Murrumbidgee Long Term Water Plan

Part A: Murrumbidgee catchment

Draft for exhibition

Cover photo: Cherax Swamp at sunset, James Maguire/OEH.

Published by:

Office of Environment and Heritage
59 Goulburn Street, Sydney NSW 2000
PO Box A290, Sydney South NSW 1232
Phone: +61 2 9995 5000 (switchboard)
Phone: 131 555 (environment information and publications requests)
Phone: 1300 361 967 (national parks, general environmental enquiries, and publications requests)
Fax: +61 2 9995 5999
TTY users: phone 133 677, then ask for 131 555
Speak and listen users: phone 1300 555 727, then ask for 131 555
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

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Acknowledgement of Traditional Owners

The Office of Environment and Heritage pays its respect to the Traditional Owners and their Nations of the Murray-Darling Basin. The contributions of earlier generations, including the Elders, who have fought for their rights in natural resource management are valued and respected.

In relation to the Murrumbidgee catchment, the Office of Environment and Heritage pays its respects to the Traditional Owners – the Barapa Barapa, Muthi Muthi, Nari Nari, Ngarigo, Ngunnawal, Nyeri Nyeri, Wadi Wadi, Walgalu, Wamba Wamba, Weki Weki and Wiradjuri Nations – past, present and future. We look forward to building upon existing relationships to improve the health of our rivers, wetlands and floodplains, including in recognition of their traditional and ongoing cultural and spiritual significance.

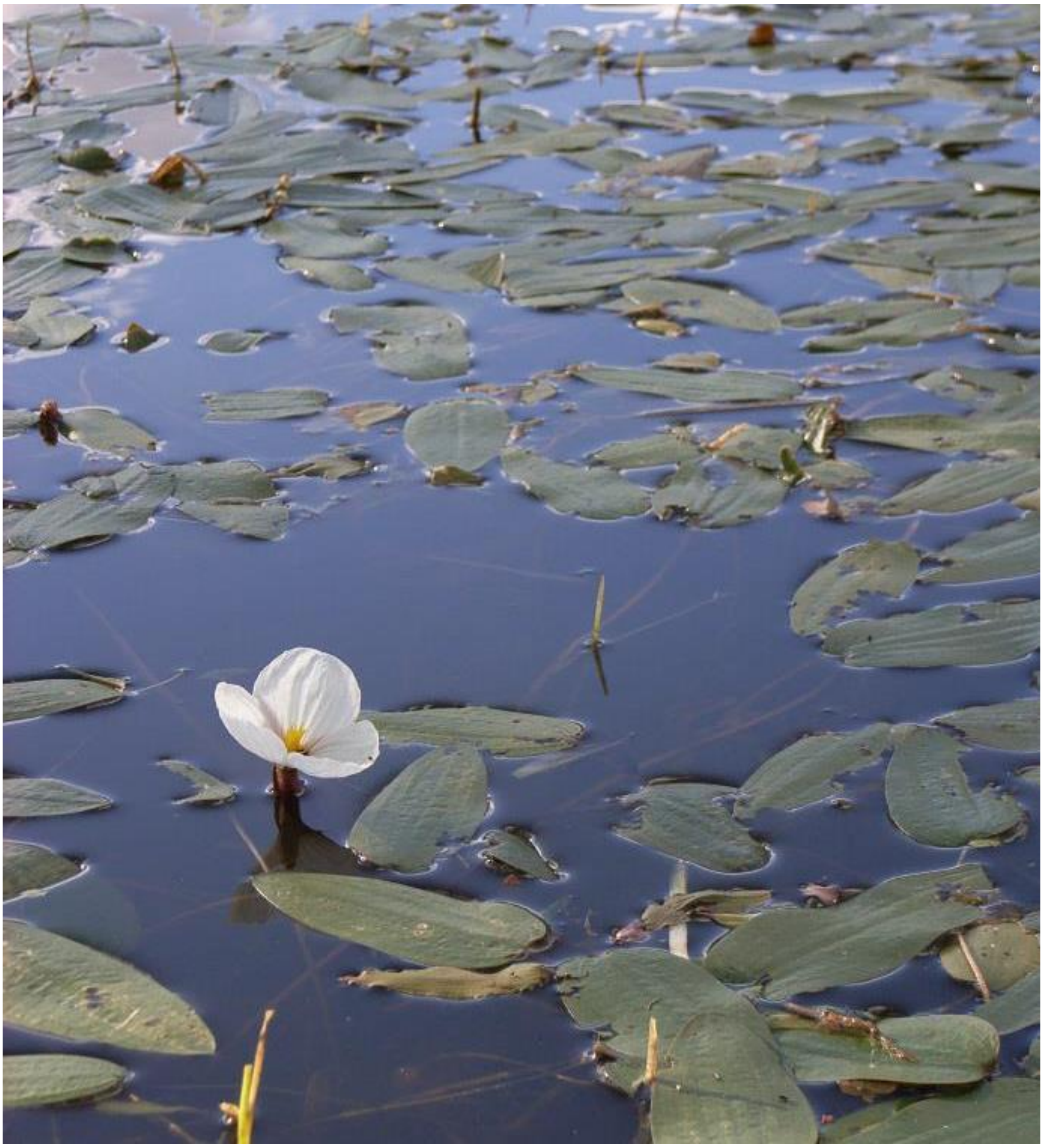


Figure 1 Swamp lily
Photo: J. Maguire/OEH

Abbreviations

AHIMS	Aboriginal Heritage Information Management System
Basin Plan	Murray-Darling Basin Plan 2012
BF	Baseflow
BK	Bankfull
BWS	Basin-wide environmental watering strategy
CAG	Customer Advisory Group
CAMBA	China-Australia Migratory Bird Agreement
CEWO	Commonwealth Environmental Water Office
CtF	Cease-to-flow
CtP	Cease-to-pump
DBH	Diameter at breast height
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DoI–W	NSW Department of Industry – Lands and Water
DPI Fisheries	NSW Department of Primary Industries Fisheries
EEC	Endangered ecological community
EWA	Environmental water allowance
EWAG	Environmental Water Advisory Group
EWR	Environmental water requirement
FFDI	Forest Fire Danger Index
GCM	Global Climate Model
GDE	Groundwater-dependent ecosystem
GL/yr	gigalitres per year
ha	hectares
HEW	Held environmental water
JAMBA	Japan-Australia Migratory Bird Agreement
LF	Large fresh
LLS	Local Land Services (NSW)
LTIM	Long-Term Intervention Monitoring
LTWP	Long Term Water Plan
m/s	metres per second
MDBA	Murray-Darling Basin Authority
MER	Monitoring, evaluation and reporting
mg/L	milligrams per litre
ML	megalitre
NPWS	NSW National Parks and Wildlife Services
NRAR	Natural Resources Access Regulator
NSW	New South Wales

OB	Overbank
OEH	Office of Environment and Heritage
PCT	Plant community type
PEW	Planned environmental water
PU	Planning unit
RAS	Resource availability scenario
RCM	Regional Climate Model
ROKAMBA	Republic of Korea-Australia Migratory Bird Agreement
SDL	Sustainable diversion limit
SF	Small fresh
VLF	Very low flow
WL	Wetland inundating flow
WQA	Water quality allowance
WQMP	Water quality management plan
WRP	Water resource plan
WRPA	Water resource plan area
WSP	Water sharing plan

Glossary

Actively managed flowpaths	The area of channels, floodplains and wetlands that can be inundated by flows from regulated rivers (see ‘Regulated river’).
Adaptive management	A procedure for implementing management while learning about which management actions are most effective at achieving specified objectives.
Allocation	The volume of water made available to water access licence or environmental water accounts in a given year by DoI-W, which is determined within the context of demand, inflows, rainfall forecasts and stored water.
Allochthonous	Organic material (leaf litter, understory plants, trees) derived from outside rivers, including riparian zones, floodplains and wetlands.
Alluvial	Comprised of material deposited by water.
Autochthonous	Organic material derived from photosynthetic organisms (algal and macrophyte growth) within rivers.
Bankfull flow	River flows at maximum channel capacity with little overflow to adjacent floodplains. These flows engage the riparian zone, anabranches, flood runners and wetlands located within the meander train. They inundate all in-channel habitats including benches, snags and backwaters.
Baseflow (BF)	Reliable background flow levels within a river channel that are generally maintained by seepage from groundwater storage, but also by surface inflows. They typically inundate geomorphic units such as pools and riffle areas.
Murray-Darling Basin Plan (Basin Plan)	The Basin Plan as developed by the Murray-Darling Basin Authority under the *Water Act 2007*.
Biota	The organisms that occupy a geographic region.
Blackwater	Occurs when water moves across the floodplain and releases organic carbon from the soil and leaf litter. The water takes on a tea colour as tannins and other carbon compounds are released from the decaying leaf litter. The movement of blackwater plays an important role in transferring essential nutrients from wetlands into rivers and vice versa. Blackwater carries carbon which is the basic building block of the aquatic food web and an essential part of a healthy river system.
Carryover	Water allocated to water licences or environmental water accounts that remains unused in storage at the end of the water year, which, under some circumstances, may be held over and used in the following water year.
Catch per unit effort (CPUE)	An indirect measure of the abundance of a target species.
Cease-to-flow (CtF)	The absence of flowing water in a river channel that leads to partial or total drying of the river channel. Streams contract to a series of isolated pools.

Cease-to-pump (access rule in WSP)	Pumping is not permitted: • from in-channel pools when the water level is lower than its full capacity • from natural off-river pools when the water level is lower than its full capacity • from pump sites when there is no visible flow. These rules apply unless there is a commence-to-pump access rule that specifies a higher flow rate that licence holders can begin pumping.
Cold water pollution	The artificial lowering of water temperature that occurs downstream of dams. In older dams, particularly those with a depth greater than 15 metres, water is typically released from the bottom of the dam where water temperatures can be significantly lower than surface readings. For native fish, that respond to temperature cues to breed, the effects of cold-water pollution can be particularly harmful. Cold water pollution can reduce the availability of food, increase fish mortality and reduce the frequency and success of breeding events. The impact of cold water pollution can extend for hundreds of kilometres along the river from the point of release.
Constraints	The physical or operational constraints that affect the delivery of water from storages to extraction or diversion points. Constraints may include structures such as bridges that can be affected by higher flows, the volume of water that can be carried through the river channel, or scheduling of downstream water deliveries from storage.
Consumptive water	Water that is removed from available supplies without return to a water resource system (such as water removed from a river for agriculture).
Cultural water-dependent asset	A place that has social, spiritual and cultural value based on its cultural significance to Aboriginal people. Related to the water resource.
Cultural water-dependent value	An object, plant, animal, spiritual connection or use that is dependent on water and has value based on its cultural significance to Aboriginal people.
Discharge	The amount of water moving through a river system, most commonly expressed in megalitres per day (ML/d).
Dissolved Organic Carbon (DOC)	A measurement of the amount of carbon from organic matter that is soluble in water. DOC is transported by water from floodplains to river systems and is a basic building block available to bacteria and algae that are food for microscopic animals that are in turn consumed by fish larvae, small bodied fish species, yabbies and shrimp. DOC is essential for building the primary food webs in rivers and ultimately generates a food source for large bodied fish like Murray cod and golden perch and predators such as waterbirds.
Ecological function	The resources and services that sustain human, plant and animal communities and are provided by the processes and interactions occurring within and between ecosystems.
Ecological objective	The defined goal for a state, condition or characteristic of an ecological asset or function.
Ecological target	Level of measured performance that must be met in order to achieve the defined objective. The targets in this long term water plan are SMART (Specific/Measurable/Achievable/Realistic/Time-bound).
Ecological value	An object, plant or animal which has value based on its ecological significance.
Ecosystem	A biological community of interacting organisms and their physical environment. It includes all the living things in that community,

	interacting with their non-living environment (weather, earth, sun, soil, climate and atmosphere) and with each other.
Environmental water	Water for the environment. It serves a multitude of benefits to not only the environment, but communities, industry and society. It includes water held in reservoirs (held environmental water) or protected from extraction from waterways (planned environmental water) for the purpose of meeting the water requirements of water-dependent ecosystems.
Environmental water allowance (EWA)	Discretionary planned environmental water that accrues to accounts under rules outlined in the Murrumbidgee WSP. This water is managed by NSW OEH.
Environmental water requirement (EWR)	The water required to support the completion of all elements of a lifecycle of an organism or group of organisms (taxonomic or spatial), consistent with the objective/target, measured at the most appropriate gauge. It includes all water in the system including natural inflows, held environmental water and planned environmental water.
Flow category	The type of flow in a river defined by its magnitude (e.g. bankfull).
Flow regime	The pattern of flows in a waterway over time that will influence the response and persistence of plants, animals and their ecosystems.
Freshes	Temporary in-channel increased flow in response to rainfall or release from water storages.
Groundwater	Water that is located below the earth’s surface in soil pore spaces and in the fractures of rock formations. Groundwater is recharged from, and eventually flows to, the surface naturally.
Held environmental water (HEW)	Water available under a water access right, a water delivery right, or an irrigation right for the purposes of achieving environmental outcomes (including water that is specified in a water access right to be for environmental use).
Hydrograph	A graph showing the rate of flow and/or water level over time past a specific point in a river. The rate of flow is typically expressed in megalitres per day (ML/d).
Hydrological connectivity	The link of natural aquatic environments.
Hydrology	The occurrence, distribution and movement of water.
Hypoxic Blackwater	Occurs when dissolved oxygen (DO) levels fall below the level needed to sustain native fish and other water dependent species. Bacteria that feed on dissolved organic carbon use oxygen in the water. When they multiply rapidly their rate of oxygen consumption can exceed the rate at which oxygen can be dissolved in the water. As a result oxygen levels fall and a hypoxic (low oxygen) condition occurs. Dissolved oxygen is measured in milligrams per litre (mg/L). Generally native fish begin to stress when DO levels fall below 4 mg/L. Fish mortality occurs when DO levels are less than 2 mg/L.
Large fresh (LF)	High-magnitude flow pulse that remains in-channel. These flows may engage flood runners with the main channel and inundate low-lying wetlands. They connect most in-channel habitats and provide partial longitudinal connectivity, as some low-level weirs and other in-channel barriers may be drowned out.
Lateral connectivity	The flow linking rivers channels and the floodplain.
Longitudinal connectivity	The consistent downstream flow along the length of a river.
Long Term Water Plan (LTWP)	A component of the Basin Plan. Long term water plans give effect to the Basin-wide environmental watering strategy (MDBA 2014) relevant for

	each river system and will guide the management of water over the longer term. These plans will identify the environmental assets that are dependent on water for their persistence, and match that need to the water available to be managed for or delivered to them. The plan will set objectives, targets and watering requirements for key plants, waterbirds, fish and ecosystem functions. OEH is responsible for the development of nine plans for river catchments across NSW, with objectives for five, 10 and 20-year timeframes.
Montane	Relating to mountainous country.
Overbank flow (OB)	Flows that spill over the riverbank or extend to floodplain surface flows.
Planned environmental water (PEW)	Water that is committed by the Basin Plan, a WRP or a plan made under state water management law to achieving environmental outcomes.
Planning Unit (PU)	A division of a WRP area based on water requirements (in catchment areas in which water is actively managed), or a sub-catchment boundary (all other areas).
Population structure	A healthy population structure has individuals in a range of age and size classes. These populations demonstrate regular recruitment and good numbers of sexually mature individuals.
Priority ecological asset	In the context of this plan, is a place of particular ecological significance that contains values and functions that are water-dependent and can be influenced by environmental water.
Priority ecological function	In the context of this plan, is a water-dependent ecological function that can be influenced by environmental water.
Ramsar Convention	An international treaty to maintain the ecological character of key wetlands.
Recruitment	Successful development and growth of offspring; such that they have the ability to contribute to the next generation.
Refugium	An area in which a population of plants or animals can survive through a period of decreased water availability.
Regulated river	A river that is gazetted under the *NSW Water Management Act 2000.* Flow is largely controlled by major dams, water storages and weirs. River regulation brings more reliability to water supplies but has interrupted the natural flow characteristics and regimes required by native fish and other plant and animal to breed, feed and grow.
Riffle	A rocky or shallow part of a river where river flow is rapid and broken.
Riparian	The part of the landscape adjoining rivers and streams that has a direct influence on the water and aquatic ecosystems within them.
Risk management strategy	A plan of management to overcome risks to achieving environmental outcomes.
Small fresh (SF)	Low-magnitude in-channel flow pulse. Unlikely to drown out any significant barriers but can provide limited connectivity and a biological trigger for animal movement.
Small-scale colonial bird breeding event	Event with 50–250 nests/adult pairs
Stochastic	Relating to or characterised by random chance.
Substrate	A habitat surface such as a stream bed.
Supplementary access	A category of water entitlement where water is made available to licence holder accounts during periods of high river flows that cannot

	otherwise be controlled by river operations. Water can be taken and debited from licence accounts during a declared period of high flow.
Surface water	Water that exists above the ground in rivers, streams creeks, lakes and reservoirs. Although separate from groundwater, they are interrelated and over extraction of either will impact on the other.
Sustainable diversion limit (SDL)	The grossed-up amount of water that can be extracted from Murray-Darling Basin rivers for human uses while leaving enough water in the system to achieve environmental outcomes.
Unregulated river	A waterway where flow is mostly uncontrolled by dams, weirs or other structures.
Very low flow (VLF)	Small flow in the very-low flow class that joins river pools, thus providing partial or complete connectivity in a reach. These flows can improve DO saturation and reduce stratification in pools.
Water quality management plan (WQMP)	A document prepared by state authorities and accredited by the Commonwealth under the Basin Plan. It forms part of a WRP and aims to provide a framework to protect, enhance and restore water quality in each WRPA.
Water resource plan (WRP)	A document prepared by state authorities and accredited by the Commonwealth under the Basin Plan. The document describes how water will be managed and shared between users in an area.
Water resource plan area (WRPA)	Catchment-based divisions of the Murray–Darling Basin defined by a WRP.
Water sharing plan (WSP)	A plan made under the NSW *Water Management Act 2000* that sets out specific rules for sharing and trading water between the various water users and the environment in a specified water management area. It forms part of a WRP.
Water-dependent system	An ecosystem or species that depends on periodic or sustained inundation, waterlogging or significant inputs of water for natural functioning and survival.
Wetland inundation flow (WL)	Flows that fill wetlands via regulating structures below bankfull over weeks or sometimes months (i.e. longer than a typical fresh/pulse), or flows that are required to inundate wetlands in areas where there are very shallow channels or no discernible channels exist (e.g. terminal wetlands).

Summary

Rivers, creeks, wetlands and floodplains play a vital role in sustaining healthy communities and economies. They provide productivity and connections across the landscape for people, plants and animals with benefits that extend well beyond the riverbank.

Over the past 200 years, dams, weirs, floodplain development, and water regulation and extraction have disrupted the natural flow regimes of many rivers, wetlands and floodplains in New South Wales (NSW).

This Long-Term Water Plan (LTWP) is an important step to describing the flow regimes that are required to maintain or improve environmental outcomes in the Murrumbidgee. The Plan identifies water management strategies for maintaining and improving the long-term health of the Murrumbidgee's riverine and floodplain environmental assets and the ecological functions they perform. This includes detailed descriptions of ecologically important river flows and risks to water for the environment.

Importantly, the LTWP does not prescribe how environmental water should be managed in the future, rather it will help water managers and advisory groups, such as the Murrumbidgee Environmental Water Advisory Group (EWAG), make decisions about where, when and how available water can be used to achieve agreed long-term ecological objectives.

The LTWP looks at all sources of water and how these can be managed to help support environmental outcomes in the catchment. This recognises that the Murray-Darling Basin Plan (Basin Plan) specifically requires environmental water managers to act adaptively by making timely decisions based on the best-available knowledge, and monitoring and evaluating the outcomes from water use.

Background to Long Term Water Plans

The Basin Plan (Pt 4, Ch. 8) establishes a framework for managing environmental water at the Basin and catchment-scale. The framework is designed to ensure environmental water managers work collaboratively to prioritise water use to meet the long-term needs of native fish, water-dependent native vegetation and waterbirds, and co-ordinate water use across multiple catchments to achieve Basin-scale outcomes.

The *Basin-wide environmental watering strategy* (BWS) (MDBA 2014) and LTWPs are central features of this framework. The BWS establishes long-term environmental outcomes and targets for the Basin and its catchments. LTWPs, which apply to WRP areas (WRPA) (catchment-scale), must contribute to the achievement of the BWS by identifying:

- priority environmental assets and functions in a WRPA
- ecological objectives and ecological targets for those assets and functions
- environmental watering requirements needed to meet those targets and achieve the objectives.

Water resource plans (WRPs) must have regard to LTWPs.

The Murrumbidgee Long Term Water Plan

The Murrumbidgee LTWP is one of nine plans being developed by the Office of Environment and Heritage (OEH) to cover the NSW portion of the Murray-Darling Basin. Development of the LTWP has involved six main steps.

- Undertaking a comprehensive **stocktake** of water-dependent environmental assets and ecosystem functions across the catchment to identify native fish, water-dependent bird and vegetation species, and river processes that underpin a healthy river system.

- Determining specific and quantifiable **objectives and targets** for the key species and functions in the Murrumbidgee catchment.
- Determining the **environmental water requirements (EWRs)** (including volume, frequency, timing and duration) needed to sustain and improve the health and/or extent of priority environmental assets and ecosystem functions.
- Identifying the **risks and constraints** to meeting the long-term water requirements of priority environmental assets and ecosystem functions.
- Identifying potential **management strategies** to meet EWRs.
- Identifying **complementary investments** to address **risks and constraints** to meeting the long-term water requirements of priority environmental assets and ecosystem functions.

The LTWP presents this information in nine chapters in two parts, with accompanying appendices.

Environmental values of the Murrumbidgee catchment

The Murrumbidgee catchment supports a range of water-dependent ecosystems, including instream aquatic habitats, riparian forests, and floodplain watercourses, woodlands and wetlands. The aquatic ecological community in the natural drainage system of the Murrumbidgee below Blowering and Burrinjuck dams is listed as part of the Murray River endangered ecological community (EEC) in NSW (NSW DPI 2007). The lowland Murrumbidgee provides a wide range of habitats for fish and invertebrates, including pools, runs or riffles, backwaters and billabongs, in-stream woody habitat and aquatic plants. The Murrumbidgee River floodplain also provides a mosaic of habitat types, including permanent and temporary wetlands and terrestrial habitats.

The upper Murrumbidgee (upstream of Burrinjuck Dam) supports environmental values such as threatened native fish like the Macquarie perch but is adversely affected by the diversion of the majority of flows at Tantangara Dam for the Snowy scheme.

The ecological condition of the Murrumbidgee’s water-dependent environmental assets is largely driven by flows that connect the instream benches, cut-off channels, anabranches, floodplains, wetlands and deflation basins. Flows that provide these connections support organic carbon transfer and nutrient cycling, trigger movement and breeding of native fish and waterbirds, and directly impact vegetation condition and habitat availability.

Water for the environment

The Murrumbidgee LTWP contains ecological objectives and targets for priority environmental assets and ecosystem functions in the Murrumbidgee catchment. The Basin Plan defines priority environmental assets and ecosystem functions as those that can be managed with environmental water. Objectives and targets have been identified for native fish, native vegetation, waterbirds, river connectivity and flow-dependent frogs.

The objectives express the current understanding of environmental outcomes (Table 1) that might be expected from implementation of the Basin Plan in the rivers, wetlands, floodplains and watercourses of the Murrumbidgee catchment. The targets for each ecological objective provide a transparent means of evaluating progress towards their achievement and the long-term success of management strategies.

Management strategies and complementary investments

Complementary measures that are needed to ensure the LTWPs objectives and targets are achieved have been identified in this plan (see chapter 7). These measures include addressing cold water pollution caused by water releases from Blowering and Burrinjuck dams, providing incentives to landholders to conserve riparian, wetland and floodplain vegetation and screening irrigation pumps to protect fish.

Table 1 A summary of the environmental outcomes sought in the Murrumbidgee long term water plan

Environmental outcome	Overarching objectives	Example uses of water for the environment to achieve LTWP outcomes and objectives
To maintain the extent and improve the health of water-dependent native vegetation and wetlands	Maintain or improve the viability and extent of river red gum and black box communities, lignum shrublands and non-woody wetland vegetation such as spike rush	• Maintain or improve the extent and condition of non-woody vegetation in core wetland areas of the Murrumbidgee, including the Lowbidgee floodplain • Maintain the condition of river red gum closely fringing river channels
To maintain the diversity of waterbird species and increase their numbers across the catchment	Restoration of habitat for waterbirds to contribute to recovery of waterbird populations across the Murray-Darling Basin	• Support the successful completion of colonial waterbird breeding • Improve foraging habitat for waterbirds
To maintain the diversity and improve the population of native fish in the catchment	Increase native fish distribution and abundance, and ensure stable population structures	• Provide improved conditions for native fish recruitment and dispersal • Reconnect floodplain wetlands to allow fish recruits to return to the river
To maintain and protect a variety of wetland habitats and support the movement of nutrients throughout the river system	Various objectives relating to instream and floodplain refuge and habitat, supporting productivity and the lifecycles of water-dependent biota, and connecting riverine and floodplain systems	• Provide flows to bring organic matter from the floodplain into the river. This provides productivity (food supply), increasing the river's carrying capacity for fish

Monitoring and evaluation of the long term water plan

Over the 20-year period covered by this LTWP, NSW and Commonwealth agencies will monitor the health of rivers, wetlands and floodplains within the Murrumbidgee catchment to:

- demonstrate progress (or otherwise) against the objectives and targets identified in the LTWP
- inform and support the management of environmental water
- provide early information to test the assumptions and conditions that underpin the plan.

Review and update of the long term water plan

To ensure the information in this LTWP remains relevant and up-to-date, this plan will be reviewed and updated no later than five years after it is implemented. Additional reviews may also be triggered by significant new conditions or new information.

Figure 2 Pelican rookery near Kieeta Lake, Nimmie-Caira, Balranald
Photo: V. Bucello / Midstate Video

1 Introduction

A major catchment in the Murray-Darling Basin, the Murrumbidgee WRPA is located in southern NSW. It extends from the Snowy Mountains to the confluence of the Murray near Balranald. Major towns and cities supported by the Murrumbidgee and its tributaries include Cooma, Queanbeyan, Canberra, Yass, Tumut, Gundagai, Wagga, Narrandera, Griffith, Leeton, Coleambally and Hay. The system includes the Yanco/Billabong creeks distributary system, which connects to the Edward River of the Murray system near Darlot.

Home to the Lower Murrumbidgee (known as Lowbidgee) Floodplain, this catchment supports one of the largest remaining semi-permanent wetland systems and colonial waterbird breeding sites in Australia. It also includes the nationally important Mid-Murrumbidgee wetlands, which includes the floodplain wetlands from Malebo Range (just west of Wagga Wagga) to Carrathool.

The waterways and aquifers of the Murrumbidgee are important water resources for agricultural businesses and urban communities, with the Murrumbidgee Floodplain also supporting a productive grazing industry.

The region supports a diverse range of flow-dependent threatened and iconic species including:

- native fish (e.g. trout cod, Murray cod, Macquarie perch, golden perch, freshwater catfish)
- vegetation communities (e.g. black box, river red gum, lignum, spike rush communities)
- waterbirds (e.g. Australasian bittern, Australian painted snipe, freckled duck).

River flow in the Murrumbidgee catchment, like many Murray-Darling Basin catchments, has been altered by the presence of headwater dams, weirs and large-scale irrigation. As a result, flow volumes, as well as the regularity and season of events, have been reduced. The condition of the catchment’s riverine and floodplain ecosystems, and the plants and animals they support, has declined considerably because of these developments.

The NSW Government has developed the Murrumbidgee LTWP with the aim of protecting and improving the health of the Murrumbidgee’s riverine and floodplain ecosystems. The LTWP provides key information on the long-term environmental water requirements (EWRs) in the catchment. It also recognises the Murrumbidgee River’s connection and contribution to the environmental health of the Murray-Darling Basin.

1.1. Aboriginal cultural significance

NSW LTWPs recognise the importance of rivers and wetlands to Aboriginal culture. For First Nations People, water is a sacred source of life. The natural flow of water sustains aquatic ecosystems that are central to their spirituality, culture and wellbeing. Rivers are described as ‘the veins of Country’, carrying water to sustain all parts of their sacred landscape, and the wetlands described as the ‘kidneys’, filtering the water as it passes through the land (National Cultural Flows Research Project, 2019).

The waterways of the Murrumbidgee WRPA are central to its Traditional owners, who have longstanding and continuing ties to country, the waterways and life sustained by it.

Aboriginal water-dependent cultural values of the Murrumbidgee water resource plan area

Aboriginal cultural values are related to specific places, plants and animals and to the landscape as a whole. There are important linkages between flow events and cultural outcomes. NSW LTWPs acknowledge Aboriginal connection to country and aim to protect country by maintaining the health of rivers and wetlands, and water-dependent plants and animals that have cultural value.

The Aboriginal Heritage Information Management System (AHIMS) contains information about registered Aboriginal objects or Aboriginal places in the Murrumbidgee WRPA. Querying the system is not intended to substitute for consultation about sites. It is used to demonstrate the presence and variety of sites registered with this system. Significant Aboriginal cultural water-dependent sites that are registered in AHIMS were also included as water-dependent assets in the LTWP. These identified areas include Aboriginal ceremony and dreaming sites, fish traps and sites of resource collection, scarred or modified trees, artefact sites, occupation sites and water holes.

The NSW State Heritage Register and Register of Aboriginal Places names seven sites of relevance to this LTWP (NSW OEH, 2019). It is acknowledged that this public list does not contain all records of objects and places due to the sensitive nature of this information. A sample of these sites is detailed below.

Coolamatong (Lambie Gorge) (Monaro Tributaries PU)

Coolamatong (Lambie Gorge) Aboriginal Place is a Dreaming place for the Ngarigo Aboriginal people and was a traditional campsite located along the Cooma Back Creek. Coolamatong is the name given to a Dreaming story about the snake, frog and turtle, which is associated with the local rainmaker spirit ancestor named Dyillagamberra. At Coolamatong Aboriginal Place Bagal (totem) figures can be found in the landscape that are associated with the snake, frog and turtle Dreaming stories. Coolamatong Aboriginal Place is important because of its spiritual link to this Dreaming story. Today Coolamatong Aboriginal Place is visited by local Aboriginal people to maintain their connection to the area and to pass on knowledge of its significance to younger generations (NSW OEH, 2019).

Wiradjuri Reserve and Gobba Beach (Murrumbidgee River – Tumut River Junction to Berembed Weir PU)

The Wiradjuri Reserve to Gobba Beach corridor of the Murrumbidgee River is an Aboriginal camping and meeting area that has been used from traditional to modern times. The Aboriginal Place is associated with traditional Wiradjuri stories and is significant as a former gathering, corroboree, fishing, camping, swimming and river crossing place for local Wiradjuri groups. The area is rich in resources including plants, fresh water animals and water (NSW OEH, 2019).

Koonadan (Murrumbidgee Infrastructure Dependent Floodplain Wetlands PU)

This area was a traditional and contemporary hunting and food gathering area associated with ceremonial grounds. In pre-contact times, Wiradjuri people hunted and fished around Koonadan and nearby Tuckerbil Swamp. Koonadan was also associated with ceremonies, but ceremonial grounds have been erased by land use. The area was linked to a corroboree site at Yanco. After a corroboree, Wiradjuri people would go to Koonadan and surrounds to gather food (NSW OEH, 2019).

Nap Nap Burial Ground (Lower Murrumbidgee Floodplain PU)

Nap Nap Burial Ground is located on the Murrumbidgee floodplain, about 9 kilometres south of the present-day course of the Murrumbidgee River. Nap Nap Burial Ground Aboriginal Place is a traditional burial ground and a place used by local Aboriginal community members to teach young generations about past cultural practices. The use of the burial ground may extend back as long as 5,000 years. It is especially important to members of the Hay Local Aboriginal Land Council and Nari Nari Tribal Council (Hay) (NSW OEH, 2019).

Dippo Ceremonial Ground (Lower Murrumbidgee Floodplain PU)

Dippo Ceremonial Ground Aboriginal Place is located by the Murrumbidgee River. It is the site of a birthing tree and was a traditional camping place for Muthi Muthi people and other

Aboriginal groups. The Dippo Ceremonial Ground Aboriginal Place is an important part of the Balranald cultural landscape centred on the Murrumbidgee River, with the Muthi Muthi people continuing traditional Aboriginal birthing practices here into the twentieth century (NSW OEH, 2019).

Other important Indigenous areas not described on the NSW State Heritage Register and Register of Aboriginal Places Register are provided below.

Toogimbie Indigenous Protected Area (Murrumbidgee River – Gogeldrie Weir to Maude Weir PU)

Situated on the traditional lands of the Nari Nari people, the wetlands of Toogimbie Indigenous Protected Area are home to totem animals and traditional medicines. Toogimbie Indigenous Protected Area covers an area of 4,600 ha along the Murrumbidgee River near Hay, NSW. The traditional life of the Nari Nari people revolves around Toogimbie's wetlands. These wetlands are being managed by the Nari Nari Tribal Council and watering events are undertaken in conjunction with environmental water holders (DSEWPC, 2012).

Gayini - Nimmie-Caira (Lower Murrumbidgee Floodplain PU)

The Nimmie-Caira area is a rich cultural landscape supporting many Aboriginal people as evidenced by its cultural features, including burial mounds, camp sites and other significant cultural values. There is evidence that Aboriginal people used targeted interventions to promote the productivity of regions like Nimmie-Caira, promoting fish, bird and vegetation growth. This area is managed by a consortium that includes the Nari Nari Tribal Council. (NSW DoI Water, 2019).

1.2. Approach to developing the Murrumbidgee long term water plan

The Murrumbidgee LTWP (‘the plan’) applies to the Murrumbidgee WRPA and is one of nine catchment-based plans covering the NSW portion of the Murray-Darling Basin. This plan is consistent with the requirements of the Basin Plan (MDBA 2012a).

This plan is the product of best available information and engagement with water managers, natural resource managers, environmental water holders and community members. It draws together local, traditional and scientific knowledge to identify the catchment’s priority environmental assets and ecosystem functions to guide the management of water to protect and restore condition over the long-term.

Development of the Murrumbidgee LTWP has involved six main steps.

1. **System audit:** undertaking a comprehensive stocktake of water-dependent environmental assets and ecosystem functions across the Murrumbidgee WRPA to identify native fish, water-dependent bird and vegetation species, and river processes that underpin a healthy river system.
2. **Objectives and targets:** determining specific and quantifiable objectives and targets for the key species and functions in the Murrumbidgee WRPA.
3. **EWRs:** using available science and management experience to determine the water requirements (including volume, frequency, timing and duration) needed to sustain and improve the health and/or extent of priority environmental assets and ecosystem functions.
4. **Risk assessment:** identifying the risks and constraints to meeting the long-term water requirements of priority environmental assets and ecosystem functions.
5. **Management strategies:** identifying potential management strategies for guiding water management decisions and investment into the future.

6. **Complementary measures:** identifying actions other than water management to address risks and constraints to meeting the plan's objectives.

1.3. Implementing the Murrumbidgee long term water plan

Implementation of the plan requires strong partnerships and coordination between land and water managers. This plan provides the foundation to support future coordination efforts by:

- informing annual and longer-term water management planning by environmental water managers, including strengthening collaboration between environmental water holders
- informing water planning processes that influence river and wetland health outcomes, including water sharing plans (WSPs) and WRPs
- identifying opportunities for more strategic river operations by WaterNSW
- helping target investment priorities for complementary actions that will effectively contribute to progressing the outcomes sought by this plan
- informing monitoring, evaluation and reporting processes for water management
- assisting to build community understanding of river and wetland health issues and management actions.

1.4. The long term water plan document structure

The Murrumbidgee LTWP is presented in nine chapters with accompanying appendices. It is divided into Part A and Part B.

Part A: Murrumbidgee catchment-scale information

- **Chapter 1** explains the background and purpose of the LTWP.
- **Chapters 2** and **3** identify the Murrumbidgee's water-dependent environmental assets and ecosystem functions, and articulate the environmental outcomes that are expected from implementation of the LTWP through ecological objectives and targets.
- **Chapter 4** provides the EWRs that are needed to support the achievement of ecological objectives over the next five, 10 and 20 years.
- **Chapter 5** describes the long-term risks and operational constraints to achieving the EWRs and ecological objectives in the Murrumbidgee LTWP. It also recommends management strategies for addressing these.
- **Chapter 6** identifies opportunities for the use of held and planned environmental water, and other system flows to support flow regimes to meet the EWRs of the Murrumbidgee's environmental assets and values under dry, moderate and wet water resource availability scenarios.
- **Chapter 7** describes potential cooperative arrangements between government agencies and private landholders and prioritised investment opportunities to achieve the environmental outcomes described in this LTWP.

Part B: Murrumbidgee planning unit information

- Part B presents the LTWP at the planning unit (PU) scale. This includes a summary of the environmental values the PU supports and an evaluation of the impact of water resource development on local hydrology.

Figure 3 Peron's tree frog, Yanga Lake, Balranald
Photo: C. Amos/OEH.

1.5. Planning units

The PUs shown in Figure 4 are referred to in most chapters. The PU boundaries typically align with water source boundaries in the Murrumbidgee Water Resource Plan (NSW Government 2018). However, some of these water sources have been amalgamated or split depending on how water management for the environment can be implemented. Where there are similarities between water sources they have been amalgamated; where there are differences they have been split. It is important to note that some PUs are regulated water sources or affected by regulated water (PU 1–14). Others are unregulated and not able to be influenced by regulated water deliveries (PU 15–29).

Note that the Lowbidgee Floodplain in covered by the Lower Murrumbidgee Floodplain PU. The Mid-Murrumbidgee Wetlands covers parts of the Murrumbidgee River PUs 4, 5 and 6 and PU 9 (Beavers and Old Man creeks).

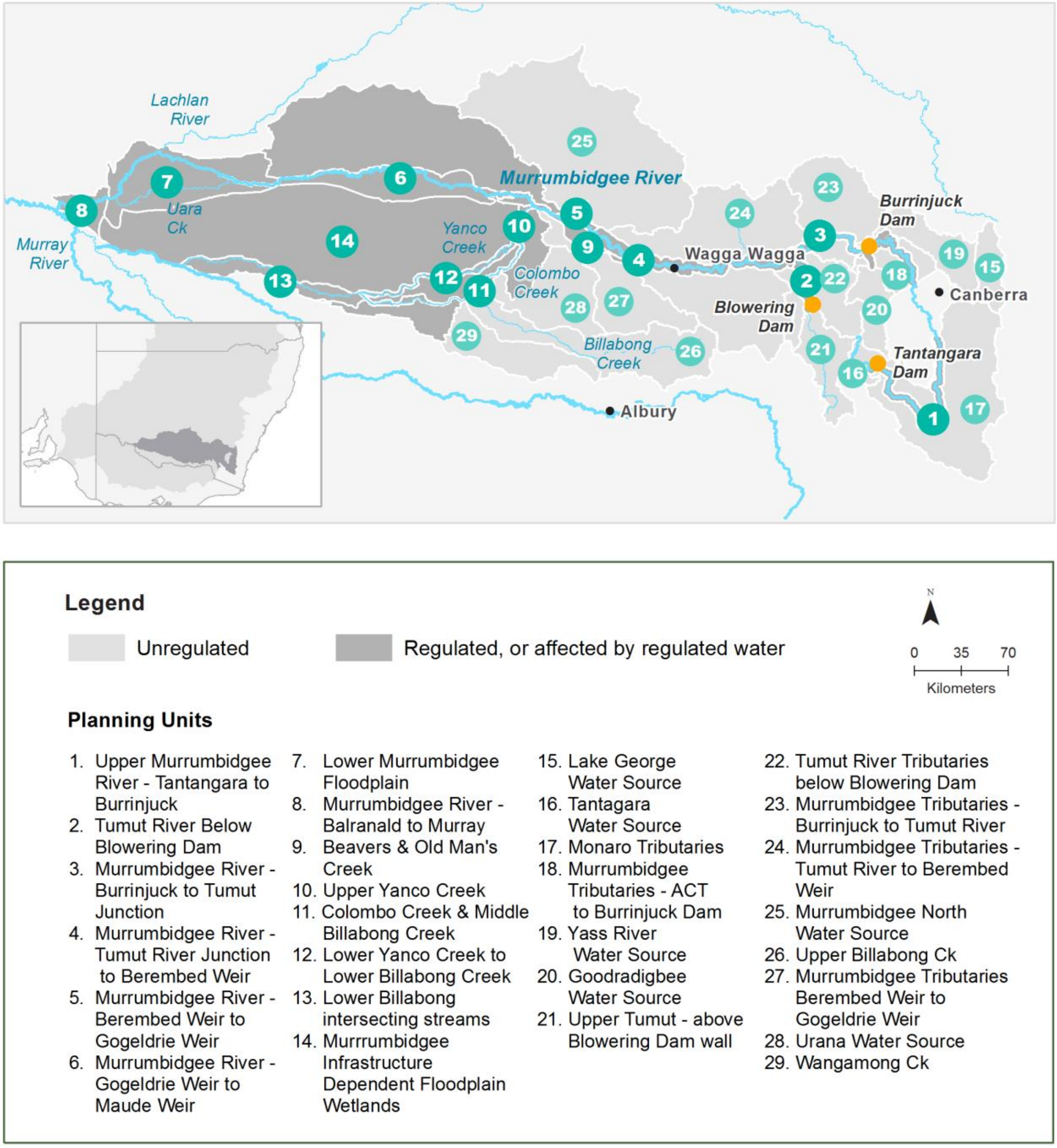


Figure 4 The Murrumbidgee catchment showing the division of planning units

2 Environmental assets: Murrumbidgee catchment

The Murrumbidgee catchment supports a variety of water-dependent ecosystems, including instream aquatic habitats, riparian forests, and floodplain woodlands and wetlands. These features are spread throughout the catchment and each has their own water requirements depending on the plants and animal species they support and ecosystem functions they perform.

2.1. Priority environmental assets in the Murrumbidgee catchment

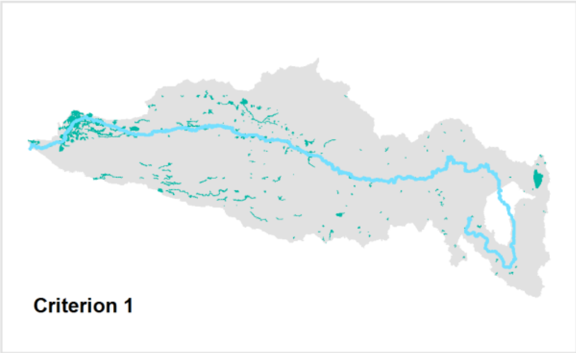
Schedule 8 of the Basin Plan outlines criteria for identifying water-dependent ecosystems that should be recognised as environmental assets in the Murray-Darling Basin. The criteria are designed to identify water-dependent ecosystems that are internationally important, natural or near-natural, provide vital habitat for native water-dependent biota, and/or can support threatened species, threatened ecological communities or significant biodiversity.

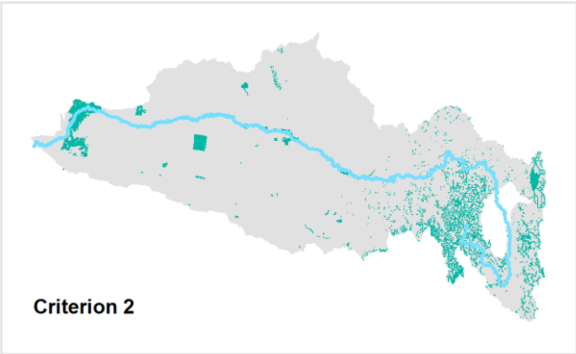
The Murrumbidgee’s water-dependent ecosystems, which are comprised of waterbodies and surrounding water-dependent vegetation, have been assessed against the Schedule 8 criteria. Significant Aboriginal cultural water-dependent sites that are registered in AHIMS were also included as water-dependent assets in the LTWP. This identified areas such as Aboriginal ceremony and Dreaming sites, fish traps, scar trees and water holes throughout the Murrumbidgee catchment. Results of the analysis are presented in Figure 5.

Priority environmental assets in LTWPs are the assets that have been identified using Schedule 8 criteria that can be managed through NSW’s planned and/or held environmental water (HEW), often in combination with other river flows. These include areas:

- subject to discretionary environmental water management, such as the Lowbidgee Wetlands and along regulated streams
- supported by implementation of the WSP rules, including regulated and unregulated streams and floodplains.

Priority environmental assets may be a reach of river channel and its floodplain features at a geographic location, or a wetland complex or anabranch.





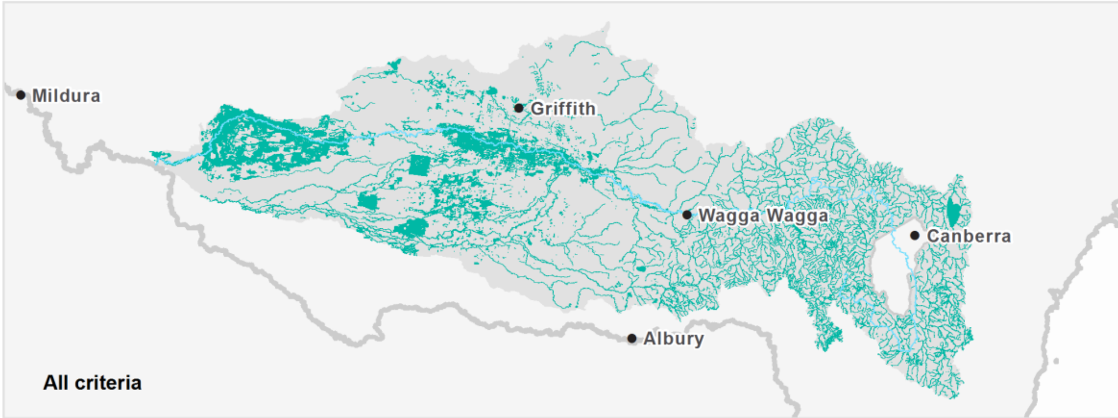
Criterion 1: The water-dependent ecosystem is formally recognised in international agreements or, with environmental watering, is capable of supporting species listed in those agreements.

Criterion 2: The water-dependent ecosystem is natural or near-natural, rare or unique.

Criterion 3: The water-dependent ecosystem provides vital habitat.

Criterion 4: Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities.

Criterion 5: The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity.



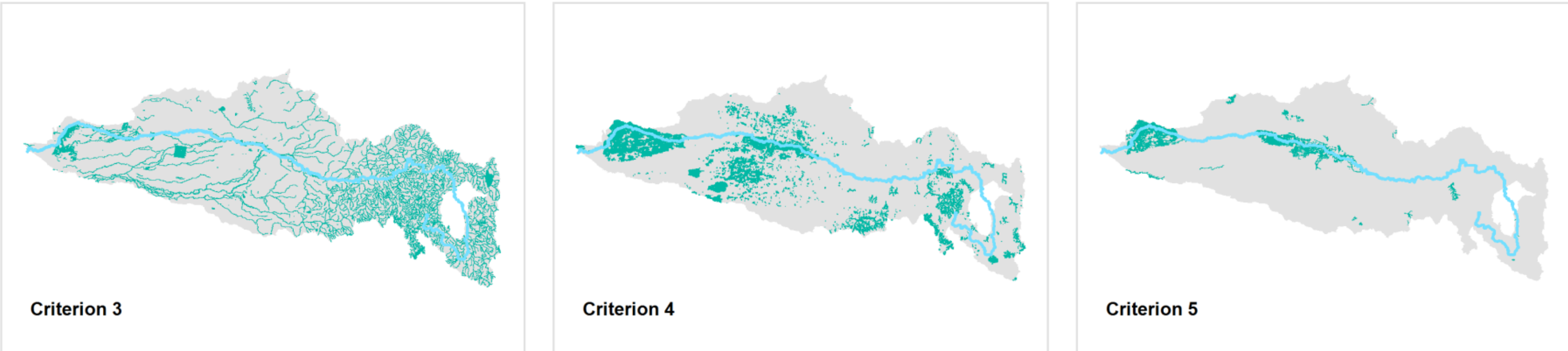


Figure 5 The five criteria for the identification of environmental assets applied to the Murrumbidgee catchment

3 Ecological objectives and targets

Ecological objectives and targets have been established for priority environmental assets in the Murrumbidgee catchment (sections 3.1–3.5). They are grouped into five themes—native vegetation, waterbirds, native fish, ecosystem functions and flow-dependent frogs. The first four themes are consistent with the BWS. Flow-dependent frogs are not highly mobile, so they require refuge between watering events. As such, the inclusion of flow-dependent frog objectives places greater emphasis on the need to maintain refuge (including permanent waterbodies for some species) in the floodplain.

Each theme is a good indicator of river system health and is responsive to flow. The water requirements of foundational species, communities or ecosystem functions within each theme are also broadly representative of those needed by many of catchment's water-dependent species that do not fit within the five themes, such as platypus, water rats (rakali), turtles, mussels and yabbies.

The ecological objectives express the environmental outcomes that are expected from implementation of the LTWP. Their achievement will also contribute to the landscape and Basin-scale environmental outcomes sought by the BWS.

The five, ten and 20-year targets for each ecological objective provide a transparent means of evaluating progress over time and test the LTWP's management strategies and their implementation. It is hoped that these targets, if achieved, will be a suitable indicator of overall trends in ecosystem health. It is recognised that prevailing conditions such as drought and floods will influence our ability to meet targets in five-year increments, and these will need to be considered in analysis of outcomes. Failure to meet targets should trigger re-assessment of the related flow regime and whether the LTWP is being implemented as intended to determine if changes are needed.

The ecological objectives for the priority environmental assets in individual PUs within the Murrumbidgee are listed in Appendix A. The selection of ecological objectives recognises the values that the priority environmental asset supports (e.g. native fish species, native vegetation communities, waterbirds) or the ecosystem function it performs (e.g. provides vital instream habitat).

3.1 Native fish objectives

The expected[1] native fish community in the Murrumbidgee catchment consists of 20 native finfish and seven crustacean species (NSW Department of Primary Industries Aquatic Ecosystem Research Database from records collected between 1994 and 2017). Threatened and vulnerable species that are expected to occur or that have a historical distribution within the catchment include southern purple-spotted gudgeon, silver perch, Murray cod, Macquarie perch, trout cod, southern pygmy perch, flathead galaxias, freshwater catfish, olive perchlet, stocky galaxias, Murray crayfish and a small gastropod, Hanley's river snail (NSW DPI 2016).

The condition of fish communities and populations throughout the Murray-Darling Basin declined significantly around 2007 following protracted drought in an already stressed river system (Davies et al. 2012; Mallen-Cooper & Zampatti 2015). NSW DPI fish community assessments for the Murrumbidgee River identified that the fish community status is generally in poor condition except for reaches between Wagga and Narrandera which are considered to be in moderate condition (Ellis et al. 2018).

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[1] Based on recent monitoring and NSW DPI Fisheries Maxent modelled data for native fish distribution (NSW DPI 2016).

Flow is a major factor structuring freshwater fish communities as it influences the range of physical habitats available to each developmental stage for fish, as well as ecological processes and functions to which their life history is linked (e.g. productivity / food availability and connectivity) (Rolls et al. 2013; Baumgartner et al. 2014; Ellis et al. 2016). Managing river health through considered water delivery that targets the protection or re-instatement of natural flow regimes, hydrological and physical habitat can be an effective way to support native fish and help restore populations. (Koehn et al. 2014; Mallen-Cooper & Zampatti 2015).

Objectives and targets for native fish in the Murrumbidgee catchment relate to increased distribution and abundance, and robust population structures that include representation of young-of-year, juvenile and adult-life-history stages (i.e. regular recruitment) (Table **2** and Appendix A). These objectives can be achieved by providing a range of flow categories (base flows, small and large within-channel freshes, and overbank flow) that meet the EWRs of native fish species.

PUs within the Murrumbidgee catchment have been identified as candidates for extending the range or establishing new populations for nine threatened fish species (MDBA 2014). These are flat-headed galaxias, Murray hardyhead, southern pygmy perch, olive perchlet, southern purple-spotted gudgeon, trout cod, Macquarie perch, freshwater catfish, and Murray crayfish. It is expected that range extensions for these species will be achievable in specific identified PUs that are likely to support the habitat and flow requirements of these species in regulated and/or unregulated sections.

Figure 6 Freshwater catfish, olive perchlet, and southern purple-spotted gudgeon
Photo: G. Schmida.

Table 2 Native fish ecological objectives

Ecological objective		Target fish species	Targets: 5 years (2024)	Targets: 10 years (2029)	Targets: 20 years (2039)
NF1	No loss of native fish species	All recorded fish species	All known species detected annually		
			-	Fish community status improved by one category compared to 2014 assessment	
NF2	Increase the distribution and abundance of short to moderate-lived generalist native fish species	Australian smelt, carp gudgeon, flat-headed gudgeon, dwarf flat-headed gudgeon, bony herring, Murray-Darling rainbowfish, unspecked hardyhead, mountain galaxias, stocky galaxias	Increased distribution and abundance of short to moderate-lived species compared to 2014 assessment No more than one year without detection of immature fish (short-lived) No more than two years without detection of immature fish (moderate-lived species)		
NF3	Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish species[2]	Southern pygmy perch, Murray hardyhead, flathead galaxias, olive perchlet, southern purple-spotted gudgeon[2, 3,]			
NF4	Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species	Golden perch, silver perch	Juvenile and adult fish detected annually No more than two consecutive years without recruitment in moderate-lived species No more than four consecutive years without recruitment in long-lived species		
NF5	Improve native fish population structure for moderate to long-lived	Murray cod, trout cod, Macquarie perch, river			

[2] In many cases achieving range expansion to historical areas for floodplain specialist species will require conservation stocking. The floodplain specialist species listed against objective NF3 are currently not known to be extant in the Murrumbidgee, but they are targeted for range expansion/reintroduction in objective NF7.

[3] Olive perchlet and southern purple-spotted gudgeon may be considered either floodplain specialist or riverine (lentic) depending on geographic location.

Ecological objective		Target fish species	Targets 5 years (2024)	10 years (2029)	20 years (2039)
	riverine specialist native fish species	blackfish, two-spined blackfish, freshwater catfish, Murray crayfish, southern purple-spotted gudgeon, olive perchlet[3, 4]	Minimum of 1 significant recruitment event in 5 years[5]	Minimum of 2 significant recruitment events in 10 years[5]	Minimum of 4 significant recruitment events in 20 years[5]
NF6	A 25% increase in abundance of mature (harvestable sized) golden perch and Murray cod	Golden perch, Murray cod	Length-frequency distributions include size classes of legal take size for golden perch and Murray cod 25% increase in abundance of mature golden perch and Murray cod		
NF7	Increase the prevalence and/or expand the population of key short to moderate-lived floodplain specialist native fish species into new areas (within historical range)	Flathead galaxias[6], Murray hardyhead[7], southern pygmy perch, olive perchlet, purple-spotted gudgeon[3]	Adults detected annually in specified PUs[8] No more than 1 year without detection of immature fish in specified PUs[8] (short-lived) No more than 2 years without detection of immature fish in specified PUs[8] (moderate-lived species) No more than 4 years without detection of immature fish in specified PUs[8] (long-lived species) Increased distribution and abundance in specified PUs[8]		
NF8	Increase the prevalence and/or expand the population of key moderate to long-lived riverine	Trout cod[9], Macquarie perch[10], freshwater			

[4] Southern purple-spotted gudgeon and olive perchlet are currently not known to be extant in the Murrumbidgee. They are targeted for range expansion/reintroduction in objectives NF8

[5] Where young-of-year comprise more than 30% of the population.

[6] In line with BWS priority of improving the core range of flathead galaxias (by 2024) in 1-2 additional locations in the southern basin. Candidate sites nominated include (among others) the Murrumbidgee.

[7] In line with BWS priority of establishing at least 3-4 additional populations of Murray hardyhead in the southern basin (by 2024), but candidate sites do not include the Murrumbidgee.

[8] PUs specified in Part B document of this Plan

[9] In line with BWS priority to 'continue downstream expansion' of the 'connected population of the Murrumbidgee–Murray–Edwards' of trout cod (by 2024); and the priority of the establishment of least 2 additional populations across the southern basin (by 2024) although no Murrumbidgee candidate sites were listed.

[10] In line with BWS priority of range extensions in at least 2 existing populations of Macquarie perch across the southern basin (by 2024) with candidate sites including (among others) the Murrumbidgee above Cooma and Adjungbilly Creek; and the priority of establishing of least 4 additional populations across the southern basin (by 2024) with candidate sites including (among others) the Goodradigbee River.

Ecological objective		Target fish species	Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
	specialist native fish species into new areas (within historical range)	catfish[11], river blackfish, olive perchlet, purple-spotted gudgeon**Error! Bookmark not defined.**,[12]		Increased distribution and abundance in specified PUs[8]	
NF9	Increase the prevalence and/or expand the population of key moderate to long-lived flow pulse specialist native fish species into new areas (within historical range)	Silver perch[13]			
NF10	Increase the prevalence and/or expand the population of key moderate to long-lived diadromous native fish species into new areas	Short-headed lamprey[14]		Adults detected annually in specified planning units[8]	

[11] In line with BWS priority of range extensions in at least 2 existing populations of freshwater catfish across the southern basin (by 2024) with candidate sites including (among others) Colombo-Billabong Creek; and the priority of increasing core range of at least 3 additional populations across the southern basin (by 2024) although no Murrumbidgee candidate sites were listed.

[12] In line with BWS priorities of establishing 3-4 additional populations of both southern pygmy perch and southern purple-spotted gudgeon across the southern basin (by 2024) with candidate sites for southern pygmy perch including (among others) the lower Murrumbidgee wetlands and for the southern purple-spotted gudgeon including (among others) Adjungbilly and Adelong creeks.

[13] In line with BWS priority for silver perch of expanding the core range of (among others) 'populations within the lower Murrumbidgee' (by 2024) and improving the core range in at least 2 additional locations, with candidate sites including (among others) the Billabong-Yanco system.

[14] In line with BWS priority for short-headed lamprey of upstream expansion facilitated through flows to operate fishways (by 2024).

3.2 Native vegetation objectives

The Murrumbidgee WRPA supports a diversity of vegetation communities, with their distribution and abundance driven primarily by patterns of flooding and drying (Brock and Casanova 1997; Boulton and Brock 1999; Capon et al. 2009; Roberts and Marston 2011). In the mid-Murrumbidgee, the Murrumbidgee River is characterised by river red gum forests interspersed with permanent to semi-permanent shallow lagoons and swamps dominated by sedgelands (e.g. *Eleocharis spp*.) (Gilligan 2005; Briggs et al. 1994; MDBA 2012b).

The permanent Fivebough Swamp and seasonally flooded Tuckerbil Swamp are two internationally Ramsar listed wetlands of importance located near Leeton (Green et al. 2011).

The Lower Murrumbidgee Floodplain (known as the Lowbidgee) provides a mosaic of aquatic habitats including in-channel habitat, swamps, lakes, lagoons and floodplains where a diverse range of plant species are found (Green et al. 2011; MDBA 2012c). Tall river red gum forests fringe the Murrumbidgee River. Across the complex system of interconnected creeks and braided channels of the Redbank region there are extensive stands of river red gum forests and river red gum and/or black box woodlands. Understory plants range from non-woody wetland plants through to shrublands depending on flooding regimes and landscape position (Kingsford and Thomas 2004; MDBA 2012c). A diverse mosaic of non-woody wetland communities, including aquatic herbs and spike rush (*Eleocharis spp.*) dominated sedgelands, characterise the Lowbidgee river red gum understory (MDBA 2012c; Roberts and Marston 2011). Lignum and nitre goose-foot shrubland also form understory habitat in river red gum and black box communities. The distributary creeks of Fiddlers and Uara are dominated by black box woodlands with lignum, nitre goosefoot and river cooba, understory (Childs 2008), The Nimmie-Caira system is characterised by extensive lignum shrubland distributed within along the channels and floodways providing important breeding waterbird habitat (Kingsford and Thomas 2004).

Loss of vegetation and decline in condition across the Lowbidgee floodplain has been attributed to altered flooding regimes from river regulation, upstream water diversions and localised land clearing (Kingsford and Thomas 2004). In the Redbank region more than half of the original wetlands have been lost or degraded (Kingsford and Thomas, 2004). Objectives for vegetation communities in the Murrumbidgee are therefore to maintain or increase, where possible, their extent and improve condition. The restoration of variable water regimes is expected to favour a wide range of plant species based on their water requirements (Blanch et al. 2000; Capon 2003; Capon et al. 2009; Gehrig 2010; Roberts and Marston 2011; Wassens et al. 2017). Specific targets have therefore been set for the broad vegetation types, to which species belong, which help support the maintenance of existing populations, recruitment and regeneration processes and to improve and restore vegetation communities, where possible (Table 3).

While it may not be possible to expand the extent of many forest and woodland communities with environmental water, the objectives of this plan are to ensure that adequate water is available to maintain their current extent and to improve their condition over the long term. Some low-lying forest and woodland areas may be watered using managed deliveries, while high elevation forest and woodland communities will generally require larger natural flood events. However, infrastructure assisted delivery flows can successfully inundate targeted wetlands (MDBA 2018).

Table 3 Native vegetation ecological objectives

Ecological objective			Targets[15]		
			5 years (2024)	10 years (2029)	20 years (2039)
NV1	Maintain the extent and viability of non-woody vegetation communities occurring within channels[16]		No loss of existing non-woody vege-tation occurring within channels or closely fringing river channels[17]	Increase the cover and viability of non-woody, inundation-dependent vegetation within river channels following inundation events (evaluated at specific sites only)[17, 18]	
NV2	Maintain or increase the extent and maintain the viability of non-woody vegetation communities occurring in wetlands and on floodplains		Maintain the extent of non -woody, inundation dependent vegetation occurring in wetlands and on floodplains[17, 19]		
			No loss of key species occurring in wetlands or on floodplains[20]	Increase viability (i.e. successful growth, flower and seed set) of key species or communities at ≥50% representative sites (10-year targets) and in ≥75% of representative sites (20-year targets) in actively managed wetland and floodplain flowpaths. Maintain elsewhere.[20]	
NV3	Maintain the extent and improve the condition of river red gum communities closely fringing river channels[21, 22]		Maintain the extent[23] of river red gum woodland communities closely fringing river channels		
			Maintain the extent of river red gum communities closely fringing river channels Maintain the proportion of river red gum communities closely fringing river channels that are in moderate or good condition[24] No further decline in the condition of river red gum communities closely fringing river channels that are in poor or degraded condition[24]		
	Maintain or increase the extent and	River red gum forest	Maintain the extent of river red gum forest and woodland communities[21, 22]		

[15] Condition and viability are measured over a 5-year rolling period to account for variation between naturally dry and wet times.

[16] In the Murrumbidgee there is no significant non-woody vegetation outside the channel apart from wetlands. This applies to in-channel vegetation in the Murrumbidgee.

[17] Establish representative sites and obtain baseline data.

[18] In line with expected outcome in BWS of increased periods of growth for communities that closely fringe or occur within the main river corridors, by 2024.

[19] In line with expected outcome in BWS to maintain the current extent of non-woody vegetation.

[20] Determine key species and/or communities, establish representative sites, determine appropriate vegetation response indicators (e.g. measurements of extent, cover, abundance and diversity) and obtain baseline data.

[21] In line with expected outcome in BWS to maintain current extent of river red gum and black box.

[22] HEW cannot generally be delivered at the bankfull flow levels required to meet some of the key needs of riparian river red gum vegetation communities (e.g. ground-cover condition). PEW services these needs by limiting the amount of water able to be extracted. Any effect on these from policy changes will risk the health of these vegetation communities.

[23] Establish baseline using best available mapping at the commencement of this plan.

[24] Measured by MDBA Stand Condition tool.

Ecological objective			Targets[15]		
			5 years (2024)	10 years (2029)	20 years (2039)
NV4a and NV4b	maintain or improve the condition of native woodland and shrubland communities on floodplains	and woodland	Maintain the proportion of river red gum forests and woodlands in moderate or good condition	Increase the proportion of river red gum forests and woodlands in moderate or good condition within actively managed flow paths and maintain the proportion outside of these[24, 25]	
			No further decline in the condition of river red gum forests and woodlands in poor or degraded condition[24] Maintain or improve the age class structure of river red gum communities (measured in selected sites only)[26]		
NV4c		Black box woodlands	Maintain the extent of black box woodland communities[21] Maintain or increase the extent and proportion of black box woodlands in moderate or good condition[24, 27] No further decline in the condition of black box woodlands in poor or degraded condition[24] Maintain or improve the age class structure of black box woodland communities (measured in selected sites only)		
NV4e[28]		Lignum shrublands	Maintain the extent of lignum shrubland communities[17, 29]	Increase the extent of lignum shrubland communities on actively managed flowpaths and maintain in remaining areas[17]	
			Increase the proportion of lignum communities in intermediate to good condition on actively managed flowpaths and maintain the proportion on the remaining areas[17, 30] No further decline in the condition of lignum shrublands in poor condition[17]		

[25] In line with expected outcome in BWS of, by 2024, improved condition of river red gum in the Murrumbidgee.

[26] In line with expected outcome in BWS of improved recruitment of trees within river red gum and black box communities—in the long term achieving a greater range of tree ages.

[27] In line with expected outcome in BWS of no decline in condition of black box.

[28] Other catchments in NSW have coolibah, which is NV4d. The Murrumbidgee has no coolibah, so no NV4d.

[29] In line with expected outcome in BWS to maintain current extent of lignum in the Lower Murrumbidgee.

[30] In line with expected outcome in BWS to improve condition of lignum in the Lower Murrumbidgee

Figure 7 River red gum, Yarradda Lagoon
Photo: J. Maguire/OEH

3.3 Waterbird objectives

Waterbirds respond to variable climatic conditions and are known to travel great distances in search of wetland habitat. Aspects of flows that are considered important to the ecological requirements of waterbirds include the timing, frequency, duration and extent of inundation, and water depth including the rate of rise and fall of water levels (Ralph & Rogers 2011). The number of waterbird species and their abundance fluctuates with wetland habitat availability.

The Murrumbidgee WRPA has records from 1900–2016 for 21 waterbird species (not including vagrants) listed under one or more international migratory bird agreements (JAMBA, CAMBA and RoKAMBA) (OEH 2018). This includes the Caspian tern, white-winged black tern, black-tailed godwit, common greenshank, curlew sandpiper, Latham's snipe, marsh sandpiper, red-necked stint, sharp-tailed sandpiper and wood sandpiper. There are also records for the Murrumbidgee WRPA from 1900–2016 for 11 waterbird species listed under the NSW Biodiversity Conservation (BC) Act (2016), including the Australasian bittern, Australian painted snipe, blue-billed duck, freckled duck, magpie goose and brolga (OEH 2018). These species are dependent upon wetlands and floodplains for foraging and breeding.

The Murrumbidgee contains important wetland habitat for waterbirds including the Ramsar listed Fivebough-Tuckerbil swamps and nationally important Lowbidgee Floodplain and Mid-Murrumbidgee Wetlands (Environment Australia 2001). These wetland areas support a rich diversity of waterbird species. At least sixty waterbird species (41 breeding) have been recorded in the Lowbidgee Floodplain (Kingsford & Thomas 2001). The Lowbidgee Floodplain can support large numbers of waterbirds in times of large floods, including some of the largest colonies of glossy ibis and straw-necked ibis in the Murray-Darling Basin (Brandis 2010). Heavy rainfall in the upper Murrumbidgee catchment can cause widespread flooding in the lower catchment and provide an important trigger for large colonial waterbird breeding events. Reductions in the frequency and size of large flood events have impacted the occurrence of large colonial breeding events in the Lowbidgee Floodplain (Kingsford & Thomas 2004). Large events in the Lowbidgee Floodplain in the last decade were recorded in 2010/11 (~55,000 nests) and 2016/17 (~65,000 nests) in response to widespread inundation of the floodplain, with smaller breeding events (generally less than 1,000 nests) recorded in the intervening years (Spencer 2017; Spencer et al. 2018). The Mid-Murrumbidgee Wetlands can also support small nesting colonies of cormorants, spoonbills and herons when inundated (Spencer 2017; Spencer et al. 2018) although the number of sites and frequency of breeding has declined compared to previous surveys (Briggs and Thornton 1999).

In the 30 years to 2012, annual waterbird surveys revealed a 72% decline in average waterbird abundance across the Murray-Darling Basin (MDBA 2014). This is a critical observation because waterbirds are an important indicator of wetland health as their abundance and diversity are related to the total area of wetland available, the health of wetland vegetation and the abundance of food resources e.g. fish and aquatic vegetation (Kingsford 1999). The Lowbidgee Floodplain and Fivebough-Tuckerbil Swamps have been identified as key areas where the restoration of wetland habitat for waterbirds, and reinstatement of flow regimes that mimic natural, can contribute to recovery of waterbird populations both in-catchment and across the Murray-Darling Basin (MDBA 2014).

Objectives and targets in this plan for waterbirds relate to maintaining species richness and maintaining (at 5 years) or improving (at 10 and 20 years) waterbird abundance compared to a 2012-16 baseline period, or, where stated, a 1992–2012 baseline (Table 4). It is proposed this will be measured through ongoing collection of annual spring aerial and ground survey data. This will be achieved mainly through maintaining and, where possible, improving key waterbird breeding and foraging habitat, and through the delivery of targeted flows to support colonial nesting events from egg laying through to post-fledging care, as was done successfully in the 2016/17 colonial waterbird breeding events.

Table 4 Waterbird ecological objectives (for the Lowbidgee and Mid-Murrumbidgee Wetlands and Fivebough Swamp unless specified)

Ecological objective		Targets[31]		
		5 years (2024)	10 years (2029)	20 years (2039)
WB1	Maintain the number and type of waterbird species[32]	Maintain a 5-year rolling average of waterbird species across the 5 functional groups in each waterbird area (compared to 5 five-year 2012–16 period)		
			Identify at least 51 waterbird species in a 10-year period	At least 58 waterbird species observed in a 20-year period
WB2	Increase total waterbird abundance across all functional groups[33]	Total abundance of the 5 functional groups maintained compared to the 5-year 2012–16 period	Total waterbird abundance increased by 20–25% compared to the 5-year 2012–16 period, with increases in all functional groups	Maintain or increase total waterbird abundance compared to the 10-year target, with increases in all functional groups
WB3	Increase opportunities for non-colonial waterbird breeding[34]	Total abundance of non-colonial waterbirds and number of breeding species maintained compared to the 5-year 2012–16 baseline period	Total abundance of non-colonial waterbirds increased by 20–25% with number of breeding species maintained compared to the 5-year 2012–16 baseline	Maintain or increase total abundance of non-colonial waterbirds and number of breeding species compared to the 10-year target
WB4	Increase opportunities for colonial waterbird breeding[35]	Support active waterbird colonies in the Lower and Mid Murrumbidgee Wetlands by maintaining the water depth and duration of inundation (as required) to support breeding through to completion (from egg laying through to fledging including post-fledgling care) and maintain duration of inundation in key foraging habitats to enhance breeding success and the survival of young		

[31] Baseline is UNSW aerial survey and OEH ground survey data collected each spring between 2012-16. Targets measured using same surveys. Targets will be further refined from 2029 onwards following additional data collection.

[32] In line with expected outcome in BWS that the number and type of waterbird species present in the Basin will not fall below current observations

[33] In line with expected outcome in BWS of a significant improvement in waterbird populations of the order of 20–25% over the baseline scenario, with increases in all waterbird functional groups. Note this is ‘by 2024’. It was considered that a longer time frame will be needed to see improvements compared to a 2012-16 baseline because the Nimmie-Caira improvements only commenced in 2019 and increases in waterbird abundance would be expected within the at the 10- and 20-year targets not 5-year target.

[34] Non-colonial waterbirds are in line with expected outcome in BWS of an increase in breeding abundance (nests and broods) for non-colonially nesting waterbirds by 30–40% across the Basin compared to the baseline scenario. Note this is ‘by 2024’ in the BWS. It was considered that a longer time frame will be needed to see improvements compared to a 2012-16 baseline because the Nimmie-Caira improvements only commenced in 2019 and increases in waterbird abundance would be expected at the 10- and 20-year targets not 5-year target. Additionally, increases in total abundance of non-colonial waterbird species at the catchment level would reflect increases in breeding opportunities (and number of broods/nests) for this group at the Basin level. Therefore, 20-25% increases in this group and the presence of breeding activity (number of breeding species) is used for this reason in the LTWP target.

[35] In line with expected outcome in BWS for, by 2024, an increase in breeding events (the opportunities to breed rather than the magnitude of breeding per se) of colonial nesting waterbirds by up to 50% compared to the baseline scenario.

Ecological objective		Targets[31]		
		5 years (2024)	10 years (2029)	20 years (2039)
		In line with natural cues, initiate and support small-scale colonial waterbird breeding in at least 5 colony sites in the Lower Murrumbidgee in 2 out of 5 years	In line with natural cues, initiate and support small-scale colonial waterbird breeding in at least 10 colony sites in the Lower Murrumbidgee in 3 out of 10 years	In line with natural cues, initiate and support small-scale colonial waterbird breeding in more than 10 colony sites in the Lower Murrumbidgee in 3 out of 10 years
		Initiate and support small-scale colonial waterbird breeding in line with natural cues in at least two colony sites in the Mid-Murrumbidgee in 2/5 years.	Initiate and support small-scale colonial waterbird breeding in line with natural cues in at least four colony sites in the Mid-Murrumbidgee in 3/10 years.[36]	Initiate and support small-scale colonial waterbird breeding in line with natural cues in more than four colony sites in the Mid-Murrumbidgee 3/10 years.[36]
WB5	Maintain the extent and improve condition of waterbird habitats	Maintain extent and improve condition of nesting vegetation, including common reed, lignum, cumbungi, river red gum and river cooba, in known colonial breeding locations		
		Maintain or increase extent and improve condition of waterbird foraging habitats and breeding locations (to be evaluated under targets set for native vegetation)		

Note: Table content does not include vagrant species.

Figure 8 Juvenile straw-necked ibis at Tori Swamp near Redbank Weir, Lower Murrumbidgee
Photo: V. Bucello/Midstate Video

[36] Requires implementation of the constraints management strategy to support achievement

3.4 Priority ecosystem function objectives

A number of key functions and processes have been identified in the Murrumbidgee and are described below.

Drought refuge for water-dependent species

Instream pools and floodplain lagoons are extremely valuable refuges in riverine landscapes. Other types of instream refugia include logs, wet undercut banks, riffles, sub-surface stream sediments and riparian vegetation (Boulton 2003). Refugia are critical to the survival of many aquatic species during dry spells and drought, and act as source populations for subsequent recolonisation and population growth (Adams & Warren 2005; Arthington et al. 2005).

Quality instream habitat

The physical form of instream habitats, including the location of riparian and instream vegetation, channel shape and bed sediment, is influenced by river flow. For example, fresh and bankfull flows with sufficient velocity are required to maintain pool depth and riffles by scouring out bed material and initiating material transportation downstream.

Movement and dispersal opportunities for water-dependent biota

Longitudinal and lateral connectivity allows organisms to move and disperse between environments. It can be essential for maintaining population viability (Amtstaetter et al. 2016) by allowing individuals to move to different habitat types for breeding and conditioning, and recolonisation following disturbances like flood and drought. Flow pulses can promote dispersal of early life stages for a range of species from the breeding site and promote genetic diversity among catchments (Humphries & King 2004). Movement is currently limited in many reaches by in-stream structures.

Instream and floodplain productivity

The supply of organic material underpins all river food webs by providing the food energy needed to drive life. The sources of organic material, the timing of its delivery and how long it remains in a section of river depend very much on the flow regime and the nature of the riparian vegetation.

River flow management can be used to increase carbon and nutrient sources in-channel by increasing the frequency of floodplain inundation. Re-wetting patches (e.g. river channels, channel benches, floodplains following drying provides a pulse of terrestrial carbon available for potential use by consumers (e.g. Lanhans & Tockner 2006) and the flow of water enhances the physical breakdown of leaves, branches and other terrestrial detritus (Mora-Gomez et al. 2015).

While pulses of organic matter from the floodplain have benefits for productivity, too much can lead to excessive oxygen demand and fish deaths. As such, frequent flushing of the floodplain is also important to reduce the build up of organic matter. When the time between flushing events is prolonged there may be hypoxic events, particularly in warmer months.

Infrastructure may be able to be used to enhance the provision of carbon and nutrient from the floodplain to the channel. An example is by providing flows wetlands in the Lower Murrumbidgee Floodplain and then using escapes to allow return flows back into the river.

Groundwater-dependent biota

While this LTWP is primarily focused on the management of surface water, the Mid and to a lesser extent the Lower Murrumbidgee Alluviums play an important ecological role in supporting terrestrial and aquatic ecosystems, particularly during extended dry periods where they can be critical for maintaining refuges.

Groundwater flows uninterrupted along the Murrumbidgee Alluvium and eventually connects with the Murray Geological Basin. The Mid Murrumbidgee Alluvium is considered to be in hydraulic connection with the regulated Murrumbidgee River and its tributaries (NSW DoI 2018). CSIRO (2008) interpreted that the Murrumbidgee River above Wagga Wagga is a gaining stream, at Wagga Wagga is a losing stream, and downstream near Narrandera is a gaining stream. It is also interpreted that at Wagga Wagga, prior to groundwater development, the Murrumbidgee River was gaining, and that downstream of Wagga Wagga a losing reach has increased since the mid 1970s due to extraction of groundwater (CSIRO, 2008). In the Lower Murrumbidgee Alluvium, the Murrumbidgee River below Narrandera is losing over a substantial length. Anabranches and distributary channels such as Yanco Creek and Colombo Creek are also losing.

The ground-water dependant vegetation communities of river red gum woodland wetlands, river red gum-lignum wetlands, freshwater wetlands, river red gum-black box and river red gum-yellow box woodland wetlands and cumbungi rushland dominate the Murrumbidgee alluvium (NSW DoI 2018).

To continue to support groundwater dependent ecosystems in the Murrumbidgee, objectives relate to maintaining the mapped extent of groundwater-dependent vegetation communities and groundwater levels within the natural range of variability over the long-term.

Sediment, carbon and nutrient exchange

The frequency of flows that connect rivers with their riparian corridors and floodplains has been substantially reduced. Water volumes released from Burrinjuck and Blowering dams typically do not exceed channel capacity. The loss of lateral connectivity between rivers and their floodplains has altered water movement, the flux of sediment, nutrients, carbon, and biota from and to the river (Baldwin et al. 2016). Consequently, the amount of dissolved organic carbon entering the main channels is reduced because of less frequent wetting of benches, flood runners and floodplains (Westhorpe et al. 2010). Longitudinal connectivity is equally important and fulfils the important environmental function of transporting nutrients and sediments between environments (MDBA 2014).

Inter-catchment flow contributions

Longitudinal connectivity between catchments fulfils important environmental functions e.g. moving nutrients and sediments, allowing for organisms to disperse and improving water quality. River regulation and diversions have reduced the volume of water passing into downstream catchments.

Connectivity between key PUs and provision of end of system flows will contribute to improved environmental outcomes in the Murrumbidgee, Lachlan and Murray catchments.

Table 5 Priority ecosystem function objectives

Ecological objective		Description and key contributing processes	Targets: 5 years (2024)	10 years (2029)	20 years (2039)
EF1	Provide and protect a diversity of refugia across the landscape	Water depth and quality in pools (in-channel), core wetlands and lakes Condition of vegetation in core wetlands and riparian zones	Core wetland habitats[37] are protected[38], including during dry times		
			Cease to flow periods do not exceed maximum durations as specified in PU EWRs		
			Adequate water depth is maintained in key refuge pools[39] during dry times		
			In key refuge pools[39] maintain daily average dissolved oxygen >4 mg/L and hourly levels >2 mg/L		
EF2	Create quality instream, floodplain and wetland habitat[40]	Regulation of dissolved oxygen, salinity and water temperature Flow variability and hydrodynamic diversity Provision of diverse wetted areas Appropriate wetting and drying cycles Geomorphic (erosion/deposition) processes that create and maintain diverse physical habitats Appropriate rates of fall to avoid excessive bank erosion Control of woody-vegetation encroachment into river channels and wetlands	Recession management: Rate of fall does not exceed the 95th percentile of natural rates[41] during regulated water deliveries		
			Minimum flow variability: Period for which small and large freshes are held at constant level (± 5%) does not exceed 20 days to avoid bank slumping and support in-stream function		
			Channel form: Watering requirements for overbank flows are met (refer to fish/vegetation/bird watering requirements)		
			Bench and pool formation and fine sediment scouring: Watering requirements for freshes are met (refer to fish/vegetation/bird watering requirements)		
			Create hydrodynamic complexity for large-bodied fish: Flows with velocities of 0.3 to 0.4 m/s provided as per watering requirements for freshes (refer to fish watering requirements)		

[37] Core wetland habitats are to be identified (see priority further work at Table 24)

[38] Maintained in a state that will provide habitat for biota and allow recovery to good condition with wet season.

[39] Key refuge pools are to be identified (see priority further work at Table 24)

[40] Also supports/supported by BWS expected outcome of “a 30 to 60% increase in the frequency of freshes, bank-full and lowland floodplain flows in the… Murrumbidgee”

[41] ‘Natural’ rates generally estimated from pre-1950 observed data where a multi-decal record exists or, where this is not available, modelled natural data.

<table>
<tr><th colspan="2" rowspan="2">Ecological objective</th><th rowspan="2">Description and key contributing processes</th><th colspan="3">Targets</th></tr>
<tr><th>5 years (2024)</th><th>10 years (2029)</th><th>20 years (2039)</th></tr>
<tr><td rowspan="3">EF3</td><td rowspan="3">Provide movement and dispersal opportunities for water-dependent biota to complete lifecycles and disperse into new habitats lifecycles[42, 40]:
(a) within catchment and
(b) between catchments</td><td rowspan="3">Dispersal of eggs, larvae, propagules and seeds downstream and into off-channel habitats
Migration to fulfil life-history requirements
Foraging of aquatic species
Recolonisation following disturbance</td><td colspan="3">Increase, compared to 2004–2017[43], dispersal opportunities between subcatchments and between river reaches for moderate to long-lived flow pulse specialist native fish through key fish passages[44].</td></tr>
<tr><td colspan="3">EWRs that support major life stages of biota in target habitat areas are met (refer to fish and veg EWRs for the end-of-system PUs)</td></tr>
<tr><td colspan="3">Minimum daily end-of-system flows (as specified in the WRP) maintained</td></tr>
<tr><td>EF4</td><td>Support instream and floodplain productivity[40]</td><td>Aquatic primary productivity (algae, macrophytes, biofilms, phytoplankton)
Terrestrial primary productivity (vegetation)</td><td colspan="3">Maintain or increase the proportion of wetland and floodplain vegetation that is in good condition[45] over a five-year rolling period
Enhance riverine productivity to support increased food availability for aquatic food webs by increasing the supply of autochthonous and allochthonous carbon and nutrients (specific targets and indicators to be developed)[46]</td></tr>
</table>

[42] In line with BWS objective (under the heading 'moderate to long-lived species') of "*annual detection of species and life stages representative of the whole fish community through key fish passages; with an increase in passage of Murray cod, trout cod, golden perch, silver perch.. [and] short-headed lamprey through key fish passages to be detected in 2019–2024; compared to passage rates detected in 2014–2019*".

[43] To be assessed against a combination of observed data and the modelled baseline scenario which represents the consumptive use and the rules and sharing arrangements as at June 2009. Comparisons will need to take into account any limitations in the model and, for the observed data, the comparability of the weather during the baseline period and target period.

[44] Key fish passages to be identified by NSW Fisheries.

[45] In line with condition targets set for the native vegetation objectives

[46] See priority further work at Table 24

Ecological objective		Description and key contributing processes	Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
		Aquatic secondary productivity (zooplankton, macroinvertebrates, fish larvae, adult fish) Decomposition of organic matter	No decline in key native fish species[47] condition metrics. Maintain the abundance and distribution of decapod crustaceans	Improve key native fish species condition metrics Improve the abundance and distribution of decapod crustaceans	
EF5	Support nutrient, carbon and sediment transport along channels, and between channels and floodplains/wetlands[40]	Sediment delivery to downstream reaches and to/from anabranches, floodplains and wetlands Mobilisation of carbon and nutrients from in-channel surfaces (e.g. benches/banks), floodplains and wetlands and transport to downstream reaches and off-channel habitats Dilution of carbon and nutrients that have returned to rivers	Maintain the frequency and duration of events that drive nutrient and carbon (DOC) processes (at selected evaluation sites) along channels (refer to freshes and overbank EWRs) Maintain extent and condition of floodplain vegetation (measured under vegetation theme targets)		
EF6	Support groundwater conditions to sustain groundwater-dependent biota	Groundwater recharge and discharge Dilution of saline/acidic groundwater Salt export from the Murray-Darling Basin	Maintain the 2016 mapped extent of groundwater-dependent vegetation communities[48] Maintain groundwater levels within the natural range of variability over the long-term		
EF7	Increase the contribution of flows into the Murray and Barwon-Darling from tributaries[49]	Provision of end of system flows to support ecological objectives in downstream catchments	A 30% overall increase in flows in the River Murray: from increased tributary contributions from the Murrumbidgee, Goulburn, Campaspe, Loddon and Lower Darling catchments collectively (with the Murrumbidgee contributing proportionally)		

[47] Key fish species that are relevant in each PU, as described in the targets for the native fish objectives.

[48] Note: Groundwater systems are not well understood and there may be a need for more information gathering before this can be meaningfully measured. These targets are one way of measuring but may not be able to be done in the first instance. In the meantime, it is known that large floods recharge the groundwater systems and flush salts from the soils. These are not able to be delivered with HEW. Hence there is a need to protect these larger events when they do occur.

[49] In line with BWS expected outcome of “30% overall increase in flows in the River Murray: from increased tributary contributions from the Murrumbidgee, Goulburn, Campaspe, Loddon and Lower Darling catchments collectively”.

3.5 Other species

The delivery of environmental watering requirements for waterbirds, native fish, vegetation and functions/processes will benefit other species. However, there are some flow-dependent species that are significant (due to their vulnerability, cultural significance or importance in the food chain) and which have watering requirements that are different to those covered by other themes.

In the Murrumbidgee this is relevant for frogs. Frogs are an important food source for waterbirds, fish and reptiles. Flow-dependent frogs have similar watering requirements to waterbirds for breeding, however, they are not highly mobile, so they require refuge between watering events. As such, the inclusion of flow-dependent frog objectives places greater emphasis on the need to maintain refuge (including permanent waterbodies for some species) in the floodplain.

Nearly half of the frog species found in floodplain wetlands of the Murray-Darling Basin are responsive to flows, and therefore, can benefit from the delivery of environmental water. These species are described as flow-dependent frog species and are the primary focus of OEH's environmental water management program.

The Murrumbidgee catchment contains important wetland habitat that supports a range of frog species. Flow-dependent species are typically non-burrowing ground or marsh frogs that have limited ability to withstand drying and are reliant on floodplain habitats (including wetlands, waterholes and creeks for refuge) and prefer to breed in recently inundated areas (Ocock *et al.* 2016; Wassens 2011). Frogs require refuge habitat to survive dry periods and inundation of floodplain breeding habitat that includes complex wetland vegetation (Ocock et al. 2016; Wassens & Maher 2011).

Extensive frog surveys have been undertaken in the Lowbidgee Floodplain and Mid-Murrumbidgee Wetlands in the last decade as part of monitoring the outcomes of managed environmental water delivery (Spencer and Wassens 2010; Wassens et al. 2018). These surveys identified six 'flow-dependent' frog species in the Mid-Murrumbidgee Wetlands and Lowbidgee Floodplain over the 2008/09 to 2017/18 period. This survey data was used to form an appropriate baseline for setting LTWP frog objectives.

The endangered southern bell frog (*NSW Biodiversity Conservation Act 2016*) is also a focus species for the Murrumbidgee LTWP frog objectives. This species was formerly widespread throughout south-eastern Australia (Pyke 2002) but now has a more restricted distribution that includes parts of the Murrumbidgee catchment. Environmental water has been delivered to wetlands in the Murrumbidgee since 2007 to maintain southern bell frog habitats through dry periods and support successful breeding (e.g. Spencer and Wassens 2010; Wassens et al. 2018). More recently the southern bell frog has been the focus of targeted monitoring across the Murrumbidgee as part of OEH's Saving our Species Program (Walcott and Waudby 2018).

The 2012–19 baseline period incorporates available datasets for five water years that experienced varying amounts of managed environmental water delivery and natural inundation. Many of the survey sites during their period supported breeding with evidence of tadpoles and metamorphs from *Limnodynastes* species (spotted marsh frogs, barking marsh frogs and giant banjo frogs), Perons tree frogs, southern bell frogs and eastern-sign bearing frogs (see Wassens et al. 2015; 2016; 2017; 2018; 2019; Walcott and Waudby 2018). This survey information has been used to develop a basleine for setting objectives and targets for maintaining and improving flow-dependent frog populations in the Murrumbidgee catchment.

Table 6 Frog ecological objectives

Ecological objective		Targets		
		5 years (2024)	10 years (2029)	20 years (2039)
OS1	Maintain species richness and distribution of flow-dependent frog communities	Detect all six flow-dependent frog species known from the Lowbidgee and Mid-Murrumbidgee wetlands based on comprehensive surveys over the 2014–19[50] period		
OS2	Maintain successful[51] breeding opportunities for flow-dependent frog species	Maintain proportion of wetlands sites where breeding activity[52] of flow-dependent frog species is detected in the Lowbidgee and Mid-Murrumbidgee wetlands compared to the 2014–19[50] period		
OS3a[53]	Maintain and increase number of wetland sites occupied by the endangered southern bell frog	Sites where southern bellfrogs are known to be present: proportion of known sites[54] where southern bellfrogs are detected is maintained on a 3-year rolling average.[50] Southern bellfrogs detected 5 years in 5	Sites where southern bellfrogs are known to be present: proportion of known sites[54] where southern bellfrogs are detected is 10% above baseline on a 3-year rolling average.[50] Southern bellfrogs detected 5 years in 5	
		Known sites of bellfrog recruitment: proportion of known sites[54] where potential recruitment[52] is detected is maintained on a 3-year rolling average.[50]	Known sites of bellfrog recruitment: proportion of known sites[54] where potential recruitment[52] is detected is increased by 10% (as measured on a 3-year rolling average).[50]	

50 Baseline data from Wassens et al. (2018) most recent field surveys 2014–19 from the Commonwealth Long-Term Intervention Monitoring (LTIM) Program. For Objective OS3a this also applies except for Murrumbidgee Infrastructure-dependent floodplain wetlands where baseline will be developed with recent and new monitoring.

51 Successful breeding relates to opportunities for species to complete breeding life cycle, i.e. laying eggs, to development of tadpoles through to metamorphs (juvenile frogs), which relates mainly to flow-dependent frog species requirements for minimum duration of inundation.

52 We consider male frog calling or tadpoles detected as evidence of breeding. We consider male frog calling [with estimated duration of water sufficient for recruitment completion – nominally 3 months], tadpoles detected and/or recently metamorphosed juvenile frogs as evidence of potential recruitment of new individuals into the breeding population.

53 OS3 objectives relate to endangered frog species. In other catchments there are additional species, hence the need to have the suffix ‘a’ to OS3a.

54 Surveyed sites in the Lowbidgee Floodplain, Mid-Murrumbidgee and the Murrumbidgee infrastructure-dependent floodplain wetlands planning unit

Figure 9 Southern bell frog at Piggery Swamp, Lowbidgee Floodplain
Photo: S. Carmichael/NSW NPWS.

4 Environmental water requirements

Flow and inundation regimes drive the ecological characteristics of rivers and floodplain wetlands (Poff & Zimmermann 2010). A flow regime represents the totality of flow events: it is the sequence of variable flow magnitudes that produce flooding and drying patterns. Flow regimes govern river channel and wetland formation, their configuration and connectivity with the floodplain. Flow regimes prompt key ecological processes such as nutrient cycling and energy flow, breeding and migration, and dispersal of plants and animals.

Flow regimes can be categorised according to hydrological and ecological similarities. Each flow category can provide for a range of ecological functions. For example, a small fresh might inundate river benches that provide access to food for native fish and support in-channel vegetation. Similarly, an overbank flow may support carbon exchange between the river and its floodplain and improve river red gum condition. Flow categories describe the height or level of a flow within a river channel or its extent across a floodplain (Figure 10 & Table 7). Flow rate or volume bands for flow categories in the Murrumbidgee catchment are shown in Table 9.

An environmental water requirement (EWR) is the flow or inundation regime that a species, or community, needs to ensure its survival and persistence. It can also be the flow regime needed to meet the water requirements of a range of species in a defined geographic area. EWRs are based on knowledge of a species' biological and ecological needs, such as what it needs to feed, breed, disperse and migrate.

Meeting the full life-history needs of an aquatic organism (plant or animal) might require a combination of several different flow categories over time. For example, a native fish species may require a 'small fresh' as a 10-day pulse in late winter to cue spawning, followed by a relatively stable flow for 2–4 weeks in early spring to support nesting. Once the fish reaches maturity (1–3 years) it may require a 'bankfull' fast-flowing river in combination with 'overbank' flows to trigger dispersal and migration.

4.1. Describing the required flow regime to support ecological objectives

Development of EWRs for LTWPs drew on the best available information from water managers, ecologists, scientific publications and analysis of gauged and modelled flows. The process started with an assessment of the water requirements of individual species, then of guilds or functional groups. Where EWR's overlapped between species or groups, the EWR's were combined to provide a single EWR for a flow category.

At the PU scale EWRs were informed by an understanding of the channel morphology and hydrology. This included an analysis of channel cross-sections, floodplain inundation data, observed flow data, modelled flow data and operational experience.

Important flow regime characteristics to meet life-history needs and each of the LTWP objectives are described in Table 13. The combined EWRs, grouped by flow category, for all biota and functions in the Murrumbidgee catchment are presented in Table 10. Each EWR is expressed as a flow category that has been assigned an ideal timing, duration and frequency based on the suite of plants, animals and functions it supports. Specific EWRs at each regulated PU in the Murrumbidgee, including flow rates and total volumes, can be found in Part B. Due to its importance, dependence on total event volumes (as opposed to just flow rates) and the size of its water requirements, separate information is provided on the flow requirements of the Lowbidgee Floodplain in Table 11 and Table 12.

Tables 8–10 and 12, and the EWR tables for each PU in Part B describe the flows that need to be maintained, and in many instances reinstated, to protect and restore the Murrumbidgee's priority environmental assets and ecosystem functions. Achieving EWRs alone does not mean objectives will be reached. There are a range of complementary measures that will improve chances of achieving objectives. Other variables such as the impact of climate change, weather and land use will also impact upon the environmental outcomes sought.

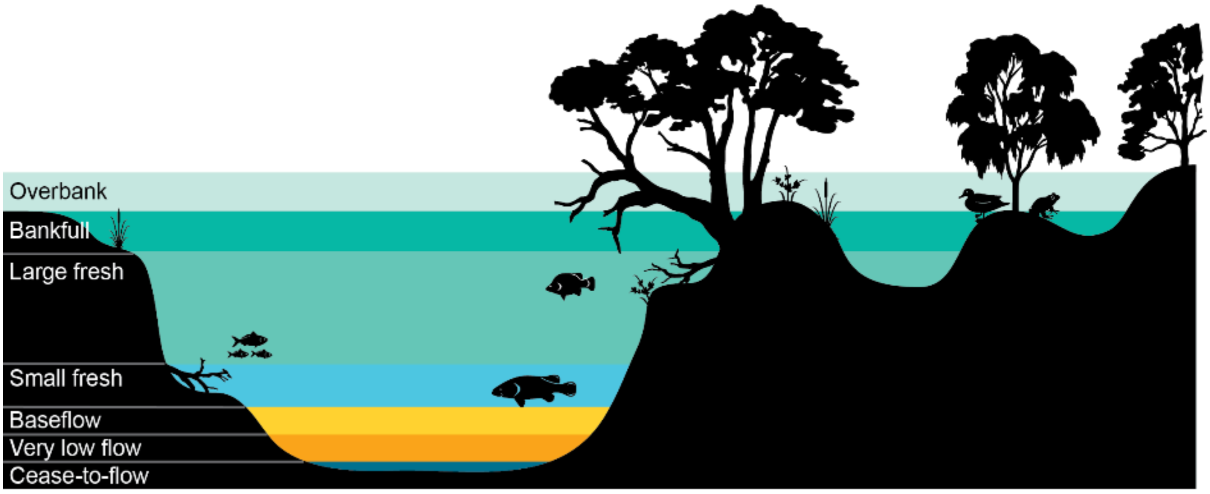

Figure 10 A simplified conceptual model of the role of each flow category

Table 7 Description of the role of each flow category

Flow category	Description
Floodplain connection flow (OB)	Floodplain connection flows provide broad scale lateral connectivity with floodplain and wetlands. They support nutrient, carbon and sediment cycling between the floodplain and channel, and promote large-scale productivity.
Bankfull flow (BK)	Inundates all in-channel habitats and connects many low-lying wetlands. They provide partial or full longitudinal connectivity and drown out of most small in-channel barriers (e.g. small weirs).
Large fresh (pulse) (LF)	Inundates benches, snags and inundation-tolerant vegetation higher in the channel. They support productivity and transfer of nutrients, carbon and sediment. They also provide fast-flowing habitat and may connect wetlands and anabranches with low commence-to-flow thresholds. The key benefit of these flows is to increase productivity and nutrient transport in the river channel and increase habitat area.
Wetland connection flow (Wetland-LF)	These (not shown in Figure 10) are larger 'large fresh' flows which provide significant connectivity to wetlands and anabranches, but which remain under bankfull level. In other catchments, connection to major wetlands systems would generally occur at and above bankfull level. The geomorphology of the Murrumbidgee system is such that many major billabong, anabranch and other off-channel wetland systems are connected below bankfull level. Hence the category of 'wetland connecting flow' is used in the Murrumbidgee. These connections happen through natural 'break outs' or low sills in the side of river banks. They can also happen via regulating structures (particularly in the Lowbidgee) or via pumping.
Small fresh (pulse) (SF)	Improves longitudinal connectivity. They inundate lower banks, bars, snags and in-channel vegetation, and can flush pools and stimulate productivity/food webs. They can provide a trigger for aquatic animal movement and breeding.
Baseflow (BF)	Provides connectivity between pools and riffles and along channels. They provide sufficient depth for fish movement along reaches.

Flow category	Description
Very low flow (VLF)	Minimum flow in a channel that prevents a cease to flow. They provide connectivity between some pools.
Cease-to-flow (CtF)	Partial or total drying of the channel. The stream contracts to a series of disconnected pools and there is no surface flow.

Table 8 Description of terms used for environmental water requirements (see Table 10)

EWR code	Each EWR is given a specific code that abbreviates the EWR name (e.g. SF1 for small fresh 1). This code is used to link ecological objectives and EWRs.
Ecological Objectives	The LTWP ecological objectives supported by the EWR. Includes reference to codes of all LTWP Objectives supported (e.g. NF1 = Objective 1 for Native Fish), and a short description of key objectives and life stages being targeted (e.g. spawning or recruitment). Bold text indicates the primary objectives of each EWR. See Table 2 to Table 6 for full objectives.
Gauge	The flow gauging station that best represents the flow within the planning unit, for the purpose of the respective EWR and associated ecological objective(s). To assess the achievement of the EWR, flow recorded at this gauge should be used.
Flow rate or flow volume	The flow rate (typically ML/d) or flow volume (typically GL over a defined period of time) that is required to achieve the relevant ecological objective(s) for the EWR. Most EWRs are defined using a flow rate, whilst flow volumes are used for EWRs that represent flows into some large wetland systems.
Timing	The required timing (or season, typically expressed as a range of months within the year) for a flow event to achieve the specified ecological objective(s) of the EWR. In some cases, a preferred timing is provided, along with a note that the event may occur at 'anytime'. This indicates that ecological objectives may be achieved outside the preferred timing window, but perhaps with sub-optimal outcomes. In these instances, for the purposes of managing and delivering environmental water, the preferred timing should be used to give greater confidence in achieving ecological objectives. Natural events may occur at other times and still achieve ecological objectives.
Duration	The duration for which flows must be above the specified flow rate for the flow event to achieve the specified ecological objective(s) of the EWR. Typically this is expressed as a minimum duration. Longer durations will often be desirable and deliver better ecological outcomes. Some species may suffer from extended durations of inundation, and where relevant a maximum duration may also be specified. Flows may persist on floodplains and within wetland systems after a flow event has past. Where relevant a second duration may also be specified, representing the duration for which water should be retained within floodplain and wetland systems.
Frequency	The frequency at which the flow event should occur to achieve the ecological objective(s) associated with the EWR. Frequency is expressed as the number of years that the event should occur within a 10-year period.

	In most instances, more frequent events will deliver better outcomes, and maximum frequencies may also be specified, where relevant. Clustering of events over successive years can occur in response to climate patterns. Clustering can be ecologically desirable for the recovery and recruitment of native fish, vegetation and waterbird populations; however extended dry periods between clustered events can be detrimental. Achieving ecological objectives will require a pattern of events over time that achieves both the frequency and maximum inter-flow period, and the two must be considered together when evaluating outcomes or managing systems. Where a range of frequencies is indicated (e.g. 3-5 years in 10), the range reflects factors including the natural variability in population requirements, uncertainty in the knowledge base, and variability in response during different climate sequences (e.g. maintenance of populations during dry climate sequences at the lower end of the range, and population improvement and recovery during wet climate sequences at the upper end of the range). The lower end of the frequency range (when applied over the long term) may not be sufficient to maintain populations and is unlikely to achieve any recovery or improvement targets. As such, when evaluating EWR achievement over the long-term through statistical analysis of modelled or observed flow records, OEH recommend that the average of the frequency range is used as the minimum long-term target frequency.
Maximum inter-flow or inter-event period	The maximum time between flow events before a significant decline in the condition, survival or viability of a particular population is likely to occur, as relevant to the ecological objective(s) associated with the EWR. This period should not be exceeded wherever possible. *Annual planning of environmental water should consider placing priority on EWRs that are approaching (or have exceeded) the maximum inter-event period, for those EWRs that can be achieved or supported by the use of environmental water or management.*
Additional requirements and comments	Other conditions that should occur to assist ecological objectives to be met – for example rates of rise and fall in flows. Also comments regarding limitations on delivering environmental flows and achieving the EWR.

4.2. Flow thresholds

Table 9 Flow threshold estimates (ML/d) of minimums for flow categories in the regulated PUs in the Murrumbidgee catchment.[55]

Gauging site	Very low flows	Baseflow	Small Fresh	Large Fresh (LF1&2)	Large Fresh: wetland connection (W-LF3-7)[56]	Small overbank (OB-S1&2)[56]	Large Overbank (OB-L1)[56]
UPPER MURRUMBIDGEE (ABOVE BURRINJUCK)							
Murrumbidgee River: Tantangara to Burrinjuck (@ Mittagang: 410033)	32	100	TBD[57]	TBD[57]	NA – limited wetlands below bankfull*	5000*	Not applicable - black box is not prevalent in this area*
REGULATED TUMUT RIVER							
Tumut: Blowering Dam to Murrumbidgee Junction (@ Tumut Town: 410006)	200	600	1,400	5,000	11,000*	18,000*	Not applicable - black box is not prevalent in this area*
REGULATED MURRUMBIDGEE RIVER (BELOW BURRINJUCK)							
Murrumbidgee: Burrinjuck Dam to Tumut Junction (@ downstream Burrinjuck: 410008)	250	450	1,300	5,000	NA – limited wetlands below bankfull*	28,000 (below bankfull level)*	Not applicable - black box is not prevalent in this area*
Murrumbidgee: Tumut Junction to Berembed Weir (@ Wagga: 410001)	250	1,400	5,000	16,000	28,000*	48,000*	Not applicable - black box is not prevalent in this area*

55 These minimums are where the benefits of flow category are likely to begin manifesting. Further substantial benefits occur, particularly for wetland connecting large freshes and overbanks, as flows increase in size. These thresholds SHOULD NOT be used to indicate that constraints only need to be raised to achieve these minimums.

56 Light green background (also marked with an asterisk) denotes that flows to this zone are not deliverable or delivery is severely limited, because of the need to avoid unacceptable impacts on third parties. Usually deliveries to these areas are only possible with pumping or where other infrastructure exists to divert water to off-channel wetlands. These flows generally only occur due to tributary rainfall events or dam spills. Under a ‘constraints relaxed’ scenario, the delivery of these flows and the ability to achieve the associated objectives of this Plan would be significantly enhanced for wetland connecting flow (W-LF3-7) (apart for the Tumut River PU where it would still not be deliverable). Constraints relaxation could also enable some flows at the lower end of the small overbank range (OB-S1&2) to be delivered, but only in the Lower Murrumbidgee and the Murrumbidgee below Balranald PUs.

57 The estimate of these thresholds is subject to work currently being undertaken

Gauging site	Very low flows	Baseflow	Small Fresh	Large Fresh (LF1&2)	Large Fresh: wetland connection (W-LF3-7)[56]	Small overbank (OB-S1&2)[56]	Large Overbank (OB-L1)[56]
Murrumbidgee: Berembed Weir to Gogelderie Weir (@ Narrandera: 410005)	230	1,000	4,000	14,000	25,000*	38,000*	Not applicable - black box is not prevalent in this area, only seen in the western portion of the PU where Darlington Point flows are equally relevant*
Murrumbidgee: Gogelderie Weir to Maude Weir (@ Darlington Point: 410021)	170	800	4,000	12,000	15,500*	28,000*	40,000*
Murrumbidgee: Lowbidgee (@ downstream Maude: 410040)	170	600	2,500	6,000	12,500*	15,000*	22,000*
Murrumbidgee: Balranald to Murray Junction (@ downstream Balranald Weir: 410130)	170	500	2,500	6,000	8,500*	10,500*	20,000*
BEAVERS & OLD MAN CREEKS							
Beavers and Old Man Creeks (Old Man Creek @ Kywong:410093)	50	100	500	2,500	5,800*	6,500*	Not applicable - black box is not prevalent in this area*
YANCO & BILLABONG CREEKS SYSTEM							
Upper Yanco Creek (Yanco Creek @ Offtake: 410007)	80	250	450	1,000	1,500*	2,500*	4,000*
Colombo & Middle Billabong Creeks (Colombo @ Morundah: 410014) – (and, by exception, at Billabong Creek at Jerilderie 410016)	40 at Morundah and 50 at Jerilderie	70 at Morundah and 70 at Jerilderie	250	400	700	1,000*	1,400*
Lower Yanco Creek (@ Morundah: 410015)	40	130	250	400	800	1,000*	2,000*
Lower Billabong Creek (@ Darlot: 410134)	30	50	200	700	1,000	1,600*	3,000*

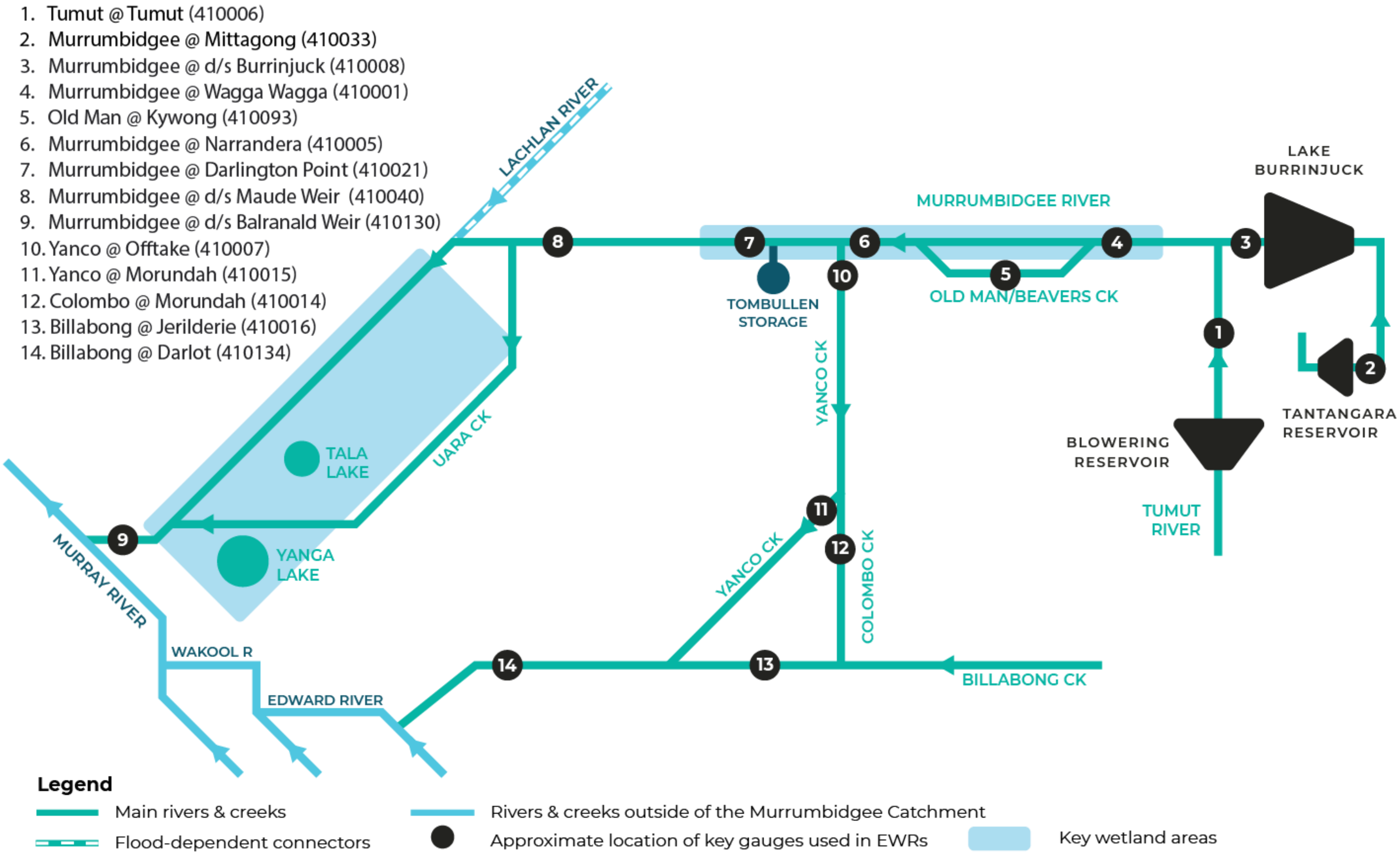

Figure 11 Schematic diagram of the main watercourses and streamflow gauges in the Murrumbidgee catchment

4.3. Catchment-scale environmental water requirements – river flows

Table 10 Catchment-scale environmental water requirements

Flow category and EWR code[58]		Ecological objectives[58]	Ideal flow timing[58]	Duration[58]	Frequency (LTA freq.)[58]	Maximum inter-event period[58]	Additional requirements/ comments[58]
Cease-to-flow	CtF1	Native Fish: NF1 – **Survival** (all species) Ecosystem Functions: EF1, 2 – **refuge** habitat	In line with historical low flow season[59]	In line with natural, unless key refuges endangered[59]	No greater than natural[59]	N/A	When restarting flows, avoid harmful water quality impacts, such as de-oxygenated refuge pools.
Very low flow	VLF1	Native Fish: NF1 – **Survival** and condition (all species) Ecosystem Functions: EF1, 2 – **refuge** habitat	**Any time**	No less than natural[59]	No less than natural[59]	No greater than natural[59]	Flow ideally >0.03–0.05 m/s to de-stratify pools
Baseflow	BF1	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9, 10 – **condition and movement** Native Vegetation: NV1 – in-channel Ecosystem Functions: EF1, 2, 3	**Any time**	No less than natural[59]	Annual	No less than natural[59]	Minimum depth of 0.3 m to allow fish passage
Weir Pool Mixing Pulse	WP 1	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9, 10 – **condition** Ecosystem Functions: EF1, 2 – maintain refuge and habitat quality	**Nov-Mar**	2 days of flow above mixing threshold flow rate	Whenever Lower Murrumbidgee weir pools thermally stratify, and lower layer is expected to become hypoxic. Flow should be delivered before bottom layer becomes hypoxic. Likely to be required multiple times in such years.	Period should not exceed time required for pools to stratify and the bottom layer to become hypoxic	Monitoring required to determine if pools are stratifying and the bottom layer is becoming hypoxic. Requires further research to refine triggers. See Table 17 and Table. Also reduces excessive blue green algal growth. Lowering or removing weir gates may reduce or negate the need for this flow. This should not be considered a requirement for environmental water. Water quality is a responsibility of general river operations.

[58] See Table 8 for definitions of terms and explanatory text for EWRs

[59] Determined using pre-1950 observed data where a multi-decadal record exists or modelled natural where observed data insufficient.

Flow category and EWR code[58]		Ecological objectives[58]	Ideal flow timing[58]	Duration[58]	Frequency (LTA freq.)[58]	Maximum inter-event period[58]	Additional requirements/ comments[58]
Nesting Support	NestS1	Native Fish NF5, 6, 8 - Nesting of riverine specialists (protect nesting sites by avoiding rapid changes in water levels) Native Vegetation: NV1,3 – in-channel & riparian	**15 Sep – 15 Nov** for trout cod and Murray cod. **1 Oct–15 Nov** for only Murray cod. (If flows are in the Baseflow or Small Fresh range at beginning of period, apply EWR requirements)	60 days minimum for trout cod and Murray cod. 45 day minimum for only Murray cod	5–10 years in 10 (75% of years)	2 years	Allow variable flows but avoid large sudden decreases in water level to prevent loss of nesting sites. Flow decreases not to exceed 20th percentile of modelled natural rate of fall (the fastest 20% of natural rates of fall – calculated from the modelled 'without-development' flow data).
Small fresh	SF1	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9, 10 – **Dispersal/condition** (all species) Native Vegetation: NV1 – in-channel Ecosystem Functions: EF1, 2, 3, 4, 5	**Anytime** – but ideally October to April and ideally 2–3 weeks after 'Large Fresh 2'	10 days minimum	2 events per year	1 year	>20°C for Oct to April (for native fish); for river blackfish >16°C; for Murray cod Sept to Dec >18°C Minimum depth of 0.5 metres to allow movement of large fish Rate of fall: No faster than 5th percentile of estimated natural Flow ideally up to 0.3 to 0.4 m/s (depending on channel form)
	SF2	Native Fish: NF1, 2, 5, 6, 8 – **Spawning (river specialists, generalists)** Native Vegetation: NV1 – in-channel Ecosystem Functions: EF1, 2, 3, 4, 5	**15 Sep to April**	14 days minimum	5–10 years in 10 (75% of years)	2 years	>20°C for Oct to April (for native fish); for river blackfish >16°C; for Murray cod Sept to Dec >18°C Minimum depth of 0.5 metres to allow movement of large fish Rate of fall: No faster than 5th percentile of estimated natural Flow ideally up to 0.3 to 0.4 m/s (depending on channel form)

Flow category and EWR code[58]		Ecological objectives[58]	Ideal flow timing[58]	Duration[58]	Frequency (LTA freq.)[58]	Maximum inter-event period[58]	Additional requirements/ comments[58]
Large fresh	LF1	Native Fish: NF1, 2, 4, 5, 6, 8, 9, 10 – **dispersal/condition** (all species) Native Vegetation: NV1, 3 – in-channel/ riparian Ecosystem Functions: EF2, 3, 4, 5, 6, 7	**Anytime**, but ideally July to September Consider delivery outside cod breeding season to avoid flushing of nests.	5 days minimum	5–10 years in 10 (75% of years)	2 years	Minimum depth of 2 m to cover in-stream features and trigger response from fish Flow ideally 0.3 to 0.4 m/s (depending on channel form) Consider delivery outside cod breeding season to avoid flushing of nests. Rate of fall: No faster than 5th percentile of estimated natural
	LF2	Native Fish: NF1, 4, 6, 9 – **spawning (flow pulse specialist fish)** Native Vegetation: NV1 – in-channel Ecosystem Functions: EF2, 3, 4, 5, 6, 7	**October to April** Consider delivery outside cod breeding season to avoid flushing of nests.	5 days minimum	6–7 years in 10 (65% of years)	2 years	Minimum depth of 2 m to cover in-stream features and trigger response from fish Flow ideally 0.3 to 0.4 m/s (depending on channel form) Rapid rise (comparable to natural rates) >17°C Ideally 2–3 weeks before SF1 Rate of fall: No faster than 5th percentile of estimated natural
*Wetland connecting large fresh[60],[61] (below bankfull: in the upper part of the 'Large fresh' band)	W-LF3	Native Fish: NF1, 3, 7 – **refuge pools for floodplain specialists** Native Vegetation: NV1, 2 – **wetland non-woody vegetation** Waterbirds: WB1, 2, 5 Ecosystem Functions: EF1 – **protection of core wetland areas** Other Species (Frogs): OS1	**Anytime** – but ideally July–February for non-woody vegetation	7–12 months water retention for non-woody vegetation. Permanent for key floodplain specialist refuge pools.	8–10 years in 10 (90% of years)	18 months (but no drying out of refuge pools for floodplain specialist native fish)	In dry years maintaining refuge pools for floodplain specialist native fish may require pumping.

[60] In other catchments, connection to major wetlands systems would generally occur at and above bankfull level. The geomorphology of the Murrumbidgee system is such that major billabong, anabranch and other off-channel wetland systems are connected below bankfull level. Hence the category of 'wetland connecting flow is used in the Murrumbidgee.

[61] Light grey background (and rows with * in first column) denotes that some flows to this zone can be delivered, but this is limited, in some planning units severely, by the need to avoid unacceptable impacts on third parties. In such cases, deliveries to these areas are only possible with pumping or where other infrastructure exists to divert water to off-channel wetlands. These flows generally only occur due to tributary rainfall events or dam spills. Under a 'constraints relaxed' scenario, the delivery of these flows and the ability to achieve the associated objectives of this Plan would be significantly enhanced. For some PUs such as the Tumut River PU, however, these flows would still not be deliverable.

Flow category and EWR code[58]		Ecological objectives[58]	Ideal flow timing[58]	Duration[58]	Frequency (LTA freq.)[58]	Maximum inter-event period[58]	Additional requirements/ comments[58]
*	W-LF4	Native Fish: NF1, 3, 7 – **Spawning (floodplain specialist fish)** Native Vegetation: NV1, 2, 3, 4 – non-woody wetland vegetation, riparian river red gum Waterbirds: WB1, 2, 5 – habitat Ecosystem Functions: EF2, 3, 4, 5, 6, 7 – connectivity, productivity Other Species (Frogs): OS1 – habitat	October to April (and August–September where remnant populations of flathead galaxias are found or where they are reintroduced)	10 days minimum[62]	5 years in 10. (50% of years) Or 7–8 years in 10 where remnant populations of flathead galaxias or Murray hardy-head are found or are reintroduced	2 years Or 1 year should remnant populations of flathead galaxias or Murray hardyhead are found or are reintroduced	>22°C Ideally, recruitment flow 2–4 weeks after spawning flow In very dry periods deliver to discrete wetlands via infrastructure to protect populations where required and feasible.
*	W-LF5	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9, 10 – **dispersal & condition** (all species) Native Vegetation: NV1, 2, 3 – riparian river red gum communities Waterbirds: WB1, 2, 5 – habitat Ecosystem Functions: EF2, 3, 4, 5, 6, 7 – lateral floodplain, productivity, bench and pool forming Other Species (Frogs): OS1 – habitat	Anytime – but ideally Sept to Feb	5 days minimum for fish dispersal	2–3 years in 10 (25% of years)	5 years	
*	W-LF6 Non-woody veg zone	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9 – dispersal & condition (all species) Native Vegetation: NV2, 3, 4 – **Non-woody vegetation in wetlands**, river red gum forest fringing wetlands/channels Waterbirds: WB1, 2, 3, 5 – habitat, small scale breeding	July to February, with benefits also outside that period including by providing bird foraging habitat	3–10 months. Refers to the persistence of standing water (minimum 3-7 months depending on vegetation community)	6–8 years in 10 (70% of years)	2 years	Ideally provide slow draw down for shallow muddy edges for bird foraging habitat. For best benefits duration of standing water of at least 90 days is required during the growing season (from September on). Some frog species are summer breeders so will need at least 3 months from October.

[62] 10 days is minimum to allow fish to promote productivity and food production in a wetland and support spawning/nesting and hatching. There may be cases where populations of floodplain specialists can be supported with shorter flows (i.e., substantial habitat already exists, and small inflows promote additional productivity and food supply). In non-permanent wetlands a follow up reconnecting flow may be required within 12 months or water levels in the wetland will need to be maintained with infrastructure until the next re-connection.

Flow category and EWR code[58]		Ecological objectives[58]	Ideal flow timing[58]	Duration[58]	Frequency (LTA freq.)[58]	Maximum inter-event period[58]	Additional requirements/ comments[58]
		Function: EF1, 2, 3, 4, 5, 6, 7 – core wetland habitats, lateral connectivity, productivity Other Species (Frogs): OS1, 2, 3 – **recruitment**					To increase cover and extent of non-woody vegetation communi-ties – clustered, sequenced flows (i.e. annual flows over 2–3 years) are required. The provision of periods of higher flow magnitude and successive flows also has the potential to increase non-woody vegetation cover and extent and/or limit encroachment of woody species (if desired).
*	W-LF7 Fish connect flow	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9, 10 – **dispersal from off channel wetlands** (all species) Native Vegetation: NV1, 2, 3 Waterbirds: WB1, 5 Ecosystem Functions: EF2, 3, 4, 5, 6, 7 – connectivity Other Species (Frogs): OS1	**Anytime**[63], but triggered by significant fish breeding in off-channel wetlands. Flow 3 to 18 months after breeding occurs. Flow must occur before habitat (depth, cover, water quality) of waterbody is lost by drying.	5 days	3 years in 10 or as required by breeding triggers (30% of years)	5 years	Ideally provide a protracted recession to promote exit to the river. This flow should occur within 3–18 months of the initial filling, so long as sufficient habitat (depth, cover) is maintained in the wetland to support the strong 0+ cohort until re-connection occurs – may be wetland specific. Trigger is verified breeding event. Where there has been insufficient monitoring to confirm/deny this, the trigger is a long duration wetland connecting large fresh (W-LF4) or an overbank (OB-S1/S2 or OB-L1) in those PUs where these have been shown to produce significant breeding responses. The 3+ month delay following the breeding event is to allow recruits to utilise the nursey habitat and reach sufficient maturity to move into the river.

[63] Return movement may vary seasonally, so future research will inform any necessary refinement in the timing of this.

Flow category and EWR code[58]		Ecological objectives[58]	Ideal flow timing[58]	Duration[58]	Frequency (LTA freq.)[58]	Maximum inter-event period[58]	Additional requirements/ comments[58]
Floodplain Connection Flow (Overbank Small 1) (Floodplain specialist fish)[64] #	OB-S1	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9, 10 – spawning (floodplain specialist) Native Vegetation: NV2, 3, 4a, 4b, 4e Waterbirds: WB1, 2, 3, 4, 5 Ecosystem Functions: EF2, 3, 4, 5, 6, 7 Other Species (Frogs): OS1, 2, 3	October to April for floodplain specialist fish spawning.	10 days min for floodplain specialist fish.[65]	5 years in 10 (50% of years)	4 years	For floodplain specialist fish – ideally >22°C and 2–4 weeks after spawning flow
#Floodplain Connection Flow (Overbank Small 2) (River red gum zone)[64]	OB-S2	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9, 10 – dispersal and condition (all species) Native Vegetation: NV2, 3, 4a, 4b, 4e river red gum (riparian and floodplain wetland), lignum Waterbirds: WB1, 2, 3, 4, 5 – habitat and potential small-scale breeding Ecosystem Functions: EF2, 3, 4, 5, 6, 7 – channel forming, lateral connectivity, productivity Other Species (Frogs): OS1, 2, 3 – recruitment	August to February, with benefits also outside that period including by providing bird foraging habitat	In line with natural59 median duration for fish dispersal and riparian river red gum communities. For wetlands 3–7 months' persistence of standing water. For streamside areas, only duration to fill the soil profile, depressions/ billabongs required.	5 years in 10 (50% of years)	4 years	Ideally maintain stable water levels in active waterbird colony sites and provide slow draw down for shallow muddy edges for bird foraging habitat. Clustered, sequenced flows (i.e. annual flows over 2–3 years) are required to support river reg gum flowering, seed set and seedling establishment to encourage veg-etative growth of lignum stands and lignum seedling germination and establishment. This also benefits river cooba. Successive flows will also improve the condition of existing river red gum, lignum and river cooba. For timing: flow can occur earlier, but for best benefits, duration of standing water of at least 90 days is required from Sep on to fit with vegetation

[64] Dark grey shading (and # in 1st column of row) denotes flows of this size are not able to be delivered as environmental water deliveries in the river. They currently only occur due to tributary rainfall events or dam spills. Deliveries to these areas are only possible with pumping or where other infrastructure exists to divert water to the flood-plain. They would also not be deliverable under a 'constraints relaxed' scenario, except for in Lower Murrumbidgee Floodplain and the Murrumbidgee below Balranald PUs.

[65] 10 days is minimum to allow fish to complete spawning cycle and for larvae/eggs to move back to channel. There may be cases where floodplain specialists can be supported with shorter flows (i.e., too short for larvae to return to the river). Here a follow up reconnecting flow is required within 6 months or water levels in the wetland will need to be maintained with infrastructure until the next reconnection.

Flow category and EWR code[58]		Ecological objectives[58]	Ideal flow timing[58]	Duration[58]	Frequency (LTA freq.)[58]	Maximum inter-event period[58]	Additional requirements/ comments[58]
							growing season and bird breeding seasonality. Some frog species are summer breeders, which will need at least 3 months from October.
#Large Floodplain Connection Flow (Overbank Large 1) (Black box zone)[66]	OB-L1	Native Fish: NF1, 3, 7, 10 Native Vegetation: NV2, 3, 4a, 4b, 4c, 4e – black box & lignum & river red gum woodland high on floodplain Waterbirds: WB1, 2, 3, 4, 5 – large-scale breeding (colonial and non-colonial) and habitat Ecosystem Functions: EF2, 3, 4, 5, 6, 7 – lateral connectivity, productivity Other Species (Frogs): OS1, 2, 3 – recruitment	September to March, with benefits also outside that period including by providing bird foraging habitat	2–6 months for black box and lignum in wetlands. 3–6 months for bird breeding. Refers to the persistence of standing water, flow can be shorter. For streamside areas, only duration sufficient to fill the soil profile, depressions/ billabongs required.	2–3 years in 10 (25% of years)	5 years	Ideally maintain stable water levels in active waterbird colony sites and slow draw down for shallow muddy edges for bird foraging habitat. To support black box flowering and seed establishment, to encourage vegetative growth of lignum stands and lignum seedling establishment clustered, sequenced flows (i.e. annual flows over 2–3 years) are required. This also benefits river cooba. The provision of periods of successive flows will also increase the potential for recovery of existing river red gum, lignum and river cooba communities
^Large Floodplain Connection Flow (Overbank Large 2) (Outer black box zone)[66]	OB-L2	Native Fish: NF1, 3, 7, 10 Native Vegetation: NV2, 3, 4a, 4b, 4c, 4e – **black box & lignum** Waterbirds: WB1, 2, 3, 4, 5 – **large-scale breeding (colonial and non-colonial) and habitat** Ecosystem Functions: EF2, 3, 4, 5, 6, 7 – lateral connectivity, productivity Other Species (Frogs): OS1, 2, 3 – **recruitment**	**Anytime,** but preferably August to March for bird and frog breeding benefits	2–6 months for black box and lignum in wetlands. 3–6 months for bird breeding. Refers to the persistence of standing water, flow can be shorter. For streamside areas, only duration sufficient to fill the soil profile, depressions/ billabongs required.	1–2 years in 10 (15% of years)	10 years	Currently only assessed for the Lowbidgee. This is assessed as a volumetric requirement (see Table 11 and Table 12).

[66] Green shading (and ^ in 1st col of row) denotes flows of this size are not able to be delivered as environmental water deliveries in the river (even under a 'constraints relaxed' scenario). They occur due to tributary rainfall events or dam spills. Deliveries to these areas are only possible with pumping or where other infrastructure exists to divert water to the floodplain

4.4. Environmental water requirements – specific Lowbidgee volumetric requirements

The MDBA (2012c) set out a number of volumetric requirements for the Lower Murrumbidgee River Floodplain. These were noted as a total flow volume over a particular number of days. These flow volumes are still relevant and are presented below. Note that they are not independent of the catchment scale EWRs (river flows) presented above – as in many cases providing those river flows will fully or partially meet some of the volumetric requirements set by the MDBA (2012c) for the Lower Murrumbidgee Floodplain.

Table 11 environmental water requirements for the Lower Murrumbidgee River Floodplain from MBDA (2012c)

Event (flows gauged at Maude Weir)		Frequency-proportion of years event required to achieve ecological target (%)		Proportion of years event occurred in modelled baseline conditions (%)	Related EWR (see Table 10)
Total inflow required (GL)	Timing	Low uncertainty	High uncertainty		
175	July–September	75	70	68	W-LF6
270	July–September	70	60	57	W-LF6
400	July–October	60	55	52	W-LF6 and OB-S2
800	July–October	50	40	39	OB-S2
1,700	July–November	25	20	18	OB-L1
2,700	May–February	15	10	9	OB-L2

Note: Volumes are for flows from days with minimum flow rates of 5,000 ML/day.

The MDBA (2012c) *Environmental Water Requirements for the Lower Murrumbidgee Floodplain* present an overall picture of volumes. In the Lowbidgee Floodplain Maude and Redbank weirs, in conjunction with a number of regulators, enable flows to be directed onto parts of the floodplain.

There is benefit in breaking down the EWRs for the Lowbidgee Floodplain into the components that can be managed through the regulators – that is:

- the Nimmie-Caira system (off Maude Weir)
- the Yanga system (from channels to the south of Redbank Weirpool and also from flows through the Nimmie-Caira)
- the North Redbank system
- the Western Lakes (supplied via the North Redbank system)

The EWR estimates in Table 12 were determined using information and modelling from NSW DoI–W (in prep) (for the Nimmie–Caira area) and information from wetland managers and environmental water managers.

Table 12 environmental water requirements for the portion of the Lower Murrumbidgee River Floodplain that can be watered from regulators off Maude and Redbank weirs. Refer to Table 10 for objectives for each flow category

Flow Category	Planning sub unit	Gauge	Flow (ML/day)	Duration (days)	Timing	Frequency	Max gap b/w events	Notes	Estimated volume (ML)
W-LF3 – wetland connecting flow – for core wetland and refuge	Nimmie-Caira	Eulimbah	200	12–15	Any time (but ideally July–February)	8–10 years in 10	18 months (but no drying out of refuge pools for floodplain specialist native fish)	For refuge creeks. In dry years, providing channel deliveries may require operating weir pools during times of potential stratification	6,750 This is the combination of Eulimbah & Nimmie Creek flows for the minimum duration
		Nimmie Creek	250						
	Yanga (South Redbank)	1AS	500	>20				Assumes no contribution via Nimmie-Caira. This is flow from 1AS to Piggery Lake (flows to Breer provided by reconnection flows from river).	10,000
	North Redbank	Glen Dee	300	10				Watering of Narwie and Steam Engine Swamp	4,500
		Pump direct from river	30	50				Deep water refuge habitat in lagoons of Moola/Baupie/ Balranald Common	
W-LF6 – wetland connecting flow – non-woody veg	Nimmie-Caira	Eulimbah	200	25	July–February	6–8 years in 10	2 years		11,250
		Nimmie Creek	250						
	Yanga (South Redbank)	1AS	500	20				Assumes no contribution via Nimmie-Caira. Flows from 1AS to Piggery Lake (flows to Breer provided by reconnection flows)	10,000
	North Redbank	Glen Dee	500	>20				Water provided from Athen to Murrundi	10,000

Flow Category	Planning sub unit	Gauge	Flow (ML/day)	Duration (days)	Timing	Frequency	Max gap b/w events	Notes	Estimated volume (ML)
	Western Lakes	Glen Dee	20	50				In addition to above Glendee volume Dependent on installation of infrastructure to get to target. Targeting Paika Creek/Dundamallee Reserve areas adjacent to Paika Lake including the Reed Bed Reserve	1,000
OB-S2 - overbank small (50%) for river red gum & small scale bird breeding	Nimmie-Caira	Eulimbah	1200	35–42	August to February	5 years in 10	4 years	Flows through Nimmie-Caira reach southern Yanga.	60,900 – Combined flows at both gauges.
		Nimmie Creek	250						
	Yanga (South Redbank)	Combined 1AS + 1ES	800	80				Assumes water via Nimmie-Caira (above)	64,000
	North Redbank	Glen Dee	800	75				Juanbung through to Balranald Common	60,000
	Western Lakes	Glen Dee	300	30				In addition to above Glendee volume. Partial top up of Paika Lake. There may be sequences of years where this will not be required where a drying down of the lake is desired.	9,000
OB-L1 – overbank large (25%)	Nimmie-Caira	Eulimbah	2000/200	22 to 24 / 66	September to March	2–3 years in 10	5 years	In addition to Maude 4 yr ARI of 20 GL/day[67]	83,700

[67] NSW DOI-LW (in prep) noted this requirement.

Flow Category	Planning sub unit	Gauge	Flow (ML/day)	Duration (days)	Timing	Frequency	Max gap b/w events	Notes	Estimated volume (ML)
for outer river red gum, lignum & lower black box & large-scale bird breeding		Nimmie Creek	250/250					Flows include initial event plus top-up volumes (event/top up) Flows pass through into Yanga	
	Yanga (South Redbank)	1AS + 1ES	800/200	50 / 60				In addition to Maude 4 yr ARI of 20 GL/day. Flows include initial event plus top-up volumes (event/top up)	52,000
	North Redbank	Glendee	500	40 (+20 if return flows)				In addition to Maude 4 yr ARI of 20 GL/day. Capacity to return ~10GL flows via Wynburn & Baupie escapes	20,000
	Western Lakes	Glendee	350	45				In addition to above Glendee volume. Top up of Paika Lake after 2 years of drying	~16,000
OB-L2 - overbank large (15%) for black box & large-scale bird breeding	Nimmie-Caira	Eulimbah	100	60	Anytime, but preferably August to March for bird & frog breeding benefits	1–2 years in 10	10 years	In addition to Maude 7 yr ARI of ~25GL/day.68 To support active major waterbird colonies which have been initiated by natural large flood events. Flows include initial event plus top-up volumes (event/top up). Flows pass through Nimmie-Caira & into Yanga. These deliveries may coincide with in-channel fish refuge flows	12,000
		Nimmie Creek	100						

[68] Based on notes in NSW DOI-LW (in prep) that delivery should be in conjunction with flow uncontrolled flood events of the order of 14% AEP which is approximately a 7 yr ARI. A 7 year ARI equates to around 25,000 ML/day.

Flow Category	Planning sub unit	Gauge	Flow (ML/day)	Duration (days)	Timing	Frequency	Max gap b/w events	Notes	Estimated volume (ML)
								to offset negative impacts of hypoxic blackwater.	
	Yanga (South Redbank)	1AS + 1ES	200	60				In addition to Maude 7 yr ARI of ~25GL/day. Flows include initial event plus top-up volumes (event/top up).	12,000
	North Redbank	Glendee	400 [200 for rookeries; 2x100 for return flows]	60 + 30				In addition to Maude 7 yr ARI of ~25GL/day.	18,000
	Western Lakes	Glendee	350	70				In addition to above Glendee volume. For the filling of Paika Lake and of Hobblers Lake.	~24,000

4.5. Important flow regime characteristics

Table 13 Important flow regime characteristics needed to deliver long term water plan objectives

Ecological objective	Important flow regime characteristics
NATIVE FISH OBJECTIVES[69]	
NF1: No loss of native fish species	Cease-to-flow: durations should not exceed the persistence of water of sufficient volume & quality in key larger river pool refuges for survival of native fish. In areas where cease-to-flow events are rare, they should be avoided to avoid stress on the fish community. Very low flows (VLF) & baseflows (BF1): for the survival & maintenance of native fish condition. These flows maintain adequate water quantity & quality (dissolved oxygen, salinity & temperature) in refuge pools. Baseflows & small freshes: deep enough along the whole channel to allow fish movement (at least 0.3 m above cease-to-flow for small & moderate bodied fish [Gippel 2013; O'Conner et al. 2015] & 0.5 m for large bodied fish [Fairfull & Witheridge 2003; Gippel 2013; O'Conner et al. 2015]). Weir pool mixing flows (WP1): in hot periods where weir pools on the lower Murrumbidgee River stratify (Webster et al., 2000) and the bottom layer becomes hypoxic. These flows are to mix the stratified layers before dissolved oxygen levels become so low that fish deaths may occur when a later mixing occurs. Timely lowering or removal of weir gates may negate the need for these flows. Large freshes (LF1): of at least 5 days duration. LF1 should occur ideally between July & September (but can occur at any time) to promote dispersal & pre-spawning condition for all native fish species 5 to 10 years in 10. LF1 should trigger some primary productivity providing food resources & improving fish condition prior to the spring/summer spawning season. Flow velocities of >0.3 m/s are ideal to trigger fish movement. Larger freshes which connect to wetlands (W-LF3, 5): W-LF3 to maintain core wetlands, including off-channel waterholes. Alternative watering actions (e.g. pumping) may be required to support floodplain habitats under very dry, dry & moderate scenarios to prevent habitat for floodplain specialists from drying out. W-LF5 should occur ideally from September to February, for at least 5 days & occurring 2 to 3 years in 10 (with a maximum inter-event period of 5 years) to support condition & movement/dispersal outcomes of all native fish groups. Larger flows that connect low-lying wetlands provide important habitat to support strong survivorship & growth of juveniles. Small overbanks (OB-S1&2): In parts of the catchment overbank flows are required to inundate wetlands. These flows should ideally occur 5–10 years in 10. Larger flows that inundate off-stream habitat also promote growth & recruitment through increased floodplain productivity & habitat availability. These flows are particularly important for floodplain specialist fish.

[69] Important flow regime characteristics for all native fish objectives are based on NSW DPI 2015.

Ecological objective	Important flow regime characteristics
NF2: Increase the distribution & abundance of short to moderate-lived **generalist** native fish species	In addition to the flows listed above for all native fish species (NF1), other important aspects of the flow regime for generalists include: Regular (ideally annual) spawning & recruitment events for the persistence of short-lived species. Spawning can occur independent of flow events, however, small freshes (SF2) enhance spawning. Events should occur during the warmer months of September to April, 5 to 10 years in 10, with a minimum event duration of 21 days to adequately cover the period of egg development & hatching. Multiple freshes during the spawning season provides flexibility in species response and opportunities for multiple spawning events.
NF3: Increase the distribution & abundance of short to moderate-lived **floodplain specialist** native fish species	In addition to the flows listed above for all native fish species (NF1), other important aspects of the flow regime for floodplain specialists include: Overbank and wetland inundating flows (W-LF4 & OB-S1): that connect low lying wetland habitats during the warmer months of October to April provide spawning habitat & floodplain productivity benefits to support fish growth. Overbank & wetland flows should inundate floodplain habitats for at least 10 days to allow for egg development & occur at least 5 years in 10, with a maximum inter-event period of 4 years. This period will depend on the persistence of floodplain habitats & time between reconnection to mainstem waterways. Flows should be of long enough duration to support isolated populations. Water temperatures should be above 22°C. Recruitment is enhanced by subsequent flows events (large fresh, bankfull or overbank & wetland inundating flows) 2–4 weeks after spawning flows. Most floodplain specialist species require spawning & recruitment every 1 to 2 years for population survival.
NF4: Improve population structure for moderate to long-lived **flow pulse specialist** native fish species	In addition to the flows listed above for all native fish species (NF1), other important aspects of the flow regime for flow pulse specialists include: A large fresh (LF2) between October to April for a minimum of 5 days for spawning. This is needed 6 to 7 years in 10 with a maximum inter-event period of 2 years. Spawning is triggered by a rapid rise or fall in flow (relative to natural rates) when temperatures are greater than 17°C. In lowland systems, spawning responses are enhanced by substantial flow depths of at least 2 m to cover in-stream features & high flow velocities of greater than 0.3 m/s. Integrity of flow events need to be maintained over long distances (10s to 100s of km) to maximise the capacity for in-stream spawning, downstream dispersal by drifting eggs & larvae & movements by adults & juveniles.
NF5: Improve population structure for moderate to long-lived **riverine specialist** native fish species	In addition to the flows listed above for all native fish species (NF1), other important aspects of the flow regime for riverine specialists include: Spawning usually occurs annually, independent of flow events. However, small freshes (SF2) may enhance spawning by promoting ecosystem productivity & inundating additional spawning habitat. Events should occur during the warmer months of September to April, 5 to 10 years in 10. Water temperatures should be >20°C. River blackfish may spawn in lower water temperatures of >16°C & Murray cod in >18°C. Murray cod have a narrower spawning window of September to December. For nesting species (e.g. Murray cod & eel-tailed catfish) preventing rapid drops in water levels (that exceed natural rates of fall) during, & for a minimum of 14 days after, spawning is important to prevent fish nests from drying (NestF1).

Ecological objective	Important flow regime characteristics
	Recruitment is enhanced by a secondary flow pulse (large fresh, bankfull or overbank) for dispersal & access to nursery habitat in low-lying wetland habitats. Overall, riverine specialists prefer hydraulically complex flowing streams containing submerged structure (snags & benches) that provides cover & spawning habitat. Flow variability through the delivery of small & large freshes, bankfull & overbank flows enhance the availability of diverse habitat, enhances growth & condition of larvae & juveniles & provides connectivity for dispersal between habitats.
NF6: A 25% increase in abundance of mature (harvestable sized) golden perch & Murray cod	Flow requirements of golden perch (flow pulse specialist) & Murray cod (riverine specialist) are outlined above under NF4 & NF5, respectively.
NF7: Increase the prevalence &/or expand the population of key short to moderate-lived **floodplain specialist** native fish species into new areas (within historical range)	Flow requirements of floodplain specialists are outlined for NF3. Expanding populations into new areas will be particularly dependent on dispersal flows, which include large freshes (LF1), & overbank & wetland inundating flows (W-LF5-7, OB-S1&2). Complementary actions such as conservation stocking &/or translocation may be required to support these watering actions. Infrastructure based watering actions (e.g. pumping) may also be required to support floodplain habitats under very dry, dry & moderate scenarios to ensure no loss of species for floodplain specialists (e.g. to prevent wetlands with threatened fish species from drying out).
NF8: Increase the prevalence &/or expand the population of key moderate to long-lived **riverine specialist** native fish species into new areas (within historical range)	Flow requirements of riverine specialists are outlined for NF5. Expanding populations into new areas will be particularly dependent on dispersal flows, which include large freshes (LF1), & overbank & wetland inundating flows (W-LF5-7, OB-S2). Complementary actions such as conservation stocking &/or translocation may be required to support these watering actions.
NF9: Increase the prevalence and/or expand the population of key moderate to long-lived **flow pulse specialists** native fish species into new areas (within historical range)	Flow requirements of flow pulse specialist are outlined for NF4. Expanding populations into new areas will be particularly dependent on dispersal flows, which include large freshes (LF1), & overbank & wetland inundating flows (W-LF5-7, OB-S2).
NF10: Increase the prevalence and/or expand the population of key moderate to long-lived **diadromous** native fish species into new areas (within historical range)	Diadromous fish species native to the Murray Darling Basin include short-headed lamprey, which was reported in the Murrumbidgee around Narrandera in the 1970s (Gilligan, 2005, pers. comm. 2018). These species undertake long distance upstream migrations (100s to 1000s km) from the sea to freshwater habitats the River Murray and its tributaries in winter-spring to spawn the following spring (Lintermans, 2007; McDowall 1996). Ammocoetes (juvenile lamprey) spend on average 3 years in the rivers before they metamorphose and return to the sea to complete their life cycles. They can take months to migrate down the rivers back to the sea, making them vulnerable to diversions and physical barriers to fish movement. Large freshes, wetland connecting large freshes and overbank flows are beneficial in winter to early spring to cue upstream migration of lamprey from the sea to upstream spawning sites. Lamprey are likely to

Ecological objective	Important flow regime characteristics
	continue to migrate upstream throughout spring so multiple large freshes or higher flows are beneficial during winter and spring to support this. Maintaining longitudinal connectivity of flows (from source to sea) is important for supporting long-distance migrations and preserving biochemical signatures from flow sources which may provide olfactory migratory cues. Diversions of flows may disrupting migration. Very-low flows (VLF1), baseflows (BF1) and small and large freshes (e.g. SF1,2; LF1,2) are required during other times of year to support survival and recruitment and to allow mature lamprey to return to the sea.
NATIVE VEGETATION OBJECTIVES[70]	
NV1: Maintain the extent & viability of non-woody vegetation communities occurring within & closely fringing channels	Non-woody plants growing on the channel bed, banks, bars and benches require regular wetting and drying to complete life cycles. Frequent (near annual) inundation through baseflows and large freshes (LF1) for eight to twelve months will promote vigorous growth and expansion of tall emergent aquatic species such as cumbungi and common reed (*Phragmites australis*) and giant rush within and closely fringing channels. Inundation of channel banks during late winter and early spring by freshes is required to replenish soil moisture to promote growth during spring. Prolonged submergence of some species (e.g. especially if there are continuous high flows during the irrigation season) may have detrimental impacts on survival. Dry phases in summer and autumn for one to four months may encourage recruitment. Regular inundation will also encourage a dominance of native species over exotic species, mostly which are adapted to dry environments. Increased cover of non-woody vegetation on river banks is likely to stabilise bank material reducing excessive bank erosion.
NV2: Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains	Non-woody vegetation communities in low-lying wetlands through to elevated parts of the floodplain require a flooding regime to complete life cycles. The required duration and frequency for growth and reproduction can vary widely within and between species. In response to variable water availability wetland vegetation communities will naturally transition between wet and dry adapted species. During flood recession and draw-down, species diversity can increase as conditions transition to suit amphibious and dry adapted species. Prolonged dry periods between flood events can inhibit the regrowth of non-woody vegetation when reflooded, an important consideration for recovery. Wetland connecting large freshes (W-LF3-5) will support non-woody wetland vegetation in low-lying wetlands. Tall emergent aquatic species such as cumbungi and common reed require annual inundation for up to eight to twelve months duration to promote vigorous growth and expansion with a maximum period between events of 18 months. Characteristic sedge species, such as tall spikerush (*Eleocharis sphacelata*) and common spikerush (*Eleocharis acuta*) require inundation from June to February, for three to eight months, three to six

[70] Important flow regime characteristics for all native vegetation objectives are based on Bowen, S. pers comms, Cassanova 2015, Roberts & Marston 2011, Roberts & Marston 2000, and Rogers & Ralph 2011.

Ecological objective		Important flow regime characteristics
		years in ten, with a maximum period between events of three to four years. Small to moderate but frequent wetland inundating events (e.g. W-LF6) will be important for maintaining the extent and viability of these species. Overbank flows (OB-S2) will support non-woody vegetation at high elevations on the floodplain. Sedge rhizome viability may be affected after more than two to four years between flow events, while seedbank viability for many species is vulnerable after more than 10 years. Other species, such as cane grass and spiny mud grass require inundation from June to February for five to 10 months, for 7–9 years in ten, with a maximum period between events of two years. If establishing from dry, some species may require inundation duration to cover two growing seasons. Slow rates of recession following inundation will enable existing species to follow the waterline and seeds to germinate and complete life cycles.
NV3: Maintain the extent & maintain or improve the condition of river red gum communities closely fringing river channels		River red gum fringing river channels will be supported by a range of flows including, wetland inundating large freshes that inundate fringing riparian zone (W-LF4-6). Larger freshes (W-LF4-6) that recharge alluvial aquifers and soil moisture in the riparian zone are also important for maintaining deep rooted vegetation between inundation events. The general condition of riparian vegetation will benefit from inundation or groundwater recharge anytime of the year, with an ideal frequency of inundation of four to ten years in ten to maintain good condition.
NV4: Maintain the extent & maintain or improve the condition of native woodland & shrubland communities on floodplains	River red gum forest	Maintaining the condition and extent of river red gum forests requires overbank flows (OB-S2) to inundate vegetation between two to seven months, during August to February. Frequency of inundation is required every 5 to 10 years in ten, with a maximum period between events of three years. Slow rates of flow recession may encourage seed fall and germination. Regeneration of river red gum forest communities will require additional, follow-up flows of shorter duration (one to two months) during August to November. These flows would ideally occur in the year following a maintenance flow to support the survival of seedlings from the previous year (where recruitment is desired). Follow-up flows that occur 12 months after a maintenance flow (or an above average rainfall year) will also support the development and maintenance of bud crops and aerial seedbanks on mature trees. The provision of periods of successive flows will also increase potential to improve the recovery of existing river red gum forest communities. Variable timing, frequency and duration of inundation will promote greater floodplain forest understorey diversity (NV2b).
	River red gum woodland	Maintaining the condition and extent of river red gum woodlands located higher on the floodplain requires overbank and wetland inundating flows (OB-S2) for two to four months during August to February. Frequency of inundation is three to five years in ten, with a maximum period between events of 5 years. Slow rates of recession may encourage seed fall and germination. An interval greater than five years between inundation events may result in decreased condition. Variable timing, frequency and duration of inundation will promote woodland understorey diversity (NV2b). Regeneration of river red gum communities will require additional, follow-up flows of shorter durations (one to two months) during August to November. These events would ideally occur in the following year to

Ecological objective		Important flow regime characteristics
		support the survival of seedlings that may have established in the previous year (where recruitment is desired). In dry years, additional inundation (one to two months) may be required in the following autumn following a maintenance inundation event to support seedling establishment. Seed yields of mature trees are affected by water availability over the 2–3 years prior to seed fall, therefore follow-up flows, 12 months after a maintenance flow (or above average rainfall) also supports bud crops and aerial seedbanks that may have developed in the previous year.
	Lignum shrubland	Maintenance of lignum shrubland communities requires inundation by wetland or large overbank inundating flows for two to seven months. For lignum located in lower parts of the floodplain overbank (OB-S2) that occur five to ten years in 10, with a maximum interflow period of four years are required. To support good condition lignum shrublands located on the elevated parts of the floodplain, larger overbank flows (OB-L1) that occur two to three years in ten, with a maximum inter flow period of 5 years are required. A higher frequency of inundation may be required in areas with saline soils. Timing of inundation is not critical. Variable timing, frequency and duration of inundation will also promote greater shrubland understory diversity (NV2b). Regeneration requires more frequent inundation for two to four months to support seedling establishment or up to twelve months to support vegetative expansion. Ideal timing is autumn to winter and regeneration events would ideally occur in the year following a maintenance flow to support the establishment of seedlings or vegetation expansion from the previous year. The provision of periods of successive flows will also increase potential to improve the recovery of existing lignum communities.
	Black box woodland	Larger overbank flows (OB-L1 and OB-L2) are required to maintain and improve condition of black box woodland communities, which tend to be located on higher parts of the floodplain. Maintenance requires inundation for two to six months, at a frequency of two to three years in ten. A maximum period between events of five years is desirable, but up to 10 years for black box areas higher on the floodplain. Timing is not critical and variable timing, frequency and duration of inundation will promote greater woodland understorey diversity (NV2b). Regeneration of black box communities will require additional, follow-up flows of shorter durations (one to two months) during August to November. These events would ideally occur in the following year to support the survival of seedlings that may have established in the previous year (where recruitment is desired). In dry years, additional inundation (one to two months) may be required in the following autumn following a maintenance inundation event to support seedling establishment. Seed yields of mature trees are affected by water availability over the 2–3 years prior to seed fall, therefore follow-up flows, 12 months after a maintenance flow (or above average rainfall) also supports bud crops and aerial seedbanks that may have developed in the previous year. The provision of periods of successive flows will also increase potential to improve the recovery of existing black box communities.

Ecological objective	Important flow regime characteristics
WATERBIRD OBJECTIVES[71]	
WB1: Maintain the number & type of waterbird species	Overbank & wetland inundating flows (W-LF3, 4, 6, OB-S2, OB-L1): to provide refuge, support feeding & breeding habitat (see WB2, 3, 4) & maintain habitat condition (WB5). Overbank & wetland inundating flows, preferably delivered in spring–summer, that inundate a mosaic of floodplain habitats including non-woody floodplain vegetation, open shallow waterbodies & deep lagoons will provide feeding habitat for a range of waterbird species including open water foragers, herbivores, emergent vegetation dependent species, large waders, wetland generalists & small waders (including migratory shorebird species). Where there is gradual draw-down of habitats over late summer–autumn this can extend feeding habitat available for migratory & resident shorebird species (small waders).
WB2: Increase total waterbird abundance across all functional groups	Overbank & wetland inundating flows (W-LF3, 4, 6, OB-S2, OB-L1): as in WB1 provide seasonal (spring–summer) inundation with gradual draw-down over summer into autumn to provide feeding & breeding habitat (WB3, 4) & maintain the habitat condition (WB5). Where possible to coordinate, these flows should be delivered to compliment events in neighbouring catchments to provide benefits to waterbird populations by providing habitat across a larger area of the southern Murray-Darling Basin. Follow-up overbank & wetland inundating flows in years following large breeding events in the Murray, Lachlan & neighbouring catchments in the southern Murray-Darling Basin will also promote the survival of juvenile birds & contribute to increased waterbird populations.
WB3: Increase opportunities for non-colonial waterbird breeding	Overbank & wetland inundating flows (W-LF6, OB-S2, OB-L1): to inundate floodplain habitats for more than 3 months. Spring & summer (preferably September to March) is the ideal season, with opportunistic breeding in autumn & winter. Habitat availability for non-colonial species will increase with increasing magnitude (both extent & duration of inundation) of overbank & wetland inundating flows. Also relies on maintaining (& in some cases improving) the condition of key native vegetation types that provide breeding & foraging habitats (see WB5).
WB4: Increase opportunities for colonial waterbird breeding	Overbank & wetland inundating flows (OB-S2, OB-L1, OB-L2): to inundate colony sites & surrounding foraging habitat for 3 to 6 more months (depending on the species) to ensure successful completion of colonial waterbird breeding (from egg laying through to fledging including post-fledgling care) & provide foraging habitats to enhance breeding success & the survival of young. Ideally September to March. Larger wetland inundation flows (OB-L1 & OB-L2) will support larger colonies & a greater number of breeding species with greater benefit to breeding success & increasing total abundance of waterbirds (WB2, WB3). These large overbank events are required on average 2 to 3 years in 10 years, with a maximum inter-event period of 5 years (ideally 4). Smaller floodplain and wetland inundation flows (OB-S2) may support smaller colonies and should ideally occur 5 years in 10.

[71] Important flow regime characteristics for all waterbird objectives are based on Brandis 2010, Brandis & Bino 2016, Rogers & Ralph 2011, and Spencer 2017.

Ecological objective	Important flow regime characteristics
WB5: Maintain the extent & improve condition of waterbird habitats	Colonial waterbird species are dependent on relatively few sites across the major wetlands of the Murray Darling Basin including known sites in the Murrumbidgee. These include sites provide nesting habitat consisting of river red gum, river cooba, lignum, reedbeds &/or cumbungi. Overbank & wetland inundating flows (W-LF3, 4, 5, 6, 7, OB-S2, OB-L1, OB-L2) are needed to maintain the extent & condition of these vegetation communities in these discrete wetland sites. This ensures that sites are in event-ready condition when medium & large events (OB-S2, OB-L1, OB-L2) initiate colonial waterbird breeding events. These flows, particularly the smaller overbank & wetland inundating flows (W-LF3-7, OB-S2), will also support a broader range of foraging habitats in the Murrumbidgee, including spike-rush sedgelands, marsh grasslands, lignum shrublands & open lagoons. The required duration & frequency of overbank flows to support these vegetation types are outlined under the native vegetation objectives.
PRIORITY ECOSYSTEM FUNCTIONS OBJECTIVES[72]	
EF1: Provide & protect a diversity of refugia across the landscape	Cease-to-flow: durations that are not longer than the persistence of water of sufficient volume & quality in key larger river pool refuges. Very low flows (VLF), baseflows (BF1): to maintain adequate water quantity & quality (dissolved oxygen, salinity & temperature) in refuge pools. Need to be of sufficient magnitude to prevent stratification of pools that can lead to de-oxygenation of the water column. They are required every year at a frequency that is no less than natural & are especially important during dry times. Weir pool mixing flows (WP1): in hot periods to mix stratified layers in lower Murrumbidgee weirpools before dissolved oxygen levels become so low that fish deaths may occur. Small freshes: when restarting flows after a cease-to-flow event, larger magnitude flows such as these may be required to prevent detrimental water quality outcomes (as poor-quality water from the bottom of pools is mixed through the water column). Wetland connection flows (W-LF3, 6): To maintain core wetlands, including off-channel waterholes. Alternative watering actions (e.g. pumping) may be required to support floodplain habitats under very dry, dry & moderate scenarios to prevent habitat for floodplain specialists from drying out.
EF2: Create quality instream & floodplain habitat	The full range of in-channel & overbank flow types are required to maintain quality instream & floodplain habitat. Variable in-channel flows (baseflows – bankfull flows) will provide a diversity of physical & hydraulic habitats. With increasing magnitude of flows, greater areas of the channel are inundated (e.g. benches, bars, snags & banks at different elevations in the channel). Baseflows & small freshes provide areas of slow flowing habitat, while large freshes provide deeper & faster flowing habitats. Small & large freshes are important for flushing fine sediment from pools, de-stratifying pools & maintaining geomorphic features such as benches & bars. Bankfull flows are important for geomorphic maintenance of all channel features.

[72] Important flow regime characteristics for all priority ecosystem function objectives are based on Alluvium 2010.

Ecological objective	Important flow regime characteristics
	Weir pool mixing flows (WP1): in hot periods to mix stratified layers in lower Murrumbidgee weirpools before dissolved oxygen levels become so low that fish deaths may occur. To protect banks from excessive erosion it is important to maintain rates of fall that do not exceed natural rates of fall for all regulated deliveries. Slow rates of fall allow water to drain from the bank slowly, preventing mass failure of the banks. Maintaining slow rates of fall is particularly important when flows are in the lower third of the channel, to protect the 'toe' of the bank, which supports the rest of the bank above. Bank notching can be avoided by varying flows (avoiding holding flows constant for too many consecutive days) & targeting different peak heights for freshes. Wetland/overbank flows (OB-S1&S2, OB-L1&L2, W-LF4, 5, 6, 7): to provide floodplain & wetland habitat for native fish, waterbirds & other aquatic fauna.
EF3a: Provide movement & dispersal opportunities within catchments for water-dependent biota to complete lifecycles	Providing longitudinal connectivity is critical for migration, recolonisation following disturbance events, allowing species to cross shallow areas, & dispersal of larvae to downstream habitats. In-channel flows of adequate depth & duration (baseflows & freshes) are important to allow for the movement of aquatic & riparian fauna & flora along rivers & creeks. For example, flows of at least 0.3 m are needed to allow medium sized native fish to move along a channel. Physical barriers, such as dams & weirs, have introduced additional barriers throughout the Murrumbidgee, making large freshes & occasionally small overbank flows important for overcoming these man-made structures where fishways are not present. Wetland/overbank flows (OB-S1&S2, OB-L1&L2, W-LF4, 5, 6, 7): to provide lateral connectivity to floodplain & wetland habitat.
EF3b: Provide movement & dispersal opportunities between catchments for water-dependent biota to complete lifecycles	Baseflows/small freshes: to allow fishways at weirs (where they exist) to operate effectively. Large freshes: of sufficient flow to allow weir gates to be removed to provide passage between the Lower Murrumbidgee to the Murray. Also, large flows of sufficient size to drown out some weirs on the lower Billabong to improve connectivity to the Edwards River. Large freshes (wetland connecting flows) and overbanks: in the Lower Murrumbidgee when high flows in the Lachlan provide some overflow from the Great Cumbung Swamp. This may only be rarely achievable, but if successful it could enhance connectivity to the Lachlan. All these flows are important to allow the movement of fish & other biota between the catchments & allow re-colonisation & the replenishment of populations.
EF4: Support instream & floodplain productivity	Freshes: to flush organic matter from stream banks & anabranches & drive small pulses of productivity. Wetland/overbank flows (OB-S1&S2, OB-L1&L2, W-LF4, 5, 6, 7): to inundate the floodplain & supporting large scale productivity, which in turns drives aquatic food webs both on the floodplain & in-stream. Primary productivity includes growth of algae, macrophyte, biofilms & phytoplankton, which in turn drives secondary productivity (zooplankton, macroinvertebrates, fish larvae etc.).
EF5: Support mobilisation & transport of sediment, carbon & nutrients along channels, between	Freshes: for mobilising organic matter & sediment from in-channel surfaces (e.g. leaf litter that has accumulated on bars, benches & banks during low flows). This material is transported downstream or deposited in other parts of the channel where it is utilised, in the case of nutrients

Ecological objective	Important flow regime characteristics
channels & floodplains, & between catchments	& carbon, to drive primary productivity, or in the case of sediment, for channel maintenance (e.g. to replenish banks & benches). Wetland/overbank flows (OB-S1&S2, OB-L1&L2, W-LF4, 5, 6, 7): for transferring nutrients & carbon from the floodplain to the channel.
EF6: Support groundwater conditions to sustain groundwater-dependent biota	Large freshes (LF1, 2) & wetland/overbank flows (OB-S1&S2, OB-L1&L2, W-LF4, 5, 6, 7): to contribute to recharging shallow groundwater aquifers in areas where there is a surface-groundwater connection. This recharge can reduce the salinity of shallow aquifers & raise water tables, providing critical soil moisture for deep-rooted vegetation in the riparian zone & on low-lying floodplains.
EF7: Increase the contribution of flows into the Murray & Barwon-Darling from tributaries	Flows from the Murrumbidgee that provide movement & dispersal opportunities between catchments (see EF3b) will also contribute to important EWRs in the Barwon-Darling WRPA. Protecting wetland/overbank flows (OB-S1&S2, OB-L1&L2, W-LF4, 5, 6, 7) will provide important flows & transfer nutrients & carbon from floodplains in the Murrumbidgee to the Lachlan and Murray rivers.
OTHER SPECIES[73]	
OS1: Maintain species richness & distribution of flow-dependent frog communities	In addition to actions which allow breeding (OS2) the flows below are important for survival & to maintain frog condition. Cease-to-flow: durations that are not longer than the persistence of water of sufficient volume & quality in key larger river pool refuges. Very low flows (VLF) & baseflows (BF1): to maintain adequate water quantity & quality (dissolved oxygen, salinity & temperature) in refuge pools. Wetland inundating and overbank flows: Flows to maintain core wetlands, including off-channel waterholes (W-LF3) for refuge. Larger flows (W-LF4, 5, 7) to maintain frog condition & habitat & allow dispersal.
OS2: Maintain successful breeding opportunities for flow-dependent frog species	Wetland inundating and overbank flows (W-LF6, OB-S2, OB-L1): to provide opportunities for breeding & recruitment (i.e. laying eggs & tadpole metamorphosis). Ideally every 1 to 2 years for 6 or more months (with a minimum of 4 months). Spring–summer breeders require flows ideally from October to March, while species with more flexible breeding are likely to benefit from flows arriving between July & April. A gradual rise & fall is likely to improve recruitment outcomes.
OS3a: Maintain and increase number of wetland sites occupied by the threatened southern bell frog	As for OS1 & OS2 plus large overbanks to facilitate movement to increase occupancy across more sites and greater breeding responses and recruitment potential of young bell frogs into breeding population.

[73] Important flow regime characteristics from J. Spencer and J. Ocock (OEH, pers. comms. 2018)

4.6. Changes to the flow regime

The flow regime in the Murrumbidgee has changed due to regulation, extraction and development in the catchment. The degree and type of change varies depending on the location within the catchment. Effects in individual PUs can be seen in Part B, which provides relevant results from the NSW DoI–W (in prep) *Risk Assessment for the Murrumbidgee WRPA*. An overview of effects in the catchment is provided here.

Blowering and Burrinjuck dams, along with other storages, capture higher natural flows and then release them later at the times and rates required to meet downstream orders. This has resulted in a number of outcomes, including those listed below.

Change in seasonality of flows

Flows in the Murrumbidgee catchment were naturally higher in winter and early spring. Now these flows are captured in the major storages and released as required to meet irrigation and other demands. Irrigation demand is highest in late spring, summer and early autumn. This results in a reversal in the seasonality of flows. This is illustrated in Figure 12, which compares the flows at Wagga Wagga under modelled natural conditions (without flow regulation) and current regulated conditions.

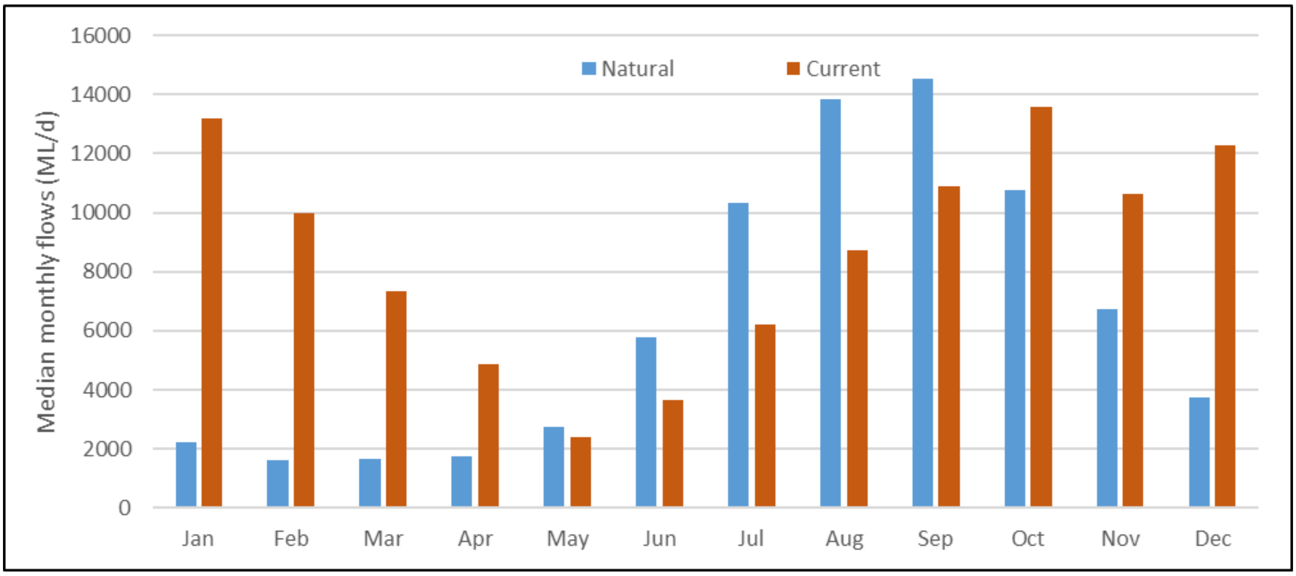

Figure 12 Median monthly flows at Wagga Wagga for modelled 'natural' conditions (without flow regulation) and modelled current 'developed' conditions

Change in the variability of flows

The capture of flow events by regulating structures means that the natural variation in flows, timed in line with rainfall events, is muted. The reduction in flow variability reduces the frequency of natural events which inundate snags, channel benches and in-channel vegetation and flush streamside organic matter into the stream. The loss of flows which are in sync with natural rainfall events also results in the loss of natural cues for native fish and other species.

Change in overall flow volumes

An average of around 550 GL is diverted from the Snowy Mountain Scheme into the Tumut River each year (Frazier and Page, 2006). This results in increased yearly flows in the Tumut River and the Murrumbidgee River downstream of the Tumut Junction. However, by the time the Murrumbidgee is below Berembed Weir, flows are again below pre-development levels. This is because flows are diverted at Berembed Weir to supply the Murrumbidgee Irrigation Area. Further diversions and extractions occur downstream and by the time flows reach the end of system, they are significantly reduced. Figure 13 shows how median flows at Balranald have been affected by regulation and extraction. It is notable that while the flows have decreased markedly, the seasonality at Balranald is less altered, because out-of-natural-season irrigation releases do not generally reach this stretch of the river.

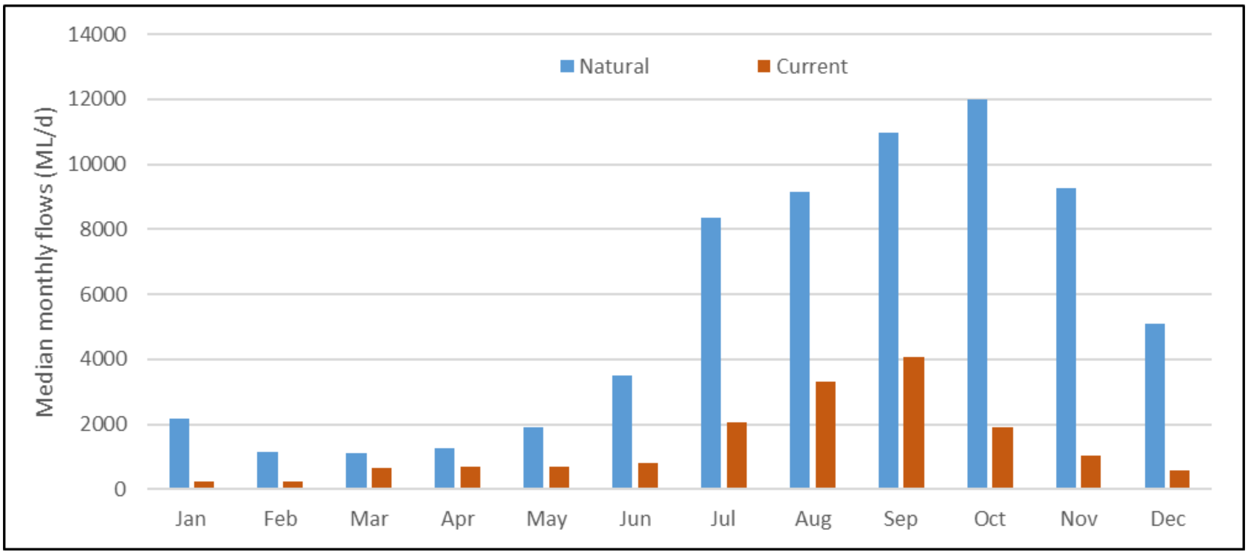

Figure 13 Median monthly flows at Balranald for modelled 'natural' conditions (without flow regulation) and modelled current 'developed' conditions

Change in flow sizes

Where previously the size of flows of the Murrumbidgee was governed by the natural sequence of rainfall events, now only very large floods remain unaffected by regulation. The size of flows is now largely dictated by the size of downstream orders and minimum flow requirements.

The overall effect of this is illustrated in the flow distribution analysis at Table 14. Overall it shows that flows are now more frequently in the middle flow range. This is at the expense of smaller baseflow-sized flows and higher flows. This is explained in detail below.

<u>Days with smaller flows like baseflows are now less common.</u> Table 14 shows flows of 2395 ML/day and below occurred 30% of the time under the modelled natural scenario. They only occur 10% of the time under the modelled current (developed) condition scenario. This means that there is less drying of channel sides and benches between events. This drying is beneficial because when freshes occur they can provide pulses of organic matter and nutrients which have built up during the drying. The pulses also provide cues for biota.

<u>The median flow size has increased</u>. CSIRO (2008) found that flows up to around 15,000 ML/day had increased at Wagga. This is because water from natural higher flow events and water from the Snowy Scheme are used to provide flows up to around 15,000 ML/day to meet irrigation demand.

<u>Higher flows are reduced</u>: Flows rarely need to exceed 15,000 ML/day to supply irrigation demand. This means the frequency of flows above 15,000 ML/day has markedly reduced. These higher flows were vital for providing connection to wetlands and the floodplain.

Table 14 Wagga Wagga flow distribution for modelled 'natural' conditions (without flow regulation) and modelled current 'developed' conditions

Percentile	Modelled natural flows (ML/d)	Modelled current flows (ML/d)
0% (minimum)	0	8
5%	578	1763
10%	909	2395
20%	1550	4129
30%	2395	5874
40%	3489	7657
50% (median)	4993	9388
60%	7019	10890
70%	9999	12576
80%	14562	14558
95%	36101	27427
100% (maximum)	387895	374335

Further downstream the overall outcome is that almost all flows have been reduced. Table 15 shows the distribution of flows at Balranald. By the time Balranald is reached there are no irrigation orders (apart from inter-valley transfers) and consequently the full effects of extractions are seen. The only flow to have increased is the 5th percentile flow, which is higher due to minimum flow rules for the end of the Murrumbidgee.

Table 15 Balranald flow distribution for modelled 'natural' conditions (without flow regulation) and modelled current 'developed' conditions

Percentile	Modelled natural flows (ML/d)	Modelled current flows (ML/d)
0% (minimum)	0	0
5%	145	222
10%	436	256
20%	1,077	313
30%	1,931	571
40%	3,021	708
50% (median)	4,793	912
60%	7,651	1,180
70%	9,080	1,834
80%	11,327	4,210
90%	18,867	8,987
95%	24,399	13,788
100% (maximum)	77,055	55,270

Changed flow environments

In addition to above effects on flow rates, regulation has had other effects. These include the creation of low flow velocity environments behind weirs and other regulating structures. The slow-moving water in weirpools favours carp over riverine specialist native fish like Murray cod and trout cod (Bice et al. 2017). These slow-moving pools of water can also stratify in warmer times, creating conditions ideal for blue-green algae and the de-oxygenation of the bottom layer which can lead to fish deaths (NSW DoI 2019). In larger structures such as Blowering and Burrinjuck dams, the stratification can lead to cold-water pollution downstream as the colder bottom layer is released from the dams.

Other notable location-specific changes: Tumut River

Tumut River is run at high levels for extended periods during peak irrigation season. Flows are capped at 9,300 ML/day to reduce effects on river banks and riparian landholders. This results in a very different regime, with flows being at or around 9,000 ML/day for extended periods in the irrigation season. Because Blowering Dam is large compared to the size of the Tumut River, unregulated flows that reach above 9,300 ML/day are now very rare. Figure 14 shows flows in 2013–14 and illustrates this change.

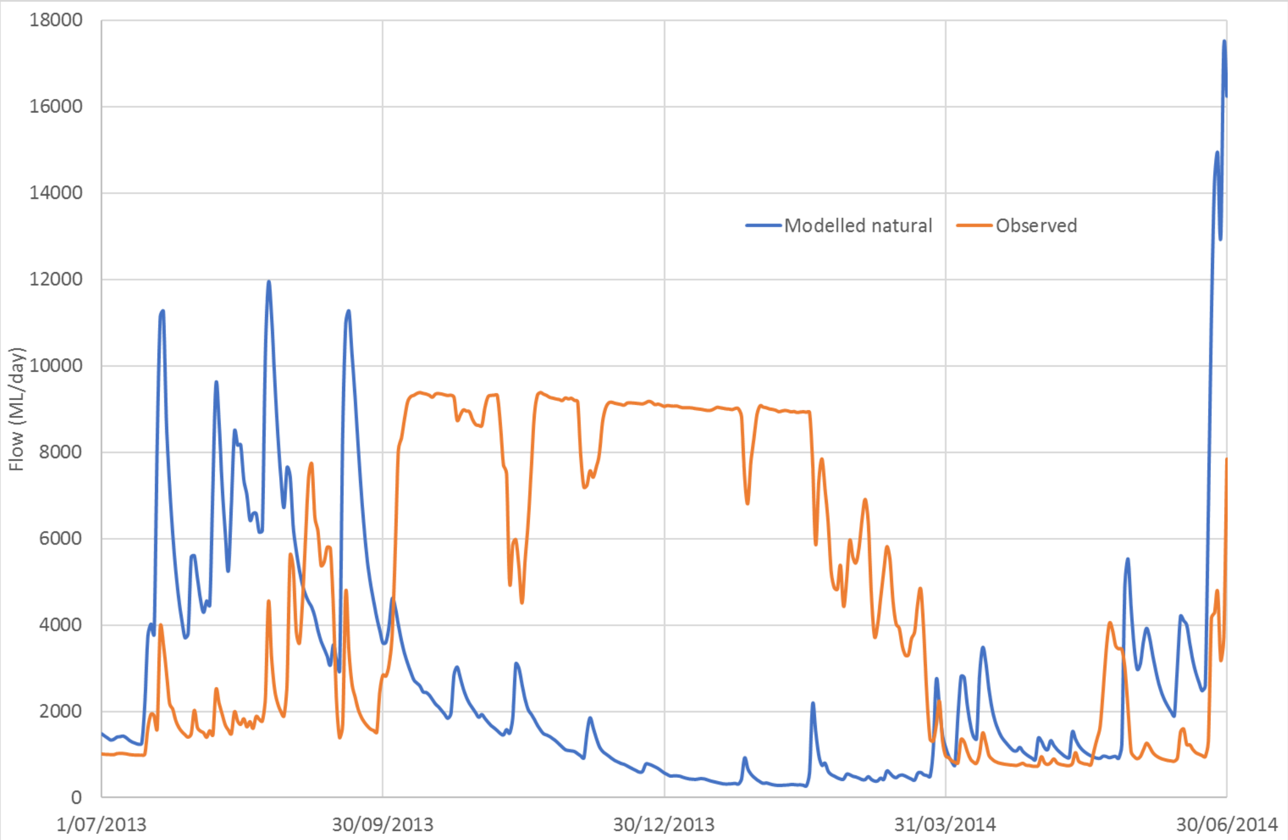

Figure 14 Tumut River at Tumut – modelled ‘natural’ conditions (without flow regulation) flow and observed flow for the 2013–14 water year

Other notable location-specific changes: the upper Murrumbidgee – below Tantangara

Tantangara Dam was completed in 1960 and until recently had captured 99% of inflows (Snowy Scientific Committee 2010). This flow is redirected to Eucumbene Dam where it is used to generate electricity (with flows redirected to the Tumut River and Upper Murray River system). Flows into the Murrumbidgee are allowed through to provide a minimum ‘base passing flow’ of 32 ML/day at Mittagang Crossing near Cooma. However, when tributaries such as Yaouk Creek provide this flow, releases are shut off and the river above these tributaries ceases to flow (Snowy Scientific Committee 2010). The Snowy Montane Rivers Increased Flows initiative was undertaken to reduce this effect and return on average around 30% of the volume of the long-term natural flow (Snowy Scientific Committee 2010). These returned flows are, however, restricted by the valve capacity of the dam, the availability of water and the requirement to set releases in advance of the water year.

Other notable location-specific changes: Yanco/Colombo/Billabong creeks system

Prior to European settlement, Yanco Creek was a high-level effluent creek and it is believed that the Murrumbidgee River only connected to the creek during flows of around 40,000 ML/day or greater (NSW DPI 2015). In the late 1800s a cutting was made to provide flows at lower levels. The Yanco Weir on the Murrumbidgee River was built in 1928 and upgraded in 1981 to control and increase flows into the creek system (NSW DPI 2015). The Yanco Creek system is now a permanently flowing one and supports a number of fish species and other biota, many of which have declined in other parts of the system.

The Yanco Creek system is subject to two sustainable diversion limit adjustment projects. One of these projects includes construction of a significantly enlarged weir on the Murrumbidgee River, directly downstream of the Yanco Creek offtake, and a regulator at the Yanco Creek offtake to control flows into the creek. While these works will provide greater capacity to control flows, elements of the project could be detrimental to the ecology of the system. Potential impacts include:

- drowning of riparian vegetation
- increased no/low flow habitat which favours carp over riverine specialist native fish (Bice *et al.* 2017) and increases the risk of stratification which has been associated with blue-green algal blooms and hypoxic conditions (Webster *et al.* 2000; NSW DoI 2019).
- increased capture of small freshes – these freshes would have provided important pulses for the downstream ecosystem.
- Reduced fish passage between the Yanco system and the Murrumbidgee (partially offset by the construction of fishways)

Any decision to proceed with this project would need to be on the basis that mitigation measures can and will be incorporated into the design, construction and operation of these works including operating protocols that are consistent with the water requirements of the system’s ecology.

5 Risks, constraints and strategies

This LTWP is focused on delivering environmental outcomes in a heavily modified landscape. There are a number of factors that could potentially impact how the plan is implemented, or how the environment responds to management actions. These are either risks to river and wetland health, or constraints on our capacity to manage water in the most appropriate and effective way.

The *Risk Assessment for the Murrumbidgee WRPA* (NSW DoI-W in prep) identifies risks to areas of conservation value, based on hydrological change within sub-catchments. It outlines how the Murrumbidgee WRP may mitigate those risks. This section complements the Murrumbidgee Risk Assessment and addresses the specific risks and constraints that may present in the implementation of the LTWP.

The risks and constraints outlined in this LTWP are those that affect our capacity to:

- meet the EWRs of environmental assets and functions (Table 16).
- achieve the ecological objectives of the LTWP (Table 17).

This risk assessment has assisted with identifying investment opportunities for improving the likelihood that EWRs can be achieved (Table 24).

Figure 15 Yanga Creek regulator, Balranald
Photo: V. Bucello/Midstate Video.

5.1. Risks and constraints to meeting environmental water requirements in the Murrumbidgee water resource plan area

Table 16 Water management related risks and constraints to meeting objectives and potential strategies for managing them

Risk	Description	Potential management strategies	Responsible organisations
Insufficient water for environmental needs to meet LTWP objectives	Availability (total volumes, season, flow rate) of water for the environment does not meet environmental demand.	**Regulated (or affected by regulated water) areas**	
		Implement the pre-requisite policy measures including by allowing for: • releases of environmental water on top of other instream flows, including unregulated events; and • the recrediting of return flows.	DoI–W & WaterNSW
		A number of projects are proposed to adjust the SDL in the Murrumbidgee. Ensure that any reduction in environmental water resulting from these projects is fully compensated by the ability to get equivalent environmental outcomes through them and any negative effects on the environment will be negated before proceeding. Refer to information on projects in the Yanco system at Section 4.6 of this plan.	MDBA, DAWR, DoI–W, OEH, DPI Fisheries
		Continue to improve water management through review of WRP outcomes against LTWP objectives in 5 years (2024).	OEH, DoI–W, DPI Fisheries
		Ensure future water management policy & WRP changes that affect the availability of water for environmental outcomes considers the impact on progress toward achieving ecological objectives.	DoI–W, MDBA
		Continue to improve monitoring, research & assessment methods to inform decision making.	OEH, CEWO, DPI Fisheries, DoI–W, WaterNSW
		Investigate options for the strategic delivery of irrigation orders to mimic natural flow events (requires interagency discussion).	WaterNSW, OEH & DoI–W

Risk	Description	Potential management strategies	Responsible organisations
		Ensure infrastructure is available to enable effective delivery of environmental water, including projects to improve connectivity such as improved and, where viable, new escapes in the Lowbidgee (see action at Table 24). However, potential infrastructure which could reduce connectivity, establish low flow areas (favouring carp) where previously higher flow environments naturally existed and increase the residence times of water where not desirable (increasing the risk of blue green algae and hypoxia) should be avoided.	OEH, WaterNSW, DoI–W
		Ensure environmental water is not used to substitute for other water (e.g. used purely for the purpose of improving water quality where normal river operations should provide for this).	DoI–W, WaterNSW, OEH, CEWO
		Continue to improve understanding of flow needs and flow thresholds to ensure water is used in the most effective manner. See projects in Table 24.	OEH, CEWO, DoI–W, DPI Fisheries
		Unregulated areas	
		See management strategies for unregulated planning units in Table 23.	DoI-W, NRAR
Extraction & diversion of environmental water for purposes that are not consistent with LTWP objectives	This includes: Currently legal extraction of environmental water orders below the gauged delivery point, reducing benefits to downstream assets & end-of-system flows Unauthorised extraction or diversion of flows.	Refer to the Natural Resources Access Regulator & MDBA water compliance policies & strategies	NRAR, MDBA
		Compliance monitoring, including for pumping of lagoon licences where lagoons are refilled with environmental water. See recommended project on lagoon licence compliance in Table 24.	NRAR, MDBA
		Targeted purchase of lagoon licences from willing sellers where maintaining water and habitat in the lagoons aids in achieving the objectives of the LTWP. See recommended investment in Table 24.	OEH, CEWO, DAWR
		Implement protection of environmental flows as recommended by the Matthews report (2017a, b), including for unregulated stream sections such as the Murrumbidgee below Tantangara. Protection of environmental flow releases	DoI–W & WaterNSW

Risk	Description	Potential management strategies	Responsible organisations
		in the upper Murrumbidgee was also a recommendation of the Snowy Scientific Committee (2010). See recommended work in Table 24.	
		Implement the pre-requisite policy measures including measures to allow environmental water to flow throughout the length of the river, and between rivers; and be protected from extraction, re-regulation or substitution.	DoI–W & WaterNSW
		Communicating the whole-of-system management approach to help improve understanding of the importance of protecting environmental flows beyond the order point.	OEH, DPI Fisheries & DoI–W
		In unregulated PUs implement management strategies outlined in Section 6 *Protection of ecologically important flows in unregulated river reaches*	DoI–W & WaterNSW
		The ACT Government policy is not to take environmental water releases from NSW (ACT 2018). So that this takes place NSW agencies should ensure ACT agencies are aware of the timing and size of NSW environmental releases upstream of the ACT.	OEH, DoI–W, ACT agencies
Floodplain structures & barriers preventing flows that would meet overbank & wetland inundation EWRs	Construction of structures (e.g. levees, diversion channels, sediment blockage of culverts) that causes barriers to flows to wetlands & ecological-important floodplain areas.	Investigate opportunities to complete a Murrumbidgee Valley Floodplain Management Plan	DoI–W
		Ensure compliance with existing rules for constructing floodplain infrastructure	NRAR
Delivery constraints to avoid potential effects on third parties on the floodplain constraining meeting some EWRs	Delivery of environmental water to wetlands is constrained by potential effects on infrastructure, cultivation, pasture, stock & disrupted access on the floodplain.	Implement the constraints management strategy in the Murrumbidgee (see Table 24)	DoI–W
		Improve stakeholder education & resources to increase understanding of floodplain inundation patterns.	OEH, CEWO, DoI–W, WaterNSW, LLS, CAG, & Landholders
		Consider inundation risks when planning water deliveries.	OEH & CEWO
		Communicate with landholders that may be affected by flows about intended water deliveries.	OEH

Risk	Description	Potential management strategies	Responsible organisations
		Monitor natural events & environmental deliveries to determine the risk of inundation under a range of flow rates.	OEH & CEWO
		Provide regular updated information for landholders during higher flows.	WaterNSW
		Investigate arrangements with irrigation corporations and other large water users so that extraction from the peaks of wetland connecting events is avoided and equivalent access is provided at other mutually beneficial times. This would protect the peak flow – the key determinant of whether wetlands are connected. It would mean smaller events would achieve more downstream. See recommended work in Table 24.	OEH, CEWO, DoI–W, CAG, Irrigation corporations
		The watering of wetlands on private land requires the cooperation of the landholders. To ensure those wetlands can be watered into the future, long term agreements should be sought with landholders. See Table 24.	OEH, CEWO, Landholders, LLS
Insufficient channel capacity to deliver flow requirements	The channel capacity of the Tumut River is limited to 9,300 ML/day at Tumut. Flows in the Murrumbidgee and Yanco Creek system are limited due to potential effects on third parties in some low-lying areas.	Environmental & irrigation entitlements should maintain the same delivery rights.	OEH, DoI–W & WaterNSW
		Develop formal supply sharing arrangements to provide a mechanism for managing the delivery of water when demands regularly exceed channel sharing capacity. See Table 24.	OEH & DoI–W
		Support the ongoing integration of environmental water planning strategies into river operations to achieve environmental outcomes with all water.	OEH & WaterNSW
Changes in extraction and delivery practices reduce ability to meet LTWP objectives	Construction of large off-river storages allows greater take of supplementary events – reducing the size of natural freshes including wetland connecting events.	If supplementary take increases, monitor usage to ensure the sustainable diversion limit for the valley is maintained.	DoI–W & MDBA
		Investigate arrangements with irrigation corporations and other large water users so that extraction from the peaks of wetland connecting events is avoided (see action above)	OEH, CEWO, DoI–W, CAG, Irrigation corporations

Risk	Description	Potential management strategies	Responsible organisations
	With changing crops (increasing cotton and tree-nut plantations) the irrigation demand profile is changing within valley and downstream (with implications for the delivery regime to meet inter-valley trade).	Government funding of water efficiency measures should consider potential impacts of off-river storages if such structures are included in proposals	DAWR, DoI–W
Restricted flexibility in timing of environmental water delivery	Deliveries of Snowy Montane Rivers Increased Flows into the Upper Murrumbidgee from Tantangara Dam are set in advance for the upcoming year.	Investigate mechanisms to provide flexibility in delivery timing to allow flows to be delivered more in line with natural rainfall events and downstream tributary flows. This would align with natural cues and allow larger downstream flows to be achieved.	DOI-W, OEH, Snowy Hydro Limited
Rate & timing of irrigation releases not optimised for environmental outcomes	Consumptive water is typically released as efficiently as possible. There are opportunities to improve the environmental performance of river operations	Investigate whether water can be in patterns that mimic natural flow conditions. The ability to implement this strategy will vary between years & seasons & must be consistent with the need for efficient & timely water delivery.	OEH, DoI–W, WaterNSW & CAG
		Gradual declines in water level after flow events will benefit the ecology & bank stability of the river. This could be achieved through changes to river operations or the use of environmental water to assist.	OEH, WaterNSW & DoI–W
Inappropriate commence & cease-to-pump rules in unregulated catchment impacting on some flow classes & EWRs	Visible flow can be an ambiguous trigger for pump rules & compliance is difficult to enforce. There are not enough gauges in some areas of the unregulated WRPA to support these rules.	Investigate improved metering of pumps. Note the Matthews (2017a, b) reports recommended universal water metering.	DoI–W
		Investigate better stream gauging to help licence holders & compliance officers determine stream flow (Table 24).	DoI–W
Inappropriate pool drawdown rules impacting on drought refuge EWRs	Pumping from pools during dry periods impacts on valuable drought refuge. Limited gauging & metering makes compliance monitoring difficult.	Ongoing & improved monitoring & evaluation to inform revision of pool drawdown rules in the Murrumbidgee WSP to ensure they mitigate impact on high-value refuge sites. See also reference above to lagoon licences in pools filled by environmental water from wetland connecting flow EWRs	OEH, DPI Fisheries & DoI–W, NRAR

5.2. Non-flow related risks and constraints to meeting long term water plan objectives

The risks and constraints to meeting the ecological objectives include non-flow-related external factors that could potentially impact on achieving the objectives outlined in this plan (Table 17). While managing these risks and constraints is outside the scope of this LTWP, they have been included to highlight their influence on river and wetland health, and linkages of this plan with broader natural resource management initiatives.

Figure 16 Kia Lake, Nimmie-Caira, Lower Murrumbidgee
Photo: V. Bucello/Midstate Video

Table 17 Non-flow management related risks and constraints to meeting long term water plan ecological objectives

Risk	Description	Potential management strategies	Responsible organisations
Poor water quality, including hypoxic blackwater, hypoxic destratification and cold-water pollution impacts affecting LTWP fish & functions objectives	Water quality affects the ecology & survival of aquatic organisms. Hypoxic blackwater events can occur with the release of water after dry or low-flow periods. This can occur from the build-up of organic material in channels & on floodplains. Can lead to low-dissolved oxygen levels & potential fish deaths. Low flow velocities in weir pools can lead to stratification with the cooler bottom layer becoming stagnant and hypoxic. Subsequent destratification can make the entire waterbody hypoxic and cause fish deaths. Cold water pollution can occur when water is released from deeper/colder parts of Blowering and Burrinjuck dams	Implement recommendations detailed in the *Water Quality Management Plan for the Murrumbidgee WRPA* (DoI–W, in prep)	DoI–W
		Manage salinity in accordance with the *Basin Salinity Management 2030 Strategy* (MDB Ministerial Council 2015)	DoI–W
		Consider potential for benefits to water quality when managing water to meet ecological objectives.	OEH, CEWO, DPI Fisheries
		Implement land management strategies to improve water quality.	LLS with Landholders, Landcare, OEH, WaterNSW, DoI–W & other community groups
		Consider risks when delivering environmental flows during high-risk periods, such as warm weather in late spring & summer. Where risks exist, monitor dissolved oxygen for active management of water actions	OEH, DPI Fisheries & CEWO
		Provide flow regimes that avoid extended dry or very low-flow periods.	Water NSW, DoI–W
		Consider implementing ‘first flush’ rules in unregulated streams which protect the first flows that follow cease-to-flow or low flow periods to reduce the risk of hypoxic blackwater.	DoI–W
		Investigate the possibility of installing curtains on the offtakes of Burrinjuck and Blowering dams or undertaking other measures to reduce cold-water pollution.	WaterNSW, DoI–W
		Consider and, where appropriate, implement recommendations of the review of the 2019 Murrumbidgee fish deaths (Baldwin, in prep.). These recommendations are likely to include improved monitoring and lowering of weirpools and provision of adequate flows during identified high risk periods. See items below and actions at Table 24.	WaterNSW, DoI–W

Risk	Description	Potential management strategies	Responsible organisations
		Provide predictive tools to assist water managers to avoid hypoxic conditions at weirs in the lower catchment. See action at Table 24.	DoI–W
		Improve water quality monitoring at weirpools susceptible to fish deaths. Monitoring should include temperature stratification and dissolved oxygen. See action at Table 24.	WaterNSW, DoI–W
Native vegetation clearing impacting on LTWP vegetation & waterbird habitat objectives	Native vegetation clearing has direct impacts on LTWP vegetation objectives & the availability of waterbird habitat Changes to riparian vegetation can impact on water quality, stream erosion & instream habitat	Work with relevant departments & organisations to identify & protect core wetland vegetation communities using legislation & native vegetation planning processes	OEH, LLS & DPI
Impacts of unmanaged total grazing pressure & stock access to waterways impacting on LTWP vegetation targets	If not managed carefully, grazing pressure from domestic & native herbivores & access of stock to riverbanks can: reduce native vegetation cover which allows weeds to establish reduce streambank stability damage important instream habitat reduce water quality.	Map & identify riparian & aquatic habitat condition to inform development of formal agreements in a unified strategy. Areas such as the Numeralla and Bredbo catchments of the Upper Murrumbidgee contribute disproportionately to fine and coarse sediment loads Prioritise reaches for management in partnership with LLS & landholders. See Table 24	OEH, DPI Fisheries & LLS
		Implement grazing strategies that protect & restore wetland vegetation.	LLS, DPI & Landholders
		Investigate incentives to improve management of wetlands on private land.	LLS, DPI, BCT
		Manage the abundance of native herbivores to control total grazing pressure.	OEH National Parks & Kangaroo Management, landholders & LLS
		Communicate wetland sensitive grazing practices to graziers	OEH and LLS

Risk	Description	Potential management strategies	Responsible organisations
Pest plant species impacting on achieving LTWP vegetation objectives	The current flow regime, including environmental water, may facilitate the growth & spread aquatic & terrestrial weed species such as lippia, Noogoora burr.	Maintain existing weed control programs.	OEH & LLS OEH National Parks, LLS & local government
		Inundate wetlands for sufficient duration to favour native wetland species & reduce the extent of terrestrial weed species like lippia.	OEH & CEWO
		Monitor for pest species, including for potential new pests.	DPI, OEH (including National Parks), LLS, landholders & local government
Pest animal species impacting on achieving LTWP vegetation, fish, frog & waterbird objectives	The current flow regime, including environmental water, supports populations of invasive animals. These populations reduce the benefit of environmental water on native species.	Support recommendations in pest species management plans, with implementation of control programs such as those for: carp (see NSW I&I 2010), including the cyprinid herpesvirus-3 if recommended by the National Carp Control Program (FRDC in prep) other invasive fish such as redfin & gambusia (competition with native fish & predation) pigs (vegetation, predation impacts) goats (vegetation impacts) foxes & cats (predation impacts).	OEH National Parks, DPI Fisheries, WaterNSW & OEH
		Refer to strategies from NSW DPI, Fisheries	DPI Fisheries
		Monitor for pest species, including for potential new pests (e.g. Tilapia).	DPI Fisheries, OEH (including National Parks), LLS, landholders & local government
		Investigate the use of regulatory structures to complement water actions. For example, close regulating structures after watering to allow wetland drying and kill invasive fauna	OEH, DPI Fisheries & WaterNSW
Problematic erosion may impact upon	Rapid flow recession can cause excessive erosion and bank	Support variable flows & ecologically desirable flow recession rates in river operations to reduce bank slumping.	OEH & WaterNSW

Risk	Description	Potential management strategies	Responsible organisations
various LTWP objectives	slumping. This can increase turbidity and reduce instream habitat quality. Other factors such as ski-boats and land management also have detrimental effects on bank stability.	Map & prioritise riparian habitat & erosion points for rehabilitation. See action at **Table 24**.	OEH, LLS, DPI Fisheries & WaterNSW
		Manage environmental waters to mimic pre-development flow patterns & variability (where possible).	OEH, DoI–W, WaterNSW, CEWO
		Protect variable flows and ecologically desirable flow recession rates	OEH and WaterNSW
Current & future instream barriers & structures impacting connectivity related LTWP objectives	Instream structures impede natural flow and connectivity which impacts on fish.	Remove priority illegal & unauthorised barriers.	DoI–W, DPI Fisheries
		Refer to strategies from DPI Fisheries	DPI Fisheries
		Implement the Fisheries Management Act 1994	DPI Fisheries
		Investigate opportunities to opportunistically remove weir gates temporarily. See action at **Table 24**.	OEH, DoI–W, WaterNSW, DPI Fisheries
Pumps & other water offtakes impacting on LTWP fish objectives	Pumps and other water offtakes can remove and trap fish and their eggs and larvae.	Refer to DPI Fisheries management plan for screens on pumps	DPI Fisheries and DoI–W

5.3. Climate change

Climate change is a key long-term risk to river, wetland and floodplain health. It will exacerbate the natural seasonal variability that exists in NSW, making it more difficult to manage our landscapes and ecosystems and the human activities that depend on them. Average temperatures have been steadily rising since the 1950s. The decade from 2001 to 2010 was the hottest on record, while 2014 was the hottest year on record in NSW (DECCW 2011). As the natural seasonal variability that exists in NSW continues to be altered, climate change will increasingly affect the environment and society in every part of the state.

The Murray–Darling Basin Sustainable Yields project investigated the potential impacts of climate change on water resources and flows to key environmental sites across the Basin, including the Murrumbidgee region (CSIRO 2008). Under the ‘Future climate and current development (Scenario C)’, by 2030 the project predicts:

- a 9% reduction in average annual runoff to rivers in the Murrumbidgee catchment
- a 17% reduction in end-of-system flows
- a 9% reduction in surface water availability
- a 29% increase in the average period between high flows to the Mid Murrumbidgee wetlands and a 32% reduction in the average annual flooding volume, leading to further degradation of the wetlands
- a 16% increase in the average period between high flows to the Lowbidgee floodplain and a 33% reduction in the average annual flooding volume

Best available climate change predictions for the Murrumbidgee catchment indicate a significant change to climatic patterns in the future. According to the NARCLiM model[74] (scenario 2), the changes in Table 10 are predicted by 2030 and 2070.

There are uncertainties with these climate change predictions, and the predicted changes will not occur in isolation. Rather, the predicted changes will occur alongside other changes owing to water resource development, land use, and environmental water management. Accordingly, it is currently unclear what impacts these changes will have on the environmental assets of the Murrumbidgee catchment.

[74] The NARCliM projections have been generated from four global climate models (GCMs) dynamically downscaled by three regional climate models (RCMs). www.climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM.

Figure 17 Lowbidgee wetland, Balranald
Photo: J. Maguire/OEH

Table 18 Potential climate-related risks in the Murrumbidgee catchment

Potential climate change risk	**Description of risk**	**NARCLiM projection** (scenario 2)				
			2020–39		**2060–79**	
			South east and tablelands	Murray Murrumbidgee	South east and tablelands	Murray Murrumbidgee
Change in rainfall	Rainfall is projected to vary across the region, with the greatest increases predicted to occur during autumn and the greatest decreases during spring. Winter rainfall is primarily decreasing across the region.	Summer	+0.8%	+4.4%	+8.8%	+10.5%
		Autumn	+6.5%	+9.4%	+11.0%	+12.7%
		Winter	-2.6%	-2.0%	-4.1%	0.2%
		Spring	-7.5%	-10.9%	-11.2%	-11.9%
Change in average temperature	Mean temperatures are projected to rise by 0.7 ºC by 2030. The increases are occurring across the region with the greatest increase during summer. All models show there are no declines in mean temperatures across the Murrumbidgee regions.	Summer	+0.88°C	+0.87°C	+2.28°C	+2.36°C
		Autumn	+0.59°C	+0.54°C	+1.87°C	+1.88°C
		Winter	+0.43°C	+0.37°C	+1.66°C	+1.42°C
		Spring	+0.69°C	+0.71°C	+2.15°C	+2.11°C
Change in number of hot days (maximum temperature >35°C)	Hots days are projected to increase across the region by an average of 8 days per year by 2030.	Annual	+2.7	+8.0	+8.2	+22.9
Change in number of cold nights (minimum temperature <2°C)	Cold nights are projected to decrease across the region by an average of 11 fewer nights per year by 2030. The Murrumbidgee region is projected to experience 7 fewer cold nights per year. Changes in cold nights can have considerable impacts on native ecosystems.	Annual	-11.5	-7.4	-35.4	-21.2

Potential climate change risk	Description of risk	NARCLiM projection (scenario 2)				
			2020–39		2060–79	
			South east and tablelands	Murray Murrumbidgee	South east and tablelands	Murray Murrumbidgee
Bushfires Changes in number of days a year FFDI>50[75]	Overall severe fire weather is projected to have a small increase across the region by 2030. However, increased severe fire weather is during spring (the prescribed burning season) and summer (peak fire risk season). Conversely declines in severe fire weather are expected in autumn due to increases in rainfall.	Annual	+0.1	+0.6	+0.5	+2.0
Hillslope erosion	Changes in erosion can have significant implications for natural assets and water quality. Removal of groundcover will increase the risk of erosion significantly.	Mean percent change	1.0%	1.4%	14.5%	13.6%
Biodiversity	Rising temperature, increased fire frequency and changing fire regimes, storm damage and potentially drought will all affect species composition					

[75] Forest Fire Danger Index (FFDI) is used in NSW to quantify fire weather. The FFDI combines observations of temperature, humidity and wind speed. Fire weather is classified as severe when the FFDI is above 50.

Strategies for mitigating climate-related risks

Environmental water management and the proactive release of water from Burrinjuck and Blowering dams to support improved river and wetland health outcomes has occurred in the Murrumbidgee catchment since the 1990s. The climate has been variable during this time, with the region experiencing extreme drought and flooding. Environmental water managers have become experienced in dealing with these highly variable conditions, using management practices and responses established over time based on real-world experience and collaboration.

Water managers currently examine the outcomes of climate change research and monitor outcomes against existing objectives and targets using real-time data, such as rainfall, to inform their understanding of the impacts of climate change at the catchment scale. This information assists in answering questions such as:

- How will the volume of water stored in Blowering and Burrinjuck dams be affected by climate change?
- How will water quality be affected by climate change?
- Will the flow pathways across the landscape change as our climate changes?
- Will the duration of floodplain inundation decrease due to higher evaporation rates, which will likely come with increased temperatures because of climate change?
- How will changes in rainfall, runoff and evaporation impact soil chemistry in a changing climate?
- How will changes in weather attributed to climate change, including increased air temperatures, flow seasonality due to changes in rainfall or severe weather events, affect the plants and animals of the Murrumbidgee?

Environmental water managers will continue to respond to the environmental demands of rivers, wetlands and floodplains, considering the range of priorities and strategies at their disposal. Climate change will be another important variable in this decision-making process.

Figure 18 Intermediate egret in breeding plumage
Photo: J. Spencer/OEH

6 Water management under different water availability scenarios

6.1. Prioritisation of ecological objectives and watering in regulated river reaches

Environmental water managers and environmental water advisory groups consider a range of factors when determining how discretionary water for the environment should be managed. Key considerations include:

- the current condition of the plants and animals, the recent history connectivity of river channels to their floodplain systems, rainfall history and predictions, and
- water availability for the range of environmental water sources.

Management of flow-dependent environmental assets amid this variability means that plans must be adaptive. They need to accommodate watering activities that range from maximising environmental outcomes from flow events when water is abundant, to managing water to maintain drought refuges when resources become scarce. Appropriate compliance activities to prevent unauthorised extractions is paramount to the success of any water management strategy’s ability to contribute to environmental outcomes.

Section 6.1 sets out a framework to help inform annual water management decisions in river reaches which are regulated or affected by regulated water. This information is presented in terms of a water resource availability scenario (RAS) as proposed by MDBA (2012e). Each RAS is described below in two tables that include:

- the broad priorities (upper tables) that are likely to apply to management under the water availability scenario along with management strategies for achieving these priorities - a ‘toolkit’ of opportunities to consider.
- the priority LTWP objectives identified for each scenario (lower tables). These tables also outline the flow types which would be required to support those priority objectives.

Note the wording of the LTWP objectives has been adjusted to highlight the most relevant aspect of the objective under the scenario. For example, an LTWP objective that over 20 years seeks ‘improvement’ may only seek to ‘maintain’ under a dry scenario. Some of the wording of the objectives has been summarised for better presentation. The full objectives can be found in Section 3.

More information about RASs and how they are defined is provided in Appendix B.

Water Resource Availability Scenario: Very dry – Protect

	Broad water management priorities	Management strategies for achieving priorities
Very dry	Avoid critical loss of species, communities and ecosystems Maintain refuges Avoid irretrievable damage or catastrophic events Avoid unnaturally prolonged dry periods between flow events Support targeted longitudinal connectivity within catchment for functional processes and a range of flora and fauna	Focus on limiting exceedance of maximum inter-flow periods, through the following strategies: Allow dry down consistent with historical wetting-drying cycles Sustain water levels and water quality in key in-channel pools, instream habitat and core wetland areas[76] Provide targeted low flows to allow localised fish movement Prevent two consecutive years of extreme dry to core wetland areas When available, use supplementary allocations to maximise the benefit of tributary flow events to meet EWRs If a critical water shortage or similar critical incident restricts the use of water for the environment, then OEH, as part of the Critical Water Advisory Panel, will work to minimise exceedances of maximum inter-flow periods for core areas.

Table 19 Priority long term water plan objectives and flow categories in a very dry RAS

Priority objectives	Flow categories							
	Cease to Flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Large Fresh -Wetland connection[77]	Small Overbank	Large Overbank
NF1: No loss of native fish species[76, 78]	x	x	x	x		x		
NV1: Maintain non-woody vegetation communities occurring within channels	x	x	x	x				
NV2: Maintain non-woody vegetation communities occurring in core wetlands						x		
WB1: Maintain waterbird species			x			x		
WB2: Maintain waterbird abundance			x			x		
WB5: Maintain waterbird habitats						x		
EF1: Provide & protect refugia	x	x	x	x		x		
EF2: Maintain quality instream & wetland habitat	x	x	x	x		x		
EF3a: Provide movement and dispersal opportunities within catchments			x	x		x		
OS1: Maintain flow-dependent frogs			x			x		
OS3a: Maintain number of wetland sites occupied by the southern bell frog						x		

[76] Pumping or other infrastructure may be required to support floodplain habitats to prevent threatened fish species from drying out.
[77] Small freshes and the large fresh for wetland connection to core wetland habitats (W-LF3) may be important and achievable in a very dry scenario to protect core wetland habitats and avoid critical habitat loss

[78] Weirpool Mixing Pulses (WP1) may also be required from operational water to prevent fish deaths.

Water resource availability scenario: Dry – Maintain

	Broad water management priorities	Key management strategies for consideration
Dry	Support the survival & viability of threatened species & communities Maintain refuges Maintain environmental assets & ecosystem functions Avoid unnaturally prolonged dry periods Support longitudinal connectivity for functional processes & a range of flora & fauna	Avoid exceedance of maximum inter-flow periods & provide events which have recently had lower than ideal frequency, through the following strategies: • Sustain water levels in key instream habitat & core wetland areas[76] • Provide low flows to allow localised fish movement • Provide freshes to channels & flows to core wetland areas at ecologically relevant times • When available, use supplementary allocations to augment the above.

Table 20 Priority objectives and flow categories in a dry resource availability scenario

Priority LTWP objective	Flow categories						
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Large Fresh -Wetland connection	Small/ Large Overbank
NF1: No loss of native fish species[76, 78]	x	x	x	x	x	x	
NF2: Maintain short to moderate-lived generalist native fish			x	x	x		
NF3: Maintain short to moderate-lived floodplain specialist native fish[76]			x	x	x	x	
NF4: Maintain moderate to long-lived flow pulse specialist native fish			x	x	x		
NF5: Maintain moderate to long-lived riverine specialist native fish			x	x	x		
NF6: Maintain mature (harvestable sized) golden perch & Murray cod			x	x	x		
NV1: Maintain non-woody vegetation communities occurring within channels			x	x	x		
NV2: Maintain non-woody vegetation communities occurring in wetlands						x	
WB1: Maintain waterbird species						x	
WB2: Maintain waterbird abundance						x	
WB5: Maintain waterbird habitats						x	
EF1: Provide & protect refugia	x	x	x	x		x	
EF2: Maintain instream & wetland habitat	x	x	x	x	x	x	
EF3a: Provide movement & dispersal opportunities within catchments			x	x	x	x	
EF4: Support instream & floodplain productivity				x	x	x	
OS1: Maintain flow-dependent frogs			x			x	
OS2: Maintain breeding opportunities for flow-dependent frogs						x	
OS3a: Maintain number of wetland sites occupied by the southern bell frog						x	

Water resource availability scenario: Moderate – Recover

	Broad water management priorities	Key management strategies for consideration
Moderate	Enable growth, reproduction & small-scale recruitment for a diverse range of flora & fauna Promote low-lying floodplain-river connectivity Support medium flow river & floodplain functional processes Support longitudinal connectivity within & between catchments for functional processes & a range of flora & fauna Support low flow lateral connectivity & end of system flows Set aside water for use in drier years	Seek to meet ideal event frequencies, prioritising EWRs that have recently had long inter-flow periods or lower than ideal frequency, through the following strategies. Provide freshes at ecologically relevant times Improve condition of key off-channel waterholes[76] Build on natural events where possible to provide wetland & floodplain inundation at ecologically relevant times[79] Use supplementary allocations to provide additional longitudinal & lateral connectivity during supplementary flow events Consider carrying over water to support water use in drier years

Table 21 Priority objectives and flow categories in a moderate resource availability scenario

Priority LTWP objective	Flow categories							
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Large Fresh -Wetland connection	Small Overbank	Large Overbank
NF1: No loss of native fish species	x	x	x	x	x	x		
NF2: Improve short to moderate-lived generalist native fish			x	x	x	x		
NF3: Improve moderate-lived floodplain specialist native fish			x	x	x	x	x	
NF4: Improve moderate to long-lived flow pulse specialist native fish			x	x	x	x		
NF5: Improve moderate to long-lived riverine specialist native fish[80]			x	x	x	x		
NF6: Increase mature (harvestable sized) golden perch & Murray Cod[80]			x	x	x	x		
NF7: Expand key short to moderate-lived floodplain specialist native fish into new areas			x	x	x	x	x	
NF8: Expand key moderate to long-lived riverine specialist native fish into new areas[80]			x	x	x	x		
NF9: Expand key moderate to long-lived flow pulse specialist native fish into new areas			x	x	x	x		

[79] Includes extending duration of flows to support waterbird colonies if they establish and need intervention.

[80] Nesting Support (NestS1), which limits the rate of fall during cod breeding season, will also be a priority

Priority LTWP objective	Flow categories							
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Large Fresh -Wetland connection	Small Overbank	Large Overbank
NF10: Expand key diadromous native fish into new areas			x	x	x			
NV1: Maintain non-woody vegetation communities occurring within channels			x	x	x			
NV2: Maintain non-woody vegetation occurring in wetlands & on floodplains						x	x	
NV3: Maintain river red gum communities closely fringing river channels					x	x		
NV4a: Maintain river red gum forests & woodlands & lignum shrublands						x	x	
NV4b:						x	x	
NV4e:							x	
WB1: Maintain waterbird species						x	x	
WB2: Increase waterbird abundance						x	x	
WB3: Increase opportunities for non-colonial waterbird breeding						x	x	
WB4: Increase opportunities for colonial waterbird breeding						x	x	
WB5: Maintain waterbird habitats						x	x	
EF1: Provide & protect refugia	x	x	x	x		x		
EF2: Create instream, floodplain & wetland habitat	x	x	x	x	x	x	x	
EF3a: Provide movement & dispersal opportunities within catchments[81]			x	x	x	x	x	
EF3b: Provide movement & dispersal opportunities between catchments				x	x			
EF4: Support instream & floodplain wetland productivity[81]			x	x	x	x	x	
EF5: Support nutrient, carbon & sediment transport & exchange[81]				x	x	x	x	
EF6: Support groundwater conditions to sustain groundwater-dependent biota					x	x	x	
EF7: Contribution of flows to the Murray				x	x			
OS1: Maintain flow-dependent frogs					x	x	x	
OS2: Breeding for flow-dependent frogs					x	x	x	
OS3a: Maintain number of wetland sites occupied by the southern bell frog					x	x	x	

[81] Infrastructure can be used to enhance connectivity and increase the provision of carbon and nutrients from the floodplain to the channel. An example is by providing flows wetlands in the Lower Murrumbidgee Floodplain and then using escapes to allow return flows back into the river.

Water resource availability scenario: Wet – Maintain and improve

	Broad water management priorities	Key management strategies for consideration
Wet	Enable growth, reproduction & large-scale recruitment for a diverse range of flora & fauna Support longitudinal connectivity within & between catchments for functional processes & a range of flora & fauna Support high flow lateral connectivity & end of system flows Set aside water for use in drier years	Provide events at ideal frequencies. Balance water use with the need to set aside water for dry times – carry over water to support water use in drier years. Where possible, build on natural events to provide wetland & floodplain inundation at ecologically relevant times[79] Protect naturally occurring floodplain wetland inundating events & high flow connectivity with the Lachlan when it is also in flood. Use supplementary allocations to provide additional longitudinal & lateral connectivity during supplementary flow events

Table 22 Priority objectives and flow categories in a wet resource availability scenario

Priority LTWP objective	Flow categories							
	Cease-to-flo	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Large Fresh Wetland connection	Small Overbank	Large Overbank
NF1: No loss of native fish species			x	x	x	x	x	x
NF2: Improve short to moderate-lived generalist native fish			x	x	x	x		
NF3: Improve moderate-lived floodplain specialist native fish			x	x	x	x	x	x
NF4: Improve moderate to long-lived flow pulse specialist native fish			x	x	x	x		
NF5: Improve moderate to long-lived riverine specialist native fish[80]			x	x	x	x		
NF6: Increase mature (harvestable sized) golden perch & Murray Cod[80]			x	x	x	x		
NF7: Expand key short to moderate-lived floodplain specialist native fish into new areas			x	x	x	x	x	x
NF8: Expand key moderate to long-lived riverine specialist native fish into new areas[80]			x	x	x	x		
NF9: Expand key moderate to long-lived flow pulse specialist native fish into new areas			x	x	x	x		
NV1: Increase non-woody vegetation communities occurring within channels			x	x	x			

<table>
<tr><th colspan="2" rowspan="2">Priority LTWP objective</th><th colspan="8">Flow categories</th></tr>
<tr><th>Cease-to-flo</th><th>Very Low Flow</th><th>Baseflow</th><th>Small Fresh</th><th>Large Fresh</th><th>Large Fresh Wetland connection</th><th>Small Overbank</th><th>Large Overbank</th></tr>
<tr><td colspan="2">NV2: Maintain non-woody vegetation occurring in wetlands & on floodplains</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">NV3: Maintain river red gum communities closely fringing river channels</td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td></td><td></td></tr>
<tr><td>NV4a:</td><td rowspan="4">Maintain extent & maintain or increase the condition of river red gum, black box & lignum</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>NV4b:</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>NV4c:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
<tr><td>NV4e:</td><td></td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td></tr>
<tr><td colspan="2">WB1: Maintain waterbird species</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">WB2: Increase waterbird abundance</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">WB3: Increase opportunities for non-colonial waterbird breeding</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">WB4: Increase opportunities for colonial waterbird breeding</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">WB5: Improve waterbird habitats</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">EF1: Protect refugia</td><td></td><td></td><td>x</td><td>x</td><td></td><td>x</td><td></td><td></td></tr>
<tr><td colspan="2">EF2: Create instream, floodplain & wetland habitat</td><td></td><td></td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">EF3a: Provide movement & dispersal opportunities within catchments[81]</td><td></td><td></td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">EF3b: Provide movement & dispersal opportunities between catchments</td><td></td><td></td><td></td><td>x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">EF4: Support instream & floodplain wetland productivity[81]</td><td></td><td></td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">EF5: Support nutrient, carbon & sediment transport & exchange[81]</td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">EF6: Support groundwater conditions to sustain groundwater-dependent biota</td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">EF7: Contribution of flows to the Murray</td><td></td><td></td><td></td><td>x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">OS1: Maintain flow-dependent frogs</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">OS2: Breeding for flow-dependent frogs</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="2">OS3a: Increase number of wetland sites occupied by the southern bell frog</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td>x</td><td>x</td></tr>
</table>

6.2. Protection of ecologically important flows in unregulated river reaches

In areas where water cannot be delivered through a regulating structure, the only means of protecting environmentally important flows is through rules in the *Murrumbidgee Unregulated Water Sharing Plan*. Table 23 sets out potential management strategies that could be implemented in the WSP to ensure important flows are protected.

Table 23 Potential management strategies to protect ecologically important flows in unregulated river reaches

	Potential management strategies
•	Investigate opportunities to reduce extraction pressure on in-channel flows in water sources with moderate to high levels of impact within five years. Measures to be considered include the following:
	o Consider reviewing existing rules to ensure that visible flow is maintained downstream of extraction points.
	o Where a cease-to-pump (CtP) rule currently exists, consider reviewing the threshold.
	o Where no CtP rule currently exists, consider introducing a CtP rule (relating to a flow or water level gauge)
	o Consider implementing a commence-to-pump threshold that is higher than the cease-to-pump (CtP) threshold.
	o Consider installing water level gauges at or near extraction sites
	o Consider installing river flow gauge
	o Consider rostering landholder water access
	o Consider Individual and/or Total Daily Extraction Limits (IDELS / TDELS)
•	Ensure compliance with water access licence conditions including through metering of all licensed extraction.
•	As a minimum, maintain existing rules in the WSP for the Murrumbidgee Unregulated Water Sources that protect environmental assets and values.
•	Monitor for changes in water demand and review access rules if current usage is high or if the pattern of use changes.
•	Consider introducing cease-to-pump and commence-to-pump rules (and any associated required amendments to WAL conditions) that protect held environmental water and water from the EWAs entering unregulated streams and off-channel pools (wetlands). This is in-line with the Basin Plan requirement for implementation of prerequisite policy measures which provide for delivered environmental water to be protected. It is also recommended by the Matthews reports (2017a, b).
•	For lagoon licences that are the target of environmental water, consider water access licence purchases from willing sellers or the negotiation of enduring agreements with licence holders.
•	Review conditions on larger in-stream storages. This should include consideration of the need for environmental releases.

7 Going forward

7.1. Cooperative water use

Cooperative river operations

The BWS notes that all water in the Murray-Darling Basin, including natural events and consumptive water, has the potential to contribute to improving the ecological condition of rivers, wetlands and floodplains (MDBA 2014). Making the best use of all water is a key strategy to achieve the objectives in this LTWP. In some cases, river operating practices need to be revised to provide the operators with a mandate to manage rivers so that environmental outcomes can be achieved. The risks and constraints to achieving EWRs (Table 16) described in this LTWP identifies some river management practices that are currently limiting or impacting on the ability to achieve ecological objectives.

The LTWP identifies the following strategies to maximise the benefit of all water in the system.

- Investigate options for the delivery of irrigation orders to more closely mimic natural flow events.
- Establish better channel sharing arrangements by permitting environmental water to build on consumptive or stock and domestic deliveries to achieve better flow regimes for the environment.
- Optimise water releases from regulating structures to mimic natural rates of fall.
- Consider environmental needs in the management of weir pools.
- Consider environmental watering needs in the scheduling of maintenance works on infrastructure and keep environmental water managers well informed of upcoming works schedules.
- Implement the prerequisite policy measures so that:
    - environmental water can be delivered on top of unregulated flows to provide higher flow components when it is most opportune, and the least water is required to achieve these flows.
    - return flows from environmental water deliveries are recredited, enabling the limited volume of environmental water to be used in multi-action events. This means less water will be needed overall and the water that is used can be supplied back to the channel with productivity inputs from off-channel wetlands.

Coordinating deliveries of HEW with consumptive deliveries can help to achieve greater flow volumes from the smarter use of all water. Such arrangements should enable larger in-channel and, where permitted, overbank flows that would not be possible with designated environmental water alone.

Similarly, controlled river flows through the system for consumptive deliveries can also meet the volumes described in many EWRs[82], without any contribution of environmental water. One of the primary recommendations of this LTWP is to investigate the potential to optimise these outcomes, by supporting collaboration between OEH and WaterNSW to assist in shaping consumptive deliveries to more closely reflect natural flow patterns and strike a balance between operational efficiency and ecological objectives.

Cooperative water management

Managing water for the environment at the catchment scale requires cooperation between stakeholders. Such cooperative arrangements support better environmental outcomes.

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[82] Consumptive deliveries can replicate the required hydrologic characteristics; however, other benefits such as nutrient transport may be removed when the water is extracted

Water for the environment in NSW is managed cooperatively by three government agencies: OEH, CEWO and DoI–W. Together these agencies manage NSW and Commonwealth HEW portfolios (OEH and CEWO) and the WSPs that provide PEW in the system (DoI–W).

7.2. Complementary actions

Cooperative arrangements for environmental outcomes

To achieve the watering required to support the ecological objectives, it is necessary to ensure that any priority environmental assets and functions on private land can be accessed for management. This includes arrangements with landholders that allow for priority assets on private land to be inundated with the required timing, frequency and duration. Access to these assets to evaluate how they are responding to management over time is also vital for the full implementation of the LTWP in these areas.

Complementary management of flow-dependent environmental assets is vital to the success of this LTWP. Degradation of assets through poor land management practices and inadequate legislative protection may undermine the benefits of environmental water management. Cooperative arrangements between government agencies such as LLS, private industry groups, individual landholders, Traditional Owners, non-government organisations and community groups that ensure adequate stewardship of environmental assets are essential.

Cooperative investment opportunities

A number of significant investment priorities have been identified in the Murrumbidgee catchment (Table 24). Identification of funding opportunities and subsequent implementation of projects to address these priorities would contribute significantly to the environmental outcomes identified in this plan.

Through the life of the plan, OEH will seek opportunities to build links and partnerships to support implementation of projects that will contribute to the ecological objectives of the LTWP.

Figure 19 Black-winged stilts, at Paika Lake, Lower Murrumbidgee
Photo: M. Todd, OEH.

Table 24 Recommended further investment and projects to improve environmental water outcomes in the Murrumbidgee water resource plan area. Projects are in no order of priority

Investment opportunity	Description	Potential project partners	Relevant LTWP section
Purchase of lagoon licences or negotiation of enduring agreements with holders of lagoon licences	This LTWP identifies the need for wetland connecting flows to fill wetlands such as off-channel lagoons. Some of these lagoons have licences which allow water to be extracted from them. The targeted purchase of these licences from willing sellers or the negotiation of enduring agreements with lagoon licence holders is recommended where maintaining water and habitat in the lagoons aids in achieving the objectives of the LTWP	CEWO, DoI–W, DAWR, OEH	Table 16
Improved compliance regime for lagoon licences	Where environmental water is provided to fill lagoons that have extraction licences (see above), compliance regimes should be designed to ensure the environmental water provided is protected. Compliance in these areas is complicated because the lagoon may also receive water from unregulated events and local runoff.	DoI–W, NRAR	Table 16
Protection of environmental flows, including in (but not limited to) the upper Murrumbidgee	Protect environmental flows as required by the Basin Plan (sections 7.15 and 10.28) and recommended by the Matthews report (2017a, b), including in unregulated stream sections such as the Murrumbidgee below Tantangara. Protection of flow releases in the upper Murrumbidgee was also a recommendation of the Snowy Scientific Committee (2010). This includes (but is not limited to) the work being done for Prerequisite Policy Measures which are to allow for the recrediting of return flows and protection of environmental flows through the length of the Murrumbidgee and (for held environmental water) into and then within the Murray River. Protecting flows through to the Murray contributes to objective EF7 (increased flows to the Murray), objective EF3 (movement and dispersal opportunities to biota) and a number of other objectives including NF10 (reintroducing diadromous fish to the catchment).	DoI–W, NRAR, WaterNSW	Table 16
Implement the Constraints Management Strategy (CMS)	The ability to meet the ecological objectives of the LTWP is critically limited by constraints which prevent environmental deliveries to connect to off-channel wetlands and the lower floodplain. The implementation of the CMS is crucial to overcome this. While the key benefits from the CMS in the Murrumbidgee will be for the Murrumbidgee's wetlands, lower floodplain and the channel itself, there will also be benefits for the Murray where co-ordinated flows enable higher overall flows in the Lower Murray to reach the floodplain there.	DOI-W, OEH, MDBA	Table 16
Reduce take from the peak of wetland connecting events by negotiating for	Investigate negotiated arrangements with irrigation corporations and other large water users so that extraction from the peaks of wetland connecting events is avoided and equivalent access is provided at other mutually beneficial times. This would protect the	OEH, CEWO, DoI–W, Irrigation corporations	Table 16

Investment opportunity	Description	Potential project partners	Relevant LTWP section
extraction to occur at other times	peak flow – the key determinant of whether wetlands are connected. It would mean smaller events would achieve more downstream.		
Upper Murrumbidgee cross border engagement	Ensure ACT agencies are informed of environmental flow events in the upper Murrumbidgee and these flows are protected through the ACT.	OEH, DoI–W, ACT agencies	Table 16
Escapes in Lowbidgee levees	Investigate the benefits and costs of building additional strategically placed escapes in the Lowbidgee levee system to improve flexibility in providing connectivity between the floodplain wetlands and the river channel. This includes for return flows and through-flows and should incorporate appropriate gauging. Investigate improvements to gauging on existing levees.	OEH, WaterNSW, DoI–W	Table 16
Improved water quality monitoring to avoid fish deaths	Improve monitoring of stratification, including with thermistor chains and dissolved oxygen monitoring near surface and at depth. Monitoring equipment should be regularly maintained and calibrated. This is particularly relevant at weirs in the lower catchment. A fish death event occurred in January 2019 and with climate change and accompanying increasing heat wave events, the risk of fish deahts is increasing. Refer to recommendations of the report being undertaken by Baldwin (in prep) for further details. This report is expected to recommend that dissolved oxygen monitoring should be taken upstream of weir structures rather that downstream (where such monitoring is often undertaken) because there is a localised aeration effect downstream of the weir that can skew results.	WaterNSW, DoI–W, DPI Fisheries	Table 17
Improved tools to manage potential fish death events	Provide improved modelling of how stratification and hypoxia events may occur. This is required to help avoid fish death events including through the establishment of triggers for flows to flush and mix weirpools or where gates should be lowered or removed. Calibrate the model with monitoring. Some modelling has already been undertaken (Webster *et al*. 2000) and this project should expand on that work.	DoI–W, OEH, DPI Fisheries	Table 17
Investigate opportunities to temporarily remove (or lower) weir gates to improve connectivity and improve habitat for native fish	Weirs are barriers to fish movement. Their weirpools are very low flow velocity habitats – which favour carp and blue green algae and increase the risk of hypoxia which can lead to fish deaths (Baldwin, in prep). Investigate the possibility of removing or lowering weir gates at times when other customers have a reduced need for the weir pools. This will only be applicable at some weirs and may only be applicable for short periods. Third party impacts will need to be considered.	OEH, DoI–W, WaterNSW, DPI Fisheries	Table 17

Investment opportunity	Description	Potential project partners	Relevant LTWP section
Undertake work to refine flow thresholds for EWRs	Continue to improve flow threshold estimates for EWRs, including by: Refining existing and establishing new commence to fill levels for off-channel wetlands, through monitoring of coming events, analysis of previous events using satellite imagery and through modelling. Work on the constraints project may be able to provide some of this information Refining overbank flow threshold estimates including by improving estimates of flow levels at which black box areas are inundated. Again, work on the constraints project may be able to provide some of this information Refining information about levels at which in-channel benches, snags and other in-channel features are inundated to improve estimates for small and large fresh thresholds. This work should include features such as riffles in the Upper Murrumbidgee, as the need for this was identified in Williams (2017). Undertake work to determine flows required to move sediment from gravel beds and scour cobbles, particularly in the Upper Murrumbidgee.	OEH, DoI–W, DPI Fisheries	Table 16
Undertake work to refine indicators for LTWP ecological targets	Develop specific targets and indicators for the objective of instream and floodplain productivity. These should relate to enhancing riverine productivity to support increased food availability for aquatic food webs by increasing the supply of autochthonous and allochthonous carbon and nutrients.	OEH, DoI–W	Chapter 3
Provide incentives to improve management of wetlands on private land	The protection of native vegetation requires good knowledge, the cooperation of various stakeholders, & multiple different projects, which could include: • habitat mapping to identify riparian & aquatic habitat condition & prioritise reaches for management actions in partnership with LLS & landholders, to develop formal agreements & unified strategies • implement grazing strategies required to protect & restore wetland vegetation, bank stability & adequate water quality in collaboration with LLS & landholders • provide incentives to landholders to improve management of wetlands on private land.	OEH, LLS, NPWS, CEWO, DPI Fisheries, DPI, Landholders, Biodiversity Conservation Trust	Table 17
Long-term arrangements with landholders for watering wetlands on private properties	To ensure wetlands on private properties can be watered into the future, enduring agreements should be sought with landholders. Wetlands with such arrangements should be prioritised over other privately held wetlands.	OEH, CEWO, Landholders, LLS	Table 16

Investment opportunity	Description	Potential project partners	Relevant LTWP section
Implement improved land management practices in areas that contribute disproportionately to sediment loads	Prioritise areas which disproportionately contribute to sediment loads and poor water quality. Work with landholders to improve land management practices.	OEH and LLS	Table 17
Formalise channel sharing arrangements	Develop formal supply sharing arrangements to provide a mechanism for managing the delivery of water when demands regularly exceed channel sharing capacity.	OEH, DoI-W, Water NSW, CAG	Table 16
Implementation of a native fish restoration project	To assist in improving the aquatic habitat that supports native fish there is an opportunity to implement various instream management activities, including: • assessing & addressing priority barriers to fish passage in the WRPA • estimating the flow rates required to drown out barriers and provide connectivity through important river reaches • the implementation of pump screening methods to prevent entrainment of native fish, larvae & eggs • works to achieve instream habitat improvement including re-snagging & aquatic revegetation (re-snagging would also improve turbulence which reduces the risk of stratification and therefore blue green algal blooms and hypoxia – see Baldwin (in prep)) • instream habitat mapping to help identify high-risk & priority refuge areas and core wetlands • implementation of the carp management strategy (see NSW I&I 2010) and National Carp Control Plan (FRDC, in prep). • Installation of carp screens on intakes into wetlands where infrastructure is used to fill wetlands. • reintroduction, translocation & stocking of threatened fish species in key locations.	DPI Fisheries, LLS, OEH	Table 17
Investigate the feasibility of modifications to Burrinjuck and Blowering dams to reduce thermal (cold-water) pollution	The combined impact of the releases from Burrinjuck and Blowering dams extends 300 km downstream of the confluence of the Tumut and Murrumbidgee rivers (affecting a combined total of 440 km of river) (Lugg and Copeland 2014). Temperature is a key driver of fish breeding and productivity.	WaterNSW, OEH, DoI–W, DPI Fisheries.	Table 17

Investment opportunity	Description	Potential project partners	Relevant LTWP section
	Changes to the dams' offtakes, including through the use of curtains, such as used at Burrendong Dam on the Macquarie River, may allow water to be released from above the thermocline so downstream water is within natural temperature ranges.		
Improve understanding of climate change impacts, thresholds & adaptive management strategies	Potential changes in weather, bushfires & erosion due to climate change are outlined in Section 5. This task involves assessing the potential impact of these changes on the environmental assets of the Murrumbidgee WRPA, identifying management adaptations to respond to change & developing indicators to trigger responses.	DPI Fisheries, NPWS, DoI–W.	Section 5
Infrastructure for filling wetlands	In the Mid-Murrumbidgee, where delivery is difficult due to constraints, investigate the use of channels and pumps to wet additional wetlands. This may allow the vegetation of a core group of wetlands to recover. These may then provide the propagules for improvement in other wetlands when constraints are relaxed. Opportunities should be sought to use existing infrastructure, preferably with long term agreements with the owners of such infrastructure. Carp screens and other carp management practices should be implemented.	OEH	Constraints – Table 16
Engagement with Traditional Owners	Traditional Owners hold unique knowledge about the values and requirements of the Murrumbidgee. They are also land holders and managers. Further engagement with Traditional Owners will improve the achievement of LTWP objectives and will positively influence further revisions of the LTWP.	OEH, DoI–W	Section 1.1
Management of lippia	Lippia (*Phyla canescens*) is a problem weed on the fringes of riverbanks and wetlands, particularly in the Mid-Murrumbidgee. It was identified in the Murrumbidgee reach report of the constraints management strategy as a significant concern of landholders. Projects to investigate improved management of this weed, including through biological control, should be encouraged.	DPI	Table 17
Knowledge gaps-vegetation mapping	Improved mapping, including in, but not limited to, the riparian areas of the upper Murrumbidgee, would assist in management of these areas.	LLS, OEH.	

7.3. Measuring progress

Monitoring, evaluating and reporting (MER) to support adaptive management are integral to informing planning and operational decisions. Monitoring how water moves through the system and how the environment responds informs ongoing improvements to water management. This information also assists in informing revisions of this LTWP every five years.

Monitoring and evaluating environmental targets in the Murrumbidgee catchment draws on contributions from Australian and NSW Government agencies, universities, other research organisations, non-government organisations, individuals and land managers.

The MER program provides a coordinated approach to delivering Basin Plan and NSW evaluation and reporting requirements. The NSW-wide MER program consists of:

- a NSW MER Framework that describes the principles, types of monitoring, alignment across NSW agencies efforts, knowledge gaps, externalities and constraints, and relationships to the BWS and Basin Plan. It also describes how existing knowledge and programs are used to create a cost-effective and coordinated program
- the OEH-specific parts, called the *Healthy Inland Wetlands Environmental Water Program* that describes the approach to developing LTWP MER objectives, evaluation of management actions and reporting
- customised MER Plans that summarise the proposed MER activities for each WRPA
- monitoring *Methods Manuals* that describe methods for each monitoring theme (e.g. fish, hydrology, vegetation, water quality, macroinvertebrates, waterbirds) considered in broader NSW water monitoring. These manuals, when developed, will contain information relating to survey, data handling and analysis techniques, conceptual models and cooperative research arrangements.

The NSW MER Framework, which includes NSW Fisheries Basin Plan Environmental Outcomes Monitoring program and OEH’s MER program, provides the structure within which various NSW-led monitoring activities are brought together for tracking progress towards stated LTWP and WSP outcomes; and improved decision making for environmental water planning and operations (supporting adaptive management).

To do this, the NSW MER Framework aims to:

- evaluate progress towards achieving outcomes defined within LTWPs and WSPs
- extend, augment and respect current and historical monitoring
- address information and monitoring gaps or shortfalls
- provide scientifically-robust information to support both continual improvement of operations and a growing information base for wetland and river conservation generally
- collaborate with water delivery partners (particularly the CEWO), DoI–W, wetland managers, other agencies and researchers to value-add to monitoring outcomes and prevent duplication
- provide information that supports community engagement and improved reporting of environmental water outcomes which will increase government and community confidence and awareness of environmental water management
- streamline reporting requirements under WRPs, LTWPs, Schedule 12 of the Basin Plan and the National Partnership Agreement.

The detail of the monitoring to be undertaken under the MER program is being finalised and is dependent on the level of available funding. Monitoring progress reports are made available following each watering year.

Figure 20 Golden perch, freshwater prawns and Australian smelt sampled at Yanga Lake, Balranald
Photo: J. Dyer/OEH

7.4. Review and update

This LTWP brings together the best available information from a range of water management, community, traditional and scientific sources. To ensure the information remains relevant and up-to-date, this LTWP will be reviewed and updated no later than five years after it is implemented, being 2024.

Additional reviews may also be triggered by:

- accreditation or amendment to the WSP or WRP for the Murrumbidgee catchment
- revision of the BWS that materially affects this LTWP
- a SDL adjustment
- significant new information arising from evaluating responses to environmental watering
- significant new knowledge about the ecology of the Murrumbidgee catchment that is relevant to environmental watering
- improved understanding of the effects of climate change and its impacts on the Murrumbidgee catchment
- significant changes to the river operating environment or the removal of constraints that affect watering strategies
- material changes to river and wetland health, not considered within this LTWP.

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Appendix A. Ecological objectives relevant to each planning unit

Table 25 Long term water plan objectives relevant to each planning unit in the Murrumbidgee water resource plan area

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
			Regulated or affected by regulated releases														Predominantly unregulated														
					Murrumbidgee River																										
	Code	Ecological objective	Upper Murrumbidgee: Tantangara to Burrinjuck	Tumut River Below Blowering Dam	Burrinjuck to Tumut Junction	Tumut River Junction to Berembed Weir	Berembed Weir to Gogeldrie Weir	Gogeldrie Weir to Maude Weir	Lower Murrumbidgee Floodplain	Balranald to Murray	Beavers & Old Mans creeks	Upper Yanco Creek	Colombo Ck & Middle Billabong Ck	Lower Yanco Creek	Lower Billabong and Intersecting Streams	Murrumbidgee Infrastructure Dependent Floodplain Wetlands	Lake George water source	Tantangara water source	Monaro tributaries	Murrumbidgee tributaries: ACT to Burrinjuck Dam	Yass River water source	Goodradigbee water source	Upper Tumut River above Blowering Dam	Tumut River tributaries below Blowering Dam	Murrumbidgee tributaries: Burrinjuck to Tumut River	Murrumbidgee tributaries: Tumut River to Berembed Weir	Murrumbidgee North water source	Upper Billabong Creek	Murrumbidgee tributaries: Berembed Weir to Gogeldrie Weir	Urana water source	Wangamong Creek
Native fish	NF1	No loss of native fish species	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NF2	Distribution and abundance of short to moderate-lived generalists	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NF3	Distribution and abundance of short to moderate-lived floodplain specialists																						X				X			
	NF4	Population structure for moderate to long-lived flow pulse specialists	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X		X	
	NF5	Population structure for moderate to long-lived riverine specialists	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X
	NF6	A 25% increase in abundance of harvestable sized Golden Perch and Murray Cod	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X		X	
	NF7	Key short to moderate-lived floodplain specialists into new areas (in historical range)		X		X	X	X	X						X	X								X		X	X	X	X	X	X
	NF8	Key moderate to long-lived riverine specialists into new areas (within historical range)	X		X	X	X	X				X	X	X	X			X	X			X		X	X	X					
	NF9	Key moderate to long-lived flow pulse specialists into new areas (in historical range)			X	X	X	X	X	X	X	X	X	X	X	X									X	X		X			
	NF10	Key diadromous fish into new areas (in historical range)					X	X	X	X																					
Waterbirds	WB1	Number and type of waterbird present				X	X	X	X		X					X															
	WB2	Total waterbird abundance				X	X	X	X		X					X															
	WB3	Breeding activity in non-colonial nesters				X	X	X	X		X					X															
	WB4	Opportunities for colonial breeding events				X	X	X	X		X																				
	WB5	Condition of waterbird habitats				X	X	X	X		X					X															
Vegetation	NV1	Non-woody vegetation communities occurring within channels	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV2	Non-woody vegetation communities occurring in wetlands and on floodplains	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV3	River red gum communities closely fringing river channels		X	X	X	X	X	X	X	X	X	X	X	X	X					X	X		X	X	X	X	X	X	X	X
	NV4a	River red gum forest		X	X	X	X	X	X	X	X	X	X	X	X											X	X	X	X	X	X
	NV4b	Red gum woodland		X	X	X	X	X	X	X	X	X	X	X	X	X										X	X	X	X	X	X

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
			Regulated or affected by regulated releases														Predominantly unregulated														
					Murrumbidgee River																										
	Code	Ecological objective	Upper Murrumbidgee: Tantangara to Burrinjuck	Tumut River Below Blowering Dam	Burrinjuck to Tumut Junction	Tumut River Junction to Berembed Weir	Berembed Weir to Gogeldrie Weir	Gogeldrie Weir to Maude Weir	Lower Murrumbidgee Floodplain	Balranald to Murray	Beavers & Old Mans creeks	Upper Yanco Creek	Colombo Ck & Middle Billabong Ck	Lower Yanco Creek	Lower Billabong and Intersecting Streams	Murrumbidgee Infrastructure Dependent Floodplain Wetlands	Lake George water source	Tantangara water source	Monaro tributaries	Murrumbidgee tributaries: ACT to Burrinjuck Dam	Yass River water source	Goodradigbee water source	Upper Tumut River above Blowering Dam	Tumut River tributaries below Blowering Dam	Murrumbidgee tributaries: Burrinjuck to Tumut River	Murrumbidgee tributaries: Tumut River to Berembed Weir	Murrumbidgee North water source	Upper Billabong Creek	Murrumbidgee tributaries: Berembed Weir to Gogeldrie Weir	Urana water source	Wangamong Creek
	NV4c	Black box woodland					X	X	X	X		X	X	X	X	X											X				
	NV4e	Lignum shrubland					X	X	X	X			X	X	X	X											X	X			X
Ecosystem functions	EF1	Provide and protect a diversity of refugia	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF2	Create quality instream, floodplain and wetland habitat.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF3a	Provide movement and dispersal opportunities within catchments.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF3b	Provide movement and dispersal opportunities between catchments.		X			X		X	X	X	X	X	X	X				X	X	X	X		X	X	X	X	X	X		X
	EF4	Support instream and floodplain productivity.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF5	Support mobilisation and transport of sediment, carbon and nutrients.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF6	Support groundwater conditions to sustain groundwater dependent biota.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF7	Increase the contribution of flows into the Murray and Barwon-Darling tributaries.								X					X																
Other Species (frogs)	OS1	Maintain species richness and distribution of flow-dependent frog communities				X	X	X	X																						
	OS2	Maintain successful breeding opportunities for flow-dependent frog species				X	X	X	X																						
	OS3a	Maintain and increase number of wetland sites occupied by southern bell frog						X	X					X		X															

Appendix B. Resource availability scenario

Guidelines for the method to determine priorities for applying environmental water[83]

The assessment of the RAS occurs throughout the water year. The critical information required for this assessment is the water availability and the condition of the environment (antecedent conditions). These can be determined with reference to existing data sourced from the Bureau of Meteorology and state water agencies. As set out in section 8.61 of the Basin Plan, a RAS will be one of: very dry, dry, moderate, wet, or very wet.

To determine the RAS, the following steps are followed:

a. determine the antecedent conditions for a given WRPA by (the 'X' axis of the matrix in Table 22):
   - i selecting a representative number of water accounting periods preceding the current water year (e.g. 3–5 years)
   - ii assessing the water received by the environment for those years
   - iii comparing the amount in (ii) to all the historical data
   - iv categorising the antecedent conditions as a percentile relative to all historical water years

b. determine the surface water availability by (the 'Y' axis of the matrix in Table 22):
   - i assessing all sources of water available for the environment for a given period
   - ii comparing these to all the historical data
   - iii categorising the surface water availability as a percentile relative to all historical water years

c. for the relevant water accounting period, determine the surface water availability relative to the antecedent conditions for the WRPA using all of the historical climate condition data that are available (in Table 22, this is the surface water availability percentile)

d. using the following matrix below, determine the applicable water RAS.

Table 26 Default matrix for determining the RAS

Surface water availability	Antecedent conditions				
	Very dry (0–15%)	Dry (16–45%)	Medium (46–60%)	Wet84 (61–85%)	Very wet[22] (86–100%)
Very low (0–15%)	Very dry	Very dry	Dry	Dry	N/A
Low (16–45%)	Very dry	Dry	Dry	Moderate	Wet
Medium (46–60%)	Dry	Dry	Moderate	Wet	Wet
High (61–85%)	Dry	Moderate	Wet	Wet	Very wet
Very high (86–100%)	N/A	Moderate	Wet	Very wet	Very wet

[83] As outlined by MDBA 2012d
[84] Wet and Very wet RAS are combined in this LTWP because the management strategies are the same.