanent, freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, The Living Murray program, Victorian Environmental Water Holder, NSW)
Waterbird community	
Abundance	Maximum– 25,806 (2011 survey) 75th percentile – 208 50th percentile – 80 25th percentile – 36
Diversity	Maximum – 15 (2011 survey) Average – 7
Dominant functional groups (≥25% of abundance composition)	Ducks and large waders
Shorebird abundance	Maximum – 4 (2011 survey) Average – <1
Group-nesting	Frequency - 24% of survey years (4 in 17 years) Maximum nest abundance – 150 (2019 survey) Average nest abundance – 52
Other notes	• Second largest river red gum forest in Australia. • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (for both obligate and non-obligate wetland-feeding large waders) (McGinness et al. 2023).

Asset name	**20) Lindsay-Wallpolla-Chowilla**
Site details	
Location	Lower Murray, Vic/NSW/SA Lindsay Island (-34.107588, 141.162341) Wallpolla Island (-34.118815, 141.736033) Chowilla (-33.941840, 140.930598)
Area	43,856 ha
Recognition/protection	Ramsar (Chowilla) Directory of Important Wetlands in Australia (Lindsay and Wallpolla Islands) Murray-Sunset National Park (Lindsay and Wallpolla Islands) River Murray Reserve Icon Site – The Living Murray program
Key sub-sites within asset	Lindsay Island, Wallpolla Island and Chowilla
Hydrology	Supplied from the Murray River. Permanent and semi-permanent areas Freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, The Living Murray program, Victorian Environmental Water Holder, SA)
Waterbird community	
Abundance	Maximum– 47,313 (2009 survey) (Kingsford et al. 2013) 75th percentile – 21,036 50th percentile – 19,060 25th percentile – 10,768
Diversity	Maximum – 38 (2014 and 2020 surveys) Average – 34
Dominant functional groups (≥25% of abundance composition)	Ducks and herbivores
Shorebird abundance	Maximum – 4,949 (2014 survey) Average – 1,505
Group-nesting	Frequency - 41% of survey years (7 in 17 years) Maximum nest abundance – 871 (2021 survey) Average nest abundance – 393
Other notes	One of only a small number of known breeding sites in the Basin for Australian pelican.

Asset name	**21) Kerang Wetlands**
Site details	
Location	North central Victoria (-35.604191, 143.794025)
Area	9,784 ha
Recognition/protection	Ramsar
Key sub-sites within asset	The 23 lakes, marshes and swamps that form the Ramsar site (Ramsar 2019)
Hydrology	Supplied from the Avoca River, Loddon River and Pyramid Creek. Permanent and ephemeral areas. Freshwater and saline.
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, Victorian Environmental Water Holder)
Waterbird community	
Abundance	Maximum – Over 75,000 (2018 survey) (Cook 2023) 75^{th} percentile – 30,714 50^{th} percentile – 19,430 25^{th} percentile – 8,614
Diversity	Maximum – 75 (2023 survey) (Cook 2023) Average – 29
Dominant functional groups (≥25% of abundance composition)	Herbivores, ducks and large waders
Shorebird abundance	Maximum – 13,898 (2014 survey) Average – 2,178
Group-nesting	Frequency - 76% of survey years (13 in 17 years) Maximum nest abundance – 53,420 (2010 survey) Average nest abundance – 5,454
Other notes	• One of a small number of locations in the Basin where group-nesting occurs frequently (50 percent or more of years). • One of only a small number of known breeding sites in the Basin for Australian pelican. • Confirmed as having a large area of foraging habitat surrounding the group-nesting sites (for both obligate and non-obligate wetland-feeding large waders) (McGinness et al. 2023). • More than 50 waterbird species have been recorded breeding at the site (Ramsar 2019). • Supports breeding across a high diversity of group-nesting species (7 species recorded breeding from 2008 –2023).

Asset name	22) Corop Wetlands
Site details	
Location	North central Victoria (-36.474981, 144.840041)
Area	Over 3,000 ha
Recognition/protection	Directory of Important Wetlands in Australia (part of asset) Several wildlife and conservation reserve areas
Key sub-sites within asset	Over 21 individual wetlands including Gaynor Swamp, Mansfield Swamp, Lake Stewart, Greens Lake, Horseshoe Lake, Lake Cooper, Wallenjoe Swamp, Little Wallenjoe Swamp, Two Tree Swamp, One Tree Swamp and the Fresh Lake.
Hydrology	Supplied from the Cornella Creek and Wanalta Creek. Some wetlands can also be supplied from the Goulburn River via the irrigation channel network. Greens Lake was used as an off-stream irrigation storage until its decommissioning in 2019. Semi-permanent and ephemeral areas. Freshwater
Water management	Regulated (part of asset) Can receive water for the environment (Victorian Environmental Water Holder) – Gaynor Swamp only.
Waterbird community	
Abundance	Maximum – 32,717 (2017 survey) 75th percentile – 10,172 50th percentile – 2,548 25th percentile – 1,566
Diversity	Maximum – 37 (2017 survey) Average – 22
Dominant functional groups ($\geq$25% of abundance composition)	Herbivores
Shorebird abundance	Maximum – 5,375 (Kingsford et al. 2013) Average – 485
Group-nesting	No records
Other notes	-

Asset name	23) Winton Wetlands
Site details	
Location	North east Victoria (-36.454482, 146.076725)
Area	3,800 ha
Recognition/protection	Reserve area
Key sub-sites within asset	Series of approximately 30 wetland basins.
Hydrology	Supplied from local catchment runoff. Was used as an off-stream irrigation storage until its decommissioning in 2010. Permanent (constructed) and semi-permanent areas. Freshwater
Water management	Currently unregulated (but historically regulated). Unable to receive water for the environment.
Waterbird community	
Abundance	Maximum – 13,020 (2014 survey) 75th percentile – 3,434 50th percentile – 400 25th percentile – 107
Diversity	Maximum – 27 (2017 survey) Average – 12
Dominant functional groups (≥25% of abundance composition)	Ducks
Shorebird abundance	Maximum – 330 (2014 survey) Average – 62
Group-nesting	Frequency - 6% of survey years (1 in 17 years) Maximum nest abundance – 2 (2016 survey)
Other notes	• Previously known as Lake Mokoan. • Includes large areas of cane grass wetland. • Confirmed as having a large area of foraging habitat (for both obligate and non-obligate wetland-feeding large waders) (McGinness et al. 2023).

Asset name	**24) Hattah Lakes**
Site details	
Location	Lower Murray (-34.757203, 142.346711)
Area	1,120 ha
Recognition/protection	Ramsar Directory of Important Wetlands in Australia Icon Site – The Living Murray program Hattah-Kulkyne National Park
Key sub-sites within asset	Lake Arawak, Lake Bitterang, Lake Brockie, Lake Bulla, Lake Cantala, Lake Hattah, Lake Konardin, Lake Kramen, Lake Lockie, Lake Mournpall, Lake Yelwell and Lake Yerang
Hydrology	Supplied from the Murray River via Chalka Creek (an anabranch of the Murray River). Permanent, semi-permanent and ephemeral areas. Parts can retain water for up to 10 years post filling. Freshwater
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, The Living Murray program, Victorian Environmental Water Holder)
Waterbird community	
Abundance	Maximum – 35,339 (2007 survey) (Kingsford et al. 2013) 75th percentile – 2,486 50th percentile – 1,240 25th percentile – 558
Diversity	Maximum – 28 (2019 survey) Average – 17
Dominant functional groups (≥25% of abundance composition)	Ducks
Shorebird abundance	Maximum – 2,529 (Kingsford et al. 2013) Average – 100
Group-nesting	Frequency - 29% of survey years (5 in 17 years) Maximum nest abundance – 6,979 (2022 survey) (GHD 2023) Average nest abundance – 530
Other notes	-

Asset name	**25) Lake Albacutya**
Site details	
Location	Wimmera Mallee, Victoria (-35.755202, 141.972214)
Area	5,660 ha
Recognition/protection	Ramsar Directory of Important Wetlands in Australia
Key sub-sites within asset	None identified
Hydrology	Supplied from the Wimmera River. Ephemeral but can retain water for several years post filling. Freshwater
Water management	Unregulated Unable to receive water for the environment
Waterbird community	
Abundance	Several species have been recorded in high numbers including (Cibilic & White 2010): • up to 20,000 grey teal. • 2,000 Australian wood duck. • over 10,000 banded stilt (1983), which represented over 4.5% of the estimated Australian population. • up to 1,000 freckled duck (1982 and 1983), which represented more than 5% of the estimated south-east Australian population. • 1,000 Australasian shoveler (1993), which represented 1% of the south-east Australian population. • over 1,000 red-necked stint, 750 sharp-tailed sandpiper and 87 curlew sandpiper.
Diversity	60 waterbird species have been historically recorded at the site (Cibilic & White 2010).
Dominant functional groups (≥25% of abundance composition)	Ducks
Shorebird abundance	High numbers of banded stilt, red-necked stint, sharp-tailed sandpiper, curlew sandpiper, red-necked avocet, red-capped plover, black-winged stilt, red-kneed dotterel and black-fronted dotterel have been recorded (Cibilic & White 2010).
Group-nesting	No records
Other notes	• No waterbird data from aerial surveys (2013 –2023) due to the dry lake conditions. • 12 species have been recorded breeding at the site (Cibilic & White 2010).

Asset name	26) Lake Buloke
Site details	
Location	North central Victoria (-36.267526, 142.959586)
Area	4,300 ha
Recognition/protection	Directory of Important Wetlands in Australia
Key sub-sites within asset	Lake Buloke and Little Lake Buloke
Hydrology	Supplied from the Richardson River Semi-permanent Freshwater (with increasing salinity on draw down)
Water management	Unregulated Unable to receive water for the environment
Waterbird community	
Abundance	Maximum – 39,743 (2012 survey) Average – 12,615
Diversity	Maximum – 24 (2011 survey) Average – 20
Dominant functional groups (≥25% of abundance composition)	Ducks
Shorebird abundance	Maximum – 203 (2010 survey) Average – 87
Group-nesting	Frequency - 8% of survey years (1 in 13 years) Maximum nest abundance – 2 (2010 survey) Average nest abundance – <1
Other notes	-

Asset name	27) Lake Hindmarsh
Site details	
Location	Wimmera Mallee, Victoria (-36.047512, 141.900971)
Area	13,500 ha
Recognition/protection	Directory of Important Wetlands in Australia
Key sub-sites within asset	None identified
Hydrology	Supplied from the Wimmera River Ephemeral Freshwater
Water management	Unregulated Unable to receive water for the environment
Waterbird community	
Abundance	Maximum – 19,303 (2013 survey) Average – 5,706
Diversity	Maximum – 26 (2011 survey) Average – 19
Dominant functional groups (≥25% of abundance composition)	Ducks and piscivores
Shorebird abundance	Maximum – 381 (2013 survey) Average – 79
Group-nesting	No records
Other notes	Largest natural freshwater lake in Victoria

Asset name	28) Coorong, Lower Lakes and Murray Mouth
Site details	
Location	South Australia (-35.541322, 139.042291)
Area	140,500 ha
Recognition/protection	Ramsar Directory of Important Wetlands in Australia Icon Site – The Living Murray program Coorong National Park
Key sub-sites within asset	Coorong, Lake Alexandrina, Lake Albert, River Murray mouth
Hydrology	Supplied from the Murray River Permanent Freshwater (Lower Lakes) Estuarine to hypersaline (Coorong)
Water management	Regulated Can receive water for the environment (Commonwealth Environmental Water Holder, The Living Murray program, SA)
Waterbird community	
Abundance	Maximum – 511,063 (2009 survey) 75th percentile – 169,409 50th percentile – 128,290 25th percentile – 91,920
Diversity	Maximum – 51 (2017 survey) Average – 44
Dominant functional groups (≥25% of abundance composition)	Shorebirds and piscivores
Shorebird abundance	Maximum – 401,083 (2009 survey) Average – 46,422
Group-nesting	Frequency - 94% of survey years (16 in 17 years) Maximum nest abundance – 22,060 (2022 survey) Average nest abundance – 7,787
Other notes	• Supports the highest waterbird diversity and abundance in the Basin. • One of only two locations in the Basin recognised as internationally important to migratory waterbirds along the East Asian-Australasian Flyway. Can support >1% of the sharp-tailed sandpiper, red-necked stint, sanderling and curlew sandpiper population (East Asian-Australasian Flyway Partnership 2013). • One of a small number of locations in the Basin where group-nesting occurs frequently (50 percent or more of years). • One of only a small number of known breeding sites in the Basin for Australian pelican. • Supports breeding across a high diversity of group-nesting species (9 species recorded breeding from 2007 –2023).

Native fish

Context

Within the Murray–Darling Basin, there are 69 species of native freshwater, estuarine, marine and migratory fish (Lintermans 2023). These species play important roles within aquatic ecosystem function, for example:

- Vital sources of food for other species—for other fish, waterbirds, turtles and other aquatic fauna (Ye et al. 2020).
- Occupation of multiple trophic levels within aquatic food webs, from high-level predator species to detritivores, herbivores and invertivores (Davis 1977, Ebner 2006, Pusey et al. 1995, 2000).
- Interspecies interactions including the phoretic relationship between fish hosts and developing/dispersing glochidia (freshwater mussel larvae) (Modesto et al. 2018, Walker 1981).
- Contribution to cycling and transport of nutrients, carbon and minerals (Macadam & Stockan 2015).

Further to their importance within ecosystem function, native fish are a highly valued commodity to people. Through tens of thousands of years of stewardship and deeply developed cultural connections, native fish are highly valued by First Nations people for their totemic and cultural significance, and are a fundamental source of food, trade and commerce, recreation, spirituality and traditional customs (Noble et al. 2016).

Throughout the Basin's more recent history, fish have also been widely recognised for their social and economic value. Recreational fishing is an important pastime that provides social and health benefits. In 2020, it was estimated that there are almost half a million recreational anglers in the Murray–Darling Basin, and that recreational fishing is worth around $403 million a year to Australia's Gross Domestic Product through supporting jobs and direct expenditure (Basin Plan Evaluation 2020). The ongoing benefits of tourism and recreational fishing in the Basin depend upon healthy native fish populations and functional ecosystems.

Native fish in the Basin have been subject to a range of anthropogenic stressors leading to severe declines in population abundances and distributions. It is critical that water resources are managed appropriately to support native fish recovery and population resilience, which in turn will lead to healthy and functioning ecosystems.

Typology

Native fishes of the Murray–Darling Basin display a range of behavioural traits and life history strategies that have evolved in response to the conditions and flow regimes under which these species evolved, prior to river regulation and climate change (Humphries et al. 1999, Baumgartner et al. 2014, Rolls et al. 2013, 2014; Cheshire et al. 2015, Bice et al. 2019). Therefore, different fish species are likely to exhibit individual responses to variations in river hydrology (Table 11).

To give due regard to the flow requirement of native fish in the Murray–Darling Basin, species can be categorised into broad functional groups using similarities in reproductive strategies, movement capabilities and habitat requirements. A total of six functional native fish groups were described for the Basin, with two groups specific to those species that utilise the estuary (NSW Department of Primary Industries 2015, Ellis et al. 2022). A simple summary of the functional native fish groups of the Murray–Darling Basin can be found in Table 11.

Table 11: Simplified summary of fish and flows of the northern and southern basin (NSW Department of Primary Industries 2015 and Ellis et al. 2022)

Functional Native fish Group	Key life history elements and implications for flow management
1) Flow Pulse Specialists **e.g., Golden Perch, Silver Perch, Spangled Perch**	Characterised by species that generally respond to seasonal flow pulses and shifts in temperature to cue spawning and migration events. Adults may be highly fecund and can undertake moderate to large scale migrations in response to flow. Eggs and larvae can drift over long distances, with minimal parental care. Higher flow and 'freshes' events provide longitudinal connectivity and opportunity for upstream re-colonisation movements.
2) River Specialists **e.g., Murray Cod, Macquarie Perch, Freshwater Catfish**	Characterised by species where adults undertake shorter migrations for spawning in response to increased temperature or flow. Spawn in nests or require specific spawning substrate, and flowing water helps to maximise spawning and hatching success. Eggs require stable flow events during this period to avoid nest abandonment, desiccation, or premature dispersal. Larvae may drift semi-passively over short for moderate distances. 'Freshes' provide connectivity and cues for juvenile upstream recolonisation movement.
3) Floodplain Specialists **e.g., Olive Perchlet, Southern Pygmy Perch, Flat-headed Galaxias**	Characterised by species that require overbank flooding to stimulate dispersal for re-colonisation, establishment of new populations, and mixing between populations. They are relatively short to medium-lived species with low fecundity, that require regular spawning and recruitment events for persistence of populations. Adults may migrate short distances into or within lentic off-channel habitats for spawning in response to increasing water temperature. May have specific spawning substrate preferences. Increases in flow can enhance breeding opportunities by inundating additional spawning habitat.
4) Generalist **e.g., Carp Gudgeon, Murray–Darling Rainbowfish, Australian Smelt**	Generally, includes short to medium-lived species with low fecundity and require regular spawning and recruitment events for persistence. They have flexible spawning strategies, but generally spawning is associated with increased temperature.

Functional Native fish Group	Key life history elements and implications for flow management
	Adults may move short distances and may spawn more than once per year. Low to moderate flow events that inundate in-channel habitat may enhance spawning conditions and connectivity of drought refuges.
5) Diadromous **e.g., Pouched Lamprey, Congolli, Common Galaxias**	Characterized by species require movement between freshwater and marine habitats for the completion of their lifecycles, and connectivity of and ability to migrate to spawning habitats are vital for spawning and recruitment. Spawning migration can be downstream (catadromous) or upstream (anadromous).
6) Estuarine Dependent **e.g., Tamar River Goby, Black Bream, Yellow-eyed Mullet**	Characterized by species that occur in estuarine environments that are either required for the full lifecycle of species or particular life stages. Display a range of spawning and recruitment strategies, but freshwater discharge may be important in promoting recruitment in all species.

Note: Groups 5 and 6 only occur in the Southern Murray–Darling Basin.

Within the Murray–Darling Basin, there are three broad geographical regions; the Northern Basin, Southern Basin and Coorong/Estuarine. Within each of these regions, native fish experience different environmental conditions and habitat availability (Davies et al. 2012, NSW Department of Primary Industries 2015, Ellis et al. 2022):

Northern Basin:

- Many of the river flows are highly intermittent due to variable rainfall, and these natural wetting and drying cycles have a strong influence on fish communities.
- Survival through drying phases governs the long-term persistence of native fish and is heavily dependent on quality refuge habitat during dry times and the ability to recolonise habitats when moderate to high flow conditions return.

Southern Basin:

- Rainfall is generally higher and less variable in winter and spring, but river regulation has reversed or inverted some of this seasonality. In some locations, high base flows now occur in summer, with low flows or even drying in winter.
- Unregulated systems still support remnant populations of threatened species and are important for overall fish biodiversity.
- Most of the environment has been highly modified (e.g., areas in and around the River Murray), but the habitat still supports many iconic riverine specialists such as Murray Cod and Trout Cod.

Coorong/Estuarine:

- These habitats are unique within the Murray–Darling Basin and are home to fish communities that differ from the rest of the Basin.

- Connectivity, productivity and salinity are the three major factors that regulate these fish communities. Each of these are heavily influenced by freshwater inflow to the Coorong, largely originating from the lower Murray, and marine water exchange through the Murray Mouth.
- Unfortunately, connectivity between the ocean, the estuary and the river, which is essential for many species, is now restricted and fish must use constructed fishways and the barrages—making flows that operate these structures particularly important.

Condition

Currently there are 18 estuarine/marine species and 51 native freshwater fish species occurring within the Murray–Darling Basin (Lintermans et al. 2024). Eleven 'new' species had been added since 2011, largely due to the taxonomic resolution of species complexes. Although still debated, the Silver Tandan (*Porochilus argenteus*) is the only genuine addition of the eleven 'new' native fish species having been observed in the Basin for the first time following flooding. The Yarra Pygmy Perch (*Nannoperca obscura*) has been the first known extinction of a native species in the Murray–Darling Basin, following the Millennium drought in 2010.

For many decades Murray–Darling Basin native fish species and populations have seen extensive declines in the abundance and distribution (Murray–Darling Basin Commission 2004, Koehn et al. 2014a). Long-term trends published in 2003, and again in 2023, estimated that native fish populations in the Basin have reduced ~90% since European settlement (mid-1800s) (Murray–Darling Basin Commission 2004, Koehn et al. 2014a, Murray–Darling Basin Authority 2020, Lintermans 2024).

Many anthropogenic stressors have resulted in significant declines of native fish populations within the Murray–Darling Basin (Koehn et al. 2020a, Lintermans et al. 2024). Broadly, alterations to flow and loss of hydrodynamic diversity have been key drivers of declines in native fish populations (Hammer et al. 2013, Koehn et al. 2020b). This is evident for riverine and flow specialists, such as Trout cod, Southern purple-spotted gudgeon, Macquarie perch and silver perch that depend on flow for spawning and hatching success, and connectivity for upstream recolonisation movements by juveniles (Ellis et al. 2022).

Many small-bodied native fish species continue to observe drastic declines in abundance and distribution, with some species experiencing local and regional extinctions within the Murray–Darling Basin (Saddlier et al. 2013, Whiterod et al. 2021). Small-bodied species have shared traits which make them more vulnerable to threats such as limited dispersal, short lifespan and small ranges (Kopf et al. 2017, Lintermans et al. 2020, Whiterod et al. 2021). Furthermore, many are highly dependent on off-channel habitats and require regular recruitment and spawning events for long-term persistence (Lyon et al. 2010). Constraints to water delivery that reduce connectivity between river channels and floodplains are likely to impact spawning movement and dispersal to refuge habitat (Ellis et al. 2022). For example, the range of the small-bodied Southern pygmy perch has been drastically reduced due to drought, degradation and loss of wetland habitat and impacts of alien species (Todd et al. 2017, Whiterod et al. 2021). Local extirpations have occurred at middle and upland Murray catchment sites. On the other hand, changes to river regulations and water management have allowed alien species such as common carp, redfin and trout to flourish within the Murray–Darling Basin. Predation from and competition with these alien fish species can contribute substantially to the extinction risk of small-bodied native fish (Lintermans et al. 2020).

More recent temporal trends of six large-bodied fish species in NSW (2000 –2020) have indicated that Murray cod and golden perch have shown an overall increase in abundance trends (Crook et al. 2023). These trends could be attributed to targeted recovery actions that support population recovery such as extensive stocking, delivering seasonally appropriate flows, ceasing commercial fishing, and habitat re-installation (Kearney & Kildea 2004; Lintermans 2004; Forbes et al. 2020).

Numerous management activities to aid native fish recovery have been implemented across the Murray–Darling Basin. While some conservation successes have been observed (for example, the expanded distribution and abundance of Trout cod), it needs to be recognised that native fish populations took many years to decline and their recovery will require considerable effort. A series of complementary measures combined with ongoing conservation management and consistent funding is required. Furthermore, many native fish populations in the Murray–Darling Basin are still experiencing significant declines. For example, Silver perch in the Northern Basin are now only present in very low numbers, with reduced recruitment success and declines in subpopulations. Indeed, population modelling found the species to be functionally extinct in the Northern Basin (Lintermans 2023).

Threatened species

Many of the Basin's 51 native freshwater fish are unique to Australia. Almost 50% of these species are now considered rare or threatened on state, federal or international listing. This trend is predicted to continue, especially under harsher conditions associated with climate change (Morrongiello et al. 2011, Lintermans et al. 2024). Several Murray–Darling Basin fish communities, such as the Lowland Riverine Fish Community of the Southern Murray–Darling Basin (Victoria) and the Lower Murray River aquatic ecological community (NSW), are also listed as threatened within specific jurisdictions.

Potential impacts of large-scale disturbances, such as bushfires, drought and climate change, and interactions with other threatening processes, are of major concern for many native fish species (Bond et al. 2008, Wedderburn et al. 2012, Baumgartner et al. 2017, Silva et al. 2020).

Most threatened species and community listings are assessed at the state or national management level, which has led to discrepancies and misalignment of some species listings. More recently, a common assessment method is being implemented for the assessment and listing of threatened species to address this [17]. At a purely Basin Scale perspective, it should be noted that national and/or state threatened species listings may not always reflect the status of native fish within the Murray–Darling Basin. For example, Yarra pygmy perch (*Nannoperca obscura*) is listed as Endangered nationally, Critically Endangered in South Australia and Vulnerable in Victoria. However, the Yarra pygmy perch is now considered extinct from the Murray–Darling Basin, having not been detected since 2010 (Wedderburn et al. 2012, 2022).

[17] https://www.dcceew.gov.au/environment/biodiversity/threatened/cam (accessed August 2024)

A Key Threatening Process is a term used to identify a process that threatens the survive of a native species or community. Currently there are no Key Threatening Processes for native fish under the *Environment Protection and Biodiversity Conservation Act 1999*, which is of concern as the trend in number of Basin fish listed as threatened at the national level since 2010 has continuously been increasing. The following are some of the Key Threatening Processes under NSW and Victorian biodiversity Acts[18] which are relevant to native fish populations in the Murray–Darling Basin, directly or indirectly:

- Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams;
- Removal of large woody debris;
- Alteration to the natural flow regimes of rivers and streams
- Alteration to the natural temperature regimes of rivers and streams
- Introduction of live fish into waters outside their natural range within a Victorian river catchment after 1770
- degradation of native riparian vegetation;
- novel biota and their impact on biodiversity;
- fire regimes that cause declines in biodiversity;
- loss of climatic habitat caused by anthropogenic emissions of greenhouse gases, and
- land clearing.

While state listings of key threatening processes are important for the recovery and protection of native fish species, a Basin-wide inventory of the prevalence of key threatening process to native fish populations should be undertaken and management responses to these threats identified (Lintermans et al. 2024).

Interactions between native fish and flows

Key ecological processes that are vital to supporting native fish populations include flow regimes that support key life history processes, habitat condition and availability, and hydrological connectivity (Figure 15). The interaction of hydrological flows with the physical structure of rivers creates heterogeneous sections of habitats with fast-flowing, slow flowing and still water at local through to landscape scales (Humphries et al 2020) (hydrodynamic diversity, refer to Longitudinal Connectivity). Flows also influence the quality, size, and persistence of refuge habitats during dry periods; and maintain aquatic vegetation upon which many fish are dependent (Koehn et al. 2014b).

Hydrological connectivity and movement between habitats are important for maintaining healthy, genetically diverse native fish populations in the Basin. Seasonally appropriate flows give fish physical access to a range of aquatic habitats and provide cues for spawning and that stimulate movement—a key ecological process for native fish. In addition, seasonal flows that inundate in-channel benches and floodplains increases carbon input, which in turn drives productivity and food webs. This is critical for larval and juvenile fish, as they have low energy reserves and need ready access to food in order to survive (Koehn et al. 2014b). To restore and maintain resilient fish populations and maintain healthy levels of genetic diversity, fish communities require regular

[18] NSW Fisheries Management Act 1994, Flora and Fauna Guarantee Act 1988

connectivity between populations (Zampatti et al. 2021). 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 kms) (e.g., Hutchison et al. 2008). Flows need to be managed in a coordinated way to ensure permanent support for native fishes and ecosystem processes (Koehn et al. 2020a) and to achieve recovery of fisheries.

The restoration of more natural flow regimes in regulated systems through the use of water for the environment is now a major aspect of ecosystem management within the Murray–Darling Basin and such improved water management will achieve many beneficial outcomes for native fish. For example (NSW Department of Primary Industries 2015, Ellis et al. 2022):

- Temporal flow regimes that meet life-cycle requirements
    - Annually suitable flow regimes that maintain rates of water levels/velocities that support nesting river specialists during the breeding season, such as Murray cod and Trout cod, that increase breeding success and survival of offspring.
    - Within-channel flow pulses in spring/summer may cue spawning responses in and support recruitment of flow pulse specialists, such as Silver perch and Golden perch, with juvenile survival improved through access to inundated off-channel habitat and ephemeral wetlands, which may offer productive and sheltered nursery habitats.
    - Freshwater discharge through the Murray Mouth that estuarine dependent species, such as Mulloway, depend on to stimulate spawning aggregations.
- Movement between and connectivity of habitat:
    - Connection events and secondary connection events allow floodplain species to access wetland habitats to recruit and survive.
    - Connectivity over large spatial scales is essential for many flow pulse specialists, such as Golden Perch, to enable movement for spawning and to aid upstream re-colonisation movements by juveniles.
- Maintenance of habitat
    - Base flows in perennial system that support the condition of habitats, such as maintenance of water quality in winter habitats for Galaxids and Blackfish species in the Northern Basin.
    - Maintenance of critical refuge habitat, particularly for low-flow species.

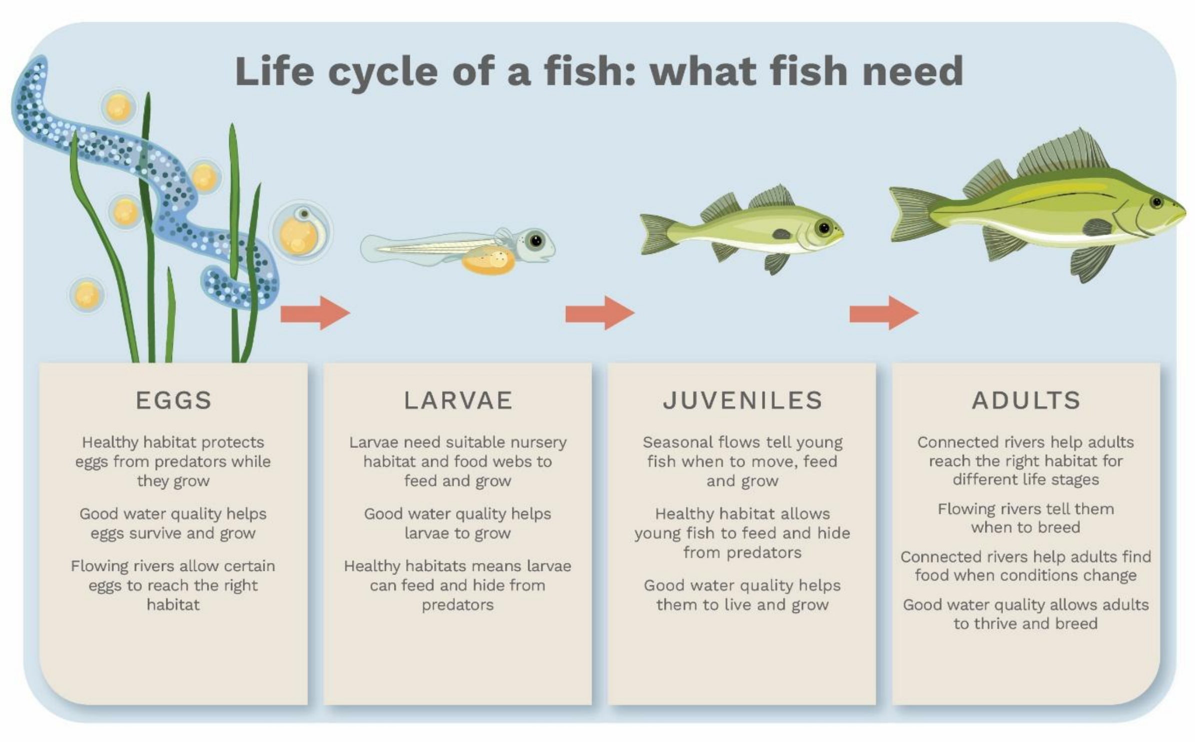

Figure 15: The key life cycle events and habitat requirements of fish (Finterest).

Expected environmental outcomes for native fish

The Expected Environmental Outcomes for native fish are provided in the Basin-wide Environmental Watering Strategy. They include outcomes for all native fish, short-lived native fish species and moderate to long-lived native fish species and are summarised below in Table 12.

Table 12: Summary of native fish expected environmental outcomes (refer to Basin-wide environmental watering strategy for full expected environmental outcome descriptions).

Maintain current species diversity, extend distributions, improve breeding success and numbers
Improved distribution: • of key short- and long-lived fish species across the Basin • 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. **Improved breeding success for:** • short-lived species (every 1 to 2 years) • moderate to long-lived species in at least 8 out of 10 years at 80% of key sites **Improved populations of:** • short-lived species (numbers at pre-2007 levels) • moderate to long-lived species (with a spread of age classes represented) at key sites • Murray cod and golden perch (10% –15% more mature fish at key sites) **Improved movement:** • annual detection of species and life stages representative of the whole fish community through key fish passages

Estuarine species:
• detection of all estuarine-dependent fish families
• maintenance of key estuarine prey species (sandy sprat and small-mouthed hardyhead)
• detection of black bream and greenback flounder within the CLLMM
• improved population structure of mulloway, including spawning aggregations at the Murray Mouth
• detection of bidirectional movement of diadromous fish in Lower Lakes and Coorong in nine out of 10 years
• increased rates of native fish passage in 2019–2027 compared to 2014 –2019

Context

Ongoing delivery of water for the environment is an essential component to ensure the persistence of native freshwater fish populations in the Murray–Darling Basin. Long-term strategies to address multiple threats and stressors impacting on Murray–Darling Basin fishes are also urgently required to ensure that current population declines are halted, recovery of populations at threat are expedited and populations are supported for ongoing resilience in future climate scenarios.

The overarching objective for native fish in the Murray–Darling Basin is to advance species recovery and resilience so more native fish can occupy a greater share of their historic distribution and to return diversity to native fish communities. To achieve these objectives a greater variability of flows is required to support a mosaic of habitats with facilitated connectivity and movement between these habitats. Furthermore, flows need to provide opportunities for a range of species with various life history requirements to support stable populations.

Basis for expected outcomes

The native 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. Nine workshops were held in 2014 with subject matter experts from government, academia and private consulting firms to consider fish outcomes and water management strategies to improve native fish populations. 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 (improved 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.

Key terms for expected outcomes

Community structure: Refers to the presence of a range of different species with varying life histories that are appropriate for specific location. Needs to be considered at various spatial and temporal scales.

Detection of estuarine-dependent fish families: 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.

Increasing distribution: The intent of outcomes that refer to 'increasing distribution' is to expand on the 'core range' of a species. The core range is considered to be where populations are in reasonable condition and abundance. It is not expected that expanded distributions will be uniform, spatially, temporally or across all key fish species. Priorities for increasing distribution are identified in Table 13.

Key Fish Species: Species that were identified as being flow dependant (listed below). These species were selected by a conceptual modelling process, along with expert opinion, to identify the likelihood of their response to improved water management. Priority was given to species with a threatened status in the Basin and social and economic value. At the same time, it was deemed feasible to evaluate progress towards the Expected Environmental Outcomes for these key fish species using existing approaches and knowledge. There is potential to update the list of key fish species during the review of the Strategy as relevant knowledge becomes available. Please note that not all key fish species are relevant to each Expected Environmental Outcome for various reasons (such as lack of available data).

Increased movement: This refers to improved connectivity (lateral, longitudinal and vertical) that allows for fish movement that is critical for the completion of species' life cycles.

Population structure: This refers to a healthy population structure expected to manifest through improved survival, a mix of age classes (including sex ratios for some species), regular recruitment (younger classes) and good numbers of adults to breed future generations.

Recruitment: The successful development and growth of juveniles; such that they have the ability to contribute to the next generation.

Regular recruitment: Adequate recruitment opportunities for species to ensure sustainable populations. This can be represented through the presence of a balanced curve of all life stages required to maintain a healthy **population structure**. For an example of this, see figure 9a and b in Koehn et al (2014b).

Re-introductions in the northern Basin: By extending the range of existing populations and establishing additional populations, two outcomes for expanded distributions of key fish species in the northern basin are expected by 2024 (refer to Table 13 for details).

Strong recruitment: What constitutes a 'strong' recruitment event will depend on the species and its status at a given location.

Supporting detail for native fish outcomes

Supporting detail for native fish outcomes for freshwater species is provided in Table 13, whilst Table 14 provides information for estuarine species targeted by this Strategy. These species were identified as good indicator species due to their flow requirements, conservation importance, and importance in the recreational and commercial fishing industries. Some threatened species were included owing to insufficient information on their flow requirements. The tables also provide details on priorities for expanding distributions of some key native fish by 2024.

Longevity and recruitment, habitat and flow requirements

Longevity and species-specific recruitment requirements for key fish species are outlined in Table 13 and Table 14 (see Longevity & Recruitment columns). Furthermore, detail on links between species' life histories and flow needs is provided (see Flow requirement columns), as well as key habitat features (see Key habitat columns).

It is important to note that:

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

Priorities for increasing the distribution

The tables outline priorities for increasing the distribution of key fish species (see Priorities for increasing distribution columns) with the aim of expanding species distributions of particular species identified during expert workshops held during the development of the Strategy (such as Southern purple-spotted gudgeon in the Northern Basin).

Increasing the distribution of native fish relies on expansion of existing populations (see Range extension in the Priorities for increasing distribution columns) and/or the establishment of new populations within their natural range (see Additional populations in the Priorities for increasing distribution columns), facilitated by improved water management and flows. Table 15 suggests candidate sites where this outcome can increase distribution of native fish species. Agencies may also consider additional or substitute sites in their planning. For some threatened species, complementary measures, such as stocking and translocations, may be needed if flow-mediated range expansion is not feasible. These measures may 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 outcomes that are targeted at increasing distributions in relation to the overall distribution of species can be more challenging. Some species are 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 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 historically). The content in the tables is based on the best information currently available. Future application of this information can consider more recent data, if available.

Threats and complementary measures

Overarching, complementary measures and threats to achieving Expected Environmental Outcomes are identified in the Strategy. For threatened species listed under jurisdictional or national legislation, threats to native fish species and species-specific complementary measures that aid the progress towards the outcomes can be found in Table 15Table 13 (see Threats & complementary measures columns). Complementary measures should be implemented in order to maximise the full benefits of the provision of environmental water for native fish.

Freshwater species

Table 13: Supporting detail for native fish outcomes for short-, moderate- and long-lived key freshwater fish species. Base habitat flow: Usually confined to deeper low-lying parts of the river channel and generally occur on a near-ongoing basis in perennial systems thereby maintaining longitudinal connectivity and dispersal opportunities. May be important in sustaining drought refuges when low flow conditions persist, and help maintain water quality; life cycle flow: Required to complete species' life cycles. Requirements vary for different species and are also life-stage dependent.

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
Flathead galaxias (*Galaxias rostratus*) **National: CE {VU}, NSW: CE, Vic: VU, SA: [EX]** **Southern Basin (Basin endemic)**	Short (3 –5 years), annual	Lowland and foot hill habitats Still or slow flowing water with rocky and sandy bottoms and macrophyte bed habitats Generally breed in off-channel habitats	*Base habitat flows* Maintenance of drought refuges is important for survival. *Life cycle flows* Secondary connection events between rivers and lagoons and wetlands are required to enable recruits to enter the river.	*South* Considered locally extinct in the lower Murray. The species is known to occur in the upper catchments in Victoria, though rarely caught. 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). *North* This species is considered locally extinct in the Northern Basin. Reintroduction using southern populations may be an option.	*Threats* Competition and/or predation from alien fish such as Redfin perch and trout River regulation and reduced fish passage Habitat degradation such as loss of aquatic vegetation Potential impacts from transferred native Climbing galaxias *Complementary measures* Management and engineering solutions to physical barriers to improve connectivity between rivers and floodplains Control programs for alien fish species Seeding of native aquatic plants to increase quality of habitat

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
				Candidate sites may be considered within their former range in the Lachlan and Macquarie catchments.	
Freshwater catfish (*Tandanus tandanus*) **NSW: EN POP, Vic: EN, SA: PROT [EN]** **Basin Wide**	Moderate to long, 8 in 10 years	Benthic species, generally sedentary Slow-moving streams and lakes Utilises cover such as macrophytes and woody debris and high cover of cobble/gravel (Lintermans 2023) Breeding habitat is preferred in areas with a high abundance of bedrock, riffle/rapids, macrophytes and low flows (Duncan et al. 2017).	*Base habitat flows* Lateral connectivity between lagoons and tributaries Prefers slow-moving habitat. Sites where daily average flow is greater than approx. 1,300 ML/day are unlikely to support catfish populations, especially if there is a lack of gravel (Duncan et al. 2017). *Life cycle flows* Flow events enhance recruitment in this species and secondary connection events between rivers, and lagoons and wetlands are required to enable recruits to enter the river Nest-building triggered where water temperatures reach ~24 degrees (Duncan et al. 2017). Requires stable water depths and flowing water for the	*South* Range extension: Expand the core range of ≥ two existing populations (candidate sites include Columbo-Billabong Creek and Wakool system and Wimmera River). Additional populations: Improve core range in ≥ three additional locations (candidate sites include the Avoca River, Loddon River upstream Laanecoorie Reserve, Merran Creek area in NSW). *North* Range extension: Expand the core range of ≥ 3–5 existing populations (candidate sites include the Gwydir, Namoi, Border Rivers, Macquarie, Warrego	*Threats* Reduced connectivity and reduced opportunities for longitudinal and lateral movement due to reduced frequency and magnitude of low and medium flow events Loss of suitable habitat and refuge pools during low flow conditions through water extraction or flow regulation Disturbance and predation from alien species such as Carp and Redfin perch Habitat degradation such as cold-water pollution and sedimentation of spawning sites *Complementary measures* Control programs for alien fish species

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
			duration of nesting to ensure adults do not abandon nests.	and Condamine catchments and the Paroo River)	
Golden perch (*Macquaria ambigua*) **Vic: Part of threatened Lowland Riverine Fish Community of the Southern Murray Darling Basin** **Basin Wide**	Moderate to long, 8 in 10 years	Main channel specialist Deep, pool habitats with instream woody debris Spawn and recruit in flowing habitats	*Base habitat flows* Preferred habitat flows of water velocities of <0.31 m/sec (Lintermans 2023). *Life cycle flows* Flows cue spawning and govern recruitment, with spawning and recruitment enhanced with spring/summer flooding and high within-channel flow pulses Flows stimulate movement and disperse early life stages	N/A	*Threats* Disruption of migration and spawning cues through river regulation Cold-water pollution below large dams Barries to migration and recolonisation such as weirs and dams Overfishing
Hyrtl's tandan (*Neosilurus hyrtlii*) **Northern Basin**	Moderate to long, 8 in 10 years	Range of habitats, including flowing waters or still areas Water temperatures below 8–12°C likely unfavourable for survival (Lintermans 2023). Connectivity between lagoons and tributaries	*Base habitat flows* Lateral connectivity between lagoons and tributaries Protection of drought refugia *Life cycle flows* High flow events in summer to drive spawning of adult (upstream) and juvenile (downstream) migration	N/A	*Threats* Water extraction reducing the number and quality of refuge pools during low-flow conditions

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
			Adults migrate into lagoon habitats and tributaries.		
Macquarie perch (*Macquaria australasica*) **National, ACT, NSW, Vic: EN, SA: [EX]** **Basin Wide**	Moderate to long, 8 in 10 years	Clear water and deep, rocky holes with abundant cover (woody debris, boulders, riparian vegetation etc) (DEE 2018) Water depth usually between 0.2–0.9 m and water velocity between 0.3–0.6m/sec (DEE 2018) Flowing water (that retains stable depths) in conjunction with riffle and pool habitats containing cobble and gravel substrates required for spawning	*Base habitat flows* Provide flows to maintain water quality. Natural freshes are required to scour fine sediment and prepare spawning habitats. *Life cycle flows* Flowing water is required to disperse eggs and larvae Suitable flows for connectivity are required as the species spawns spawn in aggregations and barriers may prevent access to suitable spawning habitat or other adult fish.	*South* Range extension: Expand ≥ two existing populations (candidate sites include Cotter River, Murrumbidgee above Cooma, Adjungbilly Creek, King Parrot Creek, Hughes Creek, and Hollands Creek). Note: Cotter and Murrumbidgee rivers populations – translocation to the upper Cotter and upper Murrumbidgee undertaken Additional populations: Establish ≥ four additional riverine populations (candidate sites include mid-Goulburn River, Ovens	*Threats* Alterations to hydrology and loss of connectivity between populations and habitat, e.g.: Late spring flushes may negatively impact recruitment by disturbing eggs High flows during and following the spawning season reduce successful recruitment of young-of-year (YOY) fish Loss of suitable refuge habitat either through water extraction or flow regulation reducing the number and quality of refuge pools during low flow conditions in summer and autumn

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
			Spawning occurs from October to December when water temperature rise to ~16 °C (DEE 2018, Lintermans 2023).	River, Kiewa River and Goodradigbee River). Note: Ovens and Goulburn rivers populations –stocking and translocations to re-establish populations undertaken. *North* Range extension: The distribution of Macquarie perch in the northern Basin is limited to the Lachlan catchment. Range expansion of at least two existing populations is a priority. Additional populations: Establish 1–3 additional riverine populations within the Lachlan catchment.	Barriers to migration and recolonisation such as dams Cold-water pollution Habitat degradation (e.g., sedimentation) through changes to land use Competition, predation and exposure to Epizootic Haematopoietic Necrosis Virus through interactions with alien fish species such as Redfin Perch and Carp *Complementary measures* Management and engineering solutions to physical barriers to improve movement. Control programs for alien fish species. Restoration and re-establishment of populations through translocations and conservation stocking Habitat rehabilitation, restoration and enhancement works, such as restoration of riffle habitat and rehabilitation of riparian vegetation

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
Murray cod (*Maccullochella peelii*) **National: VU, Vic: EN, SA: [EN]** **Basin Wide**	Moderate to long, 8 in 10 years	In-channel specialist Range of flowing and standing waters, however, usually associated with complex structural cover (such as large rocks, woody debris and riparian vegetation) (National Murray Cod Recovery Team 2010) Spawning and recruitment in moderate to fast flowing in-channel habitat	*Life cycle flows* Spawning independent of flooding Recruitment can be enhanced by elevated flows Pairing and spawning in spring/summer in response to rising water temperatures of 16.5–23.5°C (National Murray Cod Recovery Team 2010) Seasonally appropriate flows (with rising water levels) required to stimulate migration Flow that prevents unnatural variations in depth or inundation to protect eggs and nests during spawning periods, to guard against nest abandonment by adults Flow disperses larval stages	N/A	*Threats* River regulation and altered flow regimes, e.g.: Interruption of large-scale movements that are critical for the species' life cycle (e.g., spawning migrations and larval drift) due to loss of fast and moderate flows; barriers (such as dams and weirds) that interrupt fish movement and lead to population fragmentation. Lower water quality, e.g.: Relies on flow to maintain water quality as it is highly susceptible to hypoxic blackwater events; nutrient run-off initiating plankton blooms that reduce oxygen levels Habitat degradation through desnagging, increased siltation through runoff after land clearing and bushfires, etc. Predation, competition, habitat degradation and spread of diseases through interactions with alien fish species Unsustainable levels of recreational fishing *Complementary measures*

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
					Restoration of aquatic and riparian habitat Sustainable management of recreational fishery Facilitate upstream and downstream movement through fishways or removal of redundant weirs
Murray hardyhead (*Craterocephalus fluviatilis*) **National: EN{CE}, NSW and Vic: CE, SA: [EN]** **Southern Basin**	Short, annual	Still or slow moving shallow waters Often associated with dense aquatic vegetation, such as stands of *Ruppia* or fringing emergent rushes Also inhabit saline lakes and wetlands (Backhouse et al. 2008) Occupied habitat might not be representative of preferred habitat but of marginal refuge habitat	*Base habitat flows* Ensure water quality is kept within acceptable parameters (e.g., elevated salinity) (Backhouse et al. 2008) Regulation and water extraction influence amount and quality of inflows to floodplain, riverine and lake habitats (e.g., off-channel habitats in the lower River Murray dry out due to low river flows and extraction) *Life cycle flows* Flooding of off-channel habitats that leads to large zooplankton blooms can augment recruitment success	*South* Range extension: Expand the range of ≥ two existing populations. Additional populations: Establish 3–4 additional populations; at least two within the lower Murray conservation unit; one in the mid-Murray conservation unit; one population potentially within the Kerang Lakes region.	***Threats*** Alter flow regimes that reduce the connectivity (including secondary connectivity) between the main river channel and floodplain habitat Changed salinity levels (increases and decreases) Drought Impacts of alien fish species such as Eastern gambusia Habitat degradation such as the loss of macrophytes which are required for spawning and shelter *Complementary measures* Establish translocated populations

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
			Overbank flooding facilitates dispersal for re-colonisation and establishment of new populations and mixing between populations		Maintain captive/surrogate populations to mitigate extinction risk Control programs for alien fish species
Northern river blackfish (Qld population) (*Gadopsis marmorata*) **Qld: REG (no take)** **Northern Basin**	Moderate to long, 8 in 10 years	Areas of perennial water flows, as well as good physical cover and water quality Usually spawns inside hollow logs, although rocks and undercut banks may also be used	*Base habitat flows* Requires protection of flows to maintain levels and water quality in drought refuges. *Life cycle flows* Spawns in October–January in response to increasing temperature (>~16°C).	*North* Range extension: Expand the range of ≥ two existing 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.	*Threats* Pumping from pools during summer can be an issue, leading to reduction in available habitat and lethal water temperatures. Major threat of sedimentation which smothers spawning sites and eggs Predation and competition from alien fish species such as Redfin perch Habitat modification such as desnagging, removal of riparian vegetation and cold-water pollution *Complementary measures* Control programs for alien fish species

Species **Threat status** **Fish community**	**Longevity & recruitment**	**Key habitat**	**Flow requirements**	**Priorities for increasing distribution**	**Threats & complementary measures**
Olive perchlet (*Ambassis agassizii*) **NSW: EN POP, Vic: EX, SA: PROT [EX]** **Basin Wide**	Short, annual	Slow flowing or still waters and wetlands Often associated with aquatic vegetation and woody habitat in areas with little/no flow Dependent on off–channel lagoons and wetlands during its life cycle	*Base habitat flows* Flows to sustain healthy and diverse aquatic vegetation *Life cycle flows* Suitable refuges are required during summer low flows as it require stable water levels during spawning season Secondary connection events between rivers and lagoons and wetlands are required to enable recruits to enter the river.	*South* Additional populations: Considered extinct in the southern Basin (the Lachlan populations are included in the northern Basin in this report). Reintroduction using northern populations. Candidate sites may result from improved flow that reinstates suitable habitat in River Murray and mid-Murrumbidgee wetlands). *North* Range extension: Expand the range (or core range) of ≥ 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).	*Threats* River regulation and infrastructure, e.g.: artificially prolonged, elevated flows can kill off aquatic vegetation; disconnection of off–channel habitats Interactions with alien fish species such as Redfin perch and Eastern Gambusia Habitat degradation through the removal of vegetation and snags Cold-water pollution can cause spawning failure *Complementary measures* Control programs for alien fish species

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
Rendahl's tandan (*Porochilus rendahli*) **Northern Basin**	Moderate to long, 8 in 10 years	Specific habitat preferences and movement behaviour are poorly understood Floodplain specialist Probable link with good stands of aquatic vegetation	*Base habitat flows* Drought refugia require protection Life cycle flows Migration of adults into lagoons and tributaries driven by high-flow events in summer	N/A	*Threats* Wetland degradation (including by feral pig) and loss Loss of macrophytes Knowledge gaps in habitat requirements and threats for populations within the Murray–Darling Basin *Complementary measures* Aquatic weed removal
River blackfish (*Gadopsis marmorata*) **NSW: EN POP[b], SA: PROT [EN]** **Basin Wide** **Note: Recent genetic work has identified numerous undescribed candidate species under the genus *Gadopsis.* Four are present within the Basin. This may require adapting outcomes and approaches for**	Moderate to long, 8 in 10 years	Areas of perennial water flows with good physical cover and good water quality. Usually spawns inside hollow logs, although rocks and undercut banks may also be used	*Base habitat flows* Flow protection to maintain levels and water quality in drought refuges *Life cycle flows* Requires flowing water for successful spawning and hatching	*South* Range extension: Expand the range of ≥ two existing 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). *North* Range extension:	*Threats* Loss of suitable refuge pools during low-flow conditions through water extraction or flow regulation

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
management of these species.				Expand the range of ≥ two existing 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.	
Silver perch (*Bidyanus bidyanus*) **National: CE[a] {VU}, ACT, Vic : EN, NSW: VU, SA: PROT [EN], Qld: REG Warrego and Paroo** **Basin Wide**	Moderate to long, 8 in 10 years	General preference for fast-flowing water, around riffles and runs Spawning and recruitment in flowing habitats over gravel or rocky substrate	*Life cycle flows* Flows cue spawning and govern recruitment strength Spawning and recruitment enhanced by spring/summer flooding and high within-channel flow pulses Flows critical to stimulate movement of both adults and juveniles.	*South* 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 ≥ two additional locations (candidate sites include Gunbower Creek, Broken Creek, the lower Loddon, lower Darling, Billabong–Yanco system	*Threats* River regulation and associated infrastructure, e.g.: large-scale spawning migrations and dispersal of early life stages (larval drift) are interrupted by loss of flows and barriers to connectivity; Cold-water pollution reduces growth rates. Habitat degradation through desnagging, removal of riparian vegetation, increased turbidity, etc. Interactions with alien fish species such as Carp and Redfin perch *Complementary measures* Modify structures that are barriers to movement (e.g., fishways on weirs)

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
				and Campaspe rivers, and ACT reaches of the Murrumbidgee). *North* Range extension: Expand the core range of ≥ two 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).	Control programs for alien fish species Limit habitat degradation caused by trampling from cattle through the implementation of stock management plans
Southern purple-spotted gudgeon (*Mogurnda adspersa*) **NSW: EN, Vic: CE, SA: PROT [CE]** **Basin Wide**	Short, biennial	Slow moving or still waters of creeks, rivers, wetlands and billabong Hard substrates or macrophytes required for spawning High site fidelity to permanent pools in unregulated streams Remnant populations in NSW often found in small high-order streams and off-	*Base habitat flows* Broadscale factors (e.g., spring inundation and summer low-flow periods) required to create suitable local habitat conditions and heterogeneity (e.g., inundate edge vegetation during spring allowing fish access to shallow dense habitat and food resources) *Life cycle flows*	*South* Range extension: Expand the range ≥ two existing populations (candidate sites include the Jury Swamp populations). Additional populations: Establish 3–4 additional populations (candidate sites include the Murrumbidgee in	*Threats* River regulation/extraction have exacerbated water availability, creating habitat loss through drying Predation by alien fish species such as Redfin perch and Eastern Gambusia Habitat degradation such as the loss of aquatic plants *Complementary measures*

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
		stream habitats (particularly wetlands with dense macrophytes)	Spring inundation benefits the first pulse of larvae as adults come into peak spawning with the return of warmer water temperatures 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 Secondary connection events between rivers, and lagoons and wetlands are required to enable recruits to enter the river.	Adjungbilly and Adelong creeks and Murray wetlands). *North* Range extension: Expand the range (or core range) of ≥ three 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, Lachlan and Condamine in Oakey Creek).	Control programs for alien fish species Improved land management practices to reduce sedimentation and poor water quality

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
Southern pygmy perch (*Nannoperca australis*) **National: VU LIN, NSW: EN, Vic: VU [MDB LIN], SA: PROT [EN]** **Southern Basin**	Short, annual	Slow flowing or still waters, usually with dense aquatic vegetation, such as ribbon weed, and plenty of cover Small streams, well-vegetated lakes (or wetlands within), billabongs and irrigation channels	*Base habitat flows* Persistence of drought refuges required *Life cycle flows* Secondary connection events between rivers, and lagoons and wetlands are required to enable recruits to enter rivers	*South* Range extension: Expand the range of ≥two existing 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). *North* Range extension: Expand the range of the Lachlan populations. Additional populations: Establish 1–3 additional populations in the Lachlan catchment.	*Threats* Predation by and interactions with alien fish species such as Redfin perch and Carp Loss of connectivity between rivers and floodplains Habitat degradation including the removal of riparian and aquatic vegetation, cold-water pollution and floodplain alienation Prolonged drought leading to isolation and /or desiccation of habitats, and subsequent flooding and hypoxic blackwater events *Complementary measures* *Revegetation of riparian area and seeding of native aquatic plants* *Management and engineering solutions to physical barriers, such as dams, weirs, levees, culverts, to improve river-floodplain connectivity* Control programs for alien fish species

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
Trout cod (*Maccullochella macquariensis*) **National: EN {CE},** **ACT, NSW, Vic : EN,** **SA: PROT [EX]** **Basin Wide**	Moderate to long, 8 in 10 years	Usually associated with deeper water (pools) and instream cover such as logs and boulders Nesting river specialist that requires stable water depths and flowing water for the duration of nesting to ensure adults do not abandon nests Flow disperses larval stages	*Life cycle flows* Spawns and recruits in fast and moderate flowing in-channel habitat of good quality Spawning is independent of flooding but recruitment can be enhanced by elevated flows. Seasonally appropriate flows (with rising water levels) are required to stimulate migration.	*South* 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. *North* Range extension: The distribution of the species 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	*Threats* River regulations as it is highly susceptible to hypoxic blackwater events and requires flow to maintain water quality Barriers to movement, such as dams and weirs Interactions with alien fish species such as trout and Redfin perch Habitat degradation including desnagging, sedimentation, and removal of riparian vegetation Overfishing through recreational angling Hybridisation with Murray cod *Complementary measures* Habitat enhancement Reintroductions through conservation stocking and translocations Revegetation and protection of riparian zone Captive breeding population at hatchery

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
				catchment; within the Lachlan, a candidate site is downstream of Wyangala Dam).	Control programs for alien fish species
Two-spined blackfish (*Gadopsis bispinosus*) **ACT: VU** **Southern Basin** **Note: Recent genetic work has identified numerous undescribed candidate species under the genus *Gadopsis.* Four are present within the Basin. This may require adapting outcomes and approaches for management of these species.**	Moderate to long, 8 in 10 years	Cool, clear upland or montane streams with abundant instream cover (such as boulders and cobble) Upland reservoirs with suitable rocky margins Dense submerged and riparian structure	*Base habitat flows* *Life cycle flows*	*South* Range extension: Expand the range of ≥ two existing populations (candidate sites include the Kiewa/Ovens population and upper Goulburn tributaries). Additional populations: Establish 1–3 additional populations.	*Threats* This species is vulnerable to loss of suitable refuge pools during low-flow conditions through water extraction or flow regulation Sedimentation smothering eggs and spawning sites Cold-water pollution Interactions with alien trout *Complementary measures* Revegetation and management of riparian zone Minimise sedimentation Control programs for alien fish species
Yarra pygmy perch (*Nannoperca obscura*) **National: EN, Vic: VU, SA: [CE]**	Short, annual	Slow-flowing or still waters, wetland or drainage channel habitats with abundant submerged aquatic vegetation.	*Base habitat flows* Flows to sustain healthy and diverse aquatic vegetation *Life cycle flows*	*South* This species has not been detected in the Southern Basin since translocations attempted to restore a population in the Lower Lakes in	*Threats* Artificially prolonged, elevated flows should be avoided as these can kill off aquatic vegetation.

Species Threat status Fish community	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
Southern Basin		Close association with aquatic vegetation (particularly emergent vegetation)	Secondary connection events between rivers, and lagoons and wetlands are required to enable recruits to enter rivers	2015. Possibly lost to the Basin. Remnant population exists in captive breeding program. Range extension: Establish 1–2 population in suitable habitat (candidate sites include the Lower Lakes/Coorong region)	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. Predation by alien fish species Redfin perch *Complementary measures* Captive breeding populations and translocations to establish new populations

EX = Extinct in the Wild; CE = Critically Endangered; EN = Endangered; VU = Vulnerable; EN POP = Endangered Population; LIN = MDB Lineage; R = Rare; PROT = Protected under SA Fisheries Management Act 2007; REG (no take) = Regulated under Qld Fisheries Act 1994; [xx] = provisional SA status (Department for Environment and Water, unpublished data September 2022): administrative status assessments that are yet to be adopted under legislation; {xx} status under the Australian Society for Fish Biology list (if listed and different to EPBC Act)

a Proposed for reclassification as Endangered in 2021.

b Only populations outside the Murray–Darling Basin listed.

Note: Relevant legislation:

Environment Protection and Biodiversity Conservation Act 1999 (national)

Flora and Fauna Guarantee Act 1988 (Vic)

Nature Conservation Act 2014 (ACT)

Fisheries Management Act 1994 (NSW)

Fisheries Management Act 2007 (SA)

Fisheries Regulation 2008 (Schedule 2), under the *Fisheries Act 1994* (Qld)

Estuarine species

Table 14: Details for short-, moderate- and long-lived key fish species South – Estuarine fish species .

Species Threat status	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
Mulloway (*Argyrosomus japonicus*)	Moderate to long, 5 in 10 years	Estuarine–dependent marine species Adults prefer nearshore marine habitats Juveniles mostly occur in estuaries and lagoons	*Life cycle flows* Requires freshwater flows as a cue for spawning as river discharge cues aggregations of adults at the Murray Mouth. Strong recruitment age classes in this species are linked to years of high freshwater flows 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 Note: the Coorong estuary likely provides the largest area of protected juvenile habitat for mulloway in southern Australia.	N/A	

Species **Threat status**	**Longevity & recruitment**	**Key habitat**	**Flow requirements**	**Priorities for increasing distribution**	**Threats & complementary measures**
Black bream (*Acanthopagrus butcheri*)	Moderate to long, 8 in 10 years	Completes life cycle within estuarine environments Salt wedges(haloclines) habitat is favourable for spawning cues and larval nursery habitats (Ye et al. 2019)	*Base habitat flows* Freshwater flows influence the salinity gradient which governs the amount of estuarine habitat available for this species *Life cycle flows* A suitable salinity gradient is critical for larval survival and development in spring/early summer Variability of freshwater inflows is a key factor influencing recruitment success, with good recruitment occurring during years of intermediate river flows	N/A	
Greenback flounder (*Rhombosolea tapirina*)	Moderate to long, 8 in 10 years	Estuarine-dependent marine species Occurs in estuaries and coastal waters Adults occur over sand, silt and mud substrates in bays, estuaries and coastal waters Juveniles more commonly unvegetated sand and mudflat habitats in shallower water, often > 1 m deep (Earl 2014)	*Base habitat flows* Freshwater flows influence the salinity gradient which governs the amount of estuarine habitat available for this species *Life cycle flows* Increased freshwater flows are linked to good recruitment and extensive	N/A	

Species Threat status	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
			distribution of juvenile fish across the Coorong Freshwater flows to estuaries influence recruitment success through affecting salinities (suitable habitat) and productivity (food availability)		
Sandy sprat (*Hyperlophus vittatus*)	Short, annual	Estuarine-dependent marine species Distributional pattern is mainly dependent on the salinity gradients regulated by freshwater flows and water transparency (Hossain et al. 2016) Spawns in-shore marine habitat and commonly migrates to the estuaries for development in early life stages (Rogers & Ward 2007).	*Base habitat flows* Freshwater flows, particularly through productivity, drives population abundances with the species being most abundant during years of high freshwater inflows to the estuary	N/A	

Species Threat status	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
Small-mouthed hardyhead (*Atherinosoma microstoma*)	Short, annual	Completes life cycle within estuarine environments Inhabits hypersaline estuaries Distributional pattern is mainly dependent on the salinity gradients regulated by freshwater flows and water transparency (Hossain et al. 2016).	*Base habitat flows* This is an indicator species for salinity conditions in the estuary *Life cycle flows* Salinity and productivity in the estuary drives population abundances	N/A	
Diadromous species					
Congolli (*Pseudaphritis urvilii*) SA: [R]	Moderate to long, 8 in 10 years; maintaining stable sex ratios	Must move between freshwater and marine environments to complete its life cycle	*Life cycle flows* To maintain stable sex ratios, segregation of the sexes during breeding seasons must be avoided Spring–summer upstream movements of juveniles and winter downstream movement of adult females are key requirements for the species Freshwater discharge and associated connectivity enhance population abundance Major improvements in population abundance linked	Range extension: Upstream expansion facilitated through flows to operate fishways	*Threats* Disruption to spawning migrations from barriers and unsuitable hydrological change Habitat loss and deterioration including declines in water quality, deterioration of habitat due to livestock Netting of spawning aggregations and loss from fishing

Species Threat status	Longevity & recruitment	Key habitat	Flow requirements	Priorities for increasing distribution	Threats & complementary measures
			to consecutive years of good freshwater flows		
Common galaxias **(*Galaxias maculatus*)**	Short, annual	Must move between freshwater and marine environments to complete its life cycle	*Life cycle flows* Spring–summer upstream movement of juveniles is critical	N/A	*Threats* Reduced connectivity can lead to segregation of the sexes of this species, which inhibits breeding
Short-headed lamprey (*Mordacia mordax*) National: {VU}, SA: [R]	Moderate to long, 8 in 10 years	Must move between freshwater and marine environments to complete its life cycle	*Life cycle flows* Large-scale migrations of adults are required to complete the life cycle Winter upstream movements of adults are critical	Range extension: Upstream expansion facilitated through flows to operate fishways.	*Threats* Heavily impacted by reduced connectivity among habitats in the Coorong.
Pouched lamprey **(*Geotria australis*)** SA: [R]	Moderate to long, 8 in 10 years	Must move between freshwater and marine environments to complete its life cycle	*Life cycle flows* Winter upstream movements of adults are critical	Range extension: Upstream expansion facilitated through flows to operate fishways.	*Threats* Heavily impacted by reduced connectivity among habitats affecting spawning migrations Alteration in freshwater outflows limiting cues for migration movements

VU = Vulnerable; R = Rare, [xx] = provisional SA status (Department for Environment and Water, unpublished data September 2022): administrative status assessments that are yet to be adopted under legislation; {xx} status under the Australian Society for Fish Biology list (if listed and different to EPBC Act)

Note: Relevant legislation:

Environment Protection and Biodiversity Conservation Act 1999 (national)

Fisheries Management Act 2007 (SA)

Important Basin environmental assets for native fish

In applying the water management strategies for native fish, environmental water holders and managers should target the Basin-significant assets and locally significant assets identified in long-term environmental watering plans.

The Murray–Darling Basin Authority'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 water for the environment 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 water for the environment (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.

- Key movement corridors-
- High Biodiversity-
- Key site of hydrodynamic diversity-
- Threatened species (sites should align with species-specific Recovery Plans)
- Dry period / drought refuge

Table 15: 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	Yes	Yes	Yes		Yes	Yes
2. Swamps on the lower Murray channel, between Wellington and Mannum (swamp geomorphic region)		Yes			Yes	

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge
3. Kerang Lakes					Yes	Yes
4. Katarapko anabranch	Yes			Yes		
5. Pike anabranch	Yes			Yes		
6. Lower River Murray main channel	Yes	Yes	Yes		Yes	Yes
7. Murray main channel (from Hume Dam to Darling junction)	Yes	Yes	Yes	Yes	Yes	Yes
8. Chowilla anabranch	Yes	Yes	Yes	Yes	Yes	Yes
9. Lindsay–Walpolla– Mularoo Creek	Yes	Yes	Yes	Yes	Yes	Yes
10. Lower Darling main channel	Yes	Yes	Yes	Yes	Yes	Yes
11. Darling anabranch			Yes			Yes
12. Hattah Lakes			Yes			Yes
13 Euston Lakes (including Washpen and Taila creeks)					Yes	
14. Lowbidgee Floodplain			Yes			

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge
15. Murrumbidgee main channel (including upland reaches)	Yes		Yes		Yes	
16. Upland Murrumbidgee main channel	Yes		Yes		Yes	
17. Cotter River			Yes		Yes	
18. Koondrook–Perricoota	Yes	Yes	Yes	Yes	Yes	
19. Gunbower	Yes	Yes	Yes	Yes	Yes	
20. Barmah–Millewa	Yes	Yes	Yes	Yes	Yes	Yes
21. Edward–Wakool system	Yes		Yes	Yes		Yes
22. Werai Forest			Yes	Yes		
23. Billabong–Yanco–Columbo creeks		Yes	Yes	Yes	Yes	Yes
24. Lake Mulwala	Yes		Yes	Yes	Yes	Yes
25. Ovens River	Yes	Yes	Yes	Yes	Yes	Yes
26. Lower Goulburn River	Yes	Yes	Yes	Yes	Yes	Yes
27. Upper Mitta River			Yes		Yes	

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge
28. King River		Yes		Yes	Yes	Yes
29. Broken River	Yes	Yes	Yes		Yes	Yes
30. Broken Creek					Yes	Yes
Northern Basin						
31. Warrego (Darling to Ward rivers)	Yes	Yes		Yes	Yes	Yes
32. Anabranches laterally connecting the Paroo and Warrego rivers (including Bow, Gumholes and Cuttaburra creeks)	Yes					
33. Barwon–Darling (Menindee to Mungindi)	Yes	Yes		Yes	Yes	Yes
34. Namoi (Gunnedah to Walgett)	Yes	Yes	Yes	Yes	Yes	Yes
35. Culgoa junction to St George (including lateral connectivity to the floodplain and wetlands)	Yes	Yes			Yes	Yes
36. Macintyre River – floodplain lagoons between Goondiwindi and Boomi	Yes	Yes	Yes		Yes	Yes

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

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

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.

Water management strategies

Overall water management strategies

These overall water management strategies match the strategies outlined in the Basin-wide environmental watering strategy with additional technical detail provided in this document.

The water management strategies outlined in the following pages have been developed to maximise the environmental outcomes that can be obtained from active management of flows in the Basin, including through the use of HEW and the discretionary component of PEW. These strategies occur in addition to the passive management of flows that results from the various rules within State water plans (which also play an important role in the achievement of environmental outcomes). Further details on passive management are available at The managed floodplain.

It is acknowledged that there are key differences in northern and southern Basin water management. The southern Basin has a greater ability to regulate and store water and actively manage flow. In the northern Basin, water supplied on demand from storages is limited to a smaller number of valleys and/or smaller volumes. Management is instead driven largely by rules for when water can be extracted and individual event-based protections (i.e. passive management) (Murray–Darling Basin Authority 2024a).

The water management strategies below include overarching strategies and approaches that have emerged from experience gained from environmental watering over the preceding decades. The strategies align with many of the Basin Plan's *Principles to be applied in environmental watering*.

Adaptively manage environmental water

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

The key components of adaptively managing water for the environment are outlined in Figure 16.

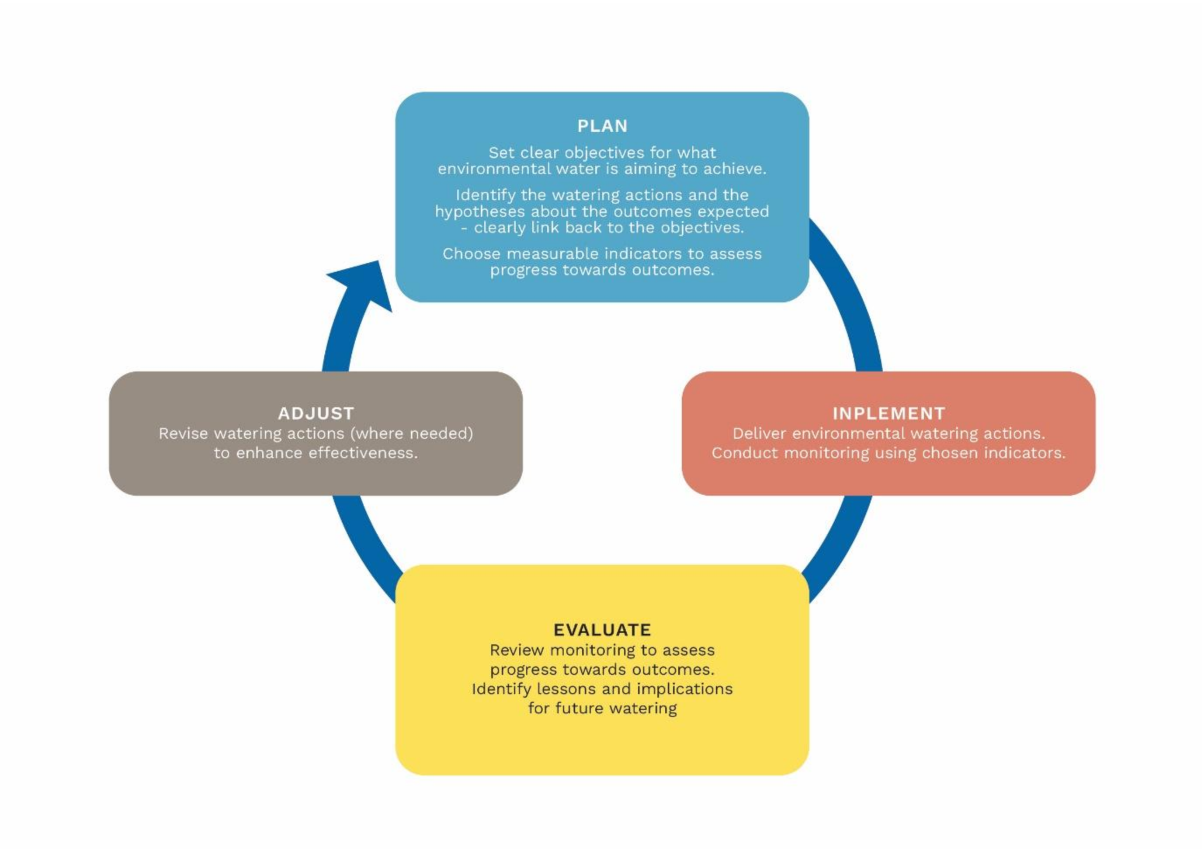

Figure 16: Adaptive management of environmental water.

Successful adaptive management benefits from:

- planning for all climatic/resource availability scenarios and adjusting implementation in response to changing conditions.
- well-resourced long-term environmental water monitoring and research that is well-informed and adaptive.
- consideration of cultural, social and economic aspects of management (along with technical environmental aspects).
- effective communication and collaboration between First Nations, communities, water management agencies and scientists.
- well established pathways to implement on-going improvements including clear roles and responsibilities.
- clear and accessible documentation on the outcomes of the adaptive management process including the rationale for adaptive management decisions and changes to environmental water management over time.

New sites and approaches for environmental water delivery are continually being identified. Constraints relaxation into the future also provides opportunity for delivery of water for the environment at higher flow rates than currently managed. Pursuing these new opportunities via trials within an adaptive management framework enables managers to continually improve and evolve environmental water delivery across the Basin.

This strategy aligns with Basin Plan Environmental Watering Principle 8 – *Adaptive management.*

Manage water in harmony with natural biological processes

The aquatic ecosystem of the Basin has evolved under a highly variable flow regime. Consequently, the life-history stages of the Basin's native aquatic flora and fauna have strong associations with physical and/or chemical environmental cues such as changes in river flow, water temperature or carbon and nutrient input. Provision of the appropriate cues is a key factor in triggering biological responses to achieve an ecological outcome. For example, some native fish will not spawn unless a certain water temperature is reached, regardless of flow conditions. Large breeding events for group-nesting waterbirds will only occur if an adequate degree of inundation (and therefore breeding habitat and food) is present in the landscape. Herbaceous floodplain wetland plants require a particular duration of inundation at the right time of year for them to successfully flower and set seed.

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 dry phase survival strategies such as movement of fish and waterbirds to drought refuges and dormancy of wetland plants.

Where possible, delivery of water for the environment should occur in a way that is considerate of the interactions between biological processes and environmental cues. This should be guided by the latest scientific knowledge, including First Nations science, and lessons from adaptive management at a given site (or from other sites, if monitoring is limited).

Ideally, delivery of water for the environment should occur in a way that creates and/or enhances existing environmental cues to optimise the ecological outcomes achieved. This can occur through delivering water in consideration of large-scale climatic conditions (such as those driven by El Niño and La Niña) and local weather events (such as periods of high rainfall). By delivering in association with climatic cues and unregulated inflows, water for the environment can magnify fresh events, improve the extent and duration of floodplain and wetland inundation, complement other water in the landscape and ultimately lead to an improved ecological response. The aim, particularly in highly-developed parts of the Basin, is not to reinstate the natural flow regime, but to use water for the environment to deliver flows that consider the flow-ecology relationships which drive the natural biological processes to support the health of key parts of the ecosystem.

The Enhanced Environmental Water Delivery project (EEWD) is currently being implemented and aims to improve the ability of environmental water managers and river operators to release water for the environment in conjunction with other flows to improve environmental outcomes in the southern Basin.

In some instances, water for the environment cannot be delivered in sync with natural environmental cues, for example, in order to arrest decline or avoid irretrievable loss. In these cases, water holders should weigh up the relative environmental need, the expected effectiveness (ecological outcome) of the delivery and the potential risks (including projected future condition) of taking or not taking action.

Further strategies to manage water for the environment 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.

This strategy aligns with Basin Plan Environmental Watering Principle 3 – *Maximising environmental benefits*, Principle 4 – *Risks* and Principle 5 – *Cost of environmental watering*.

Use First Nations and community knowledge

The success of environmental water delivery relies on knowledge from First Nations and local people being considered together with the latest ecological science.

First Nations in the Murray–Darling Basin have an in-depth connection to, and understanding of, Country developed over tens of thousands of years. First Nations science (or Traditional Ecological Knowledge) provides valuable lessons into how land and waters across the Basin can be sustainably managed. First Nations involvement in environmental water management continues to grow, with many examples across the Basin of First Nations people having a lead role in the planning, prioritisation, delivery[19] and monitoring of environmental water.

Landholders, land managers and community members also have detailed knowledge about their local rivers and wetlands. This includes the movement of water through the landscape, the condition of sites, the response to environmental water delivery, possible risks from different flows and opportunities to achieve complementary social, recreational and economic outcomes.

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
- engagement forums and facilitators
- direct engagement of industry groups, local government, non-government groups (including water trusts) and individual landholders.

For example, the Murray–Darling Basin Authority has engaged several regional engagement officers and opened regional offices across the Basin. The Environmental Water Sub-Committee of the Murray–Darling Basin Authority's Basin Community Committee includes key local contacts that advise on community matters relating to environmental water management and feedback information on the environmental water program to Basin communities. The Commonwealth Environmental Water Holder also has an established network of local engagement officers throughout the Basin.

This strategy aligns with Basin Plan Environmental Watering Principle 7 – *Working effectively with local communities.*

[19] For example, Taungurung's pumped deliveries of environmental water to Horseshoe Lagoon on the Goulburn (Waring) River. [Case Study: Horseshoe Lagoon - DCCEEW]

Manage and coordinate all water to realise environmental benefits

Storage releases in regulated waterways occur for multiple reasons using different 'types' of water e.g. consumptive water; operational water (Table 16). Each release from storage has the potential to provide environmental benefits. Some releases provide these benefits automatically, while others need to be managed in a specific way, if their environmental benefit is to be realised. This includes managing releases in a way to minimise potential environmental harm.

Collaboration between ecologists, environmental water managers and river operators is essential for such opportunities to be explored, tested (within an adaptive management framework – described further below) and where successful, embedded into contemporary river management. Any amendments to the management of other water resources to achieve environmental outcomes should avoid causing additional risks to river operations or the reliability or usability of the associated entitlements.

Water for the environment can complement other water resources to further improve ecological outcomes or can be the primary source of water for achieving environmental benefits within a given waterway, wetland or floodplain. The role of water for the environment in each system can change over time depending on changes in the availability and management of the other water resources.

Some examples of different Basin water resources/flows and their potential contribution to environmental outcomes are provided below. The EEWD Project (described under the 'Manage water in harmony with natural biological processes' strategy) will improve the coordination of environmental water deliveries with other deliveries to improve environmental outcomes.

This strategy aligns with Basin Plan Environmental Watering Principle 10 - *Other management and operational practices* and Principle 11 – *Management of water for consumptive use*.

Table 16: Examples of actively managed Basin water resources and flows that can provide environmental benefit (in addition to environmental water)

Water resource	Potential environmental benefit
Unregulated flow	Occurs in response to rainfall, and therefore reflects natural flow patterns. Can occur in isolation (e.g. in unregulated systems) or in conjunction with other regulated deliveries. Contributes to base flow and flow variability including the provision of freshes and other high flow events, which may inundate floodplain wetlands. Environmental benefit does not rely on specific management intervention but may be enhanced through complementary environmental water deliveries.
Consumptive deliveries	Regulated releases to meet customer demands (such as irrigation water orders). Can occur in isolation or in conjunction with other water resources. Can contribute to base flow from August to May (over the irrigation season) and may provide flow variability if consumptive demands are variable over time. The environmental benefit relies on the flow rate of consumptive deliveries reflecting the environmental water flow targets — exceeding these flow targets during the irrigation season can lead to an undesirable reversed natural flow regime.

Water resource	Potential environmental benefit
	Environmental benefit may be enhanced through complementary environmental water deliveries that maintain adequate base flow (should consumptive demand reduce) or provide freshes and larger flow events at appropriate times of the year.
Operational flows	Includes bulk water transfers (between instream storages) and airspace management releases from storages. Can occur in isolation or in conjunction with other water resources. Typically provides consistent higher flows for a period of time. Depending on the time of year and where operationally possible, environmental benefit can be provided by shaping the flow hydrograph to provide a fresh event, which may also inundate floodplain wetlands. Water retained in wetlands would require debiting from an environmental water account(s).
Water-in-transit	Includes Inter-Valley Transfers (where water is transferred from one region or zone to another) and bypass flows (such as those around the Barmah Narrows in the Murray River). Can contribute to base flow from August to May (over the irrigation season) and may provide flow variability if downstream demands are variable over time. The environmental benefit relies on the flow rate of water-in-transit deliveries reflecting the environmental water flow targets — if not, the provision of consistent high flows can lead to an undesirable reversed natural flow regime or issues such as bank notching. Where operationally possible, water-in-transit deliveries can be shaped to provide greater flow variability (i.e. lower base flows and higher pulses). The environmental benefit depends on the degree to which the shaping reflects the natural flow pattern. The 2021-22 Goulburn IVT Operating Plan is an example of Inter-Valley Transfers being delivered in a more variable way with the aim to achieve better environmental outcomes. Environmental benefits from water-in-transit deliveries may be enhanced through complementary environmental water deliveries that maintain adequate base flow (should deliveries reduce) or provide freshes and larger flow events at appropriate times of the year.

Collaborate to target multi-site and system-scale outcomes

Within the Basin, sites that can be managed with water for the environment (termed Priority Environmental Assets in the Basin Plan) vary in their degree of hydrological connectivity to other sites.

For those locations that are hydrologically isolated under managed delivery events (e.g. pumping to individual wetlands), water for the environment can be used to support values and Priority Ecosystem Functions at the individual site. However, the benefits at a site and broader ecosystem functions can be enhanced when these deliveries occur in a coordinated way across the landscape. For example, watering a collection of individual wetlands in a particular area can create a wetland mosaic that increases the total area of foraging habitat available and the number of waterbirds that can be supported.

In many cases, sites that receive water for the environment are hydrologically connected to other sites in the Basin. This includes longitudinal connections between waterways and lateral connections between waterways, floodplains and wetlands. The movement of water for the environment into, through and out of one site and into another (known as return flows) provides multiple benefits. Apart from improving the efficiency of environmental water deliveries, re-using water at multiple sites helps support ecological processes such as transporting carbon, nutrients, plants and animals between connected parts of the Basin. This helps build ecosystem resilience through the replenishment of resources, expansion of population distributions for native plants and animals and promotion of genetic diversity.

Delivering water in a coordinated way across hydrologically connected assets (e.g. aligning flows in rivers and tributaries at desired times) provides an opportunity to achieve flow magnitudes and durations that may not be possible through independent deliveries. This includes the potential to improve lateral connectivity and the inundation of floodplain (and associated wetland) habitats, thereby improving the ecological outcomes that can be achieved. A key consideration in coordinating water delivery is the existing operational constraints of each river, and the extent to which ecological outcomes could be improved if these constraints were relaxed.

Delivering water for the environment in a way that targets multiple assets and ecosystem functions to improve the achievement of outcomes across multiple themes, relies on successful collaboration between stakeholders. Environmental water managers and holders, owners and managers of environmental assets, and river operators need to work together across site, catchment, and state boundaries to coordinate the planning and delivery of environmental water. This includes considering the local watering priorities under different climate and resource availability scenarios (including priority locations and the water regime being targeted), to inform how multi-site watering can be best delivered to maximise ecological outcomes while minimising any site-specific risks or trade-offs.

A range of forums and agreements are needed to coordinate environmental watering across the Basin. The ideal forum and 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. Coordination forums such as the Southern Connected Basin Environmental Watering Committee (SCBEWC) and the Northern Basin Environmental Watering Group (NBEWG) 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 *'Manage and coordinate all water to realise environmental benefits'*).

State Water Resource Plans (WRPs) also have a pivotal role, as they must enable environmental watering to occur between connected water resources. This can include providing for coordinated governance or decision-making processes, information sharing pathways, shared or coordinated environmental water planning processes, or new rules relating to the delivery, use and protection of environmental water. At a minimum, WRPs should not inhibit the movement of water for the environment from one WRP area to another or constrain the ability of water managers to coordinate and adaptively respond to natural flows events.

There are examples of coordinated deliveries across multiple catchments and states to achieve system-scale outcomes in both the northern and southern Basin. Since 2018, several coordinated delivery events[20] have occurred in the northern Basin, with different combinations of releases from the Border Rivers, Gwydir, Namoi and Macquarie catchments occurring to provide environmental benefits within the source waterways, as well as connections with (and associated benefits for) the Barwon – Darling (Baawan-Baaka) River. In the southern Basin, the Southern Spring Flow events have coordinated River Murray releases from Hume Dam with inflows from the Goulburn, Murrumbidgee and Baaka (Lower Darling) rivers to achieve environmental outcomes along the full length of the River Murray (all the way to the Coorong in South Australia).

This strategy aligns with Basin Plan Environmental Watering Principle 3 – *Maximising environmental benefits* and Principle 5 – *Cost of environmental watering*.

Identify and deliver multi-year priorities necessary to achieve outcomes

Some environmental outcomes are highly responsive to environmental water deliveries and can be observed and measured during or shortly following a single delivery event – for example, movement and spawning of native fish in response to a fresh. Other environmental outcomes have a slower response time, relying on several years of appropriate hydrology (and other variables) to occur. For example, improvements in the condition of floodplain forest and woodland vegetation will rely on more than one inundation event for canopy density to recover post drought (Figure 17) and/or for newly germinated plants to successfully establish. Multiple years of appropriate hydrology may be needed for native fish to successfully complete large-scale recruitment events and establish viable populations in new locations. An increase in waterbird numbers is reliant upon multiple consecutive inundation periods to build food resources, initiate breeding events, and then support the recruitment of juvenile birds to adulthood. Many of the quantified Expected Environmental Outcomes across all four BWS themes require multi-year watering events.

Multi-year priorities (also known as 'rolling priorities') describe where the pattern of water for the environment is important across multiple years to enable cumulative progress towards long-term outcomes, whilst accommodating and responding to antecedent conditions and climate forecasts. Multi-year priorities therefore remain in focus over several years and are complemented by annual priorities.

Environmental water holders and managers should plan for and deliver water for the environment considering both multi-year and annual priorities relevant to each site. Example multi-year priorities for river flows and connectivity, native vegetation, waterbirds and native fish are summarised below (Table 17).

Further details can be viewed at [Water for the environment multi-year priorities | Murray–Darling Basin Authority (mdba.gov.au)]

This strategy aligns with Basin Plan Environmental Watering Principle 3 – *Maximising environmental benefits* and Principle 5 – *Cost of environmental watering*.

[20] Northern Refresh (autumn 2023), Northern Waterhole Top-up (summer 2020-21), Northern Fish Flow (autumn/winter 2019), Northern Connectivity Event (autumn/winter 2018).

Table 17: Multi-year priorities that progress achievement of Expected Environmental Outcomes for each theme as published in June 2024 (MDBA 2024).

Theme	Expected environmental outcome	Multi-year priorities
River flows and connectivity	Improve connections along rivers and between rivers and their floodplains	RFC1. Manage water to maximise lateral and longitudinal connectivity along the river systems and provide opportunities for high ecological productivity. RFC2. Support freshwater connectivity through and between the Lower Lakes, Coorong and Murray Mouth.
Native vegetation	Maintain the extent and improve the condition	RV1. Allow opportunities for growth of non-woody wetland vegetation. RV2. Allow opportunities for growth of non-woody riparian vegetation. RV3. Maintain the extent, improve condition and promote recruitment of forests and woodlands. RV4. Maintain the extent and improve the condition of lignum shrublands. RV5. Support vegetation that contributes to the ecological character of Ramsar wetlands. RV6. Expand the extent and improve resilience of the *Ruppia tuberosa* community in the Southern Coorong.
Waterbirds	Maintain current species diversity, improve breeding success and numbers	RB1. Maintain the diversity and improve the abundance of the Basin's waterbird population. RB2. Maintain the abundance of key shorebird species in the Lower Lakes and Coorong.
Native fish	Maintain current species diversity, extend distributions, improve breeding success and numbers	RF1. Support Basin-scale population recovery and resilience of native fish by reinstating flows that promote ecological processes across local, regional and system scales in the southern connected Basin. RF2. Improve flow regimes and connectivity in northern Basin rivers to support native fish populations across local, regional and system scales. RF3. Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations.

Autumn 2008

Pre-environmental water delivery and during the Millenium drought.

Autumn 2015

Following the first environmental water delivery in May –December 2014. Natural flooding occurred in 2010 –11 and 2011 –12.

Autumn 2019

Following environmental water deliveries over June-November in 2015 and 2018. Natural flooding occurred in 2016.

Source: North Central CMA

Figure 17: Visual improvements in the health of river red gum forest (Gunbower Forest) in response to the restoration of the natural flow regime over successive years.

Manage risks around environmental water

There are potential risks associated with environmental watering across multiple risk categories including environmental, cultural, social, economic, operational and organisational risks. Some example risks are provided in the table below (Table 18).

Risks associated with environmental watering need to be identified and managed throughout the planning and delivery phases, to ensure that:

- people, property and cultural heritage are not subject to unintended impacts.
- any environmental trade-offs are understood and managed to maximise net benefits.
- environmental outcomes are achieved or lessons learned are incorporated into the adaptive management cycle.
- environmental water is protected from extraction for consumptive use.
- water for the environment is delivered efficiently.
- public land management activities are adjusted in advance, where necessary.
- delivery of environmental water occurs safely e.g. through adequately maintained infrastructure.
- good stewardship of environmental water holdings is maintained fostering public support.
- rules to support priority assets and functions and enable environmental watering are included in WRPs.

Table 18: Example risks associated with environmental watering.

Risk category	Example risks associated with environmental watering
Environmental	Potential for hypoxic blackwater following floodplain inundation. Potential additional carp spawning and biomass.
Cultural	Impacts to cultural heritage sites.
Social	Reduced access to recreational areas.
Economic	Impacts to public land use such as forestry and bee-keeping. Limitations on the use of infrastructure such as irrigation pumps.
Operational	Constraints (e.g. channel capacity limitations) preventing environmental water delivery. Vandalism of water delivery infrastructure preventing or hindering deliveries.
Organisational	Inability to demonstrate outcomes achieved through environmental watering leading to a loss of public support. Insufficient resources (such as staff or funding for infrastructure maintenance) leading to cancellation or interruption of deliveries.

The degree to which the Strategy’s expected environmental outcomes can be achieved is highly dependent upon constraints throughout the system. Constraints are river management practices that govern the volume and timing of regulated water delivery through the river system. These constraints — the result of years of river regulation and regional development — limit the delivery of overbank flow events and water for the environment reaching the floodplain. Yet native flora and fauna rely on floodplain inundation, and ecosystem processes (and more generally a healthy and working river system) depend on the exchange of material between the rivers and low-lying wetlands. Ongoing efforts to relax constraints across the Basin will ensure that the benefits of water for the environment are maximised.

Consideration must also be given to the unintended impacts that result from the delivery of overbank flow. Unintended impacts of system inundation and flooding are poor water quality (e.g. hypoxic blackwater events), erosion and algal blooms. Rapid declines in water quality directly impact aquatic biota (most notably through significant events such as fish deaths) as well as the availability of good quality water for stock and domestic use, irrigation or recreation. The ability to respond to such events is likely to be further impacted by climate change. Changes to rainfall patterns and air temperature, in conjunction with water resource availability, will likely influence water quality throughout the system (upstream and downstream). These risks will require increasingly careful consideration and management throughout the planning and delivery phases to minimise the likelihood of unintended outcomes.

Environmental watering risks depend on the type of delivery event and can vary over time and space. For example, a fresh event in one location may be deemed low risk, while a similar fresh elsewhere may pose a higher risk rating that warrants further management attention. Risk assessments for environmental watering should be conducted for each site and each water year to ensure any site-specific considerations or changes in the risk profile over time are factored into risk management activities.

Risk assessments for environmental watering cover a broad range of considerations and should involve input from a range of relevant stakeholders including environmental water holders and managers, river operators, land managers, First Nations and community representatives, as well as ecologists.

Arrangements for addressing risks to environmental watering should clearly identify the responsible organisation(s), be adaptive and based on robust analysis of the risk, the causal factors contributing to the risk and the consequence to the environment and water users. Environmental water accounting information provides key information underpinning processes of monitoring and review of risk treatments. Ensuring that risk treatments are commensurate to the actual risks is strengthened through structured and evidence-based risk assessment procedures, and review processes that are embedded within an adaptive management framework.

Evaluating risks post-delivery is an important part of the process for identifying new (previously unforeseen) risks, assessing the accuracy of past risk ratings, assessing the effectiveness of mitigating actions and identifying any risks that are no longer relevant.

This strategy aligns with Basin Plan Environmental Watering Principle 4 - *Risks*.

Where environmental outcomes are not compromised, seek to contribute to social and economic outcomes

Environmental water holders and managers are obligated under their respective legislation to focus on achieving environmental outcomes that create resilient ecosystems. These resilient ecosystems underpin the social, economic and cultural fabric of the Basin, and the extent, condition and diversity of these ecosystems are ultimately what provides many of the goods and services enjoyed by Basin communities.

While the primary purpose of water for the environment will always be to achieve environmental outcomes, water for the environment can nonetheless also contribute to related social and economic outcomes. For example, maintaining healthy populations of native fish and associated brood stocks with water for the environment can benefit commercial aquaculture. Coinciding water for the environment with peak recreation periods on waterways can increase local tourism, with flow on benefits to businesses (see https://www.vewh.vic.gov.au/water-for-the-environment/shared-community-benefits).

Managing water for the environment to reduce erosion; aid the transportation of nutrients, salts, pesticides and herbicides; and reduce the spread of invasive species, can help mitigate the negative impacts of catchment land use and the delivery of consumptive water. Environmental watering events that involve community participation and education also foster a greater sense of connection to the local environment (see https://www.dcceew.gov.au/water/cewo/water-for-environment/local-stories/local-citizen-scientists-deniliquin-locals-monitoring-native-fish-responses-water-environment).

Figure 18 provides a framework for thinking about the types of secondary social and economic outcomes that water for the environment can contribute to, and how these benefit government, industry, and households. This framework aligns with the Australian Government's national approach for identifying the relationships between ecosystem assets, their ecosystem service flows and the complementary social and economic outcomes. The approach is known as the System for Environmental Economic Accounting – Ecosystem Services (SEEA-EA).

Two notable assessments of ecosystem services have been undertaken in the Basin as part of the national SEEA-EA strategy:

- Asset scale assessment of social and economic benefits provided by the Gunbower – Koondrook – Perricoota (GKP) Living Murray Icon Site (see Experimental ecosystem accounts for the Gunbower-Koondrook-Perricoota Forest Icon site - CSIRO).
- Basin-wide experimental ecosystem accounts (see Experimental ecosystem accounts for the Murray–Darling Basin - CSIRO).

These assessments provide useful information for managers seeking an appreciation of ecosystem services.

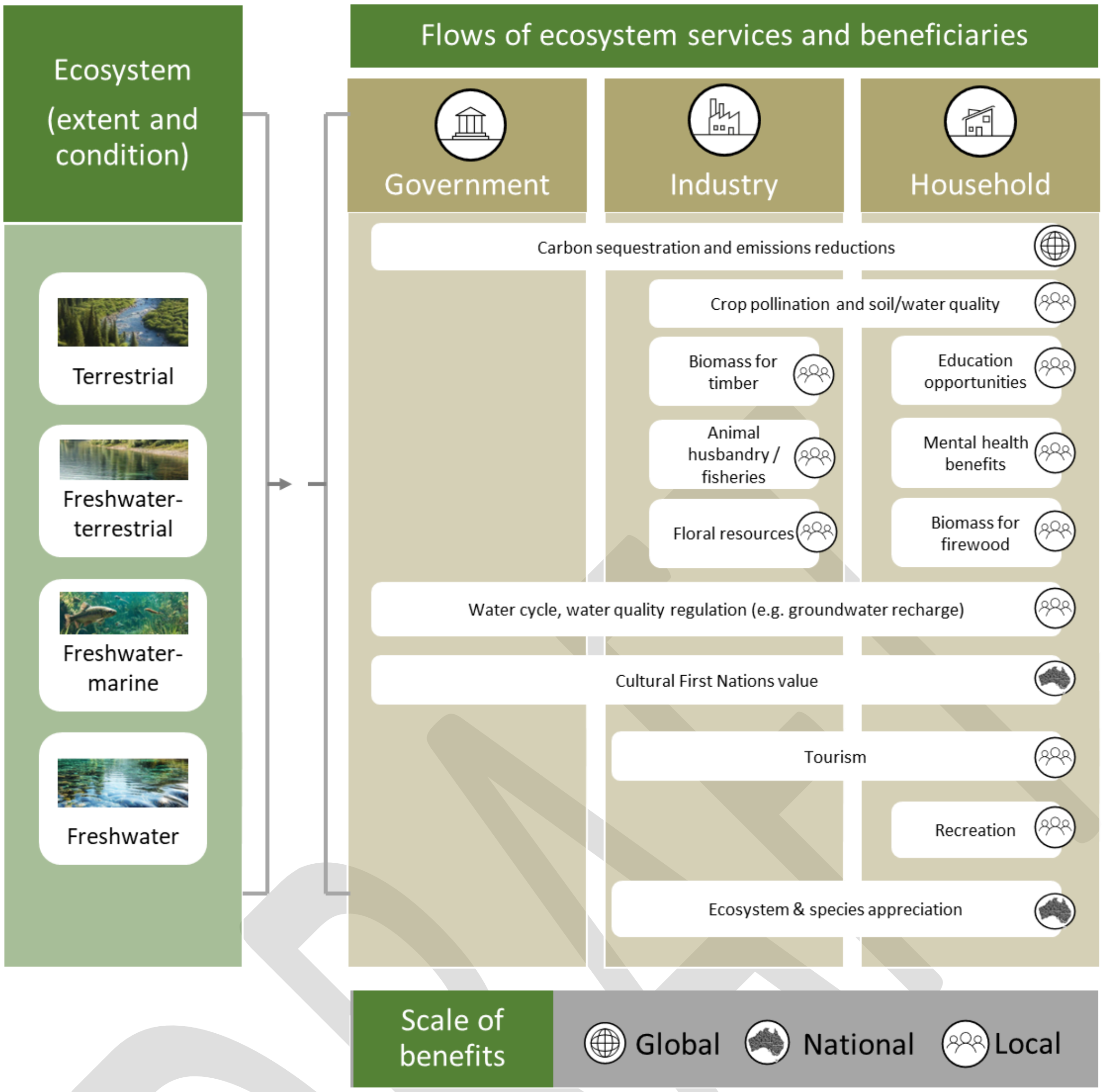

Figure 18: Framing relationships between ecosystems, ecosystem services and beneficiaries.

Local knowledge and relationships have been crucial to seeing water for the environment benefit related social and economic outcomes. However, there are opportunities for water managers to consider related social and economic outcomes more formally within the water and delivery process, as outlined in Figure 19. These suggestions are intended by be supportive, not prescriptive, in how environmental water managers make environmental watering decisions through the cycle, and how social and economic outcomes are considered in this process.

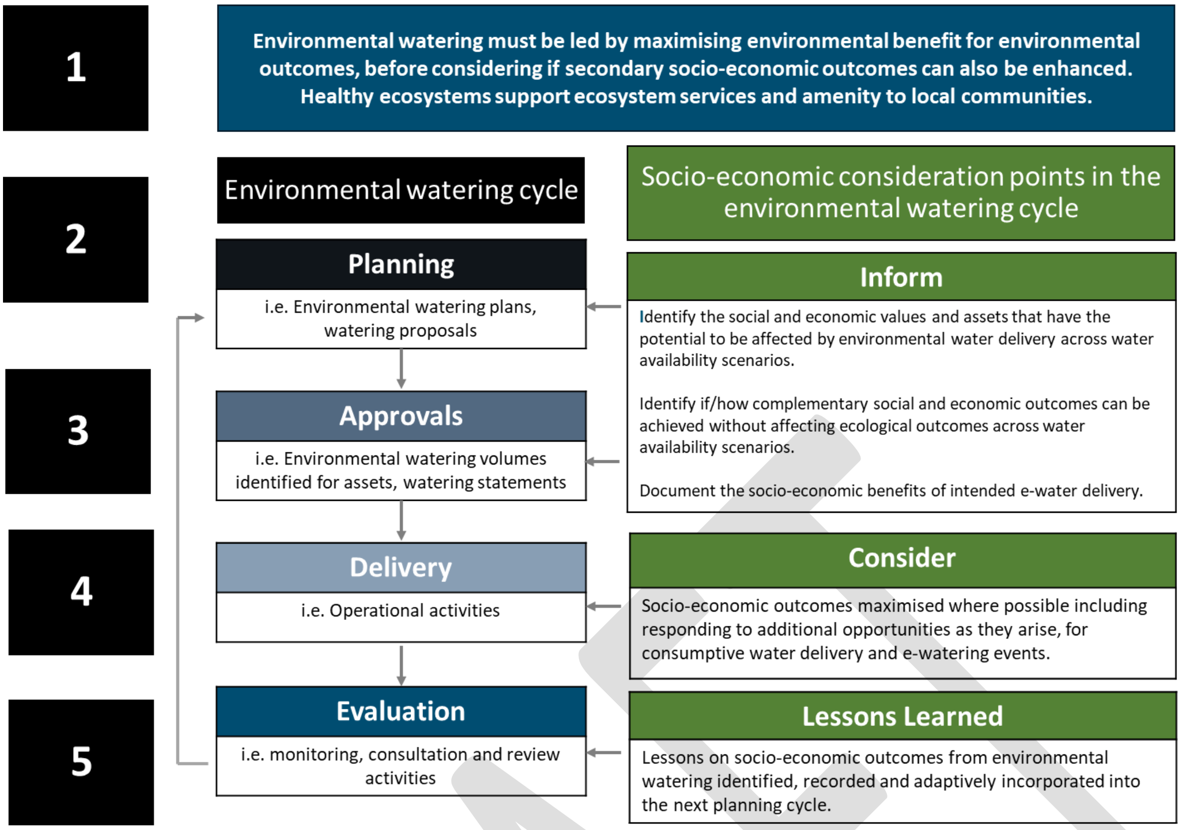

Figure 19: Identifying related social and economic outcomes through the environmental water planning and delivery cycle.

Managing water for the environment is an evolving practice and more work is required to optimise the delivery of water for the environment. Thus, the use of water for the environment to achieve social and economic outcomes should only be considered if environmental outcomes will not be compromised. This include considering downstream impacts of any changes to the timing or magnitude of environmental water delivery.

This strategy aligns with Basin Plan Environmental Watering Principle 3 – *Maximising environmental benefit (having regard to social and economic outcomes).*

Theme-specific water management strategies

The second set of strategies provided in this chapter focus on achieving outcomes for the four themes (river flows and connectivity, native vegetation, waterbirds and native fish). These strategies are targeted to assist environmental water holders, managers and river operators when making specific decisions about environmental watering events (e.g. how to design a delivery targeting fish outcomes), and when preparing theme-specific material for long-term watering plans. They reflect the learnings from environmental water management over many years, and are designed to support the achievement of theme-specific Expected Environmental Outcomes.

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).

Water management strategies for river flows and connectivity

The broad strategies to achieve the anticipated changes in flow and connectivity are outlined in this section; while those specific to achieving ecological outcomes for vegetation, waterbirds and fish are in the following sections. These theme-specific management strategies match the strategies outlined in the Basin-wide environmental watering strategy with additional technical detailed provided in this document.

Environmental water holders and managers, and river operators, have significant experience supplementing the 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 deliver environmental watering events using a variety of strategies. These include the need to:

- release water in a way that reshapes or adds to the flow hydrograph (e.g. filling in what would otherwise be ‘dips’ or ‘troughs’, extending the ‘tail’ of events, increasing the magnitude of the peak) to best support natural biological processes, such as fish and waterbird breeding, that are being targeted. 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 or a combination of both.
- operate 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.
- augment and coordinate tributary flows in regulated parts of the Basin (particularly those which naturally contribute large flows downstream) to help in meeting downstream environmental outcomes.

- protect natural patterns of flow in less-regulated rivers – this can be achieved using rules in water resource plans, one-off arrangements with third parties, or temporary purchases of water allocations.
- deliver flows in a way that is seasonally appropriate and in patterns/flow sequences that provide cues for triggering ecological processes.
- maintain the integrity of flows throughout the length of the river and protecting flows from re-regulation, extraction or substitution with other water.
- operate rivers to reduce the frequency and length of artificial dry periods.
- operate all infrastructure (including infrastructure built to support environmental outcomes) in a way the reduces its impact on achieving environmental outcomes (e.g. maintain fishway function, improve instream hydraulics, reduce cold water pollution).
- coordinate the use of planned and held environmental water with other water in the system.
- address impediments to environmental water delivery. For example, addressing physical constraints and reviewing operating practices to provide more flexible river operations will improve the environmental outcomes.

Water management strategies for native vegetation

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

- maintain healthy, diverse, and representative[21] species, communities, and landscape mosaics.
- support native vegetation over the short to long-term.
- protect iconic and threatened species and communities.
- integrate water and land management.

These strategies align with the overall objectives of the Basin Plan (8.04) to protect and restore the biodiversity, functions and resilience of water-dependent ecosystems. The strategies also incorporate guiding principles to support water management for vegetation outcomes (e.g. Campbell et al. 2021, 2022).

Maintain healthy, diverse, and representative species, communities and landscape mosaics

Planning and management should:

- manage the spatial extent and temporal frequency of inundation to optimise representativeness. Inundate a mosaic of vegetation types to support a diverse range of plants, communities and landscapes.

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[21] Section 8.05(3) of the Basin Plan states ‘An objective is to protect and restore biodiversity that is dependent on Basin water resources by ensuring that: (b) representative populations and communities of native biota are protected and, if necessary, restored. For the purposes of this Strategy ‘representative’ is interpreted as water-dependent ecosystems that typically occur within river, wetland and floodplain areas of the Basin. The intent is to ensure a proportion of all ‘representative’ ecosystems are protected via water management actions under the Basin Plan.

- provide flows that create lateral and/or longitudinal connections between different plant communities for example, by supporting lateral connections between rivers, wetlands and floodplains and / or supporting longitudinal connections along riparian corridors.
- ensure water regimes adequately align with and support life-cycle requirements for targeted vegetation, acknowledging regional variability and the influence of other factors (for example, access to saline or fresh groundwater).
- deliver water at seasonally appropriate times.
- allow for appropriate water level and soil moisture variability (including drying in ephemeral habitats) to promote processes typical of wet-dry systems including shifts in species composition. Acknowledge the permanent, or near permanent water requirements of particular native vegetation.
- be specific about the objective of watering actions and regimes. Identify the target outcome and establish the relationship between outcome and proposed regime.
- be responsive to monitoring data. Incorporate knowledge from monitoring of responses to watering events to inform future management. Undertake monitoring across a range of different scales.

Support native vegetation over the short to long-term

Planning and management should:

- provide water regimes that support native plants through each stage of their life cycles, from maintenance of healthy adult plants, to flowering, seed set, dispersal, and successful recruitment or regeneration.
- provide water regimes that promote viable population demographics in perennial species, to ensure germination and establishment through life history stages (e.g. seedling, sapling, adult tree, hollow bearing trees) to maintain characteristics of the population, such as habitat value.
- ensure the frequency and timing of water regimes provides adequate opportunities for reproduction and seed set to maintain healthy seed and propagule banks, in terms of viability, abundance, and diversity, to sustain non-woody vegetation communities.
- factor in the range of timescales over which native vegetation responds to environmental watering. This includes timescales and types of water regimes that can be required to rebuild health and resilience from a degraded state (e.g. state-and-transition models).
- continue to consider both annual and multi-year planning cycles to provide multi-year water regimes to generate the desired response.
- incorporate consideration of antecedent conditions, including weather, hydrology, and the health of vegetation.
- incorporate the predicted impacts of climate change.

Protect iconic and threatened species, communities and habitat

Planning and management should:

- incorporate the best available information on the water needs of threatened, or otherwise iconic[22], species and communities and prioritise them for management where appropriate.
- provide water regimes that support high-value habitat. In heavily-modified landscapes, remnant native vegetation such as that in riparian corridors or wetland complexes can provide critical habitat for threatened fauna species. Native vegetation known to support threatened species should be prioritised for management.

[22] Where iconic may include plant species or communities that form the ecological character of nationally or internationally recognised wetlands (e.g. Ramsar or Directory of Important Wetlands), are of cultural importance to First Nations people, or are important to Basin communities.

Water management strategies for waterbirds

To achieve the expected outcomes for waterbirds, environmental water holders and managers will need to plan and deliver water for the environment (where possible, depending on the conditions and availability of water) in a way that:

- maximises habitat availability and quality on an annual basis, including for migratory and resident shorebirds in the Coorong and Lower Lakes.
- supports breeding and recruitment whenever possible.
- adopts 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 Table 10) and locally significant assets identified in long-term environmental watering plans.

Maximise habitat availability and quality

Planning and management should:

- maximise the extent of aquatic habitat across the landscape (within the limitations of available environmental water resources) to support as many waterbirds as possible to secure population resilience, including providing multiple refuge areas during drought.
- provide a diverse mosaic of aquatic habitats to support the foraging, roosting and breeding needs of multiple waterbird species, including (where possible) mudflats, shallow and deep open water and inundated vegetation (aquatic plants, emergent species, shrubs and trees).
- ensure the timing and duration of habitat inundation adequately aligns with and supports waterbird life-cycle requirements. This includes consideration of the lag times for production of different food resources post filling and seasonality of waterbird occurrence.
- provide a water regime that maintains or improves the quality of native vegetation within waterbird sites including the distribution, structure, diversity and health of wetland, riparian and floodplain plant communities. Healthy vegetation supports the provision of food, shelter, roosting and nesting resources for waterbirds.
- allow for appropriate water level variability (including drying in temporary habitats) to increase carbon and nutrient cycling and promote aquatic food production.
- provide productive mudflat habitat to sustain migratory and non-migratory shorebird foraging in the Coorong and Lower Lakes (including managed wetlands along the Lower Lakes shoreline) during November–March each year.
- create water levels in the Coorong and Lower Lakes 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.
- provide mudflats and shallow open water habitat throughout the Basin from February to May, for migratory shorebirds as they move from the Coorong and Lower Lakes northward to breeding locations outside Australia.

Support breeding and recruitment

Planning and management should:

- Maintain breeding habitat ready for breeding events through inundation at key breeding sites, to build up reliable food resources (so birds can build body condition prior to breeding), promote adequate vegetation growth for supply of nesting materials and improve the condition of nesting substrate (e.g. reedbeds, lignum, river cooba and river red gum).
- Inundate waterbird habitat in line with natural cues such as large rainfall events, where possible, to encourage waterbird breeding.
- Consider the frequency of breeding required for each species given their age at reaching maturity, average lifespan, mortality rates and recruitment rate, to reduce the risk of population crashes.
- Support breeding events from nest building through to post-fledging care by increasing the extent and prolonging the duration of flooding where required and maintaining stable water levels at an appropriate depth at active nesting sites to limit nest abandonment and incursion by predatory foxes and pigs.
- Prioritise inundation of foraging habitat as close as possible to active group-nesting waterbird sites (compared to foraging areas further away), as this is where food demands from congregated birds are highest. Focus deliveries on those nesting sites with relatively less foraging habitat available or where foraging habitats have the potential to decline rapidly. Prioritise supporting obligate wetland feeders[23] assuming non-obligate wetland feeders will also benefit from the foraging habitat provision.
- Consider the proximity of potential watering sites to other surface water in the landscape and, where beneficial, progress opportunities to leverage off this existing water to maximise the collective foraging habitat within a particular area.
- Ensure a slow draw down of water level following a breeding event and maximise the extent of foraging habitat near nesting areas in the three years following breeding, to encourage the recruitment of juvenile waterbirds to adulthood.
- Consider opportunities to stagger watering of different wetlands over time to maximise productivity and foraging opportunities, including watering opportunities over autumn, winter and spring where possible (particularly for obligate wetland feeding group-nesting species).

Adopt a Basin-scale approach

Many Basin waterbirds are highly mobile and a Basin-scale approach to management is required to improve waterbird outcomes. Planning and management should consider:

- The types of movement strategies and ranges adopted by various waterbird species including migratory, seasonal and sedentary movement patterns.
- The range and extent of waterbird movement including the degree of connectivity between Basin habitats and habitats outside the Basin.
- Common movement pathways within the Basin for different species and the need for adequate stop-over habitat to be provided at suitable intervals.

[23] Obligate wetland feeding waterbirds are those that are highly dependent on surface water for feeding and include species such as Australian white ibis (*Threskiornis molucca*), eastern great egret (*Ardea alba modesta*), intermediate egret (*Ardea intermedia*), little egret (*Egretta garzetta*), nankeen night heron (*Nycticorax caledonicus*), royal spoonbill (*Platalea regia*) and yellow-billed spoonbill (*Platalea flavipes*) (McGinness et al. 2023).

- Key times of year for waterbird movements, such as autumn for migratory shorebirds as they travel northwards through the Basin.
- The need to coordinate environmental watering across the Basin to account for waterbird movements including foraging patterns at different life-history stages, seasonal movements and annual migrations.

Water management strategies for native fish

To achieve the outcomes for native fish, water planning should be done at the scale appropriate to the targeted species and populations. Consideration should also be given to populations that occur and/or move throughout the Basin, as well as Basin-scale hydrological connectivity.

Environmental water planning and delivery needs to:

- support the whole fish community
- support native fish species to complete their lifecycles
- improve native fish habitat
- protect and improve existing populations of threatened species.

These key considerations are expanded below.

Environmental water managers identify important environmental assets that can be managed with water for the environment (termed priority environmental assets by the Basin Plan). The section on Important Basin environmental assets for native fish should be used as an input into identifying those. Further management of regional and local scale assets will also need to be considered in planning and management, particularly to achieve outcomes for threatened species.

Support the whole fish community

Planning and management should:

- include planning for fish outcomes on a decadal time scale. Cease-to-flow, base flows, low flows, freshes and over-bank events can all contribute to fish outcomes. Planning may specify options for decadal flow regimes that outline inter-annual, annual, biennial, and multi-year flow requirements for fish
- prioritise and protect natural inflows, especially those that coincide with naturally high periods of in stream productivity as these trigger greater responses from native fish compared to water sourced from large dams and storages. In the northern Basin, the first post-winter flow event is one of the most biologically significant events for the fish community and should be protected
- protect unregulated systems for native fish, recognising the importance of these areas for the overall biodiversity of the Murray–Darling Basin, particularly in the northern Basin
- maximise opportunities for longitudinal and lateral fish movement. This may include optimising fishway operation, periodic drown-out of low level natural and man-made barriers (e.g. weirs), connectivity to off-stream habitats, and secondary connection events that allow fish recruited in off-channel habitats to return to the river.
- allow water levels to fall gradually, and implement actions that mitigate large short-term fluctuations in water levels through river and channel management (including extraction). Flows

that follow natural hydrographs as far as possible will prevent fish stranding in off-channel habitats, abandonment of nests, and loss of nursery habitats.

- identify and protect 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 small inflows during dry conditions can be important for resilience.
- prioritise flows that prevent fish death events, and when they do occur prioritise flows that support population recovery in the years following.

Support native fish species to complete their lifecycles

Planning and management should:

- coordinate the planning and management of water to enable fish to complete key lifecycle requirements that occur across site and catchment boundaries.
- include consideration of spawning and recruitment outcomes for both flow-cued spawning species, and for species where flow affects other parts of their lifecycles, flows need to provide cues for migration and aggregation, as well as for spawning
- include consideration of recruitment requirements for flow-cued spawning species that recruit over large spatial scales and over multiple flow events
- align environmental water delivery (and/or protection of flows) with natural productivity, seasonality and timing of fish growth, movement, and reproduction, for example:
    - delivery or protection of flows in the northern Basin should be prioritised to coincide with peak spawning, movement and recruitment of many fish species
    - provide spring-summer pulse(s) in regulated systems to stimulate food production for fish, breeding cues, and movement opportunities
    - in regulated systems, reinstate in-channel winter flows to improve larval and juvenile survival (particularly in systems where flows are significantly reduced during winter)
    - reinstate in-channel flow variation, including at in-channel habitats with unnaturally stable water levels
    - provide flows to create faster-flowing habitats e.g. >0.2m/sec in the lower Murray in spring & early summer to support Golden perch and Murray cod recruitment
    - in the southern Basin, provide flows that enable winter migrations through the Coorong barrages and fishways.

Improve native fish habitat

Planning and management should:

- manage water quality risks to vulnerable populations and species:
    - Cold water temperatures for example can limit reproduction and growth of native fish and should be mitigated where possible.
    - Flows may also be needed to prevent extreme hypoxic blackwater events or to reduce their frequency, intensity and duration.
- reinstate in-channel flow variation, including at in-channel habitats with unnaturally stable water levels. Short-term flow variation can stimulate movement of juvenile fish, e.g. Silver perch can respond positively to flow variation over only 2 days with height changes up to 0.2m;

gradual increases in normally stable water levels can trigger spawning responses in some species such as Golden perch
- protect and restore hydrodynamic diversity, including through innovative delivery of all water. Hydrodynamic diversity creates a range of habitats for fish. Faster-flowing habitats with instream habitat structure are particularly important to achieve outcomes for Murray cod, trout cod, Macquarie perch, golden perch and silver perch
- provide flows to maintain and improve aquatic plant communities. Healthy and diverse aquatic plant communities are essential for fish but are easily drowned-out by artificially prolonged high water levels. Flows to maintain aquatic plant communities should allow adequate light penetration.
- maintain a salinity gradient in the estuary, whilst ensuring that the spatial extent of the gradient varies.

Protect and improve existing populations of threatened species

To support known populations of threatened species, establish new populations, and encourage range expansions, planning and management should:

- identify populations of threatened species, and sites that could support reintroductions of new populations and encourage range expansions
- coordinate the planning and management of flows to support recovery of threatened species that complete life cycles over large distances.

Managers should provide appropriate flow regimes that:

- Prevent the loss of existing populations of threatened species.
- Maintain reintroduction sites that support establishment of new populations of threatened species.
- Allow range expansions of threatened species from reintroduction sites.
- Be coordinated across site and catchment boundaries so that flows that support recovery of threatened species that complete life cycles over large distances are delivered.

Climate risks to achieving outcomes

Australia's climate is changing (CSIRO 2022 State of the Climate). Air and ocean temperatures are warming, and there has been an increase in the frequency of extreme heat events, the number of extreme fire weather days, and longer fire seasons. Rainfall patterns are changing, with a ~15% decline in rainfall between April and October in parts of southern Australia since 1970. The northern wet season (October to April) is highly variable with more 'wetter than average' years in recent decades. The intensity of rainfall events has also changed. Heavy, short-duration (<1 day) rainfall events are becoming more intense and have increased by 10% or more in some regions in recent decades. Changes in rainfall patterns and air temperature have flow on effects for streamflow. More than 60 % of hydrologic reference stations around Australia show a declining trend in streamflow[24] (CSIRO 2022).

While there is uncertainty in how, where and when climate change will impact rainfall and runoff, there is consensus that the Murray–Darling Basin is likely to face a hotter and drier future, with climate change potentially driving stronger flood-drought oscillations against a background trend of overall drying and an underlying trend of declining water availability in the long-term (Chiew et al. 2022; CSIRO 2022; Alexandra 2023).

The Early Insights Paper (Murray–Darling Basin Authority 2024) highlights that the severity and frequency of extreme weather events are expected to increase across the entire Basin, and considers three different climate scenarios for the northern and southern Basins. The northern Basin projections encompass both wetter and drier futures, and the southern Basin may become much drier or maintain its historical state but is unlikely to become wetter (Figure 20). The Early Insights Paper also explores options for how to best manage the transition across the Basin in a changing climate.

[24]Hydrologic reference stations are an indicator of long-term impacts from climate change on streamflow as they are gauges in catchments with little disturbance from human activities and with at least a 30-year record (CSIRO and BoM 2022 State of the Climate).

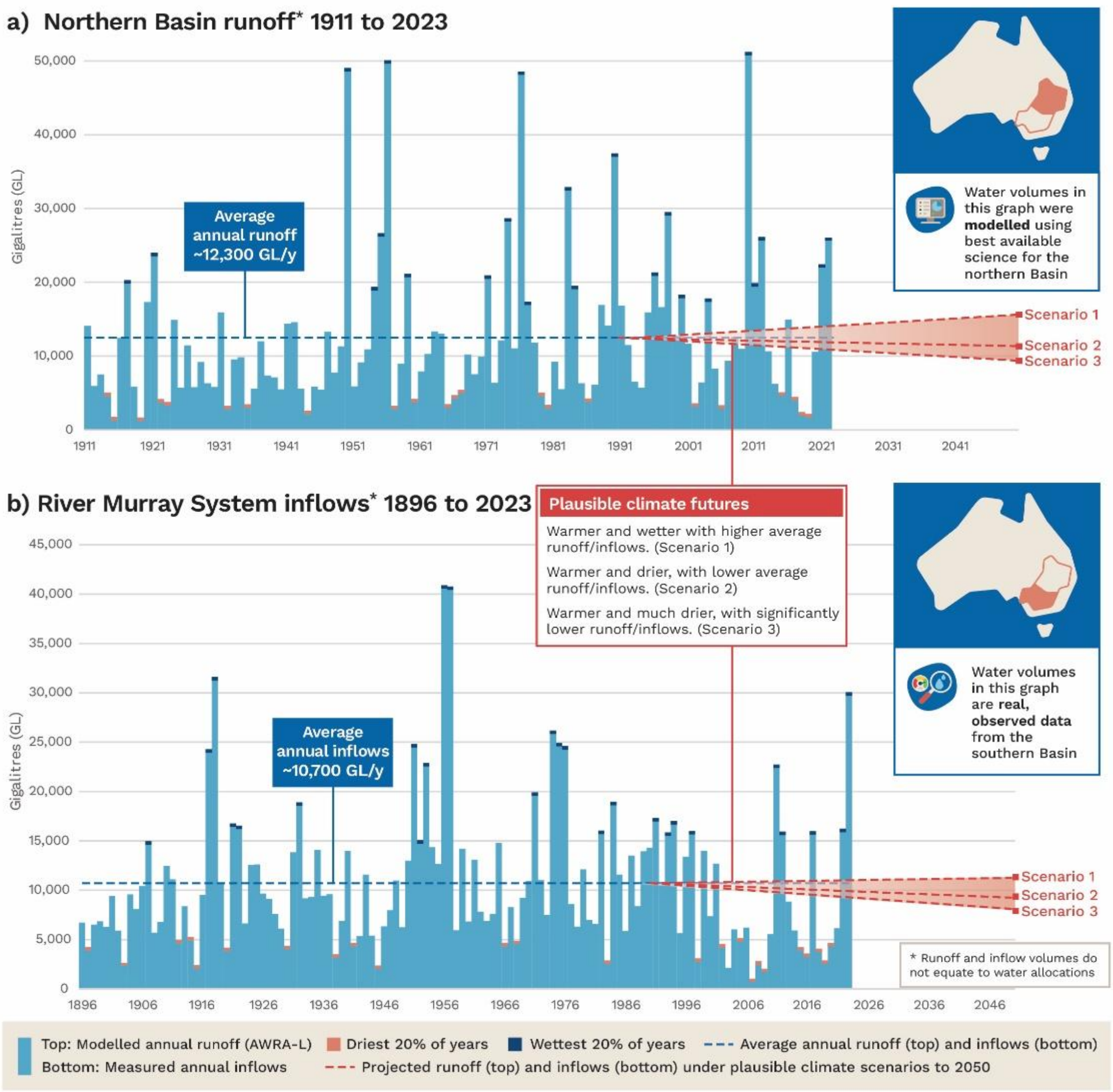

Figure 20: (a) Northern Basin: After Prosser et al. 2021. Climate projections are for the 10th (warmer and wetter), 50th (warmer and drier), and 90th (warmer and much drier) percentile results from hydrological modelling of climate change from 42 Coupled Model Intercomparison Project Phase 6 General Circulation Models CMIP GCMs under Shared Socioeconomic Pathway 2 – Middle of the Road (SSP2), adapted from Zheng et al. 2024. Runoff data from Bureau of Meteorology Australian Water Landscape Model (AWRA-L). (b) Southern Basin: After Prosser et al. 2021. Climate projections are for the 10th (warmer and wetter), 50th (warmer and drier), and 90th (warmer and much drier) percentile results from hydrological modelling of climate change from 42 Coupled Model Intercomparison Project Phase 6 General Circulation Models (CMIP6 GCMs) under Shared Socioeconomic Pathway 2 – Middle of the Road (SSP2), adapted from Zheng et al. 2024. Inflow data from River Murray Operations (Figure from the Early Insights Paper, Murray–Darling Basin Authority 2024).

A changing climate has implications for water resource management. Drying trends will likely result in reduced frequency of overbank flow events and increased time between floods (Chiew et al. 2022; CSIRO 2022). This exacerbates the impacts of regulated water take and places increased emphasis on water for the environment to support ecosystems through periods of drying. Observed climatic changes to date, and projected future changes, impact ecological processes in complex ways. Changes in rainfall patterns impact runoff, infiltration, and the recharge of water storages and groundwater (Chiew et al. 2022; Walker et al. 2021). Warming air temperatures influence evapotranspiration (Shi et al. 2020), soil moisture (Liu et al. 2023), and vegetation growth (Ding et al. 2020). Increased water temperatures impact the physiology of aquatic organisms (e.g. fish, mussels and invertebrates) and chemical processes, for example the content of dissolved oxygen in the water column (Koehn et al. 2011). Extreme heat events are likely to impact physiological processes in plants and animals (Leigh et al. 2015; Teskey et al. 2015), including heat stress in humans (Bell et al. 2018). Altered fire patterns in river-floodplain systems may also impact sediment processes and water quality. Observed impacts from bushfires in 2019 –20 in the upper catchment of the Murray River included increased sediment, nutrient and contaminant loads with both short and longer-term consequences (Biswas et al 2021). Fires are not uncommon in certain wetland complexes such as the Macquarie Marshes, however changes to fire intensity or frequency may impact the ecological character of wetlands.

The consequences of a changing climate may compound and interact to magnify the consequences (Leigh et al. 2015; Pittock et al. 2023). For example, prolonged drought can reduce vegetation cover on riverbanks, which can increase erosion, sediment and nutrient transport. This in turn can influence water quality through increased concentrations of dissolved organic matter, nitrogen and phosphorus which, coupled with higher water temperatures, may lead to cyanobacterial blooms or hypoxia. Declines in water quality impact aquatic biota (e.g. fish deaths) as well as the availability of water for stock and domestic use, irrigation or recreation. The ability to manage events, such as hypoxic blackwater or algal blooms, may also be influenced by a changing climate. Upstream changes in rainfall patterns and air temperature, in conjunction with water resource management, may influence the accessibility of good quality water downstream. Consequences of a changing climate may be further exacerbated through interactions with other pressures and threats such as water extraction and regulation, pest plants and animals, intensive grazing pressure, chemical runoff, and vegetation clearance that alters microclimates (e.g. shading and water temperature). More holistic integration of water and land management may help to reduce some of the risks posed by climate change (see also Other factors influencing outcomes).

Ongoing changes to climate are expected in the coming decades (CSIRO 2022 State of the Climate). There is projected to be continued increases in air temperature, more extreme heat days, and a continued decrease, on average, in cool season rainfall across many regions of southern and eastern Australia. This is projected to result in more time spent in drought on average in the south and east, but with ongoing climate variability that will give rise to short-duration heavy-rainfall events, which increases the chance of flash flooding in some areas. A continued increase in the number of dangerous fire weather days and a longer fire season for southern and eastern Australia is also predicted. The potential for stronger drought-flood oscillations and increased severity and frequency of extreme weather events, coupled with a potential increase in fire frequency has notable implications for the security and quality of water resources and the resilience of all biota reliant on those water resources, including human communities and First Nations' spiritual, Cultural, customary, economic, heritage, water rights and interests.

The literature to inform the Early Insights Paper (Murray–Darling Basin Authority 2024) identified six key climate risks to the Basin, including adverse impacts to water-dependent ecosystems, habitats and environmental assets due to the risk of reductions in water volumes and quality, changes in timing and intensity of rainfall, higher temperatures and extremes, and other environmental change and degradation. Environmental water management will play an increasingly important role in the protection and recovery of these water-dependent ecosystems in a changing climate. Environmental water management will need to consider resilience and adaptability of water-dependent ecosystems and will be an important management action to support native vegetation, waterbirds, native fish and ecosystem functions in the Basin. This may require further innovation in planning, policy and operations to protect key values and assets of the Basin in line with community expectations, whilst also considerate of the inevitable changes ecosystems will experience.

The *Water Act 2007* (Cth) includes a new provision (following the Restoring our Rivers reforms); section 50 that requires the Basin Plan Review to consider and report on the management of climate change risks. In response, as part of the Basin Plan Review, the MBDA has adopted a planning horizon of 2050 to consider climate change impacts, risks and responses. Climate change is one of four key focus areas for the 2026 Basin Plan Review and aims to address *'how can the Basin Plan be improved to respond to climate change?'.* The Basin Plan (section 6.06(3) and the MDBA's *Early Insights Paper* (MDBA 2024) (https://www.mdba.gov.au/water-management/basin-plan-review/early-insights-paper) also recognise the need to incorporate up to date climate data and science in the Basin Plan's strategies and activities.

This Strategy should not, and does not, pre-empt the climate adaptation recommendations expected to come out of the 2026 Basin Plan Review and 2027 Water Act Review. While climate change poses enhanced risks to the Expected Environmental Outcomes in this Strategy, this Strategy has left the existing Expected Environmental Outcomes unchanged.

The climate adaptation pathway will be mapped out in potential subsequent changes to the Basin Plan and the Water Act and reflected in future revisions of this Strategy.

Other factors influencing outcomes

The achievement of the Expected Environmental Outcomes relies upon both flow and non-flow related threats being adequately managed.

Non-flow threats can include land clearing for urban and agricultural expansion, introduced pest species (both flora and fauna), climate change, overgrazing, poisoning by herbicides/pesticides, diseases, and hunting/fishing. For migratory birds, threats also include the clearing and draining of wetlands along international flyways. These anthropogenic drivers cause changes including predation, health issues, poor water quality and reduced available habitat; and ultimately affect the abundance and condition of important native flora and fauna at the asset and Basin-scale.

It is important that the planning and delivery of water for the environment is supported by other management activities to maximise the benefits to ecosystem functions in the Basin. The implementation of actions, projects and programs that work to address non-flow threats can enhance the outcomes achieved from flow restoration and delivering water for the environment.

These projects and programs, commonly known as complementary measures (but referred to in this document as complementary management actions), follow an approach to environmental management that is more than 'just add water'.

In 2017, the Murray Darling Basin Authority engaged CSIRO to lead and convene the development of a science-based assessment framework and method to evaluate the relative environmental benefits of complementary measures to contribute to achievement of Basin Plan outcomes (CSIRO 2018).

As outlined by CSIRO (2018), complementary management actions:

> *are non-flow based actions or measures such as infrastructure works, vegetation management and pest control. Although flow restoration and environmental watering are necessary, they will not be sufficient to achieve the environmental outcomes sought by the Basin Plan alone, particularly where other factors limit the ecosystem response to hydrological change.*

Complementary management actions can support the ecological improvements that water for the environment is seeking to achieve, by aiming to increase the abundance of waterbirds, increase the diversity and distribution of native fish, enhance the condition and extent of native vegetation, and improve river connectivity in strategic locations (CSIRO 2018).

Examples of complementary management actions can be seen across:

- Infrastructure works e.g. fishways, earthworks, flume gates, pipelines, box culverts, cold water pollution mitigation technology, and fish screening at water extraction points)
- Vegetation and land management e.g. grazing management, land clearing, fire management
- Threatened species recovery e.g. rescues and relocations, captive breeding, conservation stocking
- Feral species control, including biological control methods
- Restoring natural habitats e.g. revegetation, resnagging

- Installation of ‘artificial’ habitats e.g. artificial hollows for birds, ‘fish hotels’.

For further examples, refer to Table 18 of CSIRO (2018) and Appendix 2 of MDBA (2020e) (NFRS).

Complementary management actions for native fish

Native fish populations in the Basin are impacted by several non-flow factors, including alien species, dispersal barriers, poor water quality, and cold-water pollution. The *Native Fish Recovery Strategy* (Murray–Darling Basin Authority 2020e) documents the threats, stressors and impacts on native fish (Table 1); potential threat mitigation measures (Appendix 2); and the areas for further investment to achieve native fish outcomes.

The *Native Fish Recovery Strategy* identifies both flow and non-flow related threats but focuses on investment in non-flow measures to complement the Basin Plan and its related instruments such as this Strategy. In addition to the flow-related and climate change threats already discussed, this Strategy considers the threats from infrastructure in rivers and floodplains, introduced fish species, and habitat degradation of primary concern at the whole-of-basin scale.

Mitigation of threats caused by infrastructure in rivers and on floodplains

Infrastructure in rivers and on floodplains results in:

- reduced movements of all life stages of fish
- reduced breeding success
- reduced habitat availability and connectivity between habitats
- disconnected populations and undesirable translocations
- increased fish mortality.

There are many infrastructure options available that aid native fish populations against the multitude of threats they face.

Fishways (also referred to as fish ladders or fish passages) enable fish to migrate around in-stream barriers and are an effective complementary measure to improved flow regimes at the Basin-scale. In the Basin, there are thousands of barriers to fish migration; these include dams, weirs, and other infrastructure such as regulators and road crossings. The construction of fishways at weirs maximises connectivity benefits in the Basin. They increase the range of fish species, enhance breeding, provide access to a wider range of habitat, and give native fish the chance to mix across otherwise isolated populations (Murray–Darling Basin Authority 2020e).

Every year, millions of native fish are removed from the Basin from pump extraction and channel diversions. Fish are particularly vulnerable in the egg and larval stages and are at risk of reduced populations with associated impacts to food web biomass. Installation of modern fish screens that stop fish, fish larvae, and eggs from entering pumps and diversion points are effective at reducing fish losses by 90% (NSW Government 2024). The widespread adoption of modern fish screening at irrigation diversions has strong complementarity with the flow-related actions supported under this Strategy.

Cold water pollution is one of the key factors behind the reduction in the range and abundance of native freshwater fish species across the Basin. Cold water pollution can reduce the growth of fish and even reduce their chance of survival. As a result of cold water pollution, native fish may fail to breed, they may breed late in the season, fish eggs may fail to hatch or the young may die or develop more slowly. In regulated rivers, in both the northern and southern Basin, river flows are influenced by releases from large storages and therefore are regularly affected by cold water pollution. Mitigation of cold water pollution has a strong link to the achievement of the native fish outcomes expected at the Basin-scale from the flow-related actions supported under this Strategy.

Mitigation of threats caused by introduced fish species

Introduced fish species results in:

- increased competition and predation of native fish
- destruction of habitat available for native fish
- increased transmission of disease to native fish
- increased fish mortality.

Alien fish, particularly 'ecosystem engineers' (Jones et al. 1994) such as carp, pose risks to meeting the expected outcomes from environmental watering. Additionally, 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.

It is typically not possible for delivery of water for the environment to benefit only native fish species, and exclude benefit to alien fish species. Hence, complementary management actions that minimise the risk and impact of alien species would support the achievement of outcomes for native fish.

It is usually impossible to eradicate an entrenched invasive species but there has been increasing success against isolated populations. The most promising approaches to controlling introduced fish species are biological and/or genetic control methods, supported by other actions in an integrated pest management approach. However, focus should also be on prevention of initial incursions.

Mitigation of threats caused by habitat degradation

Habitat degradation results in:

- loss of, or lower quality of habitats available, leading to reduced survival of eggs, larvae, juveniles and adults
- increased predation of fish seeking refuge
- degraded foodwebs resulting in less and poorer quality food.

Instream woody habitat (snags) provide fish stable habitat with conditions appropriate for feeding, breeding, shelter, and rest. They also play a crucial role in supplying other independent organisms like algae, bacteria, and micro-organisms with a place to grow (Department for Environment and Water 2023). Historically, snags were removed from large parts of the Basin for things like aiding boat navigation and reducing flood damage. However, this contributed to declining fish populations, and has left areas of habitat highly fragmented with many species increasingly vulnerable to extreme environmental events.

Resnagging and other habitat improvement programs are most efficient and cost effective at the local scale. Physical habitat improvement programs will complement native fish outcomes when they can be undertaken in systems where water for the environment can be managed and delivered, for example resnagging in the River Murray (Lyon et al. 2019). Multiple actions addressing multiple threats will ensure the cumulative benefit of local scale habitat repair with water for the environment to boost survival and recruitment of native fish species.

Vegetation and waterbird related complementary management actions

Native vegetation contributes to biodiversity, provides habitat and food sources for fauna species, helps protect against salinity and soil erosion, is a natural pest control and maintains water quality (National Parks and Wildlife 2023). Land management practices impact native vegetation populations and can threaten habitat quality in the Murray–Darling Basin.

Mitigation of threats to native vegetation and wetlands

Threats and impacts to native vegetation and wetland habitats include (but are not limited to):

- Feral, native, and stocked animals – reducing vegetation diversity, condition, and recruitment through grazing and trampling.
- Cropping on areas which have been historically cleared – impacting remnant vegetation by physically isolating individuals and populations, and exposing adjacent vegetation to spray drift.
- Agricultural run-off – impacting water quality, reducing light visibility and suitability for aquatic plants species.
- Weeds (introduced and native plants in inappropriate locations) compete with native vegetation for resources such as water, space and light, impacting on the diversity, condition and recruitment of native vegetation.

Protecting and restoring native vegetation can involve various on-ground methods that will differ depending on the needs of the site and the land use. These methods can include weed control, fencing areas to reduce grazing and trampling by stocked animals, providing off river water sources (e.g. troughs), reducing feral animal numbers, planting native species (including riparian zone vegetation), bioaccumulation monitoring, and fire management. It is important to conserve remnant native vegetation through land and water management, in and off-reserves through collaboration with landholders and land managers.

The enhancement of wetland habitat is critical for native species and will have benefits on populations by improving food availability and diversity, protection from predators, places for rest, and appropriate breeding habitat (Water and Rivers Commission 2000). Improvement of habitat may be undertaken by private landholders and potentially incentivised, as well as local and state governments. An example of wetland habitat enhancement is at Wirra-Lo (a 180 hectare private property) in northern Victoria. Two wetlands at the property were designed, constructed and planted specifically for the Australasian Bittern, while another was created for Brolga breeding habitat (Wetland Revival Trust 2022).

To complement water for the environment, State government infrastructure works can support water level management to support shorebird habitats, consolidate sediment for aquatic vegetation growth and reduce the impacts of pest plants and animals (for example the Teringie Wetlands). Equally, Commonwealth infrastructure changes (such as those undertaken at Toorale and Kinnairds Wetland), have also improved hydrologic connectivity and delivery of water for the environment to achieve outcomes for waterbirds, vegetation, and fish.

Mitigation of threats to waterbirds and vegetation from introduced species

Introduced species have a large impact on fish, waterbird and vegetation outcomes across the Basin. Feral species like carp, pigs, horses, cats, foxes, rabbits, and goats have contributed to the decline of native flora and fauna through direct and indirect impacts. Populations of native species can be harmed by feral animals at all life stages, from juvenile to adult (e.g., predation of waterbird eggs and juvenile birds, carp uprooting aquatic vegetation).

Complementary conservation management to address feral animals and pests will support environmental outcomes from this Strategy. Conventional control methods such as baiting, shooting, exclusion fencing, and trapping are currently available to land managers (DCCEEW 2021). Whilst biological control, the management of pests through natural predators, viruses, disease-carrying bacteria, or parasites, is in effect for species such as rabbits, and is being considered for other widespread species such as carp.

Baiting is used to control feral animals on a broader scale. In extensive or inaccessible areas, aerial baiting is a successful method to target feral animals and is used by NSW Parks and Wildlife Service. However, in most locations it is suggested that on-ground baiting has the most success. While baiting is an efficient opportunity to remove a high number of feral animals at a cost-effective rate, it does come with risks of harming non-target species.

Exclusion fencing has been used to target feral animals like European red fox, cats, pigs, rabbits, horses, and goats. Implementation of exclusion fencing is primarily placed in locations of high conservation value to protect native animals and plants from vertebrate pest species. Two examples within the Basin include the Moira grass exclusion fence in Barmah – Millewa Forest and the use of carp exclusion plots to allow native wetland plants to grow and complete their life cycle. The design of an exclusion fence to tailor the targeted feral species is critical for its effectiveness. This means considering characteristics like the behaviour and physical capability of species, to prevent the damage to non-target species (Department of Sustainability and Environment 2004). It is recommended that to achieve maximum effectiveness, exclusion fencing should be implemented alongside lethal feral animal control programs like baiting (Department of Sustainability and Environment 2004).

Managing feral animals has a high degree of effectiveness in supporting environmental outcomes if carried out appropriately, particularly to support native vegetation and waterbird survival (particularly at key rookery, foraging, and nesting sites).

In the Basin, it is important to consider the opportunities for integrating water for the environment and complementary conservation management through considering the impact of non-water related threats (e.g., adjacent land use), addressing constraints and having effective networks to identify complementary measure activities. Waterbirds, native fish, native vegetation, and flow connectivity outcomes can be enhanced and supported by applying the appropriate complementary measures. Complementary conservation management priorities should be determined at an asset scale by managers who have a detailed understanding of a site and its challenges.

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