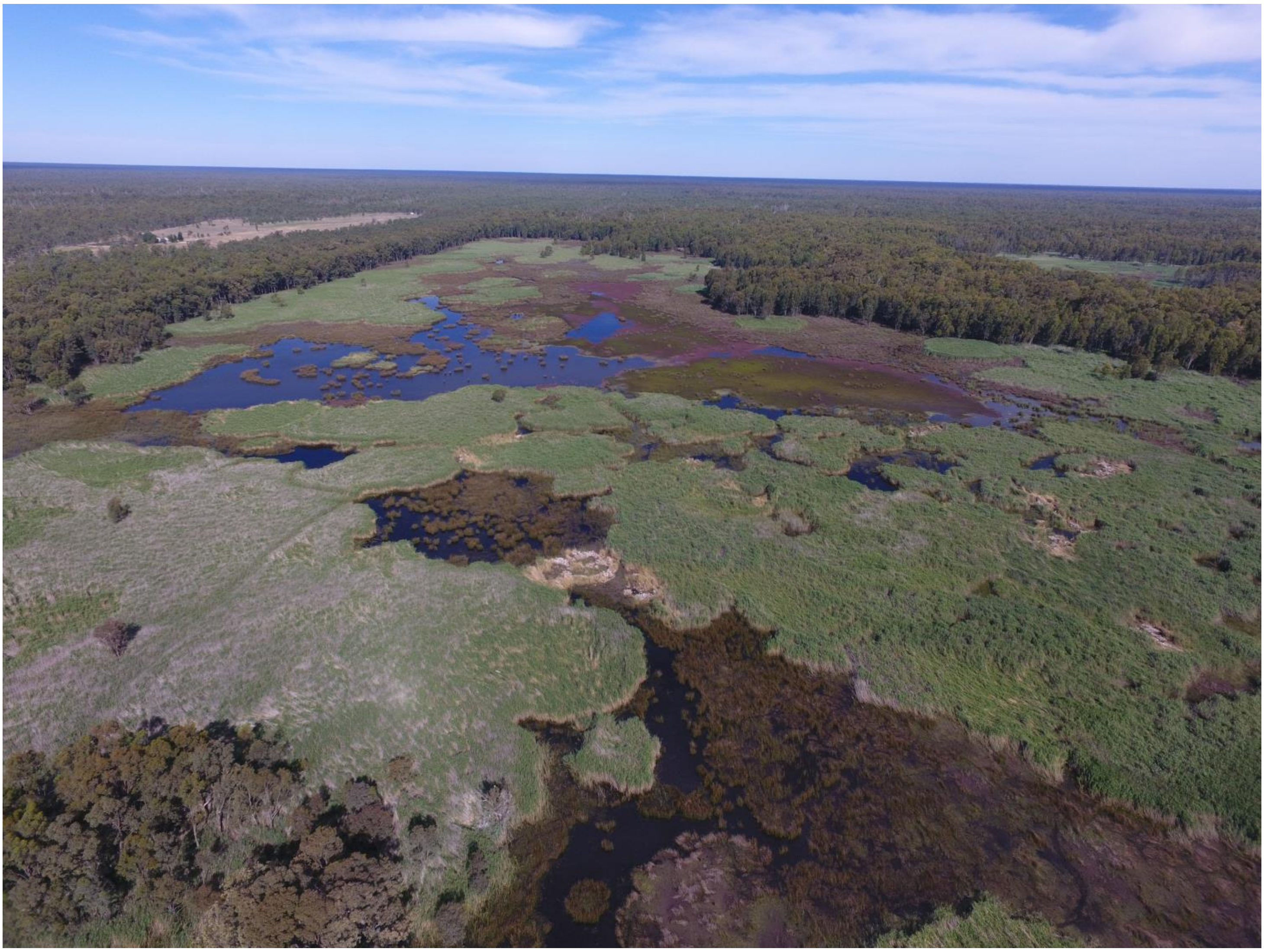
DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

Murray–Lower Darling Long Term Water Plan

Part A: Murray–Lower Darling catchment



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Cover photo: Reed Beds wetland and key colonial waterbird breeding area in Millewa forest (Murray Valley National Park), Vince Bucello

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Environment, Energy and Science
Department of Planning, Industry and Environment
4 Parramatta Square, 12 Darcy Street, Parramatta NSW 2150
Phone: +61 2 9995 5000 (switchboard)
Phone: 1300 361 967 (Environment, Energy and Science enquiries)
TTY users: phone 133 677, then ask for 1300 361 967
Speak and listen users: phone 1300 555 727, then ask for 1300 361 967
Email: info@environment.nsw.gov.au
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Contents

List of tables

List of figures

Acknowledgement of Traditional Owners

The Department of Planning, Industry and Environment 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 Murray-Lower Darling catchment, the Department of Planning, Industry and Environment pays its respects to the Traditional Owners – the Bangerang, Barkindji, Barapa Barapa, Maljangapa, Maraura, Muthi Muthi, Ngiyampaa, Nyeri Nyeri, Tati Tati, Wadi Wadi, Wamba Wamba, Weki Weki, Yorta Yorta and Wiradjuri Nations – past, present and future, as well as those of other Nations for whom the rivers of the Murray-Lower Darling are significant. 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 Australian white ibis chick and eggs, Reed Beds Swamp, Millewa forest
Photo: Vince Bucello

Abbreviations

Basin Plan	Murray–Darling Basin Plan
BF	Baseflow
BK	Bankfull
BWS	Basin-wide environmental watering strategy
CAG	Customer Advisory Group
CAMBA	China – Australia Migratory Bird Agreement
CEWH	Commonwealth Environmental Water Holder
CEWO	Commonwealth Environmental Water Office
CF	Cease-to-flow
CTP	Cease-to-pump
DBH	Diameter at breast height
DELWP	Department of Environment, Land, Water and Planning (Victoria)
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DoA	Department of Agriculture (Federal)
DPIE	Department of Planning, Industry and Environment
DPIE-BC	Department of Planning, Industry and Environment – Biodiversity and Conservation Division
DPIE–Water	Department of Planning, Industry and Environment – Water (NSW)
DPIF	Department of Primary Industries Fisheries (NSW)
d/s	Downstream
EEC	Endangered ecological community
EWA	Environmental water allowance
EWAG	Environmental Water Advisory Group
EWR	Environmental water requirement
FSL	Full Supply Level
GDE	Groundwater-dependent ecosystem
HEW	Held environmental water
HLLF	High-level lake fill
JAMBA	Japan – Australia Migratory Bird Agreement
LALC	Local Aboriginal Land Council
LF	Large fresh
LLLF	Low-level lake fill
LLS	Local Land Services (NSW)
LTWP	Long Term Water Plan
m/s	metres per second
MDBA	Murray–Darling Basin Authority
MER	Monitoring, evaluation and reporting

MIL	Murray Irrigation Limited
MLLF	Mid-level lake fill
mg/L	milligrams per litre
ML	megalitre
NPWS	National Parks and Wildlife Services (NSW)
NRAR	Natural Resources Access Regulator (NSW)
NSW	New South Wales
OB	Overbank
OEH	Office of Environment and Heritage (NSW) – *DPIE-BC as of 1 July 2019*
PCT	Plant community type
PEW	Planned environmental water
PPM	Pre-requisite Policy Measure
PU	Planning unit
RAS	Resource availability scenario
ROKAMBA	Republic of Korea – Australia Migratory Bird Agreement
SDL	Sustainable diversion limit
RMIF	River Murray Increased Flows
SF	Small fresh
VF	Very low flow
VHLLF	Very high-level lake fill
WL	Wetland inundating flow
WQMP	Water quality management plan
WRP	Water resource plan
WRPA	Water resource plan area
WSP	Water sharing plan

Figure 2 Egret in Reed Beds Swamp, Millewa forest.
Photo: Vince Bucello

Glossary

Actively-managed floodplain	The area of 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 DPIE–Water, which is determined within the context of demand, inflows, rainfall forecasts and stored water.
Alluvial	Comprised of material deposited by water.
Bankfull flow (BK)	River flows at maximum channel capacity with little overflow to adjacent floodplains. Engages the riparian zone, anabranches and flood runners and wetlands located within the meander train. Inundates all in channel habitats including all 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. Typically inundates geomorphic units such as pools and riffle areas.
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 remain un-used 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 (CF)	The absence of flowing water in a river channel. Partial or total drying of the river channel. Streams contract to a series of isolated pools.
Cease-to-pump (access rule in WSP) (CTP)	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, or 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 asset	The physical features that make up an ecosystem.
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	Objective for the protection and/or restoration 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 that 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 to 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)	Planned environmental water established under the *Water Sharing Plan (WSP) for the NSW Murray and Lower Darling Regulated Rivers Water Sources 2016*. Includes the Barmah-Millewa EWA (or Barmah-Millewa Allowance), Barmah-Millewa Overdraw EWA, the Murray Additional EWA and an EWA for the Lower Darling water source.
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. 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	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 which 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, oxygen levels fall and a hypoxic (low oxygen) condition occurs. Dissolved oxygen is measured in milligrams per litre (mg/litre). Generally native fish begin to stress when DO levels fall below 4 mg/litre. Fish mortality occurs when DO levels are less than 2 mg/litre.
Large fresh (LF)	High-magnitude flow pulse that remains in-channel. May engage flood runners with the main channel and inundate low-lying wetlands. Connects most in channel habitats and provides 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 Murray–Darling Basin Plan, long-term water plans give effect to the Basin-Wide Watering Strategy 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. DPIE 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	Water that is committed by the Basin Plan, a water resource plan or a plan made under state water management law to achieving environmental outcomes.
Planning Unit (PU)	A division of a water resource plan 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	A place of particular ecological significance that is water-dependent and can be managed with environmental water. This includes planned and held environmental water.
Priority ecological function	Ecological functions that can be managed with 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	Areas 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.
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.
SDL Supply Measure	A measure that increases the quantity of water available for extraction under the Sustainable Diversion Limit (SDL) (i.e. reduces how much water needs to be recovered from consumptive users for the environment). Supply measure projects need to provide equivalent environmental outcomes with a smaller quantity of water than was required under the benchmark conditions of development. Examples of measures include changes to water infrastructure, changes to river management and river operational practices, or changes in methods of delivering environmental water. The water saved is used to adjust (increase) the Sustainable Diversion Limit.

Unregulated river	A waterway where flow is mostly uncontrolled by dams, weirs or other structures.
Very low flow (VF)	Small flow in the very-low flow class that joins river pools, thus providing partial or complete connectivity in a reach. 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. Makes up part of the Water Resource Plan. It aims to provide a framework to protect, enhance and restore water quality in each water resource plan area.
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 water resource plan.
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. A water sharing plan (WSP) will be a component of a water resource plan (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.

Figure 3 Water ribbon seed heads and with common spike rush
Photo: Vince Bucello

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, many rivers, wetlands and floodplains in New South Wales (NSW) have had their natural flow regimes disrupted because of dams, weirs, floodplain development, and water regulation and extraction. In the case of the Murray–Lower Darling, the frequency, duration and timing of large freshes and wetland and floodplain inundating flows have experienced the greatest alteration.

The NSW Government's first Murray–Lower Darling 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 Murray–Lower Darling Water Resource Plan Area (WRPA). The Plan identifies water management strategies for maintaining and improving the long-term health of the Murray-Lower Darling 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 Murray–Lower Darling 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, research 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, waterbirds and ecosystem functions and co-ordinate water use across multiple catchments to achieve Basin-scale outcomes.

The *Basin-wide Environmental Watering Strategy* (BWS) 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 water resource plan areas (catchment-scale), must contribute to the achievement of the BWS by identifying:

- priority environmental assets and functions in a water resource plan area
- 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 Murray–Lower Darling Long Term Water Plan

The Murray–Lower Darling LTWP is one of nine plans being developed by the Department of Planning, Industry and Environment (DPIE) to cover the NSW portion of the Murray–Darling Basin. Development of the LTWP has involved five 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 Murray–Lower Darling catchment.
- Determining the **environmental 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.
- Identifying potential **management strategies** to meet environmental water requirements
- 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 Murray–Lower Darling catchment

The Murray–Lower Darling catchment supports a range of water-dependent ecosystems, including instream aquatic habitats, riparian forests, and floodplain watercourses, woodlands and wetlands. Notably, the NSW Central Murray Forests (Millewa, Werai and Koondrook–Perricoota forests) are internationally recognised on the Ramsar Convention list of Wetlands of International Importance. These ecosystems benefit many water-dependent species, including threatened ecological communities, threatened, endangered and migratory waterbirds, and threatened native fish species, by providing habitat and food resources. The lower Darling River and Menindee Lakes which provide important breeding and recruitment habitat for native fish are also notable. Recent monitoring has shown that native fish recruits from the Darling system will disperse through large parts of the Murray-Darling Basin system and are therefore are a vital source population.

The future ecological condition of the Murray and Lower Darling water-dependent environmental assets will be largely driven by our ability to deliver flows that connect rivers with cut-off channels, anabranches, floodplains and wetlands. Flows that provide these connections support organic carbon transfer and nutrient cycling, primary productivity to drive food webs, trigger movement and breeding of native fish and waterbirds, and directly influence vegetation condition and habitat availability.

Extensive local, traditional and scientific knowledge about the Murray–Lower Darling riverine environmental assets and ecosystem functions underpins this LTWP. This has been collected in partnership with water managers, natural resource managers, environmental water holders, landholders, and community members. Information about the Murray–Lower Darling's environmental values closely aligns with material in the Department of Planning, Industry and Environment's *NSW Murray and Lower Darling Surface Water Resource Plan Area Risk Assessment* (NSW DPIE 2019a).

Water for the environment

The Murray–Lower Darling LTWP contains ecological objectives and targets for priority environmental assets and ecosystem functions in the Murray–Lower Darling catchment. The Basin Plan defines priorities as those assets and functions that can be managed with environmental water. The objectives and targets have been identified for native fish, native vegetation, waterbirds and river connectivity. As noted in the BWS, each of these themes is a good indicator of river system health and is responsive to flow.

The objectives express the current understanding of environmental outcomes that might be expected from implementation of the Basin Plan in the rivers, wetlands, floodplains, and watercourses of the Murray–Lower Darling 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.

Table 1 A summary of the environmental outcomes sought in the Murray–Lower Darling LTWP

Broad outcome	Overarching objectives	Example uses of water for the environment to achieve LTWP objectives
To maintain the extent and improve the health of water-dependent native vegetation and wetlands	Maintain and improve the viability and extent of river red gum, black box and coolabah communities, lignum shrublands and non-woody wetland and in-channel vegetation	• Provide in-channel flows to support non-woody vegetation growth on riverbanks, benches and in low-lying wetlands • Improve the extent and condition of vegetation in low-lying floodplain forests including Millewa, Koondrook–Perricoota and Werai forests • Provide larger flows to support floodplain vegetation along riparian corridors
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 • Provide 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 flow conditions for native fish in the Murray, Edward–Wakool and Lower Darling systems, including regular connectivity with lakes, low-lying floodplains and wetlands to promote recruitment • Replenish refuge waterholes for native fish
To maintain and protect a variety of wetland habitats and support the movement of carbon and 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	• Restart flows after cease-to-flow conditions at sufficient flow rates to reduce the risk of hypoxic conditions and fish kills • Provide wetland and floodplain connecting flows to promote dispersal of biota, exchange of carbon and nutrients and primary productivity • Coordinate flows between the Murray, Edward–Wakool, lower Darling and Murrumbidgee Rivers to maximise productivity outcomes and potential for native fish dispersal and recruitment
Maintain the number and type of water-dependent species throughout the catchment	Maintain the number and range of water-dependent species including flow-dependent frogs support successful breeding.	• Maintain wetland habitats where breeding activity of flow-dependent frog species are detected

Management strategies and complementary investments

Complementary measures that are needed to ensure the LTWPs objectives and targets are achieved have been identified in the plan (see Chapter 7 and Appendix C). These include addressing physical constraints to the delivery of higher flows and implementation of Basin Plan Prerequisite Policy Measures (PPMs) to protect environmental water from extraction and to allow the delivery of environmental water together with unregulated flows. Other measures include coordination of environmental and operational flows across the southern connected basin, addressing barriers to fish movement and cold water pollution caused by water releases from Hume Dam, providing incentives to landholders to conserve riparian, wetland and floodplain vegetation and screening irrigation pumps to protect fish.

A critical complementary measure is the resolution of flow constraints to the delivery of environmental water in the Murray River between Hume and Yarrawonga; downstream of Yarrawonga (including the Edward-Wakool system); and in the lower Darling River. The Murray–Darling Basin Authority (MDBA) has consulted with many wetland and inner floodplain landholders on the implementation of a series of measures that would allow environmental water delivery to be made through critical periods of cropping activity, like planting and harvesting, without impact on these important agricultural activities.

Monitoring and evaluation of the Long Term Water Plan

Over the 20-year duration of this LTWP, NSW and Commonwealth agencies will monitor the health of rivers, wetlands and floodplains within the Murray–Lower Darling catchment to:

- monitor and 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:

- accreditation or amendment to the WSP or WRP for the Murray–Lower Darling catchment
- revision of the BWS that materially affects this LTWP
- a sustainable diversion limit (SDL) adjustment
- new information arising from evaluating responses to environmental watering
- new knowledge about the ecology of the Murray–Lower Darling catchment that is relevant to environmental watering
- improved understanding of the effects of climate change and its impacts on the Murray–Lower Darling catchment
- 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.

1. Introduction

The NSW Murray and Lower Darling (MLD) Water Resource Planning Area (WRPA) is located in southern NSW, covering a combined catchment area of 98,300 square kilometres. The area includes over 1700 kilometres of the Murray River, which flows westward from the Hume Dam water storage to the South Australian border. It also incorporates the lower Darling River and ephemeral Darling Anabranch system, which flow from the Menindee Lakes water storage to the confluence of Murray and Darling rivers at Wentworth. The MLD WRPA encompasses numerous hydrologically and ecologically diverse freshwater habitats, including in-stream habitats, river and creek channels, floodplain forests and woodlands, lakes and wetlands (NSW OEH 2016a). For the purpose of this LTWP, the MLD WRPA has been divided into four key water management areas: Mid Murray, Edward–Wakool, Lower Murray and Lower Darling.

The NSW Murray and Lower Darling WRPA is primarily characterised by flat, low-relief floodplain. At Hume Dam, the Murray River is approximately 150 metres above sea level but flows over hundreds of kilometres to an elevation of less than 50 metres above sea level at the Murray–Darling confluence. The Lower Darling water management area also has a flat topography with an elevation less than 100 metres across most of the floodplain area. Rainfall across the MLD WRPA is highly variable from year to year with a strong east-west rainfall gradient. Annual rainfall averages are typically much higher in the east (~700 mm per year) but the climate becomes increasingly more arid, with rainfall ranging from 500 mm to as little as 220 mm in the west. Rainfall is highly seasonal, predominantly occurring winter and spring. Summers are typically hot and dry with high evaporative demands, especially in the west.

The Mid Murray water management area is a highly developed section between Hume Dam and the Murray–Wakool river junction, downstream of Swan Hill. Major tributaries include the Kiewa, Ovens-King, Goulburn–Broken, Campaspe, Loddon and Murrumbidgee rivers and Broken Creek. Major storages and infrastructure include Yarrawonga, Torrumbarry and Stevens weirs. The Edward–Wakool water management area is a large anabranch system: a complex network of interconnected streams, ephemeral creeks, flood runners and wetlands, including the Edward, Wakool and Niemur Rivers, and Yallakool, Merran, Colligen, Jimaringle, Cockran, Yarrain and Thule creeks to name some. Major storages and infrastructure include Stevens Weir.

The Lower Murray water management area is also highly developed, including the Murray River downstream of the Wakool and Murray River junction to the South Australian border. There are major anabranches such as Frenchmans Creek and Rufus River, and the major water storage of Lake Victoria located downstream of the Murray–Darling confluence. Within this section there are six weirs (Weirs 7-11 and Weir 15, often referred to as 'Locks' as they also serve as navigation locks for vessels) that regulate flow and service irrigation areas.

The Lower Darling water management area includes the Menindee Lakes, lower Darling River and Darling Anabranch. The lower Darling River channel commences downstream of Main Weir and Lake Wetherell and meanders its way to the Murray–Darling confluence at the township of Wentworth. The Menindee Lakes storage (including lakes Menindee, Cawndilla, Pamamaroo and Wetherell), cover a combined area of around 45,000 hectares). The Darling Anabranch (also referred to as the Great Darling Anabranch) branches away from the lower Darling River downstream of the Menindee Lakes and joins the Murray River downstream of Wentworth. The Darling Anabranch receives inflows from several sources, including managed releases from Lake Cawndilla, overland flows from the Darling River, backwater from the Murray River and groundwater reservoirs (particularly in the lower reaches) and overland run-off (NSW DPI 2006).

The Mid Murray, Edward–Wakool and Lower Murray management areas are home to river red gum forests, wetland and floodplains including Barmah–Millewa, Gunbower, Koondrook–

Perricoota and Werai forests, which are internationally recognised Wetlands of International Importance under the Ramsar Convention (Ramsar 2009; Harrington and Hale 2011) and icon sites through the MDBAs 'The Living Murray' (TLM) Program (MDBA 2018). Collectively these forest, wetland and floodplain areas support over 550 plants and 270 animal species, including threatened species such as floating swamp wallaby grass, Murray Cod, trout cod, silver perch, flathead galaxias, Australian painted snipe, Australasian bittern, brolga, bush stone curlew, superb parrot and the southern bell frog (NSW DPI 2018).

The Edward–Wakool streams support a high proportion of native fish, at all stages of their life cycle, and provide critical refuge habitat during drought, including for threatened species such as Murray cod, trout cod, silver perch and Murray crayfish (Watts et al. 2015; NSW DPI 2007a).

Aquatic ecological communities of the lower Murray River and the Lower Darling catchment are listed as an Endangered Ecological Communities (EEC) in NSW (NSW DPI 2007a). Areas covered by the EECs include the lower Murray River downstream of Hume Dam, Frenchmans Creek, Edward and Wakool rivers and their tributaries, Rufus River and Lake Victoria. The Lower Darling River catchment from Mungindi (Queensland–NSW border) to the convergence with the Murray River is also listed as an EEC (NSW DPI 2007b).

The Murray and Lower Darling WRPA supplies water for domestic and extensive agriculture purposes (CEWO 2017). The main agricultural industries supported by this water source include wheat, rice, dairy, beef, wool, lamb, grapes, almonds and citrus. Other water users in the valley include local councils, water utilities, forestry and tourism (NSW OEH 2016a).

Flow in the MLD WRPA has been significantly altered by the presence of water storages and weirs, resulting in an alteration to flow volumes as well as reduced frequency of in-channel freshes and small to moderate-sized overbank events. As a result, condition of the catchment's flow dependent ecosystems and the vegetation and animals they support has declined. The NSW Government has developed the Murray–Lower Darling LTWP with the aim of protecting and restoring the health and function of the WRPA and contributing to the overall health and resilience of the Murray–Darling Basin.

Figure 4 Egret chick
Photo: Vince Bucello

1.1 Approach to developing the Murray–Lower Darling Long Term Water Plan

The Murray-Lower Darling LTWP applies to the NSW Murray and Lower Darling Surface-water WRPA and is one of nine catchment-based plans covering the NSW portion of the Murray–Darling Basin. The LTWP is consistent with the requirements of the Basin Plan (MDBA 2012a).

The Murray–Lower Darling LTWP 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 Murray–Lower Darling LTWP has involved five main steps:

- undertaking a comprehensive stocktake of water-dependent environmental assets and ecosystem functions across the Murray–Lower Darling 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 Murray–Lower Darling catchment.
- determining 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.
- identifying the risks and constraints to meeting the long-term water requirements of priority environmental assets and ecosystem functions.
- identifying potential management strategies for guiding water management decisions and investment into the future.

1.2 Implementing the Murray-Lower Darling Long Term Water Plan

Implementation of the LTWP requires strong partnerships and coordination between all land managers, water users and the community. The LTWP provides the foundation to support future coordination efforts by:

- guiding annual water management deliberations and planning by DPIE
- informing planning processes that influence river and wetland health outcomes, including development of water sharing plans and water resource plans
- identifying opportunities for more strategic river operations and strengthening collaboration between holders of environmental water
- helping target investment priorities for complementary actions that will effectively contribute to progressing the outcomes sought by this LTWP
- building broad community understanding of river and wetland health issues.

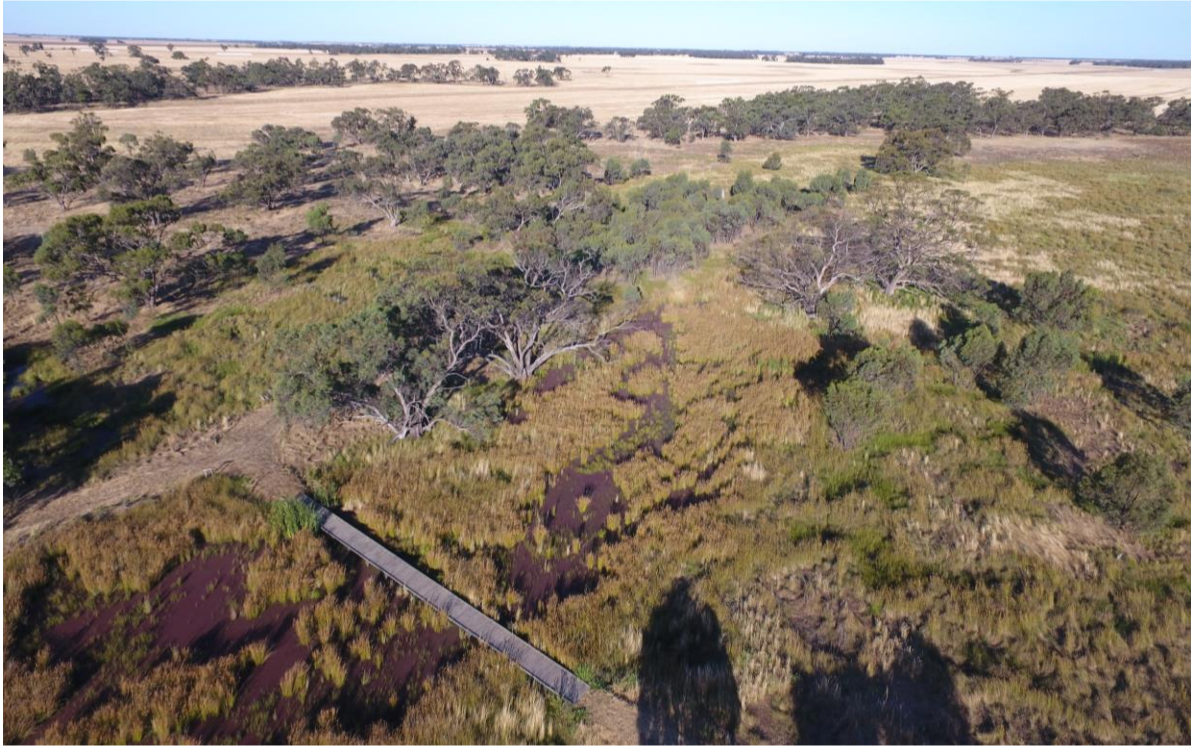

Figure 5 **Private property wetland in the Murray Irrigation Area. Environmental water supports wetland health on private as well as public land.**
Photo: Vince Bucello

1.3 The Long Term Water Plan document structure

The Murray–Lower Darling LTWP is presented in nine chapters with accompanying appendices. It is divided into Part A and Part B.

Part A: Murray–Lower Darling catchment

- **Chapter 1** explains the background and purpose of the LTWP.
- **Chapters 2** and **3** identify the water-dependent environmental assets and ecosystem functions in the Murray–Lower Darling catchment and articulate the environmental outcomes that are expected from implementation of the LTWP through ecological objectives and targets.
- **Chapter 4** provides the environmental water requirements (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 Murray–Lower Darling 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 Murray–Lower Darling 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: Murray–Lower Darling planning units

- **Chapters 1** and **2** present the LTWP at the planning unit (PU) scale. This includes a summary of the environmental values the planning unit supports, complete EWRs at representative gauge/s in the planning unit and an evaluation of the impact of water resource development on local hydrology.

The planning units shown in Figure 7 and Figure 8 are referred to in most chapters. Planning units delineate areas with a unique set of mechanisms for managing water for environmental outcomes. Planning units are classified as either: a) regulated (or that can be influenced by regulated water); or b) unregulated areas. Regulated planning unit boundaries (PUs 1–19) were delineated to reflect how storage and diversion infrastructure can be used to manage water for environmental outcomes. Unregulated planning unit boundaries (PUs 20–37) typically align with the water source boundaries in the NSW Murray and Lower Darling Surface Water Resource Plan Area (NSW DPIE 2019b). Environmental outcomes in unregulated planning units are influences primarily through Water Sharing Plan rules.

Figure 6 Wedge-tailed eagle
Photo: John Spencer

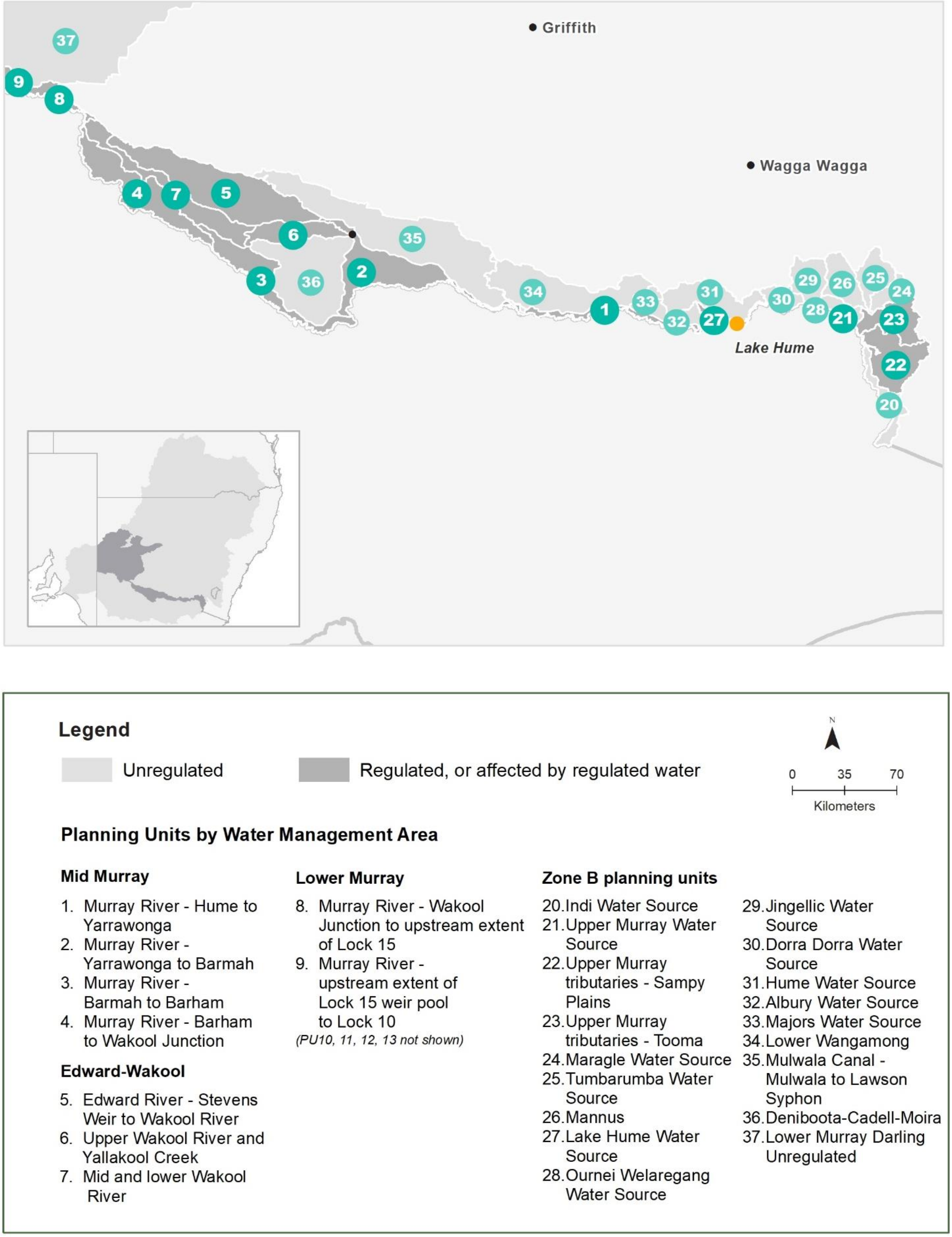

Figure 7 **The eastern section of the Murray–Lower Darling catchment showing the division of PUs into: a. regulated (or affected by regulated water); and b. unregulated areas in the LTWP**

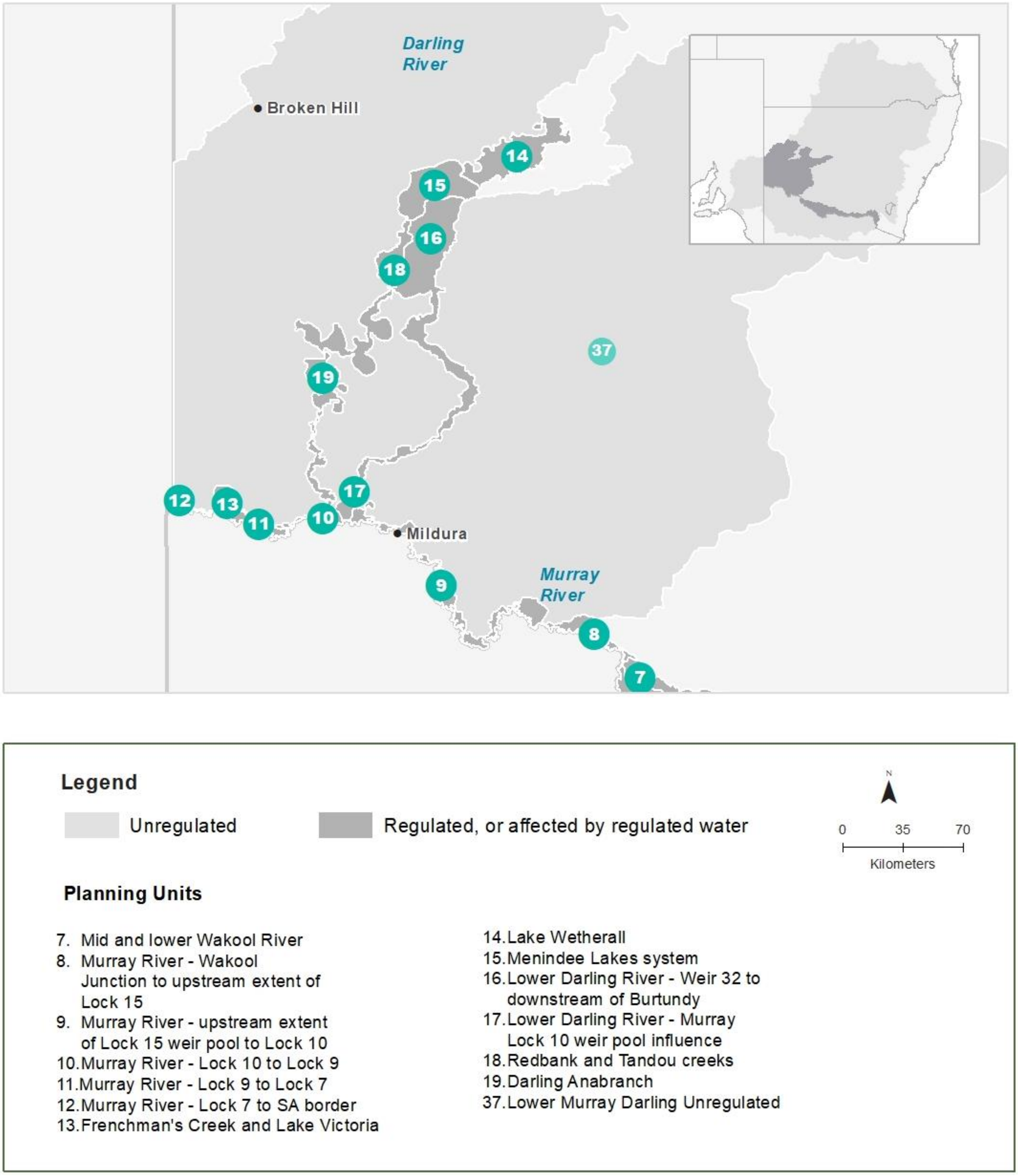

Figure 8 **The western section of the Murray–Lower Darling catchment showing the division of PUs into: a. regulated (or affected by regulated water); and b. unregulated areas in the LTWP**

2. Environmental assets of the Murray–Lower Darling catchment

The Murray–Lower Darling 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 Murray–Lower Darling 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.

Water-dependent ecosystems, which are comprised of waterbodies and surrounding water-dependent vegetation, have been assessed against the Schedule 8 criteria. Results of the analysis are presented in Figure 10.

Priority environmental assets in LTWP's are the assets that have been identified using Schedule 8 criteria that can be managed through NSW's planned and/or held approach to providing environmental water, often in combination with other river flows. Priority environmental assets may be, for example, a reach of river channel and its floodplain features at a geographic location, or a wetland complex or anabranch.

Priority environmental assets in the Murray–Lower Darling LTWP are mapped and listed in the relevant planning units in Part B: Murray–Lower Darling planning units.

Figure 9 Moira Lake in Millewa forest. Priority environmental assets identified in the LTWP include rivers, creeks, wetlands and lakes, and surrounding water-dependent native vegetation.
Photo: Vince Bucello.

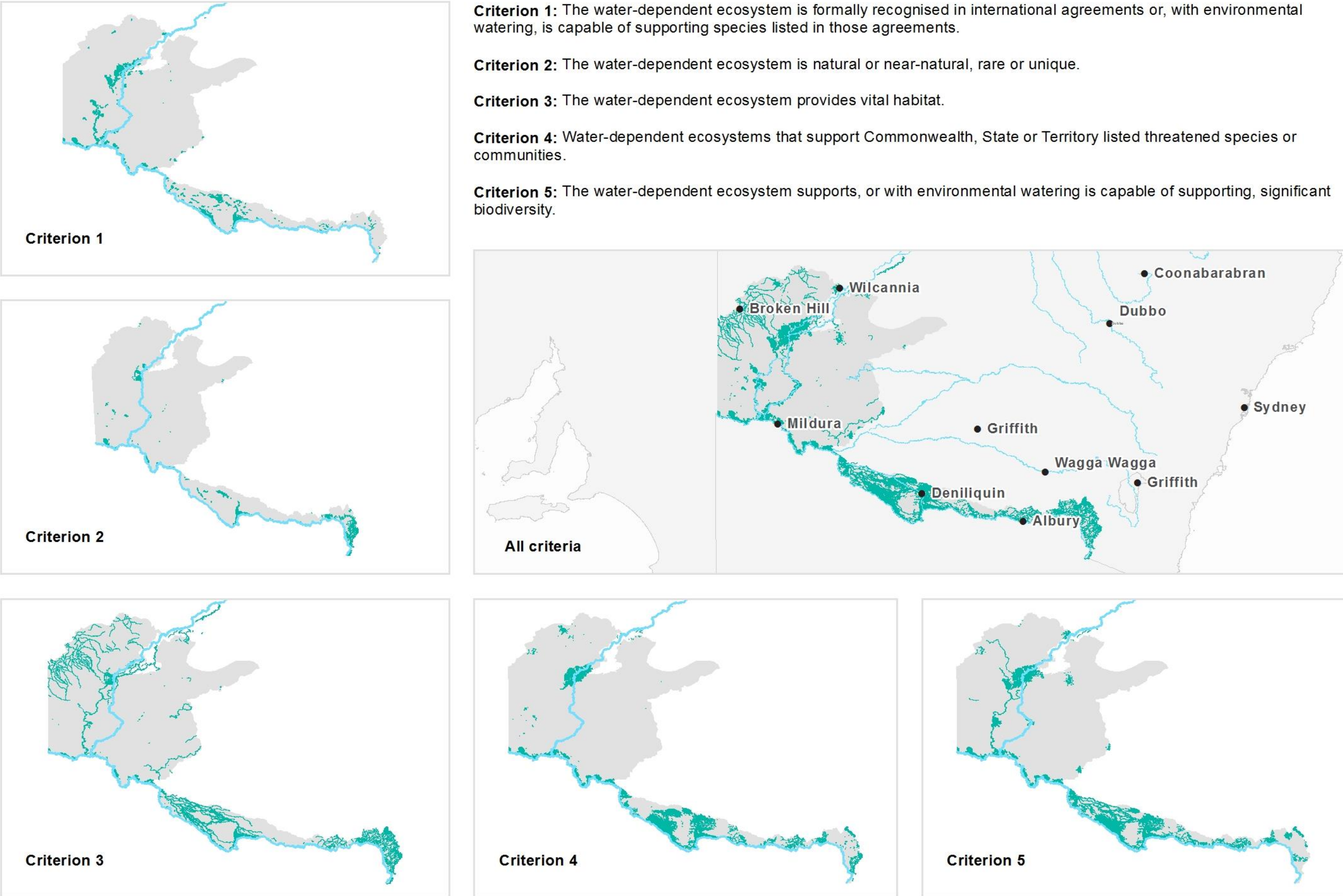

Figure 10 The five criteria for the identification of environmental assets applied to the Murray–Lower Darling catchment. See Part B of LTWP for planning unit scale maps of priority environmental assets.

3. Ecological objectives and targets

Ecological objectives and targets have been established for priority environmental assets in the Murray–Lower Darling catchment (sections 3.1–3.5). They are grouped into five themes: native vegetation; waterbirds; native fish, ecosystem functions and other species, which are consistent with the BWS (MDBA 2014). Each theme is a good indicator of river system health and is responsive to flow. The water requirements of foundational species or ecosystem functions within each theme are also representative of those needed by many of the catchment's water-dependent species, such as frogs and turtles.

The Murray–Lower Darling 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 and benefit other water-dependent species.

The five, ten and 20-year targets for each ecological objective provide a transparent means of evaluating progress towards their achievement and the long-term success of the LTWP's management strategies and their implementation. If achieved, the targets will indicate that the environment is responding positively to water management. 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. It is important to note that the 20-year targets in the LTWP assume the relaxation or removal of flow constraints to allow more flexibility in water delivery.

The ecological objectives for Murray–Lower Darling priority environmental assets as they relate to individual planning units 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 values and objectives

Twenty-five native fish species have been identified (or are expected to occur) in the Murray-Lower Darling catchment (NSW Department of Primary Industries Aquatic Ecosystem Research Database, from records collected between 1994 and 2017). Several are listed as threatened or vulnerable, including flathead galaxias, purple spotted gudgeon, Murray hardyhead, silver perch, Murray cod, Macquarie perch, trout cod, southern pygmy perch, olive perchlet and Murray crayfish (NSW DPI 2016).

The extent and condition of fish populations in the Murray–Darling Basin declined significantly after 2007, largely owing to ongoing drought in the already stressed river systems (Mallen-Cooper and Zampatti 2018). The *'NSW Fish Community Status Project'* undertaken by DPIF is the most recent assessment of fish community condition across NSW (NSW DPI 2016). The project consolidated and analysed fish data collected over twenty years of biological surveys (prior to 2013) and spatial distribution models. Importantly, the fish communities in the Lower Murray and Lower Darling regions have been subject to a series of negative influences since the NSW DPI 2016 community status assessment was completed. These include widespread fish deaths in the Mid and Lower Murray associated with hypoxic floodwaters in late 2016, and substantial fish kills in the Lower Darling River near Menindee in the 2018-19 summer related to water shortages. Cease to flow conditions persist in the Lower Darling at the time of writing. Thus, although the lower NSW Darling and Murray River region reaches were assessed to be in a 'Good' and 'Moderate' condition respectively in 2016, the long term impacts of these fish kills are yet to be confirmed (Iain Ellis DPIF pers. comm. 2019).

Managing water to improve the condition and increase the distribution and abundance of native fish populations involves restoring hydrology and physical habitat to expand the extent and carrying capacity of suitable habitat (Baumgartner et al 2014, Arthington 2012; Koehn et al. 2014; Mallen-Cooper and Zampatti 2015). Building the carrying capacity of the Murray and lower Darling river systems require watering regimes with increased frequency, extent and duration of overbank flows. This will help build native fish populations by fuelling the aquatic food web with additional carbon, nutrients and micro-organisms, and thereby increasing the food resource for native fish.

Fish population structure is closely tied to the frequency of successful breeding events and subsequent recruitment, as well as improved condition and movement outcomes for all life-history stages (Ellis et al. 2018). Objectives and targets for native fish in the Murray–Lower Darling catchment relate to increasing distribution and abundance, and ensuring a stable population structure that includes representation of young-of-year, juvenile and adult-life-history stages (Table 2 and Appendix A). These objectives can be achieved by providing flows across the spectrum of the former natural flow regime (from baseflows through to bankfull and overbank flow events) that meet the requirements for all fish species.

The Murray–Lower Darling catchment has been identified as capable of supporting range extensions for eight threatened fish species (MDBA 2014). It is expected that range extensions for these species will be achievable in certain planning units that provide suitable connectivity, habitat and flow requirements (Table 2 and Appendix A).

Figure 11 Juvenile Murray cod, River Murray fish sampling near Tocumwal, June 2018
Photo: Terry Korodaj

Table 2 Native fish (NF) ecological objectives and targets

Ecological objective		Target fish species	Targets		
			5 years (2024)	10 years (2029)	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 & abundance of short to moderate-lived generalist native fish species	Australian smelt, carp gudgeon (species complex), flat-headed gudgeon, dwarf flat-headed gudgeon, bony herring, Murray–Darling rainbowfish, unspecked hardyhead, mountain galaxias (species complex), climbing galaxias	Increased distribution & 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 & abundance of short to moderate-lived floodplain specialist native fish species	southern pygmy perch[1], Murray hardyhead, olive perchlet[1], flathead galaxias, purple-spotted gudgeon[1]			
NF4	Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species	golden perch, silver perch	Juvenile & 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		

[1] Olive perchlet, southern pygmy perch and purple spotted gudgeon may be considered either Floodplain specialist or Riverine (lentic) depending on geographical location.

Ecological objective		Target fish species	Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
NF5	Improve native fish population structure for moderate to long-lived riverine specialist native fish species	Murray cod, trout cod, Macquarie perch, river blackfish, two-spined blackfish, freshwater catfish (eel-tailed catfish), Murray crayfish, southern pygmy perch[1], purple-spotted gudgeon[1], olive perchlet[1]	Minimum of 1 significant recruitment event in 5 years	Minimum of 2 significant recruitment events in 10 years	Minimum of 4 significant recruitment events in 20 years
NF6	A 25% increase in abundance of mature (harvestable sized) golden perch & Murray cod	golden perch, Murray cod	Length-frequency distributions include size classes of legal take size for golden perch & Murray cod 25% increase in abundance of mature golden perch & 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, Murray hardyhead, southern pygmy perch[1], olive perchlet[1], purple-spotted gudgeon[1]	Adults detected annually in specified PUs[2] No more than 1 year without detection of immature fish in specified PUs (short-lived) No more than 2 years without detection of immature fish in specified PUs (moderate-lived species)		
			-	Increased distribution and abundance in specified PUs[2]	
NF8	Increase the prevalence and/or expand the population of key moderate to long-lived riverine specialist native fish species into new areas (within historical range)	trout cod, Macquarie perch, freshwater catfish, two-spined blackfish, Murray crayfish, purple-spotted gudgeon[1], olive perchlet[1]	Adults detected annually in specified PUs[2] No more than 2 years without detection of immature fish in specified PUs (moderate-lived species) No more than 4 years without detection of immature fish in specified PUs (long-lived species)		

[2] Relevant planning units are identified in Appendix A

Ecological objective		Target fish species	Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
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)	silver perch	-		
			Adults detected annually in specified PUs[2]	Increased distribution & abundance in specified PUs	
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, pouched lamprey, short-finned eel	Adults detected annually in specified PUs[2]		

3.2 Native vegetation values and objectives

The Murray-Lower Darling WRPA supports a wide range of vegetation communities. The diversity, distribution, abundance and cover of these communities are primarily driven by patterns of flooding and drying (Brock and Casanova 1997; Boulton and Brock 1999; Capon et al. 2009; Roberts and Marston 2011). In frequently inundated areas, extensive riverine forests such as Millewa, Koondrook-Perricoota and Werai are dominated by river red gums, while mixed floodplain woodlands dominated by black box (and to a lesser extent species such as river red gums and river cooba) tend to occur on higher, drier elevations. Lignum and nitre-goosefoot shrublands are widely distributed across the area as well as a diverse mosaic of non-woody wetland communities, ranging from instream vegetation, vegetation closely fringing river, stream and creek channels, permanent to semi-permanent freshwater lakes and billabongs, intermittent, temporary or ephemeral floodplain wetlands, shallow swamps and mashes, perennial and annual herbfields, sedgelands, rushlands, reedbeds and grasslands (Roberts and Marston 2011).

Figure 12 Nardoo
Photo: Vince Bucello

Millewa Forest contains the largest area of remaining river red gum in Australia, the largest plains of moira grass, large areas of giant rush, isolated stands of common reed and cumbungi and numerous lakes and billabongs are also found (MDBA 2012b; Kingsford et al. 2013). Koondrook–Perricoota Forest is predominantly river red gum forest with flood-dependent understorey that are dissected by intermittent flood runners. Black box woodlands fringe the river red gum forests on the higher, drier elevations (MDBA 2012c).

The Edward–Wakool region supports large areas of river red gum forests, black box woodlands, lignum shrublands and non-woody vegetation associated with its complex network of watercourses and ephemeral wetlands. Werai Forest in the north of the Edward–Wakool region comprises 11,000 hectares of river red gum forests and woodlands and significant areas of reed beds and several large, deep ox-bow lagoons that provide suitable habitat for waterbirds and native fish (MDBA 2012e).

The Lower Murray region is characterised by riparian river red gums along watercourses and wetlands, with black box woodlands on higher elevations and a mosaic of widely distributed lignum and nitre-goosefoot shrublands, floodplain lakes, wetlands and grassy swamps (MDBA 2012f). The semi-arid Lower Darling region is similarly diverse. Stands of black box and to a lesser extent river red gum and coolibah woodlands fringe the ephemeral watercourses and lakes. Lignum and nitre-goose foot shrublands are also present, with lignum being especially abundant and dense on the lakebed of Lake Menindee. Ephemeral water-dependent herbs and grasses colonise watercourses, channel benches, woodlands, open floodplain areas, wetlands and lakebeds following flooding (Kingsford et al. 2013).

Across the Murray–Lower Darling WRPA, vegetation has declined in condition and extent due to a reduction in flood frequency/duration and an increase in land clearing (Keith et al. 2009; LeBlanc et al. 2012). Currently, only small, fragmented remnants of wetland and floodplain habitat remain (25% and 8% respectively) (Bowen and Simpson 2010). In years of lower than average inflow, non-woody wetland vegetation communities can be outcompeted and replaced by drought tolerant species and weeds (Cooling et al. 2002; Capon 2005; McCarthy et al. 2008; Nicol 2012).

Table 3 describes the ecological objectives and targets for native vegetation in the Murray–Lower Darling WRPA. Objectives for vegetation communities are 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; Roberts and Marston 2011). 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.

While it may not be possible to expand the extent of many forest and woodland communities with environmental water, the objectives of this LTWP are to ensure that ensure adequate water is available to maintain their current extent and to improve their condition over the longer-term. Low-lying forest and woodland areas may be watered using managed deliveries, while high elevation forest and woodland communities will generally require natural flood events, except in some areas where infrastructure assisted delivery can be undertaken (MDBA 2018).

Targeted delivery of environmental water to key areas during dry to moderate water availability may stabilise condition and maintain existing populations, but in high to very high-water availability scenarios, sequenced flows over 1–3 years may improve tree condition, promote recruitment processes and support establishing seedlings (Bond et al. 2018; Doody et al. 2015; Roberts and Marston 2011; Wen et al. 2009; Overton et al. 2014).

The objectives for floodplain shrublands communities are to maintain or improve their extent and condition. Targeted delivery of environmental water to key areas during dry to moderate water availability can stabilise condition and maintain existing populations (Freestone et al. 2017; Overton et al. 2014; Roberts and Marston 2011), but in high to very high-water availability scenarios, sequenced flows over 1–3 years can improve condition, promote recruitment processes/support establishing seedlings, or flows of longer duration may promote vegetative growth and help to increase shrubland extent (Chong and Walker 2005; Jensen 2008; Overton et al. 2014; Roberts and Marston 2011).

Most non-woody vegetation communities require variable flooding regimes to complete life cycles, although the required duration and frequency of flows can vary widely within and between species (Brock et al. 2006). To promote vigorous growth and stands in tall, emergent species (e.g. cumbungi, common reed and aquatic species), regular flows of longer durations are required. Submerged species may require short dry spells to expose soils and encourage recruitment. To increase the extent of non-woody vegetation (or to limit the encroachment of woody species where desired), sequenced large flows over 1–3 years may be required in high to very high-water availability scenarios.

Table 3 Native vegetation (NV) ecological objectives and targets

Ecological objective			Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
NV1	Maintain the extent & viability of non-woody vegetation communities occurring within or closely fringing river channels		No loss of existing non-woody vegetation occurring within channels or closely fringing river channels[3]	Increase extent & viability of water-dependent non-woody vegetation in at least 50% representative sites[4] (10-years) & in at least 75% representative sites[4] (20-years) within channels or closely fringing river channels	
NV2a	Maintain or increase the extent & maintain the viability of non-woody vegetation communities occurring in wetlands & on floodplains	Non-woody vegetation communities within semi-permanent, intermittent, temporal & ephemeral wetland & floodplain areas	Over a 5-year rolling period, maintain the extent of non-woody, inundation dependent vegetation occurring in wetlands & floodplains		
			No loss of key species, populations or communities occurring in wetlands or on floodplains[5]. Evaluated at selected sites only	Increase[6] viability of key species, populations or communities in at least 40% representative sites (within 10-year period actively managed floodplain, current constraints) & in at least 60% representative sites (within 20-year period, actively managed floodplain, constraints relaxed) following inundation events	
NV2b		Ephemeral understorey vegetation within forests, woodland & open floodplain areas	No loss of key species, populations or communities occurring in wetlands or on floodplains[5]. Evaluated at selected sites only.	Increase[6] viability of key species, populations or communities in at least 40% representative sites (within 10-year period on the actively managed floodplain, current constraints) & in at least 60% of representative sites (within the 20-year period on the actively managed floodplain, constraints relaxed) following inundation events	

[3] Establish representative sites, determine appropriate vegetation response indicators and obtain baseline data. Provide appropriate maintenance flows during first 5-year period while establishing baseline.

[4] Evaluated at representative sites and using response indicators determined in the first 5-year targets. Measured over a 5-year rolling period to account for variation between naturally dry and wet times.

[5] Determine key species, populations and/or communities, establish representative sites, determine appropriate vegetation response indicators and obtain baseline data. Provide appropriate maintenance flows for specific vegetation type during first 5-year period while establishing baseline.

[6] To improve viability (growth/reproduction) of key species, populations and/or communities, may need to provide at least two occurrences of clustered, successive flows (over 2–3 years) within the 20-year period. Measured over a 5-year rolling period to account for variation between naturally dry and wet times. Evaluated at selected sites determined during first 5-year period.

Ecological objective		Targets		
		5 years (2024)	10 years (2029)	20 years (2039)
NV3	Maintain the extent & improve the condition of river red gum communities closely fringing river channels	Maintain the 2016 mapped extent[7] of river red gum communities closely fringing river channels		
		Over a 5-year rolling period, maintain the proportion of river red gum communities closely fringing river channels (within 50 m) that are in moderate or good condition[8] Over a 5-year rolling period, no further decline in the condition of river red gum communities closely fringing river channels (within 50 m) that are in poor or degraded condition[8]	Over a 5-year rolling period, increase[9] the proportion of river red gum communities closely fringing river channels (within 50 m) that are in moderate or good condition[8] by at least 35% (within the 10-year period) & at least 65% (within the 20-year period) Over a 5-year rolling period, improve[9] the condition score of at least 20% (within the 10-year period) & at least ≥40% (within the 20-year period) of river red gum communities closely fringing river channels (within 50 m) that are in poor, degraded or severely degraded condition[8] by at least one condition score	

[7] Extent based on compiled native vegetation plant community type (PCT) mapping of the NSW Murray-Lower Darling catchment. Map compiled by DPIE from best available PCT mapping as at 2016 from sources 2002-2016, including Bowen et al. (2010) and NSW OEH (2016b; 2016c).

[8] Condition score according to the MDBA Stand Condition tool (Cunningham et al. 2009).

[9] To improve condition of river red gum, black box and coolibah forests and/or woodlands, may need to provide a higher frequency of flows (than required to just maintain condition) or delivery of sequenced flows over 1–3 years.

Ecological objective			Targets		
			5 years (2024)	**10 years (2029)**	**20 years (2039)**
NV4a	Maintain or increase the extent & maintain or improve the condition of native woodland & shrubland communities on floodplains	River red gum forest	Maintain the 2016 mapped extent[7] of river red gum forest and woodland communities[10]		
			Over a 5-year rolling period, maintain the proportion of river red gum forests & woodlands in moderate or good condition[8,10]	Over a 5-year rolling period, maintain the proportion of river red gum forests & woodlands in moderate or good condition[8,10]	
NV4b		River red gum woodlands	Over a 5-year rolling period, no further decline in the condition of river red gum forests & woodlands in poor or degraded condition[8,10] Over a 5-year rolling period, increase the abundance of river red gum seedlings & saplings[11] in degraded river red gum forests & woodlands on the activity-managed floodplain, including the Lower Murray & Lower Darling floodplains[12]	Over a 5-year rolling period, increase[9] the proportion of river red gum forests & woodlands in moderate or good condition by at least 25% (within 10-year period, on the actively managed floodplain – current constraints) & at least 50% (within 20-year period, on the actively managed floodplain – constraints relaxed) Over a 5-year rolling average, improve[9] the condition score of at least 15% (within 10-year period, on the actively managed floodplain, current constraints) & at least 30% (within 20-year period, on the actively managed floodplain, constraints relaxed) of river red gum forests & woodlands in poor, degraded or severely degraded condition by at least one condition score Support successful recruitment[11] of river red gum trees in the long-term by increasing the abundance of young adult trees (10–30 cm DBH) compared to the previous target periods	

[10] Target applies to (a) the actively management floodplain (current constraints for 5-10-year targets; relaxed constraints for 20-year targets); and b) in all priority environmental assets (the 1:10 year ARI floodplain).

[11] To support the recruitment processes and establishment of seedlings and saplings, may need to provide at least two occurrences of clustered, successive flows (over 2-3 years) within the 20-year period. Measured over a 5-year rolling period to account for variation between naturally dry and wet times.

[12] Establish representative sites, determine appropriate vegetation response indicators and obtain baseline data where required (e.g. Lower Darling). Provide appropriate maintenance flows during the first 5-year period while establishing baseline.

<table>
<tr><th colspan="3" rowspan="2">Ecological objective</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">NV4c</td><td rowspan="4">Maintain or increase the extent & maintain or improve the condition of native woodland & shrubland communities on floodplains</td><td rowspan="3">Black box woodland</td><td colspan="3">Maintain the 2016 mapped extent[7] of black box woodland communities[10]</td></tr>
<tr><td>Over a 5-year rolling period, maintain the proportion of black box woodlands in moderate or good condition[8,10]

Over a 5-year rolling period, no further decline in the condition of black box woodlands in poor or degraded condition[8,10]</td><td colspan="2">Over a 5-year rolling period, increase[9] the proportion of black box woodlands in moderate or good condition by at least 20% (within 10-year period on the actively managed floodplain – current constraints) & at least 40% (within 20-year period on the actively managed floodplain – constraints relaxed)

Over a 5-year rolling period, improve[9] the condition score of at least 10% (within 10-year period, on the actively managed floodplain – current constraints) & at least 20% (within 20-year period, on the actively managed floodplain – constraints relaxed) of black box woodlands in poor, degraded or severely degraded condition by at least one condition score</td></tr>
<tr><td>Over a 5-year rolling period, increase the abundance[9] of black box seedlings & saplings in degraded black box woodlands on the managed floodplain, including the Lower Murray & Lower Darling floodplains[10]</td><td colspan="2">Support successful recruitment[11] of trees in the long term by increasing the abundance of young adult black box trees (10–30cm DBH) compared to the previous target periods</td></tr>
<tr><td>NV4d</td><td>Coolibah woodlands</td><td colspan="3">Maintain the 2016 mapped extent[7] of coolibah communities on the Lower Darling and Talyawalka Creek floodplains</td></tr>
</table>

Ecological objective			Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
N4e	Maintain or increase the extent & maintain or improve the condition of native woodland & shrubland communities on floodplains	Lignum shrublands	Maintain the total area of lignum shrubland communities[13,14]	Increase the extent of lignum shrubland communities within priority areas[15] and maintain in remaining areas.	
			Over a 5-year rolling period, maintain or increase the proportion of lignum communities in intermediate to good condition[16] Over a 5-year rolling period, no further decline in the condition of lignum shrublands in poor condition	Over a 5-year rolling period, increase the proportion of lignum shrubland communities in good condition by at least 20% (within 10-year period, on the actively-managed floodplain – current constraints) & at least 40% (within 20-year period, on the actively managed floodplain, constraints relaxed).	
			Over a 5-year rolling period increase the abundance of lignum recruits in degraded lignum shrublands[17]. Evaluated at selected sites.	Promote recruitment processes in lignum at least 2 years in 10 (on the actively-managed floodplain, current constraints) & at least 4 years in 20 (on the actively managed floodplain, constraints relaxed)[17]. Evaluated at selected sites.	

[13] Obtain baseline data. Provide appropriate maintenance flows during the first 5-year period while establishing baseline.

[14] Target applies to (a) the actively managed floodplain (current constraints for 5-10-year targets; relaxed constraints for 20-year targets); and b) in all priority environmental assets (the 1:10 year ARI floodplain).

[15] To promote vegetative expansion of lignum at least two sets of clustered, successive flows (over 2-3 years) within the 20-year period may need to be provided. Measured at selected sites only and improvement monitored over a 5-year rolling period to account for variation between naturally dry and wet times.

[16] Establish representative sites, determine appropriate vegetation response indicators (e.g. Scholz et al. 2007) and obtain baseline data. Provide appropriate maintenance flows during first 5-year period while establishing baseline.

[17] To promote recruitment processes and support establishment of lignum recruits, may need to provide at least two sets of clustered, successive flows (over 2–3 years) within the 20-year period. Measured at selected sites only and improvement monitored over a 5-year rolling period to account for variation between naturally dry and wet times.

3.3 Waterbird values and objectives

Waterbirds are an important indicator of wetland health (Kingsford 1999) and many floodplain wetlands in the NSW Murray and Lower Darling WRPA provide important feeding and breeding habitat (Arthur et al. 2012; Brandis et al. 2009; Kingsford et al. 2013;). Being highly mobile, waterbirds respond to flows over large spatial scales (Kingsford et al. 2013; Kingsford and Norman 2002; Amat and Green 2010) and waterbird abundance is influenced by available wetland area and condition (Arthur et al. 2011; Kingsford 2013). Whilst the decline of an individual wetland or river may not significantly impact upon an individual species, the degradation of multiple wetlands and rivers can lead to cumulative impacts on their populations (Birdlife 2014). Since records began in the 1920s, at least 90 waterbird species have been recorded in the Murray–Lower Darling (NSW OEH 2018), but for the past 50–70 years, waterbird populations have been in decline across the Murray–Darling Basin (Bino et al. 2014; Birdlife 2017; Kingsford et al. 2017).

Waterbirds can be grouped according to their breeding requirements. Non-colonial waterbirds (waterfowl, grebes, crakes, rails/waterhens and resident shorebirds) do not tend to congregate in large number to breed but are still reliant on wetlands for nesting and feeding, whereas colonial waterbirds (pelicans, cormorants, darters, ibis, egrets, herons and spoonbills) gather in large colonies, when suitable breeding and feeding habitats are inundated (Spencer 2017). Wetland habitat conditions that result in colonial waterbird breeding also provide suitable habitat for other waterbird species, such as ducks and waders.

There are several key floodplain habitats that support waterbird communities within the Murray–Lower Darling WRPA. When flooded, populations of the endangered Australasian Bittern and regionally important numbers of other breeding waterbirds, including egrets, ibis, spoonbills and herons have been recorded in Barmah–Millewa (Birdlife 2014, Borrell 2018). During the 2010–11 natural flood, around 50 species of waterbirds bred in the Barmah–Millewa forest, including the largest heron breeding event recorded in 40 years and the first successful fledging of two brolga chicks in approximately 60 years (Birdlife 2014). Likewise, Menindee Lakes has supported over 222,000 waterbirds, including more than one per cent of the world populations of the congregating freckled duck, grey teal, pink-eared duck, red-necked avocet, sharp-tailed sandpiper and red-capped plover (Birdlife 2014).

The lakes associated with the Darling Anabranch also provide extensive areas of productive waterbird habitat when inundated (King and Green 1993). Species of high conservation importance that have been recorded include brolga, blue-billed duck, freckled duck, whimbrel, bar-tailed godwit, common greenshank, Latham's snipe, sharp-tailed sandpiper and Caspian tern (Environment Australia 2001). Other key areas for waterbirds within the Murray–Lower Darling WRPA include Koondrook–Perricoota forest, the River Murray, Niemur River and Euston Lakes (BWS 2014, Bino et al. 2014, Hutton 2017).

Under natural modelled conditions, it is predicted that colonial waterbird breeding in the Barmah–Millewa forest would have occurred almost annually with around 20 successful breeding episodes each century. However, construction of water storages and increased diversions has reduced the frequency of breeding to an average of four years in ten, with less than three episodes of successful breeding occurring per century (Leslie 2001). These changes are largely related to a reduced frequency, magnitude, duration and timing of flows (Leslie 2001).

For many colonial waterbird species, breeding is initiated once the extent of inundated habitat reaches a certain magnitude. In many catchments, larger and longer overbank events provide opportunities for more waterbird species to breed in greater numbers (Spencer 2017). Maintaining adequate flow duration, water depth and extent in colony sites (and surrounding habitats) is therefore critical to allow time for birds to build nests, lay eggs, raise and fledge their young until they are independent. Colonial nesting species such as egrets and ibis are particularly sensitive to falling water levels, and adults may abandon their nests if conditions are not met (Kingsford and Auld 2005; Brandis et al. 2011). Colonial waterbird breeding sites in the MLD have been predominately observed in the Barmah–Millewa forest, with other breeding sites observed in the Darling Anabranch and associated lakes (Brandis et al. 2009), the Niemur River (Webster, R. and Borell, A, pers comm. 2018) and Pollack Swamp in Koondrook Forest (Hutton 2017). Several historical rookery sites have also been recorded in Koondrook–Perricoota Forest (Harrington and Hale 2011, MDBA 2012c; 2000g) and Campbells Island (Rick Webster, pers. comm. 2018).

Key waterbird objectives for the Murray–Lower Darling WRPA (Table 4) are to maintain the diversity and abundance of waterbird species, increase opportunities for colonial waterbird breeding and to maintain the extent and improve condition of waterbird habitats. At some sites, smaller events may be initiated and maintained using water deliveries. Water deliveries are also essential following large-scale events to ensure water levels are maintained in active colonies to support successful breeding. Therefore, the primary focus of waterbird objectives in this LTWP is to provide the delivery of target flows to support large breeding events by extending the duration and extent of natural flooding.

Targeted delivery of environmental water to wetland regions during moderate water availability can also be used to trigger (and support to completion) smaller scale breeding events. Smaller-scale breeding events are likely to be critical to maintaining waterbird populations over the long-term given the significant reduction in frequency and duration of larger natural flood events. In dry and moderate water availability scenarios, targeted deliver of environmental water to wetlands and riparian zones is also important for providing foraging opportunities for a diverse range of waterbird species. Wetland-inundating flows of moderate extent and duration following high flow years (when large breeding events occur in Murray-Lower Darling and neighbouring catchments) are likely to benefit waterbirds by helping to ensure the survival of young birds and providing further small-scale breeding opportunities.

Successful environmental water delivery to meet waterbird objectives is highlighted in recent surveys of sentinel wetlands of the Barmah–Millewa TLM Icon Site Condition Monitoring Program. The 2017–18 monitoring period coincided with environmental water delivery where 33% of Barmah–Millewa was inundated. The 2017–18 surveys indicated that average species diversity (45 species) was higher in 2017–18 compared to previous monitoring which began in 1999, but total waterbird abundance was lower (7306 individuals) than previous years of monitoring (Borrell 2018).

Figure 13
Ibis eggs on nesting platforms, Reed Beds Swamp, Millewa forest

Photo. Vince Bucello

Table 4 Waterbird (WB) ecological objectives and targets

Ecological objective		Targets		
		5 years (2024)	10 years (2029)	20 years (2039)
WB1	Maintain the number & type of waterbird species	Maintain a 5-year rolling average of 23 or more waterbird species across the 5 functional groups in the Mid Murray		
		-	Identify at least 67 waterbird species in the Mid Murray in a 10-year period	Identify at least 74 waterbird species in the Mid Murray in a 20-year period
		Maintain a 5-year rolling average of 18 or more waterbird species across the 5 functional groups in the Lower Murray		
		-	Identify at least 53 waterbird species in the Lower Murray in a 10-year period	Identify at least 61 waterbird species in the Lower Murray in a 20-year period
		Maintain a 5-year rolling average of 25 or more waterbird species across the 5 functional groups in the Lower Darling		
		-	Identify at least 53 waterbird species in the Lower Darling in a 10-year period	Identify at least 68 waterbird species in the Lower Darling in a 20-year period
WB2	Increase total waterbird abundance across all functional groups	Total waterbird abundance of the 5 functional groups maintained in the Mid Murray, Lower Murray and Lower Darling compared to 5-year 2012–16 period	Total waterbird abundance increased by 20–25% in the Mid Murray, Lower Murray and Lower Darling compared to the 5-year 2012–16 period, with increases in all functional groups	Maintain or increase total waterbird abundance in the Mid Murray, Lower Murray and Lower Darling compared to the 10-year target, with increases in all functional groups

<table>
<tr><th colspan="2" rowspan="2">Ecological objective</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>WB3</td><td>Increase opportunities for non-colonial waterbird breeding</td><td>Total abundance of non-colonial waterbirds in the Mid Murray maintained & breeding recorded in at least 1 non-colonial waterbird species compared to the 5-year 2012–16 baseline period</td><td>Total abundance of non-colonial waterbirds in the Mid Murray maintained & breeding recorded in at least 1 non-colonial waterbird species compared to the 5-year 2012–16 baseline period</td><td>Maintain or increase total abundance of non-colonial waterbirds in the Mid Murray compared to the 10-year target, with breeding detected in at least 1 non-colonial waterbird species</td></tr>
<tr><td rowspan="3">WB4</td><td rowspan="3">Increase opportunities for colonial waterbird breeding*</td><td colspan="3">Support active waterbird colonies in the Mid Murray, Lower Murray & Lower Darling by maintaining the water depth & duration of flooding (as required) to support breeding through to completion (from egg laying through to fledging including post-fledgling care) & maintain duration of flooding in key foraging habitats to enhance breeding success & the survival of young</td></tr>
<tr><td>In line with natural cues initiate & support small-scale colonial waterbird breeding in the Mid Murray in at least 2 colony sites in 2/5 years</td><td>In line with natural cues initiate & support small-scale colonial waterbird breeding in the Mid Murray in at least 3 colony sites in 3/10 years</td><td>In line with natural cues initiate & support small-scale colonial waterbird breeding in the Mid Murray in at least 5 colony sites in the Mid Murray in 3/10 years</td></tr>
<tr><td></td><td>In line with natural cues initiate & support small-scale colonial waterbird breeding in the Lower Murray in at least 2 colony sites in 3/10 years</td><td>In line with natural cues initiate & support small-scale colonial waterbird breeding in the Mid Murray in at least 3 colony sites in the Lower Murray in 3/10 years</td></tr>
<tr><td rowspan="3">WB5</td><td rowspan="3">Maintain the extent & improve condition of waterbird habitats</td><td colspan="3">Maintain extent & improve condition of nesting vegetation, including common reed, lignum, cumbungi, river red gum, giant rush, black box, in known colonial breeding locations in the Mid Murray</td></tr>
<tr><td colspan="3">Maintain extent & improve condition of nesting vegetation, including lignum, river cooba, black-box, river red gum, in known colonial breeding locations in the Lower Murray & Lower Darling</td></tr>
<tr><td colspan="3">Maintain or increase extent & improve condition of waterbird foraging & breeding locations in the Mid Murray, Lower Murray & Lower Darling (to be evaluated under targets set for native vegetation)</td></tr>
</table>

3.4 Priority ecosystem function values and objectives

The freshwater environment of the Murray–Lower Darling catchment is comprised of streams and rivers, and floodplain features such as lagoons and semi-permanent wetlands. Within these broad habitat types, niche habitats such as deep channels, pools and riffles, instream benches, snags, aquatic vegetation and riparian vegetation are available to a diverse range of aquatic species.

Drought refugia

Instream pools and floodplain wetlands and lakes are extremely valuable refugia in riverine landscapes. Other types of instream refugia include logs, wet undercut banks, riffles, sub-surface stream sediments and riparian vegetation (Boulton 2003). Refugia is 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). Refugia should be the highest priority for protection, especially during drought. Key floodplain refuge sites in the MLD WRP area include Lake Wetherell and Copi Hollow, effluent and anabranch creeks within Millewa forest (refuge for native fish, turtles and water rats), Werai forest lagoons (native fish, turtles and waterbirds), the lower Darling River (native fish, crustaceans and turtles), Niemur River (native fish), key Australasian bittern breeding sites such as Moira Lake, Reed Beds Swamp and Duck Lagoon, several private property wetlands in the Mid Murray and Lower Murray regions that contain southern bell frogs. Regulated waterways (e.g. River Murray channel, Edward River, Gulpa Creek, Yallakool Creek, Wakool River) and storages such as Lake Hume, Lake Mulwala, Lake Benanee and Lake Victoria provide drought refuge for a wide range of aquatic and wetland dependant fauna, especially native fish and waterbirds.

Quality instream habitat

The physical form of instream habitats, including the location of riparian and instream vegetation, channel shape and bed sediment, and the presence of benches and bars is influenced by river flow and sediment supply. For example, fresh and bankfull flows with sufficient velocity are required to maintain pool depth by scouring out bed material and initiating material transport downstream. Variable flows and water levels (in the case of reaches affected by weirs) are also important for providing a diverse range of hydraulic environments for aquatic biota. These include slackwater (slow flowing) zones at channel margins and areas of fast-flowing water to support native fish movement and spawning.

Another aspect of habitat quality is appropriate wetting-drying regimes of wetlands and channel margins to allow native vegetation to complete life cycles and to support nutrient cycling. Variable flows and water levels also determine the area of woody habitat (snags) that is available to aquatic biota. A key focus of LTWP targets is to ensure appropriate wetting-drying regimes which are especially relevant in the lower Murray River channel affected by weir pools and the mid Murray River and Edward–Wakool system which receive extended periods of elevated in-channel flows during the irrigation season.

Movement and dispersal opportunities for aquatic 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 from the breeding site of early life stages for a range of species and promote genetic diversity among catchments (Humphries & King 2004).

In the Murray–Lower Darling catchment, LTWP targets focus on maintaining longitudinal connectivity and integrity (timing and shape) of flow pulses along the entire River Murray channel to the South Australian border, including pulses originating from major tributaries such as the Murrumbidgee and Goulburn rivers. An equally important focus is promoting lateral connectivity between rivers, anabranches, wetlands and floodplains.

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 surfaces (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).

Snags are important because they help retain allochthonous carbon (i.e. carbon derived from the floodplains) within upstream river reaches that would otherwise be flushed downstream. Variable flows and water levels determine the area of woody habitat (snags) that allow allochthonous carbon to grow into biofilm carbon. Biofilm carbon is an important food source for organisms such as shrimp, yabbies, juvenile fish and small-bodied fish, and therefore, it is a key component of the aquatic food web.

Groundwater-dependent biota

While the LTWP is primarily focused on the management of surface water, it is recognised that groundwater and surface water resources are inextricably linked and that connections between surface and groundwater systems can vary considerably between systems. For instance, surface water may recharge alluvial aquifers within hours to days, while surface water recharging porous rock aquifers may take years to decades. Groundwater dependent ecosystems (GDEs) are natural ecosystems which are occasionally, or wholly reliant, on access to groundwater to maintain plant and animal communities (e.g. coolibah and black box woodlands) and ecosystem processes and services (Doody et al. 2017). Groundwater sources play an important ecological role in supporting terrestrial and aquatic ecosystems, particularly during extended dry periods where groundwater can be critical for maintaining refuges.

The Upper Murray Groundwater Source is located between Hume Dam and Corowa and is primarily recharged through leakage from the Murray River and infiltration from rainfall and to a lesser extent irrigation (NSW DPI 2012). Connectivity in the Upper Murray Groundwater Source is considered moderate and interactions between surface water and groundwater can be quite dynamic in response to river flow conditions (MDBC 2005).

The Lower Murray Groundwater Source is underlain by regional shallow (Shepparton Aquifer) and deep aquifers (unconsolidated alluvial aquifers of the Calivil and Renmark Formations) systems. It extends from Corowa to the confluence of the Wakool and Murray rivers and is bound by Murray River in the south and Billabong Creek in the north (NSW DPI 2011). The shallow Shepparton aquifer is primarily recharged through direct rainfall infiltration and leakage from the Murray River (and associated anabranches) and to some extent irrigation activities and therefore connectivity and interactions between surface water and groundwater can be highly dynamic. The deep Calivil and Renmark aquifers have very minimal direct recharge from rainfall or Murray River leakage (NSW DPI 2017).

The Western Murray Porous Rock Groundwater Source covers an outcrop area that extends from the Murray River in the south to the Adelaide and Kanmantoo Fold Belts in the north, near Broken Hill. To the east, the Renmark and Calivil Formations form a major confined aquifer, which grade into Murray Group Limestone and Loxton–Parilla Sands to the southwest. Overlying the Renmark and Calivil Formations in the west are the Murray Group limestones, while the Pliocene Sands Aquifer is a layer of sands and gravels, which include the unconfined Loxton–Parilla Sands in the west, which are marine in origin, to the fresher, highly porous and permeable coarser sands of the Calivil Formation. Connectivity between surface water and the Western Murray Porous Groundwater source is considered low to moderate, with the estimated travel time between groundwater to surface water taking years to decades (NSW DPI 2012c).

The Lower Darling Alluvial Groundwater Source is adjacent to the lower Darling River, with alluvium sediments extending two to five kilometres from the river channel. Within the alluvium is a freshwater lens that extends approximately 500 metres either side of the river channel. This freshwater lens is recharged via river flows, with rainfall making an insignificant contribution due to low rainfall and high evaporation rates throughout the planning area (NSW DPI 2012b). As the freshwater lens is predominantly recharged from river flows it is considered highly connected and interactions between surface water and groundwater can be highly dynamic (NSW DPI 2012b).

To continue to support GDEs in the Murray–Lower Darling, objectives in the LTWP relate to maintaining the mapped extent of groundwater dependent vegetation communities and groundwater levels within their long-term natural ranges.

Sediment, carbon and nutrient exchange

The frequency of flows that connect rivers with their floodplain has been substantially reduced in the Murray–Lower Darling catchment because regulated released from storages 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 (Barma 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).

Figure 14 Wetland in the Lower Murray region
Photo: John Spencer

Table 5 Priority ecosystem function (EF) objectives and targets

Ecological objective		Description & key contributing processes	Targets		
			5 years (2024)	**10 years (2029)**	**20 years (2039)**
EF1	Provide & protect a diversity of refugia across the landscape	Water depth & quality in pools (in-channel), core wetlands & lakes Condition of vegetation in core wetlands & riparian zones	Very low flows (VFs) & baseflows (BF1) are provided at target magnitudes & durations as specified in PU EWRs Cease-to-flow (CTF) periods do not exceed maximum durations as specified in PU EWRs Adequate water depth is maintained in key refuge pools during dry times Maintain permanent inundation of acid sulphate soils in key areas Maintain dissolved oxygen >4 mg/L in surface water & down to 2 m below the surface at key gauges & in key refuge pools[18] for 95% of the time & >2 mg/L for 99% of the time. Monitoring should incorporate overnight data collection between 3am & 6am from November–March each year **End-of-system salinity targets[19]** Maintain salinity at <830 EC µS/cm in the lower Darling River at Burtundy, 95% of the time Maintain salinity at <580 EC µS/cm in the Murray River d/s Lock 6, 95% of the time Maintain salinity at <453 EC µS/cm in the Murray River at the SA Border, 80% of the time **Other salinity targets[20]** Maintain salinity at <410 EC µS/cm in October & November at key river gauges & refuge pools in permanent streams to promote survival of native fish larvae during breeding seasons[21]		

[18] At key refuge pools, especially those susceptible to stratification and supporting native fish populations.

[19] Existing end-of-system salinity targets of most relevance to the Darling River and NSW Murray River end-of-systems (from Basin Plan 9.15(5) and Schedule B, Appendix 1 of the Commonwealth Water Act (2007).

[20] Additional salinity targets allow for periodic variation in salinity levels at local scales, which should not impact the end-of-valley targets. There are several saline or brackish environmental assets in the MLD, which when watered will result in local and short-term increases in salinity. Periodic watering of these sites is important for maintaining a healthy salt balance in the wetland/creek and contributes to Basin Plan salt export targets. Saline/brackish wetlands provide an important habitat for the critically endangered Murray hardyhead.

[21] Recommended EC represents the critical minimum threshold level for larvae of the native fish species, Murray cod (Ye *et al.*, 2010). Note that juvenile and adult native fish have much higher salt tolerances of up to 10,000 ppm (approximately 16,700 µS/cm EC), although salt tolerance information is only available for a limited number of species (Ye *et al.,* 2010).

Ecological objective		Description & key contributing processes	Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
			Maintain salinity at < 1000/1300 EC µS/cm at key river gauges & in key in-stream refuge pools for 95% of the time & <4000[22] EC µS/cm, 99% of the time		
EF2	Create quality instream, floodplain & wetland habitat	Regulation of dissolved oxygen, salinity & temperature Protect/enhance existing densities of snags Flow variability & hydrodynamics Provision of diverse wetted areas Appropriate wetting & drying cycles Geomorphic (erosion/deposition) processes that create & maintain diverse physical habitats Appropriate rates of fall to avoid excessive bank erosion Control of woody-vegetation encroachment into rivers/wetlands	Rates of fall does not exceed the 5th percentile of modelled natural rates during regulated water deliveries Period for which instream freshes are held at constant level (± 5%) does not exceed modelled natural durations At least 2 fresh events per year in relevant planning units to inundate in-channel habitat & provide movement & breeding cues for native fish & other aquatic biota. Floodplains wetlands to undergo a drying phase (partial or full draw down) for at least 60 days, 6–10 years in 10 years (including Lower Murray wetlands & floodplains influenced by weir pools) Flow velocities[23] in lower Murray River weir pools to exceed 0.3 m/s in at least 20% or 50% of each weir pool in dry & moderate/wet years, respectively, for at least 30 days (ideally 60–150 days) during Aug–Dec & at least 60 days (ideally 120 days) in Jan–May. Incorporate habitat mapping and re-snagging activities into broad-scale MER and riverbank remediation works for native fish management and recovery.		
EF3a	Provide movement and dispersal opportunities for water dependent biota to complete lifecycles and disperse into new habitats within catchments	Dispersal of eggs, larvae, propagules & seeds downstream and into off-channel habitats Migration to fulfil life-history requirements Foraging of aquatic species Recolonisation after disturbance	Annual detection of species and life stages representative of the whole fish community through key fish passages in specified planning units The recommended frequency and duration of flows providing lateral connectivity with anabranches, low-lying wetlands and floodplains are met (see EWRs for large freshes, bankfull and overbank flows *See also target for longitudinal connectivity under objective EF3b*		

[22] Recommended ECs are within the salinity tolerance range for critical life stages of most aquatic biota and native vegetation species (Nielson et al., 2003; Ye et al., 2010). 1300 µS/cm (2500 ppm) is the salt tolerance for native fish eggs (based on a limited number of species). 4000 µS/cm *is the tolerance of many native vegetation species.*

[23] Cross-section averaged velocities.

Ecological objective		Description & key contributing processes	Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
EF3b	Provide movement and dispersal opportunities for water dependent biota to complete lifecycles and disperse into new habitats between catchments	As above for EF3a	Provide longitudinal connectivity & integrity of flows[24] to end-of-system, including flow pulses (regulated, natural or augmented natural) occurring in: • the River Murray main stem (including flows originating from the Goulburn & Murrumbidgee & lower Darling rivers) maintained from key source to South Australian (SA) border & including through lower Murray River weir pools • Edward–Wakool system rivers (including flows originating from the Murray River via Barmah–Millewa forest) • Lower Darling River (from the Barwon–Darling River to Weir 32, & continuing to the Murray River at the SA border) • Darling Anabranch from Lake Cawndilla to the Murray River (maintaining a simultaneous connection at the source i.e. lakes & Murray/Anabranch month for at least 30 days, at a minimum frequency of least 3 years in 10.		
			Provide in-channel connecting flows to the South Australia River Murray 8-10 years in 10 (>20,000 ML/d at the SA border), including at least 5 events with major contributions from the lower Darling system (including longitudinal connectivity from source to SA border).		
					Provide small overbank (>45,000 ML/d) connecting flows to the SA River Murray in at least 6 years in 10.
EF4	Support instream & floodplain productivity	Aquatic primary productivity (algae, macrophytes, biofilms, phytoplankton) Terrestrial primary productivity (vegetation)	Enhance riverine productivity to support increased food availability for aquatic food webs by increasing the supply of autochthonous & allochthonous carbon & nutrients Maintain or increase the proportion of wetland & floodplain vegetation that is in good condition over a 5 year rolling period Maintain native fish population structure that indicates successful transition from young-of-year to juveniles		

[24] Maintaining the 'integrity' of flows means preserving the overall shape, magnitude and hydraulic properties (e.g. velocity) of a flow pulse as it moves downstream (not just the volume). This is a particular issue in the lower Murray River between Lock 7 and 9, due to significant diversions into Lake Victoria which result in discontinuity of a flow pulse and hence potential capture of nutrients, sediment, plant seeds/propagules and fish larvae into Lake Victoria, to the detriment of ecological outcomes in the South Australian Murray.

Ecological objective		Description & 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	Incorporate habitat mapping and resnagging activities into broad-scale MER and riverbank remediation works for native fish management and recovery.		
			No decline in key native fish species condition metrics Maintain the abundance & distribution of decapod crustaceans	Improve key native fish species condition metrics Improve the abundance & distribution of decapod crustaceans	
EF5	Support nutrient, carbon & sediment transport along channels, & between channels & floodplains/ wetlands	Sediment delivery to downstream reaches & to/from anabranches, floodplains & wetlands Entrainment of carbon & nutrients from dry in-channel surfaces (e.g. benches/banks), floodplains & wetlands to support production by aquatic species Dilution of carbon & nutrients that have returned to rivers	Maintain nutrient & carbon (DOC) pulses at multiple locations along rivers during freshes, bankfull & overbank events, especially those associated with flows occurring in the River Murray main stem (to SA border), lower Darling River (connecting to the Murray River at the SA border), and the Edward & Wakool river systems. Increase lateral connectivity with anabranches, low-lying wetlands & floodplains, as specified in EWRs for large freshes, bankfull & overbank flows Maintain or improve the organic matter storage capacity of wetland & floodplain soils (baseline to be established).		
EF6	Support groundwater conditions to sustain groundwater dependent biota	Groundwater recharge & discharge Dilution of saline groundwater Salt export from the Murray–Darling Basin	Maintain the 2016 mapped extent of groundwater dependent vegetation communities Maintain groundwater levels within the natural range of variability over the long-term		
EF7	Increase the contribution of flows into the South Australian lower Murray River	Provision of end of system flows (NSW lower Murray & lower Darling River) to support ecological objectives in downstream catchments (South Australian River Murray)	Provide in-channel connecting flows to the South Australia River Murray 8–10 years in 10 (>20,000 ML/d at the SA border), including at least 5 events with major contributions from the Lower Darling system (including longitudinal connectivity from source to SA border).		
					Provide small overbank (>45,000 ML/d) connecting flows to the SA River Murray in at least 6 years in 10.

3.5 Other species values and objectives

The variety of water-dependent ecosystems in the Murray-Lower Darling catchment supports an equally diverse range of water-dependent species, including water rats, woodland birds, platypus, snakes, turtles, bats, and frogs. While most of these species are supported by the other four objective themes, specific objectives and targets have been developed for frogs because certain species are especially responsive to flows, particularly with regard to breeding opportunities and success. Frogs are a good indicator of wetland health and tadpoles and frogs provide an important food source for native fish and waterbirds.

The Murray–Lower Darling WRPA supports nine flow-dependent frog species that are wholly or partly-reliant on flowing water for reproduction. This includes the NSW endangered southern bell frog and vulnerable Sloane's froglet (Val et al., 2007; Bogenhuber et al. 2013; 2014; Watts et al. 2013; DPIE-BC unpublished data 2012-17). Other species include the eastern sign-bearing froglet, barking marsh frog, spotted grass frog, Peron's tree frog, giant banjo frog, common eastern froglet and eastern banjo frog.

Flow-dependant generalist frogs use and occupy a range of freshwater habitats. However, recent monitoring in the southern Murray–Darling Basin has shown that recruitment success is linked to the availability of well vegetated and seasonally (or intermittently) inundated habitats – e.g. inundation of temporary wetlands or floodplains during overbank flows (Wassens and Maher, 2011; Bogenhuber et al. 2013; 2014; Val et al. 2007). Aquatic and riparian vegetation provides a substrate for attaching eggs, tadpole feeding metamorphosis and shelter from predators (Wassens and Maher, 2011). Permanently inundated habitats (permanent wetlands, lakes and perennial streams) provide important refuge habitat for frogs during dry periods but may not necessarily support frog breeding due to high predation pressure (Wassens and Maher 2011).

Frog populations are in decline across the Murray–Lower Darling due to a range of pressures including hydrological change (Wassens 2008). Flow-dependent frog species are therefore increasingly reliant on managed overbank and wetland-inundating flows to maintain refuge and breeding habitat on the floodplain.

Environmental water delivery to private property wetlands in the Murray Irrigation area have shown strong positive breeding responses from frogs including southern bell frogs since the private watering program began in 2001 (DPIE-BC monitoring observations, unpublished).

Historical frog surveys in the Murray–Lower Darling are limited but some targeted monitoring of environmental watering events provide appropriate baselines for setting LTWP objectives and targets (DPIE-BC unpublished data). The Mid Murray and Edward–Wakool Water Management Areas (WMAs) support nine species of flow dependant frogs, including the endangered southern bell frog, which is found in wetlands along the River Murray, rivers and creeks of the Edward–Wakool system and Private Irrigation areas including the Murray Irrigation Area. The vulnerable Sloane's froglet also occurs in the Mid Murray, with historical occurrence in River Murray wetlands near Tocumwal.

Wetlands in the Lower Murray WMA support at least eight flow-dependent frog species including the southern bell frog (Wassens 2008; Val et al 2009; DPIE-BC unpublished records). Monitoring has shown frog breeding and increased activity in response to environmental water delivery to wetlands and that responses were greatest in well vegetated ephemeral wetlands (Val et al., 2009).

The Lower Darling WMA supports at least five flow-dependant frog species based on surveys conducted along the Darling Anabranch during environmental water delivery in 2010–11, 2011–12 and 2013–14 (Bogenhuber et al. 2013; 2014). No data on frogs is available for the lower Darling River, Menindee Lakes or Anabranch Lakes. The greatest frog abundances and evidence of breeding activity in the Darling Anabranch surveys was observed on newly inundated vegetated areas of the channel and adjacent floodplain (Bogenhuber et al., 2013; 2014).

LTWP objectives and targets for frogs focus on maintaining species richness and providing breeding opportunities, with specific targets for threatened species: southern bell frog and Sloane's froglet.

Figure 15 Peron's tree frog
Photo: John Spencer

Table 6 Ecological objectives for other species (OS)

Ecological objective		Targets		
		5 years (2024)	10 years (2029)	20 years (2039)
OS1	Maintain species richness of flow-dependent frog communities	Detect all flow-dependent frog species known from the Lower Darling (5 species), Lower Murray (8 species) and Mid Murray (9 species) regions based on comprehensive surveys over the 2010–2017 period[25]		
OS2	Maintain successful[26] breeding opportunities for flow-dependent frog species	Establish baseline data on the number and distribution of wetlands with breeding activity of flow-dependant frog species	Maintain proportion of wetlands sites where breeding activity[27] of flow-dependent frog species is detected in the Lower Darling, Lower Murray and Mid Murray regions compared to comprehensive surveys in the 2019–2024 period	
OS3a	Maintain and increase number of wetland sites occupied by the threatened southern bell frog	Detect southern bell frog at 80% of known sites in the Lower Murray and Mid Murray regions in the 2019–2024 period Detect potential recruitment of southern bell frog in at least 80% of targeted watered wetland sites in the LTWP area in 5 of 5 years	Detect the southern bell frog at 90% of known sites in the Lower Murray and Mid Murray regions Detect potential recruitment[28] of southern bell frog in at least 90% of targeted watered wetland sites in the LTWP area in 5 of 5 years	
OS3b	Maintain & increase number of wetland sites occupied by the threatened Sloane's froglet	Detect Sloane's froglet at 80% of known sites in the Upper and Mid Murray in the 2019–2024 period[29]	Detect the Sloane's froglet at 90% of known sites in the Upper and Mid Murray regions[29]	
OS4	Maintain water-dependent species richness	Over the longer term (20 years) no reduction in the number and range of water-dependent species that are found throughout the catchment.		

[25] Baseline data from Bogenhuber et al. (2013; 2014) for the Lower Darling WMA (data from the Darling Anabranch 2010-2014); and DPIE-BC unpublished frog survey data for the Mid and Lower Murray WMAs (2012-17).

[26] 'Successful' 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 to water requirements for minimum duration of inundation.

[27] We consider male frog calling or tadpoles detected as evidence of breeding. We consider male frog calling, tadpoles detected and/or recently metamorphosed juvenile frogs as evidence of potential recruitment of new individuals into the breeding population.

[28] We consider potential recruitment to be evidence of recently metamorphosed juvenile bell frogs in a wetland.

[29] Southern bell frog and Sloane's targets align with the NSW Save Our Species Program, with 80% maintenance and improvement to 90% occupancy at surveyed sites.

3.6 Aboriginal cultural values and objectives

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 and floodplains of the Murray-Lower Darling WRPA are central to its Traditional owners, who have longstanding and continuing ties to country, the waterways and life sustained by it.

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.

Consultation with Aboriginal Nations of the Murray-Lower Darling WRPA on cultural values and objectives related to water-dependant ecosystems and management of water more broadly is ongoing, including as part of the development of the NSW Murray and Lower Darling Surface Water Resource Plan (NSW DPIE 2019b) and the MDBA Aboriginal Partnership Program.

Aboriginal Waterways Assessments (AWA) provide a tool for Aboriginal communities to measure the health of rivers and wetlands, including a site's cultural significance and current use. These assessments provide a means for Aboriginal Traditional Owners to participate and inform various water planning processes including the development of Water Resource Plans, Long Term Water Plans, Basin annual watering priorities and the Basin Watering Strategy (MLDRIN undated). Since 2015, AWAs have been undertaken at two sites in the NSW Murray catchment: Werai Forest by the Wemba Wemba and Barapa Barapa Nations, and in Millewa Forest by the Bangerang and Yorta Yorta Nations.

Aboriginal Traditional Owners of Werai Forest have also recently completed a detailed water management plan for the forest (Webster and Nias 2018), which they hope to implement once ownership of the former state forest is transferred to the Werai Land and Water Aboriginal Corporation. DPIE-BC will continue to consult with these and other Aboriginal Nations during implementation of the LTWP. Water-dependant cultural values and objectives for Werai forest are described in Part B (Edward River planning unit).

4. Environmental water requirements

Flow and inundation regimes drive the ecological characteristics of rivers and floodplain wetlands (Poff and Zimmermann 2010). A flow regime represents the sequence of flow events over time, and it is this sequence of different flow magnitudes that produces flooding and drying patterns. Flow regimes govern river channel and wetland formation and 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.

The sequence of flows over time can be considered as a series of discrete events. These events can be placed into different flow categories (e.g. baseflows, freshes, bankfull and overbank flows) according to the magnitude of flow discharge or height within a watercourse, and the types of outcomes associated with the events (e.g. inundation of specific features such as channel benches, riparian zones, wetlands or the floodplain).

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 16 and

Table 7). Flow rates for flow categories at sites in the Murray-Lower Darling 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) typically requires 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 two to four weeks in early spring to support nesting. Once the fish reaches maturity (one to three years) it may require a 'bankfull' fast-flowing river in combination with 'overbank' flows to trigger dispersal and migration.

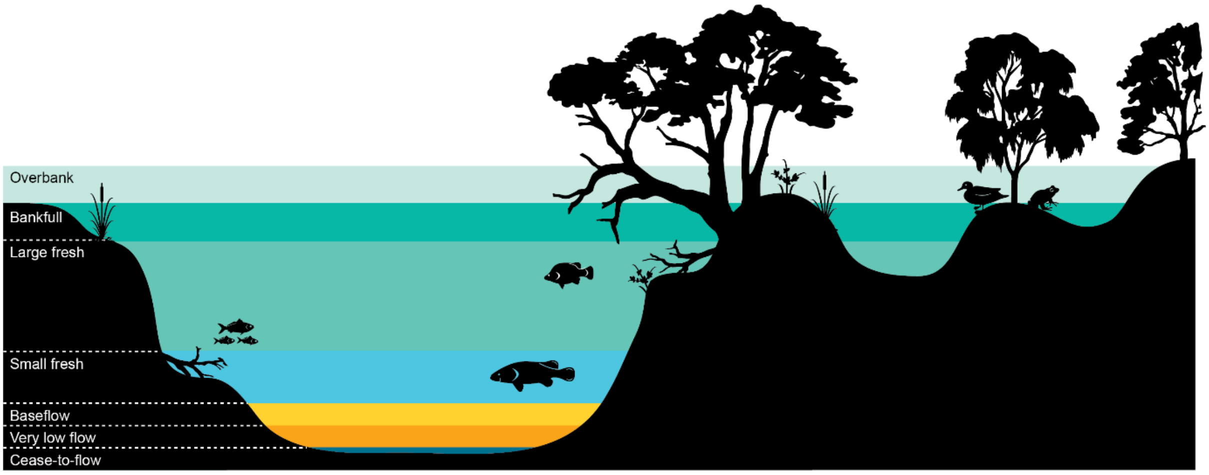

Figure 16 A simplified conceptual model of the role of each flow category

Table 7 Description of the role of each flow category shown in Figure 16

Flow category	Description
Overbank flows (OB)	Overbank flows provide broad scale lateral connectivity with floodplain & wetlands. Supports nutrient, carbon & sediment cycling between floodplain & channel. Promotes large-scale productivity. Overbank flows describe flows above bankfull.
Bankfull flow (BK)	Inundates all in-channel habitats & connects many low-lying wetlands. Partial or full longitudinal connectivity. Drown out of most small in-channel barriers (e.g. small weirs).
Large fresh (pulse) (LF)	Inundates benches, snags & inundation-tolerant vegetation higher in the channel. Supports productivity & transfer of nutrients, carbon & sediment. Provides fast-flowing habitat. May connect wetlands & anabranches with low commence-to-flow thresholds.
Small fresh (pulse) (SF)	Improves longitudinal connectivity. Inundates lower banks, bars, snags & in-channel vegetation. Trigger for aquatic animal movement & breeding. Flushes pools. May stimulate productivity/food webs.
Baseflow (BF)	Provides connectivity between pools & riffles & along channels. Provides sufficient depth for fish movement along reaches and contributes to maintaining water quality by providing hydraulic diversity and export of nutrients and salt.
Very low flow (VF)	Minimum flow in a channel that prevents cease-to-flow conditions. Provides connectivity between some pools.
Cease-to-flow (CF)	Partial or total drying of the channel. Stream contracts to a series of disconnected pools. No surface flows.

4.1 Developing environmental watering requirements 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 water requirements (flow category, duration, timing, etc.) overlapped between species or groups, the individual requirements were combined to provide a single EWR that supported the relevant group of environmental objectives.

At the planning unit 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.

Each EWR is expressed as a flow category that has been assigned a flow rate or volume, an ideal timing, duration and frequency, and a maximum inter-event period based on the suite of plants, animals and functions it supports (see the Table 8 for full description of EWR terms). Complete EWRs for each planning unit the Barwon–Darling, including flow rates and total volumes, can be found in Part B.

A summary of flow rates for flow categories at representative sites in the Murray-Lower Darling are shown in Table 9.The timing, duration and frequency components of EWRs, grouped by flow category, for all biota and functions in the Murray-Lower Darling catchment and the objectives they support are presented in Table 10. Important flow regime characteristics to meet life-history needs and each of the LTWP objectives are described in Table 11.

Table 8 Definitions and guide to interpreting environmental water requirements (EWRs)

Term	Definition & guide to interpreting information
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 & 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), & a short description of key objectives & life stages being targeted (e.g. spawning or recruitment). Bold text indicates the primary objectives of each EWR. See Tables 2–6 for full objectives.
Gauge	The flow gauging station that best represents the flow within the PU, for the purpose of the respective EWR & 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-

Term	Definition & guide to interpreting information
	optimal outcomes. In these instances, for the purposes of managing & delivering environmental water, the preferred timing should be used to give greater confidence in achieving ecological objectives. Natural events may occur at other times & still achieve ecological objectives.
Duration	The number of consecutive days that flows must be above the specified flow rate for the flow event to achieve the EWRs specified ecological objective(s) of the EWR. Typically, this is expressed as a minimum duration. Longer durations will often be desirable & deliver better ecological outcomes. Some species may suffer from extended inundation durations, & where relevant a maximum duration may also be specified. Flows may persist on floodplains & within wetland systems after a flow event has passed. Where relevant, a second duration may also be specified, representing the duration for which water should be retained within floodplain & 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 & 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 & recruitment of native fish, vegetation & waterbirds 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 & maximum inter-flow period, & 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, the LTWP recommends using a minimum long term average (LTA) target frequency that is at least the average of the recommended frequency range but may be higher than the average where required to achieve objectives. For example, for a recommended frequency range of 3-5 years in 10, the minimum LTA frequency should be at least 40% of years, but may be up to 50% of years at sites where a higher frequency should be targeted over the long term to ensure recovery in certain species/populations. Whilst these higher frequencies may exceed modelled natural event frequency in some cases, recovery in particularly degraded systems will be unlikely should lower (i.e. average) frequencies be targeted. Minimum LTA target frequencies in this LTWP are reported predominantly as the average of the recommended frequency range, however this may be refined during implementation of the LTWP and in future revisions of the LTWP based on the results of ongoing ecological monitoring.

Term	Definition & guide to interpreting information
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 & comments	Other conditions that should occur to assist ecological objectives to be met – for example rates of rise & fall in flows. Also comments regarding limitations on delivering environmental flows & achieving the EWR.

4.2 Flow category thresholds

The flow rates that define each flow category (baseflows, small freshes, etc.) and associated EWRs will vary between catchments and river reaches. Table 9 presents the range of flow rates for each flow category at representative gauge sites in the Murray–Lower Darling catchment (Figure 17 and Figure 18). The environmental outcomes associated with each flow category are expected to begin occurring at the bottom end of the flow ranges. Greater and sometimes substantially increased outcomes are likely to occur (e.g. for wetland connecting large freshes and overbank flows) as flows increase in size. While the flow rates for each flow category are expressed as ranges in Table 9, flow rates for the EWRs presented in Part B are expressed as minimum flow rates (i.e. the bottom end of the range) in most cases, meaning that an EWR may also be met by higher flows in other categories.

Table 9 Flow threshold estimates (ML/d) for flow categories in planning units (PUs) that are regulated or affected by regulated water in the Murray–Lower Darling catchment

WMA	(#) PU	Gauge	Low flows		Freshes		Bankfull flows	Overbank flows		
			Very low flow	Baseflow	Small Fresh	Large Fresh		Small overbank	Medium overbank	Large overbank
Mid Murray	(1) Murray River – Hume to Yarrawonga	Murray @ Doctors Pt 409017	1300–3000	3000–6000	6000–10,000	10,000–25,000	25,000–28,000	28,000–45,000	45,000–70,000	>70,000
Mid Murray	(2) Murray River – Yarrawonga to Barmah	Murray d/s Yarrawonga 409025	1800–4000	4000–7000	7000–12,000	12,000–29,000	29,000–37,000[30] 10,000–12,000[31]	15,000–50,000	50,000–80,000	>80,000
Mid Murray	(2) Murray River – Yarrawonga to Barmah	Tuppal Creek @ Aratula 409056	20-30	30–100	180–2000	2000–4000	4000–6000	>6000		

[30] Yarrawonga to Tocumwal reach.

[31] Tocumwal to Barmah reach – bankfull channel capacity is significantly smaller here than in the Murray River upstream of Tocumwal (Barmah–Millewa forest and Barmah choke are located in the Tocumwal to Barmah reach).

WMA	(#) PU	Gauge	Low flows		Freshes		Bankfull flows	Overbank flows		
			Very low flow	Baseflow	Small Fresh	Large Fresh		Small overbank	Medium overbank	Large overbank
	(3) Murray River – Barmah to Barham (4) Murray River – Barham to Wakool junction	Murray d/s Torrumbarry 409207	2000–4500	4500–7000	7000–12,000	12,000–22,000	16,000–18,000[32] 22,000–25,000[33] 17,000–22,000[34]	25,000–40,000	40,000–55,000	>55,000
Edward-Wakool system	(5) Edward River – Stevens Weir to Wakool junction	Edward d/s Stevens Weir 409023	170–300	300–1600	1600–3200	3200–6000	8000[35] 6000–8000[36]	8000–17,000	*Gauge not used – see 409003 below*	
Edward-Wakool system	(5) Edward River – Stevens Weir to Wakool junction	Edward River @ Deniliquin 409003	*NA – flow gauging not accurate below 15000 ML/d due to a backwater from Stevens Weir*				9000–15,000	14,000 – 28,000	28,000–53,000	53,000+
Edward-Wakool system	(5) Edward River – Stevens Weir to Wakool junction	Colligen Creek 409024	50–170	170–500	500–600	600–1600	3500–4000[37] 1600–4000[38]	4000–5100	5100+	*Flows not gauged*

32 Murray River bankfull estimate just below the flow at which overbank flows occur in Gunbower forest (Victorian side of river).

33 Murray River bankfull estimate just below the flow at which overbank flows occur in Koondrook–Perricoota forest (NSW side of river).

34 Bankfull estimate for Barham to Wakool Junction.

35 Bankfull flow estimate for the majority of the Edward River downstream of Stevens Weir (only small-scale breakouts north of Edward River at 8,000 ML/d).

36 Below bankfull in most of the Edward River downstream Stevens Weir but fills most flood runners and creates small-scale inundation of low lying areas in Werai forest.

37 Bankfull flow estimate for Colligen Creek.

38 Below bankfull in Colligen Creek itself but contributes to bankfull flows in the Niemur River and smaller creeks and small-scale inundation of low-lying areas in Werai forest.

WMA	(#) PU	Gauge	Low flows		Freshes		Bankfull flows	Overbank flows		
			Very low flow	Baseflow	Small Fresh	Large Fresh		Small overbank	Medium overbank	Large overbank
		Niemur River 409048	NA	50–800	800–1000	1000–1600	2000–3000[39] 1600–2500[40]	3000–15,000	15,000–21,000	21,000+
	(6) Upper Wakool River & Yallakool Creek	Yallakool offtake 409019	30–80	80–500	500–900	900–1600	3500[41] 1600–2100[42]	2100–3500[43]	3500–4700	4700+
		Wakool offtake 409020	20–50	50–100	100–500	500–1300	1300–2900 1200–1800[44]	1800–2900	2900–3800	3800+
		Yallakool + Wakool (for d/s junction)	NA				2500–3000	3000	5000–7000	7000+
	(7) Mid & Lower Wakool River	Wakool River @ Gee Br 409062	50–130	130–600	2000	5000	21,000	22,000	30,000	40,000

[39] Bankfull estimate for the majority of Niemur River.

[40] Below bankfull for much of Niemur River but creates bankfull flows in some reaches and small-scale inundation of low lying areas.

[41] Bankfull flow estimate for Yallakool Creek.

[42] Below bankfull in Yallakool Creek itself but contributes to bankfull flows downstream of the Yallakool-Wakool confluence (assuming a contribution from upper Wakool R).

[43] Contributed to overbank flows downstream of the Yallakool/Wakool junction. Remains in-channel in Yallakool Creek at these flow rates.

[44] Contributes to bankfull flows downstream of Yallakool/Wakool junction.

WMA	(#) PU	Gauge	Low flows		Freshes		Bankfull flows	Overbank flows		
			Very low flow	Baseflow	Small Fresh	Large Fresh		Small overbank	Medium overbank	Large overbank
Lower Murray	(8) Murray River – Wakool junction to upstream extent of Lock 15 weir pool	Murray d/s Wakool jnct 414200	2500	7000–12000	7000–12000	12,000–18,000	18,000[45] 20,000–22,000[46]	22,000	40,000	50,000
	(9) Murray River – Lock 15 weir pool to Lock 10	Murray @ Euston 414203	2500	6000–	14,000–20,000	20,000–38,000	38,000–46,000	50,000–60,000	60,000-80,000	80,000+
	(10) Murray River – Lock 10 to Lock 9 (Lock 9 weir pool)	Murray @ Wentworth 425010	3500	10,000–14,000	14,000–20,000	20,000–49,000	49,000–50,000	55,000–70,000	70,000–80,000	80,000+
	(11) Murray River – Lock 9 to Lock 7 (Lock 7 & 8 weir pools)	Murray d/s L9 4260505 Murray d/s L8 4260507	3500	10,000–14,000	14,000–20,000	20,000–49,000	40,000–50,000 35,000–40,000	55,000–70,000	70,000–80,000	80,000+
	(12) Murray River – Lock 7 to SA border (including Rufus River & NSW Chowilla)	Murray d/s L7 4260509	3500	10,000–14,000	14,000–20,000	20,000–49,000	40,000–45,000	55,000–70,000	70,000–80,000	80,000+
Lower Darling (Menindee Lakes)	(14) Lake Wetherell & Menindee Top Lakes	Lake Wetherell 4260641	NA					58.9 m AHD	61.1 m AHD	61.8 m AHD
	(15) Menindee Lakes (Cawndilla & Menindee)	Lake Menindee 425022	NA					56.0 m AHD ~60 GL	56.5 m AHD ~116 GL	58.5 m AHD ~410 GL

[45] Wakool junction to Murrumbidgee junction.

[46] Bankfull estimate for downstream of Murrumbidgee junction.

WMA	(#) PU	Gauge	Low flows		Freshes		Bankfull flows	Overbank flows		
			Very low flow	Baseflow	Small Fresh	Large Fresh		Small overbank	Medium overbank	Large overbank
		Lake Cawndilla 425023			NA			53.8 m AHD ~50 GL	54.5 m AHD ~84 GL	58.5 m AHD ~470 GL
Lower Darling	(16) Lower Darling River – Weir 32 to downstream of Burtundy	Weir 32 425012	150–250	250–2000	2000–7000	7,000–10,000	10,000–12,000	15,000–20,000	20,000–45,000	>45,000
		Burtundy 425007	140–180	180–1800	1800–6000	6,000–9,000	9,000–11,000	11,000–16,000	16,000–22,000	>22,000
	(17) Lower Darling River – Murray Lock 10 weir pool influence	Burtundy 425007	140–180	180–1800	1800–6000	6,000–9000	9,000–11,000	11,000–16,000	16,000–22,000	>22,000
	(18) Redbank & Tandou creeks	Packers Crossing 425019	NA	NA	NA	1000–1500	1500–2000	2000–2500	>2500	
	(19) Darling Anabranch	Wycot 425013	NA	NA	100–1100	800–1500	2000–3000	3000–8000	8,000–17,000	>17,000

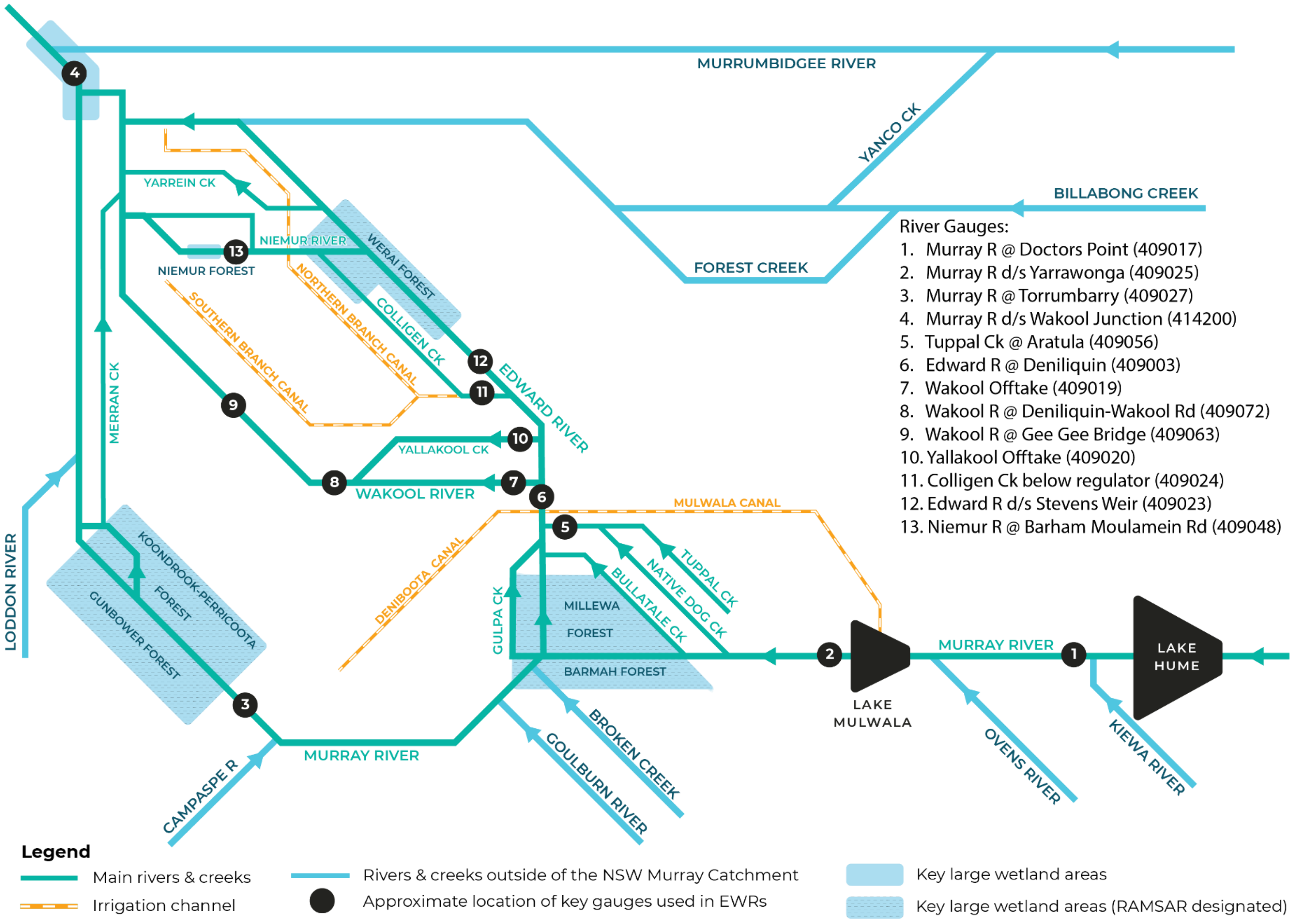

Figure 17 Schematic diagram of the main watercourses and gauges in the mid Murray and Edward–Wakool system

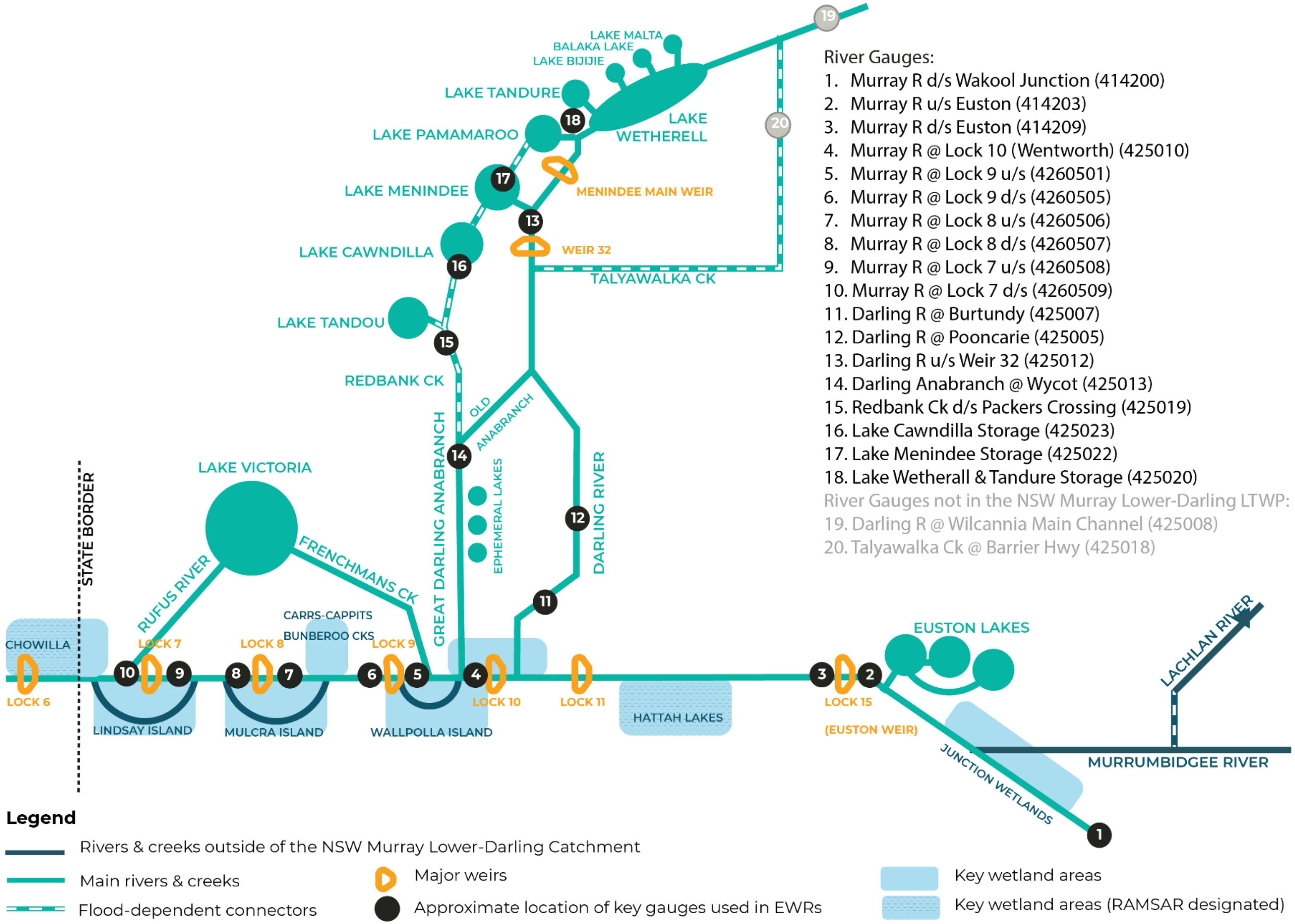

Figure 18 Schematic diagram of the main watercourses and streamflow gauges in the Lower Murray and Lower Darling Water Management Areas

4.3 Catchment-scale environmental water requirements

Table 10 Catchment scale environmental water requirements (EWRs)

Flow category and& EWR code[47]		Ecological objectives[47] (primary objectives in bold)	Timing[47]	Duration[47]	Frequency (*LTA[48] frequency)[47]*	Maximum inter-event period[47]	Additional water requirements[47]
Cease-to-flow[49]	CF1	Native Fish: NF1–9 – Survival (all species) Ecosystem Functions: EF1, 2 – refuge habitat	In line with historical low flow season (April – June).	Cease to flow (CTF) events are not desired at most sites – although CTF events did occasionally occur pre-development, the system is now significantly altered meaning that CTF events are likely to have significant negative impacts on ecosystems, especially native fish.			When restarting flows, avoid harmful water-quality impacts, such as de-oxygenated refuge pools.
Very-low flow[50]	VF1	Native Fish: NF1 – Survival (all species) Ecosystem Functions: EF1, 2 – refuge habitat	All year	Continuous or in line with natural *Varies by location[51]*	Annual *(100%)*	1 year	Flow velocity ideally >0.03–0.05 m/s to reduce risk of thermal stratification in pools (many sites will require higher flows e.g. baseflows & small freshes to achieve this).
Baseflow	BF1[52]	Native Fish: NF1–9 – **condition & movement of all fish species** Native Vegetation: NV1, 2 – **in-channel non-woody**[53] Waterbirds: WB5: habitat condition Ecosystem Functions: EF1, 2, 3, 7: **longitudinal connectivity, refuge habitat**, hydraulic diversity	All year Jul–Dec (Lower Murray)	In line with natural *Varies by location[51]*	Annual *(100%)*	In line with natural *Varies by location[51]*	Flow velocity >0.03–0.05 m/s to reduce risk of thermal stratification in pools. Flow rate should reflect contributions from upstream. Ideally would be translucent flow in most instances. Ideally, a minimum depth of 0.3 m to allow fish passage.
	BF2	Native Fish: NF1–9 – **Condition & movement** of all species during the irrigation off-season [Mid Murray & Edward–Wakool], **Recruitment of riverine specialists, generalists** [lower Darling River] Native vegetation: NV1 – in channel non-woody vegetation Ecosystem Functions: EF1, 2, 3, 4, 5, 7 – longitudinal connectivity, refuge habitat, small-scale productivity[54]	Apr–Aug (Mid Murray & Edward–Wakool) All year (lower Darling River)	In line with natural *Varies by location[51]*	Annual *(100%)* 5 years in 10 *(75%)* in lower Darling River	71 days – 2 years *Varies by location[51]*	Coordinate delivery of baseflows system wide to promote longitudinal connectivity & therefore improve conditions for native fish to disperse and recruit.
	BF3[55]	Native vegetation: NV1: in-channel & wetland non-woody vegetation (drying phase) Ecosystem Functions: EF2 **– drying phase to promote nutrient cycling & native vegetation life cycles**	Apr–Aug (although ideally in summer)	60 day minimum	6–10 years in 10 *(80%)*	2 years	Note: Achieved in the lower Murray River via weir pool lowering – see WP1

[47] See Table 8 for definitions of terms and guide to interpreting EWRs.
[48] Long Term Average frequency expressed as a percentage of years.
[49] Critical waterways where cease-to-flow (CF) should not occur include: Murray River, Edward River, Colligen Creek, Niemur and the lower Darling River.
[50] No VLF prescribed for Darling Anabranch because it is an ephemeral river.
[51] See specific EWRs for each PU at representative gauges in Part B of the LTWP.
[52] No BF1 prescribed for Darling Anabranch.
[53] BF1: Ecological Objectives NV1– 4 (in channel non-woody vegetation and floodplain black box and lignum) can be met for the Old Darling Anabranch.
[54] Productivity outcomes only likely if the baseflow is a higher magnitude than BF1 & is inundating low benches or other in-channel features.
[55] BF3: Drying phase prescribed for Mid Murray (Barmah-Millewa) and Edward-Wakool only. This EWR is designed to replace the annual drying regime that would have naturally occurred during summer/autumn but is now not possible to due typically high river flows in summer/early autumn to meet irrigation demand.

Flow category and& EWR code[47]		Ecological objectives[47] (primary objectives in bold)	Timing[47]	Duration[47]	Frequency (*LTA*[48] *frequency)*[47]	Maximum inter-event period[47]	Additional water requirements[47]
Nesting Support (see also BF2 & SF2)	NestS1 [56]	Native Fish NF5, 6 – **Nesting of riverine specialists – e.g. Murray cod & trout cod** (protect nesting sites by avoiding rapid changes in water levels) *This EWR is about minimising water level changes during the cod nesting season to protect nests under all types of water delivery including environmental, consumptive or operational flows. This EWR does not target a specific flow rate. See Baseflow 2 (for L.Darling River) & Small Fresh 2 (all locations) for specific flow targets to support spawning & nesting of riverine specialists).*	Oct–Nov Sep–Nov (in the lower Darling River & Murray River reaches with trout cod populations)	21 days minimum starting 1 October (or 14 days minimum from the detection of Murray cod spawning if monitoring is occurring) 60 days minimum (Murray d/s Yarrawonga & lower Darling River)	5–10 years in 10 *(75%)*	2 years	Maintain natural rates of change in water level (no sudden reductions in flow), ideally hold flows/water levels steady throughout the breeding period.
Small fresh	SF1	Native Fish: NF1–10 – **Dispersal/condition** (all species) Native Vegetation: NV1, 2 – **in-channel & wetland non-woody**[57] Ecosystem Functions: EF1–7 – Variable in-channel habitat; **hydraulic diversity**, water quality; transport of nutrients, sediment & carbon; small-scale productivity & replenishment of refuge pools,	Oct–Apr Jun–Sep (L.Murray) Mar–May (L.Darling) *Varies by location*[51]	10 days minimum *Varies by location*[51]	Annual *(100%)* 5–10 years in 10 *(75%)* (L.Darling) *Varies by location*[51]	1 year 2 years (Darling Anabranch)	Rate of fall: No faster than 5th percentile of natural
	SF2[58]	Native Fish: NF1–6, 8–10 – **Spawning & nesting (river specialist, generalist fish);** Vegetation: NV1–4– in-channel, non-woody wetland, fringing RRG, lignum[59] Ecosystem Functions: EF 1–7 – Variable in-channel habitat; hydraulic diversity; water quality; transport of nutrients, sediment & carbon; small-scale productivity	Sep–Dec (mid Murray & Edward-Wakool) Sep–Nov (L.Darling) Oct–Apr (L.Murray) *Varies by location*[51]	14–90 days minimum *Varies by location*[51]	5–10 years in 10 *(75%)* *Varies by location*[51]	2 years	Avoid rapid reductions in flow/water level to protect fish nests (especially Sep/Oct–Nov). Ideally hold flows steady with some small variability.
	SF3[60]	*Lower Darling River only* Native Fish: NF1–6, 8–10 – **recruitment/dispersal following spring breeding (flow pulse specialists, river specialists & generalists)**	Dec–Apr	14 days minimum	5–10 years in 10 years^ *(75%)*	2 years	Rate of fall: No faster than 5th percentile of natural
Large fresh *(in some locations such as Edward–Wakool, these events rely on relaxed flow constraints and complement*	LF1	Native Fish: NF1–10 – **dispersal/condition (all species)** [All areas]**; pre-spawning condition of flow pulse specialists** [Mid Murray & Edward–Wakool]**; spawning (flow pulse specialists)** [Lower Murray and Lower Darling]**.** Native Vegetation: NV1–4 in-channel & wetland non-woody; lignum; fringing RRG woodlands, floodplain black box Ecosystem Functions: EF1–7 **hydraulic diversity; productivity transfer from upstream, biotic dispersal & movement, hydrodynamic diversity,** lateral connectivity' nutrient & carbon transport, groundwater recharge Waterbirds: WB1,2,5 – habitat	July–Sep (but can occur any time) Sep–Feb (L.Murray) Feb–Jun (L.Darling) *Varies by location*[51]	5 days minimum *Varies by location*[51]	5–10 years in 10 *(75%)* *Varies by location*[51]	2 years 5 years, ideally 4 years (Darling Anabranch)	Water temp. > 17^{0}C for spawning of flow pulse specialists Rapid rise (at higher end of natural rates) Rapid increase in velocity (by managing water level &/or flow) to stimulate spawning Rate of fall: No faster than 5th percentile of natural

[56] NestS1: prescribed for the Murray and lower Darling rivers only. Small Fresh 2 (SF2) covers cod nesting in the Edward-–Wakool system.

[57] BF1: Ecological Objectives NV1– 4 (in channel non-woody vegetation and floodplain black box and lignum) can be met for the Old Darling Anabranch.

[58] SF2: Not prescribed for all reaches.

[59] Lignum only a target in the Darling Anabranch at small fresh magnitudes. At other sites, higher flows are typically required.

[60] SF3 prescribed for the lower Darling River only but likely to contribute to Small fresh (SF2) and Large fresh (LF1) in the lower Murray River.

Flow category and& EWR code[47]		Ecological objectives[47] (primary objectives in bold)	Timing[47]	Duration[47]	Frequency (*LTA*[48] *frequency)*[47]	Maximum inter-event period[47]	Additional water requirements[47]
ary measures)	LF2	Native Fish: NF1, 3, 4, 6, 7 – **spawning (flow pulse specialist fish),** dispersal of floodplain specialists into/from low-lying wetlands Native Vegetation: NV1–4– in-channel & wetland non-woody; lignum; fringing RRG Ecosystem Functions: EF1–7 Ecosystem Functions: EF1–7 – **hydraulic diversity; productivity transfer from upstream, biotic dispersal & movement,** lateral connectivity' nutrient & carbon transport, productivity, groundwater recharge Waterbirds: WB1, 2, 5 – habitat Other Species – OS1, 2 – frog habitat & breeding if wetlands are inundated	Oct–Apr Dec-Apr, or anytime (L.Darling, & Darling Anabranch) *Varies by location*[51]	5 days minimum *Varies by location*[51]	3–5 years in 10 *(30-40%)* to 6–10 years in 10 *(80%).* *Varies by location*[51]	2 years 4 years (Yallakool–Upper Wakool) 7 years, ideally 4 years (Darling Anabranch)	Water temp. > 17^{0}C for spawning of flow pulse specialists. Rapid rise (comparative to natural rates) Rapid increase in velocity (by managing water level &/or flow) to stimulate spawning
	LF3[61]	Native Fish: NF1, 3, 4, 6, 7 – **spawning (flathead galaxias)** [Mid–Murray]**,** dispersal of floodplain specialists into/from low-lying wetlands Native Vegetation: NV1–4– **in-channel & wetland non-woody,** lignum; fringing RRG [L.Darling, Edward–Colligen–Niemur]; Ecosystem Functions: EF1–7 **hydraulic diversity; productivity transfer from upstream, biotic dispersal & movement,** lateral connectivity' nutrient & carbon transport, productivity, groundwater recharge Other Species: OS1, 2 – frog habitat & breeding if wetlands are inundated Other species: OS2, 3b – **Breeding of Sloane's froglet** [Mid Murray]	Aug–Sep (M. Murray) Aug–Dec, or anytime (L.Darling) Aug–Mar (Edward–Colligen–Niemur) *Varies by location*[51]	8 –15 days minimum *Varies by location*[51]	5 –10 years in 10 *(75%)* to 6–8 years in 10 (70%) *Varies by location*[51]	2 years	Rate of fall: No faster than 5th percentile of natural
	LF4[62]	Native Fish: dispersal & condition (all species); spawning (floodplain specialists); Native Vegetation: NV1–4**– in-channel & wetland non-woody; lignum; fringing RRG** Waterbirds (WB1–5): maintain breeding & foraging habitat; Ecosystem functions: **lateral connectivity;** productivity; nutrient/carbon/sediment transfer	Aug–Mar (or anytime for natural flows)	120 days minimum	3–6 years in 10 *(45%)*	3 years	Rate of fall: No faster than 5th percentile of natural
Bankfull *(in many locations, event relies on relaxed constraints &/or natural events)*	BK1	Native Fish: NF2–10 – spawning & recruitment (flow pulse specialists, generalists); dispersal (all species) Vegetation: NV1–4 – in-channel & **wetland non-woody vegetation;** fringing RRG, lignum/nitre goosefoot shrublands, black box Waterbirds: WB1,2,5: habitat Functions: EF1–7 – **hydraulic diversity;** channel maintenance; **lateral connectivity,** nutrient & carbon transfer, **productivity,** groundwater recharge, **biotic dispersal** Other species: OS1,2 – frog breeding & dispersal	Aug–Mar/Apr (or anytime for natural flows) *Varies by location*[51]	10–45 days minimum *Varies by location*[51]	2–3 years in 10 *(25%)* to 6–8 years in 10 *(70%)* *Varies by location*[51]	2–3 years *Varies by location*[51] 7 years (ideally 5 years) Darling Anabranch	Rate of fall: No faster than 5th percentile of natural Annual event for 2–3 consecutive years for recovery of wetland vegetation Rapid rate of rise to support spawning of flow pulse specialists
	BK2	Only applies to Lower Darling River and Murray d/s Yarrawonga Weir Objectives as for BK1 above but higher flow rate than BK1 to reflect downstream changes to bankfull channel capacity (River Murray: Yarrawonga to Barmah) or to provide large fresh into the Darling Anabranch in the case of BK2 for the lower Darling River.	Aug-Nov or anytime for natural flows (Murray) Aug–May or anytime for natural flows (lower Darling)	15 days (Murray) 21 days (lower Darling)	5-10 years in 10 (75%) - Murray 2–3 years in 10 *(25%)* - lower Darling	3 years (Murray) 4 years (lower Darling)	

[61] LF3: only prescribed for specific reaches, such as mid Murray River (for threatened species: Sloane's froglet and flathead galaxias); and Edward, Colligen, Niemur and lower Darling river for wetland vegetation outcomes.

[62] LF4: prescribed for Edward and Niemur rivers and Colligen Creek only

Flow category and& EWR code[47]	Ecological objectives[47] (primary objectives in bold)	Timing[47]	Duration[47]	Frequency (*LTA*[48] *frequency)*[47]	Maximum inter-event period[47]	Additional water requirements[47]
Small overbank *OB1-2 (Murray River at Doctors Point, d/s Torrumbarry Weir; Edward-Wakool & lower Darling River)* *OB1-6 (Murray d/s Yarrawonga Weir)* *OB1 (lower Murray River d/s Euston & Darling Anabranch)*	Native fish: NF2–10 – **dispersal (all species); spawning & recruitment (flow pulse specialists, floodplain specialists, generalists)** Native Vegetation: NV1–4 – in-channel, **non-woody wetland & floodplain understory, fringing RRG, RRG forest & woodlands** Waterbirds: WB1–5: **small-scale colonial waterbird breeding** events; foraging Ecosystem functions (NF1–7): **lateral connectivity with low-lying floodplains, wetlands and anabranch/creek systems, productivity**, refuge habitat, nutrient & carbon transport, groundwater recharge Other species: OS1–4 – frog breeding	Aug–Nov (or anytime for natural events) *Varies by location*[51]	12–150 days *Varies by location*[51]	3–10 years in 10 *(35–75%)* *Varies by location*[51] 2 years in 10 *(20%)* (Darling Anabranch)	2–5 years *Varies by location*[51]	Rely on relaxed constraints in most locations Natural event only in some locations Rate of fall: No faster than 5th percentile of natural In some reaches, ideally clustered as groups of 2–3 sequential events 12–18 months apart to maximise ecological outcomes. If colonial waterbird breeding occurs, maintain water levels in breeding sites, where possible to ensure breeding success
Medium overbank *OB3 (Murray at Doctors Point; Edward-Wakool & lower Darling River)* *OB7-8 (Murray d/s Yarrawonga Weir)* *OB3-4 (Murray d/s Torrumbarry Weir)* *OB2 (lower Murray River d/s Euston & Darling Anabranch)*	Native Fish: NF2–10 – spawning & recruitment (floodplain specialists), dispersal/condition (all species) Native Vegetation NV1–4 – non-woody wetland & floodplain understorey; **RRG forest & woodland, black box woodland** & lignum/nitre goosefoot shrublands Waterbirds: WB1–5 – **large scale colonial waterbird breeding**; habitat Ecosystem functions: EF1–7: **large-scale lateral connectivity, productivity,** biotic dispersal, nutrient & carbon transport, groundwater recharge Other species: OS1–4 – frog breeding	July–Feb (or anytime for natural events) *Varies by location*[51]	7–30 days *Varies by location*[51]	2–5 years in 10 *(25–40%)* *Varies by location*[51] 1–2 years in 10 *(15%)* (Darling Anabranch)	4-10 years *Varies by location*[51]	Natural events only If colonial waterbird breeding occurs, maintain water levels in breeding sites, where possible to ensure breeding success
Large overbank *OB3 (Darling Anabranch)* *OB3-5 (Murray d/s Torrumbarry Weir & d/s Euston)* *OB4 (Murray at Doctors Point; Edward-Wakool)* *OB4-5 (lower Darling River)* *OB9-10 (Murray d/s Yarrawonga Weir)*	Native Fish: NF2–10 – spawning & recruitment (floodplain specialists), dispersal/condition (all species) Native Vegetation NV1–4 – non-woody floodplain understorey; RRG forest & woodland, **higher elevation black box woodland & lignum/nitre goosefoot shrublands** Waterbirds: WB1–5 – **large scale colonial waterbird breeding**; habitat Ecosystem functions: EF1–7: **large scale productivity,** biotic dispersal, nutrient & carbon transport, groundwater recharge Other species: OS1–4 – frog breeding	Anytime	3–45 days *Varies by location*[51]	1–2 years in 10 *(10–15%)*	7–14 years *Varies by location*[51]	

Flow category and& EWR code[47]		**Ecological objectives**[47] (primary objectives in bold)	**Timing**[47]	**Duration**[47]	**Frequency (*LTA*[48] *frequency)*[47]**	**Maximum inter-event period**[47]	**Additional water requirements**[47]
EWRs for river reaches affected by weir pools (lower Murray River)							
Weir pool drawdown (summer–autumn)[63]	WP1	Native Fish: NF2–10 – movement cues (all species) Vegetation: NV1, 2, 3 – **drying regime for in-channel, fringing & wetland veg** Functions: EF1,2, 3,4 – **hydraulic diversity, water quality (prevent weir pool stratification), longitudinal connectivity,** biotic dispersal & movement; drying regime for weir pool margins & wetlands, productivity, lower groundwater table	Jan–May	90 days minimum	7–10 years in 10 *(85%)*	3 years	Drawdown is especially important if flows are <14,000 ML/d during summer–autumn to improve hydraulic diversity in the lower Murray River channel
Weir pool raising (winter–spring to early summer)	WP2[64]	Native fish: NV1–9 **–** dispersal (all species), spawning (floodplain specialists – from Oct to Mar only) Native Vegetation: NV1–4 – **non-woody in-channel & floodplain black box & lignum** Waterbirds: WB1,2,5: habitat condition Functions: EF1–7 – **lateral connectivity with anabranches & wetlands**; nutrient & carbon transfer, **productivity**, groundwater recharge, biotic dispersal Other species: OS1,2 – frog breeding & dispersal	Jul–Dec	60 days minimum	6–10 years in 10 *(80%)*	3 years	
Weir pool drawdown (winter–spring to early summer)	WP3	Native Fish: NF2–10 – **movement & dispersal (all species)**, pre-spawning condition (all species), **spawning (riverine specialists**, flow pulse specialists) Functions: EF2,3 – **hydraulic diversity,** water quality, longitudinal connectivity, biotic dispersal & movement ***<u>Only required under extended dry periods in the absence of small freshes (SF1,2)</u>***	Aug–Dec	60 days minimum	Every 2–3 years during extended dry periods. Likely to be required only 0–2 years in 10 (7% LTA), depending on the occurrence of extended dry periods.	Not more than 2 consecutive years without a small fresh of at least 14,000 ML/d for at least 14 days or a winter–spring weir pool drawdown during Sep–Dec.	Ideally, lower all weir pools simultaneously to maximise movement opportunities for native fish
Weir pool drawdown (spring-early summer)	WP4	Native Fish: NF1–6, 8–10 – spawning (river specialist, generalist fish); recruitment/dispersal following spring breeding (flow pulse specialists, riverine specialists & generalists) Functions: EF2, 3, 4, 5, 7 – hydraulic diversity, longitudinal connectivity, biotic dispersal & movement, nutrient & carbon transport	Sep-Dec	14 days minimum, especially during small flow freshes	5-10 years in 10 *(75%)*	3 years	Important to consider during small freshes (~14,000-20,000 ML/d in the lower Murray River). For flows above 20,000 ML/d, lowering of weir pools is less important as these higher flows provide good hydraulic diversity at a range of weir pool levels.

[63] WP1 similar to summer-autumn drawdowns under baseflow conditions (without weirs).
[64] WP2: similar to small overbank flow (OB1).

Flow category and& EWR code[47]		**Ecological objectives[47]** (primary objectives in bold)	**Timing[47]**	**Duration[47]**	**Frequency (*LTA[48] frequency)[47]***	**Maximum inter-event period[47]**	**Additional water requirements[47]**
EWRs for the Menindee Lakes system							
Low-level Lake Fill	LLLF	Native Fish: NF1 – survival (all species) Vegetation: NV2a, 3, 4e – **non-woody wetland**, fringing RRG, **lignum-nitre goosefoot shrublands** Waterbirds: WB1, 2, 5 – **maintain habitat** Ecosystem Functions: EF1, 2, 3, 4, 5 – **refuge habitat, productivity,** groundwater recharge	Anytime[65]	Minimum retention time: 90 – 150 days[66] Continuous (Lake Wetherell & top lakes)	6–8 years in 10[67] *(70%)* - Lake Menindee & Cawndilla 9–10 years in 10 *(90%)* - Lake Wetherell & top lakes)	2 years (Lake Menindee) 7 years, ideally 3 years (Lake Cawndilla) 145 days (Lake Wetherell & top lakes)	Drawdown rates ideally <4 cm/day (need to also consider potential cultural heritage impacts - knowledge gap) Lake Menindee level: 56.0 m AHD Lake Cawndilla level: 53.8 m AHD Lake Wetherell & Tandure: 57.8 m AHD
Mid-level Lake Fill	MLLF	Native Vegetation: NV1–4 – Old anabranch **non-woody in-channel & floodplain black box & lignum** Waterbirds: WB5: habitat condition Ecosystem Functions: EF1, 2, 3, 4, 5 – Connect Old Anabranch from the lower Darling River to Wycot	Anytime[65]	Minimum retention time: 90 – 150 days[66] Minimum retention time: 30 days (Lake Wetherell & top lakes – partial connection)	3–5 years in 10 *(40%)* – Lake Menindee and Cawndilla 5-10 years in 10 *(75%)* – Lake Wetherell & top lakes	4 years (Lake Menindee, Lake Wetherell & top lakes) 7 years, ideally 4 years (Lake Cawndilla)	Drawdown rates ideally <4 cm/day Releases from Lake Cawndilla for at least 70 days to ensure connection with Murray River for >30 days Ideally sequenced as 2–3 successive events 3-18 months apart to maximise ecological outcomes Lake Menindee level: 56.5 m AHD Lake Cawndilla level: 54.5 m AHD Lake Wetherell & Tandure: 61.1 m AHD
High Level Lake Fill	HLLF	Native Fish: Native Fish: NF4, 5, 6 – **dispersal & recruitment of flow pulse specialists in Lakes Menindee & Cawndilla & dispersal to downstream river systems**; spawning & recruitment of flow pulse & riverine specialists downstream in the LDR; Vegetation: NV2a, 2b, 3, 4c, 4d, 4e – **lignum & black box** Waterbirds: WB1,2,4,5 – **colonial breeding & habitat** Ecosystem Functions: EF1, 2, 3, 4, 5, 6 – nutrient & carbon exchange, **productivity,** groundwater recharge	Anytime[65]	Minimum retention time: 90–150 days[66] Maximum retention time: 2 years Minimum retention time: 30 days (Lake Wetherell & top lakes – full connection)	1.5 years in 10 *(15%)* - Lake Menindee & Cawndilla 3–5 years in 10 *(40%)* - Lake Wetherell & top lakes	8 years	Drawdown rates ideally <4 cm/day Releases from Lake Cawndilla for at least 70 days to ensure connection with Murray River for >30 days Ideally followed by a mid-level fill 3–18 months later, subject to natural triggers, to maximise ecological outcomes Lake Menindee level: 57.5 m AHD Lake Cawndilla level: 57.5 m AHD Lake Wetherell & Tandure: 61.8 m AHD
Very High-Level Lake Fill	VHLLF	Native Fish: Native Fish: NF4, 5, 6 **– dispersal & recruitment of flow pulse specialists in Lakes Menindee & Cawndilla & dispersal to downstream river systems;** spawning & recruitment of flow pulse & riverine specialists downstream in the LDR; Vegetation: NV2a, 2b, 3, 4c, 4d, 4e – **non-woody wetland, lignum-nitre goosefoot shrublands & fringing RRG, high elevation black box & coolibah** Waterbirds: WB1, 2, 4, 5 – **colonial breeding & habitat** Ecosystem Functions: EF1, 2, 3, 4, 5, 6 – nutrient & carbon exchange, **productivity,** groundwater recharge	Anytime[65]	Minimum retention time: 90 – 150 days[66] Maximum retention time: 1 year	1 year in 10 *(10%)* – Lake Menindee & Cawndilla	10 years	Drawdown rates ideally <4 cm/day Releases from Lake Cawndilla for at least 70 days to ensure connection with Murray River for >30 days Ideally followed by a mid- or high-level fill 3–18 months later, subject to natural triggers, to maximise ecological outcomes Lake Menindee level: 58.5 m AHD Lake Cawndilla level: 58.5 m AHD

[65] Filling triggered by upstream flows in Barwon Darling river system.

[66] Minimum 120-150 day retention time if waterbird breeding is detected, to ensure breeding to completion (chicks are fledged).

[67] Low level lake fills can be met by mid to high level lake fills (i.e. not in addition to).

Table 11 Important flow regime characteristics for delivering LTWP objectives

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	**NATIVE VEGETATION OBJECTIVES**[68]	
NV1 Maintain or improve the extent & viability of non-woody vegetation communities occurring within channel or closely fringing channels *(Non-woody permanent to near permanent inundation tolerant plants)*	Non-woody plants growing on the channel bed, banks, bars & benches require regular wetting & drying to complete life cycles. Frequent (near annual) inundation through baseflows, bankfull flows (BK 1), weir pool surcharges (WP 2) & large freshes (LF2, 3) for 7–12 months will promote vigorous growth & expansion of tall emergent aquatic species such cumbungi, common reed & giant rush within & closely fringing channels. Frequent, but shorter duration flows may reduce vigour, but encourage more diverse communities. Inundation of channel banks during late winter & early spring by freshes & bankfull flows is required to replenish soil moisture to promote growth during spring. Prolonged submergence of plant species, especially if there are continuous high flows during the irrigation season, may have detrimental impacts on survival. Partial dry phases (BF3) in summer & autumn for 1–4 months encourage recruitment. Regular inundation will also encourage a dominance of native species over exotic species, which are mostly adapted to dry environments. Increased cover of non-woody vegetation on river banks is likely to stabilise bank material & therefore reduce the risk of excessive bank erosion.	All planning units (PUs)
NV2a Maintain the extent & viability of non-woody vegetation communities	Non-woody vegetation communities occurring in low-lying wetlands through to elevated parts of the floodplain require a flooding regime to complete life cycles. The required flow duration & 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 drawdown species diversity can increase as conditions transition	Focus areas include low-lying wetland & floodplain areas within Millewa Forest, Koondrook–Perricoota Forest, Werai Forest, Niemur River, Tuppal Creek, Edward River, Wakool River, Murray River,

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

Ecological objective	Important flow regime characteristics	Focus areas &/or species
occurring in wetlands & on floodplains	to suit amphibious and dry adapted species. Prolonged dry periods between flood events can inhibit regrowth of non-woody vegetation when reflooded, an important consideration for recovery.	lower Darling River & the Darling Anabranch.
a) non-woody seasonal to periodic inundation tolerant plants	Bankfull flows (BK1), large freshes (LF2, 3) & wetland inundating flows will support non-woody wetland vegetation in low-lying wetlands. Submerged aquatic species, such as pondweed and tall, emergent aquatic species such as cumbungi, common reed & giant rush require inundation for 7–12 months duration, for 8–10 years in 10 to promote vigorous growth & expansion with maximum period between events of 18 months. If establishing from dry, some species, such as ribbonweed may require inundation duration to cover 2 growing seasons. Species, such as water couch and moira grass require inundation from June–February for 5–10 months, for 7–9 years in 10, with a maximum period between events of 2 years, while other species, such as marsh clubrush & common spike rush require inundation from June–February, for 3–8 months, 3–6 years in 10, with maximum period between events of 3–4 years. Small to moderate but frequent wetland inundating & small overbank flows (OB1, OB2) will be important for maintaining the extent & viability of these species. Medium to large overbank flows will support non-woody wetland communities that are higher on the floodplain with greater commence-to-flow thresholds. These communities may require 2–6 months inundation, 2–5 years in 10, with maximum period between events of 2–7 years (depending on their floodplain position). Timing is not critical, but dry phases are ideally in summer–autumn, possibly extending into late winter. Variability in flow frequency, timing & duration is likely to increase non-woody floodplain wetland plant diversity. Slow rates of recession following inundation will enable existing species to follow the waterline & seeds to germinate & complete life cycles. Sedge rhizome viability may be affected after more than 2–4 years between flow events, while seedbank viability for many other species is vulnerable after more than 10 years.	Focus non-woody vegetation communities include moira grass (Millewa forest).

Ecological objective	Important flow regime characteristics	Focus areas &/or species
NV2b Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains b) ephemeral floodplain vegetation	The required duration & frequency varies widely by species. Bankfull flows (BK 1) through to weir pool surcharges (WP 2), wetland inundating (LF 2, 3) or small, medium & large overbank flows (OB1–10) will provide flooding regimes that replenish surface soil moisture and support the establishment & viability of short-lived floodplain understorey species, such as some herbs, grasses & sedges that may establish on exposed soils following the drawdown. These flows may be variable (1.5–5 years in 10) & shorter duration (1–3 months). Slow rates of flow recession maintain soil moisture & encourage germination. Seedbank viability is vulnerable after more than 10 years between flows.	All PUs Key focus areas, where improvements in abundance, condition & regeneration (i.e. seedbank replenishment) of ephemeral floodplain understorey vegetation communities is desired include Koondrook–Perricoota forest, floodplains of the lower Murray River, lower Darling River & Darling Anabranch & Menindee Lakes.
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, most importantly, bankfull flows (BK1), which inundate the tops of banks, larger wetland inundating flows that inundate fringing riparian zone & small, medium & large overbank flows. Larger freshes (LF2, 3) & bankfull flows (BK1) that recharge alluvial aquifers & 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 4–10 years in 10 to maintain good condition.	All PUs
NV4a Maintain the extent & improve the condition of native woodland & shrubland communities on the floodplain a) river red gum forest	Maintaining the condition & extent of river red gum forests requires wetland inundating flows & small overbank flows to inundate vegetation between 5–7 months, during August–February. Frequency of inundation is required every 3–10 years in 10, with a maximum period between events of 3 years. Slow rates of flow recession may encourage seed fall & germination. Regeneration of river red gum forest communities will require additional, follow-up flows of shorter duration (1–2 months) during August–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	Under current operational constraints, the area of floodplain RRG forests that can be managed with environmental water to achieve objective NV4a is limited, but under relaxed constraints, the condition of a substantially larger area of river red gum forests could be maintained &/or improved. Key areas include riparian corridors along all major rivers & creeks & low-lying floodplain forests, such as Werai, Niemur & Koondrook–Perricoota in the Mid Murray,

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	also support the development & maintenance of bud crops & aerial seedbanks on mature trees. The provision of periods of sequenced, successive flows will also increase potential to improve the recovery of existing river red gum forest communities that are in poorer condition. Variable timing, frequency & duration of inundation will promote greater floodplain forest understorey diversity (Objective NV2b).	where RRG forest condition is currently declining due to a lack of sufficient inundation. The need for river red gum forest regeneration may be highly site specific. For certain regions, such as the Lower Murray, increasing regeneration is a concern (i.e. too few seedlings & younger saplings compared to proportion of aging trees), while for other focus areas like Millewa, river red gum regeneration has become problematic. Areas of RRG forest outside the constraints relaxed floodplain which cannot be managed with water delivery in the future may continue to decline, remain severely degraded or transition from flood-dependent vegetation communities into other types if they do not receive enough water.
NV4b Maintain the extent & improve the condition of native woodland & shrubland communities on the floodplain b) river red gum woodland	Maintaining the condition & extent of river red gum woodlands located higher on the floodplain requires <u>medium to large overbank flows</u> for 2–4 months during August–February. Frequency of inundation is 3–5 years in 10, with a maximum period between events of 5 years. Slow rates of recession may encourage seed fall & germination. An interval greater than 5 years between inundation events may result in decreased condition. Extended dry periods may mean these communities become severely degraded and dysfunctional or potentially transition into less flood dependent vegetation communities (e.g. black box and open grasslands) or develop into ‘novel’ community types (e.g. new species assemblages, including invasive species). Other factors such as climate change, total grazing pressure and land tenure (public or private land, state forest or national park) will also influence condition and the level of impact. Where possible, the provision of periods of	Under current operational constraints, the area of floodplain RRG woodlands that can be managed with environmental water is limited, but under relaxed constraints, the condition of a substantially larger area of river red gum woodlands could be maintained & improved. Key focus areas include floodplains of the mid Murray, lower Murray & lower Darling rivers and the Darling Anabranch where condition is currently declining, & for many areas, inadequate regeneration is a concern (i.e. too few seedlings & young

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	successive flows may increase potential to improve the recovery of existing river red gum woodland communities that are in poorer condition. Variable timing, frequency & duration of inundation will promote woodland understorey diversity (Objective NV2b). Regeneration of river red gum communities will require additional, follow-up flows of shorter durations (1–2 months) during August–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 (1–2 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 & aerial seedbanks that may have developed in the previous year.	saplings compared to proportion of aging trees) due to a lack of sufficient inundation. Areas of RRG woodland outside the constraints relaxed floodplain that cannot be managed with environmental water delivery in the future may continue to decline, remain severely degraded or transition from flood-dependent vegetation communities into other types if they do not receive enough water.
NV4c Maintain the extent & improve the condition of native woodland & shrubland communities on the floodplain c) black box woodland	Medium and/or large overbank flows[69] (or medium/high/very high level lake fills MLLF – VHLF in the case of the Menindee Lakes system) 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 2–6 months, at a frequency of 2–4 years in 10. A maximum period between events of 5–7 years is desirable as greater than 7 years may result in decreased condition. Extended dry periods may mean these communities may become severely degraded and dysfunctional or potentially transition into less flood dependent vegetation communities (e.g. black box and open grasslands) or develop into 'novel' community types (e.g. new species assemblages, including invasive species). Other factors such as climate change, total grazing pressure and land tenure (public or private land, state forest or national park) will also influence condition and the level of impact. Where possible, the provision of periods of successive flows may increase potential to improve the recovery of existing black box woodland communities that are in poorer condition.	Under current operational constraints, the area of floodplain black box woodlands that can be managed with environmental water is currently limited to low-lying floodplain areas for much of the Murray–Lower Darling WRPA, but under relaxed constraints, the condition of a substantially larger area of black box woodlands could be maintained & improved. Key focus areas include floodplains of the mid Murray, lower Murray & lower Darling rivers, the Darling Anabranch & Menindee Lakes, where the condition floodplain black box woodland is poor &/or declining & inadequate regeneration is a concern (i.e.

[69] Specific to each planning unit depending on the location of black box communities.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	Timing is not critical and variable timing, frequency and duration of inundation will promote greater woodland understorey diversity (Objective NV2b). Regeneration of black box communities will require additional, follow-up flows of shorter durations (1–2 months) during August–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 (1–2 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 & aerial seedbanks that may have developed in the previous year.	too few seedlings & young saplings compared to proportion of aging trees) due to a lack of sufficient inundation. Areas of black box woodland outside the constraints relaxed floodplain that cannot be managed with water delivery in the future may continue to decline, remain severely degraded or transition from flood-dependent vegetation communities into other types if they do not receive enough water.
NV4d Maintain the extent & improve the condition of native woodland & shrubland communities on the floodplain d) coolibah woodland	Maintenance of coolibah floodplain communities requires inundation by <u>large overbank flows</u> &/or <u>lake fill events</u> for 1–3 months. For coolibah located in lower parts of the floodplain, medium overbank flows or medium to high level lake fills (MLLF, HLLF), with a duration of 2–3 months for 3–5 years in 10, with a maximum period of 5 years between events are required. For coolibah woodlands located on higher parts of the floodplain larger overbank flows or very high level lake fills (VHLF) of a shorter duration (<1 month) for 1 year in 10 are required, with a maximum period of 10–15 years between events. Extended dry periods may mean these communities may become severely degraded or potentially transition into less flood dependent vegetation communities (e.g. open grasslands) or develop into 'novel' community types (e.g. new species assemblages, including invasive species). Other factors such as climate change, total grazing pressure and land tenure (public or private land, state forest or national park) will also influence condition and the level of impact. Where possible, the provision of periods of successive flows may increase potential to improve the recovery of existing coolibah woodland communities that are in poorer condition. Ideal timing is unknown, but variable timing, frequency & duration of inundation is likely to promote greater woodland floodplain understory diversity (NV2b). Regeneration of coolibah communities will require additional, shorter duration (<1 month) during August–November. Regeneration events would ideally occur in the years following a maintenance flow to support the survival of seedlings from the	Coolibah woodlands have a limited distribution in the Murray–Lower Darling, but are found around Menindee Lakes, Lake Cawndilla, Lake Pamamaroo & Talyawalka. Coolibah woodlands are listed as an Endangered Ecological Community – *Coolibah-Black Box woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain & Mulga Lands Bioregions*, but current extent & distribution is unclear. Coolibah woodland communities located outside the floodplain that can be managed with environmental or operational water (i.e. filling of Menindee Lakes system) may continue to decline, remain severely degraded or transition from flood-dependent vegetation communities into other types if they do not receive enough water.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	previous year where recruitment is desired. In dry, low-rainfall years, flows encouraging regeneration may be required more frequently to support seedling establishment.	
NV4e Maintain the extent & improve the condition of native woodland & shrubland communities on the floodplain e) lignum shrublands	Maintenance of lignum shrubland communities requires inundation by bankfull wetland inundating flows through to small, medium or large overbank flows for 2–7 months. For lignum located in lower parts of the floodplain, bankfull, wetland inundating & small to medium overbank flows that occur 4–10 years in 10, with a maximum interflow period of 3 years are required. To support good condition of lignum shrublands located on the elevated parts of the floodplain, larger overbank flows 1–2 years in 10, with a maximum interflow period of 7 years are required. Extended dry periods may mean these communities may become severely degraded or potentially transition into less flood dependent vegetation communities (e.g. nitre-goosefoot shrublands) or develop into 'novel' community types (e.g. new species assemblages, including invasive species). Other factors such as climate change, total grazing pressure and land tenure (public or private land, state forest or national park) will also influence condition and the level of impact. Where possible, the provision of periods of successive flows may increase potential to improve the recovery of existing lignum shrubland communities that are in poorer condition. A higher frequency of inundation may also be required in areas with saline soils (e.g. Lower Murray & Lower Darling). Timing of inundation is not critical. Variable timing, frequency & duration of inundation will also promote greater shrubland understory diversity (NV2b). Regeneration requires more frequent inundation for 2–4 months to support seedling establishment or up to 12 months to support vegetative expansion. Ideal timing is autumn to winter & 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.	Under current operational constraints, the area of floodplain lignum shrublands that can be managed with environmental water is mostly limited to very low-lying floodplain areas. Under relaxed constraints, the condition of a substantially larger area of lignum shrublands could be maintained &/or improved. Key focus areas include floodplains of the Edward–Wakool system, lower Murray River (e.g. Bottlebend, Wingillie, Lindsay–Mulcra–Wallpolla Islands, Grand Junction), lower Darling River, Darling Anabranch & Menindee Lakes, where lignum shrubland abundance & condition is declining due to a lack of sufficient inundation. Many of these sites have a high potential for improvement with active environmental water management. Areas that can be recovered include the constraints relaxed floodplain. Areas beyond this may continue to decline, remain severely degraded or transition from flood-dependent vegetation communities into other types if they do not receive enough water.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	NATIVE FISH OBJECTIVES[70]	
NF1: No loss of native fish species	Cease-to-flow: durations that are not longer than the persistence of water of sufficient volume & quality in key river pool refuges for survival of native fish. Very low flows (VLF) & baseflows (BF1, 2): for the survival & maintenance of native fish condition as these flows aim to maintain adequate water quantity & quality (dissolved oxygen, salinity & temperature) in refuge pools. In some systems (e.g. lower Darling River), higher baseflows are required in summer to maintain adequate water quality by preventing or minimising the effects of thermal stratification & associated risks of hypoxia &/or algal bloom development. Winter baseflows (BF1b, 2): maintaining baseflows during the autumn–winter months is particularly important as operational (consumptive) flows are often ceased or significantly reduced. Baseflows (BF1,2) & small freshes (SF1, 2): deep enough along the whole channel to allow fish movement (at least 0.3 m above cease-to-flow for small & moderate bodied fish & 0.5 m for large bodied fish (Fairfull & Witheridge 2003; Gippel 2013; O'Conner et al. 2015). These flows also promote water column mixing to maintain water quality & reduce risk of thermal stratification & blue green algal bloom development. Baseflows (BF2): slightly higher baseflows preferably between September & March occurring annually or every second year (5–10 years in 10) to enhance recruitment outcomes for riverine specialists & generalists (e.g. Murray cod). Annual occurrence of higher baseflows would aid recovery of native fish. A large fresh (LF1): of at least 5 days duration & occurring ideally between July & September (but can occur at any time) to promote dispersal & pre-spawning condition for all native fish species 5–10 years in 10. The large fresh should trigger some primary productivity (via inundation of in channel features such as benches & snags)	All PUs & all species Key refuge sites during dry times or extreme events include: • Rivers/creeks - Murray River, lower Darling River, Edward River, Niemur River, Gulpa Creek, Yallakool Creek, Wakool River, Frenchmans Creek • Lakes &/or storages such as Lake Wetherell, Moira Lake, Lake Hume, Lake Mulwala, Lake Benanee and Lake Victoria • effluent and anabranch creeks within Millewa forest and the Lock 7-9 floodplain (e.g. Carrs-Cappits-Bunberoo creeks system) • Werai forest lagoon wetlands • Smaller creeks in the Edward-Wakool system and Tuppal Creek where freshwater can be delivered via irrigation systems.

[70] Important flow regime characteristics for all native fish objectives are based on Ellis et al. (2018); NSW DPI (in preparation) and advice from NSW DPIF and other fish ecologists during the development of the LTWP during 2016–2019.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	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. Weir pool drawdown (WP1) should be considered in reaches of the lower Murray River affected by weir pools to promote fish movement & pre-spawning condition, especially if winter–spring conditions are dry & river flows are below ~10,000–14,000 ML/d in the lower Murray River. Under these conditions, weirs substantially limit the availability of fast flowing habitat (>0.3m/s mean cross-sectional velocity) in weir pools – so effectively the whole lower Murray River from Wentworth to the SA border and beyond to the Lower Lakes. At flows of ~10,000 ML/d, weir pool drawdown increases the proportional area of weir pool reaches with flow velocities >0.3 m/s from 18% to 35% in the Lock 7 weir pool & from 0% to 16% in Lock 8 weir pool[71]. This compares with higher flows >14,000 (i.e. small freshes and above), which we would expect to generate fast flowing habitat through 70% of the Lock 7 weir pool and 33-64% of the Lock 8 weir pool, without weir drawdown. Large freshes (LF2–4): to promote in-channel spawning & juvenile dispersal to/from core low-lying (off-channel) wetlands. See objectives NF2–10 for specific spawning timing Under very dry, dry and moderate scenarios, alternative watering actions (e.g. pumping) may be required to support floodplain habitats, which contain floodplain specialists, & to prevent habitat from drying out (i.e. loss of populations) Bankfull (BK1) & overbank flows (OB1): during October–April to promote breeding & recruitment of floodplain specialists. Larger flows that connect low-lying floodplains & wetlands provide important habitat to support strong survivorship & growth of juveniles & facilitate mixing between populations to promote genetic exchange. Overbank flows (OB2–9): ideally from September–February & occurring 2–3 years in 10 (with a maximum inter-event period of 5 years) is also required to support condition & movement/dispersal outcomes of all native fish groups. Larger flows that inundate off-stream habitat also promote growth & recruitment through increased floodplain productivity & habitat availability.	

[71] Based on hydraulic modelling of Locks 7 and 8 under different flow and weir pool level scenarios (data and analysis provided by MDBA July 2017).

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	Weir pool raising (WP2) can be utilised in river reaches affected by weir pools (lower Murray River) to provide some of the important benefits of small overbank flows & promote the dispersal of native fish.	
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, in-channel freshes (e.g. small fresh SF2) may enhance spawning and recruitment outcomes. Events should occur during the warmer months of September–April, at a frequency of 5–10 years in 10, with a minimum event duration of 14 days for egg development & hatching. Multiple in-channel freshes during the spawning season provides flexibility in species response & opportunities for multiple spawning events.	All PUs
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 & wetland inundating flows (LF3–4 & OB1–2): that connect low lying wetland habitats during spring: September–November[72] (August–September for flat headed galaxias) provide spawning habitat & floodplain productivity benefits to support fish growth. In some areas, infrastructure can be used to deliver and hold water in wetlands and floodplain in some areas to mimic natural overbank events to support floodplain specialists. Overbank & wetland-inundating 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 2 years. This period will depend on the persistence of floodplain habitats & time between reconnection to main stem waterways. Flows should be of a long enough duration to support isolated populations. Water temperatures should be above 22°C.	Focus species[74]: Southern pygmy perch, flathead galaxias, Murray hardyhead The following PUs have observed records of floodplain specialist native fish. See also NF7 for other PUs that have suitable habitats to support floodplain specialists and are potential areas for expansion of populations. • upper Murray River and tributaries - Mannus Water Source - Ournei Welaregang Water Source - Jingellic Water Source

[72] Floodplain specialist may also benefit from summer and autumn flows that inundate wetland and floodplain habitat (e.g. natural floods), however overbank flows in the warmer months are likely to increase the risk of hypoxic blackwater events and promote carp breeding.

[74] Olive perchlet and purple-spotted gudgeon are additional floodplain specialist species targeted by NF7

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	Flathead galaxias, which are critically endangered in NSW, breed only in August and September and require frequent inundation (7–8 years in 10) of low-lying wetlands during these months. Large fresh 3 (LF3) in the River Murray (at Doctors Point and d/s Yarrawonga) is designed specifically to support this species. Recruitment is enhanced by subsequent flows events (large fresh, bankfull or overbank & wetland inundating flows) 2–4 weeks after initial wetland or floodplain-connection flows. Most floodplain specialist species require spawning & recruitment every 1–2 years for population survival (ideally annual events to support recovery). Weir pool raising (WP2) can be used in the Lower Murray River to mimic a small overbank event (equivalent to ~50,000 ML/d at Lock 8 for example) to provide floodplain specialist fish with access to floodplain, wetland and small creek habitats for spawning. Weir pool raising would ideally occur 6–10 years in 10 from October onwards for a minimum of 10 days[73].	• mid Murray River (and floodplain): - Hume to Yarrawonga - Yarrawonga to Barmah • lower Murray River (and floodplain) - upstream extent of Lock 15 weir pool (Euston Lakes) to Lock 10 - Lock 7–9 Infrastructure examples: • Millewa and Koondrook–Perricoota forests TLM infrastructure • regulators on numerous small wetlands along the River Murray and throughout the Edward–Wakool system • weir pool manipulation in the lower Murray River downstream of Euston. Habitat protection &/or restoration works are required in many of these infrastructure sites, particular carp control to aid the establishment of non-woody wetland vegetation (see details in Table 22 under 'Restore Wetland Habitats').
NF4: Improve population structure for **moderate to long-lived flow**	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–April for a minimum of 5 days for spawning. This is needed 3–5 years in 10 or 6–7 years in 10 where recovery is required. A	Focus species: golden, silver and spangled perch Mid Murray – all PUs

[73] Requirements for floodplain specialist spawning. NB. Longer durations and earlier timing of weir pool raising is required for vegetation outcomes. See WP2 EWR for the Lower Murray.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
pulse specialist native fish species	maximum inter-event period of 2 years is recommended. 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 (e.g. benches & snags) & generate high velocities of greater than 0.3 m/s (mean cross-sectional velocity). Integrity of flow events need to be maintained over long distances (10s–100s of km) to maximise the capacity for in-stream spawning, downstream dispersal by drifting eggs and larvae, and flow-induced movements by adults & juveniles. Weir pool drawdown (WP1,3,4) should be considered in river reaches affected by weir pools to promote fish movement and spawning in main river channel, especially if spring conditions are dry and river flows are below ~10,000–14,000 ML/d in the lower Murray River. Under these conditions, there is little to no availability of fast flowing habitat (>0.3m/s) in weir pools – so effectively the whole Lower Murray River from Wentworth to the SA border. At flows of ~10,000 ML/d, weir pool drawdown increases the proportional area of weir pool reaches with flow velocities >0.3 m/s from 18% to 35% in the Lock 7 weir pool & from 0% to 16% in Lock 8 weir pool[75]. This compares with higher flows >14,000 (i.e. small freshes and above), which we would expect to generate fast flowing habitat through 70% of the Lock 7 weir pool and 33-64% of the Lock 8 weir pool, without weir drawdown. Lake and wetland-connecting flows (LF3–4, BK1 and OB1–10) are important to support dispersal and recruitment of flow pulse specialists. Off-channel wetlands and lakes can provide important nursery grounds for larvae and juvenile native fish. Wetland and lake-connecting flows can occur anytime but ideally would be triggered by high flows &/or evidence of spawning upstream (Oct–Mar). Inundation of lakes and wetlands should occur for a minimum of 3–5 months and be followed by a subsequent filling event 3–18 months later to promote juvenile and adult fish to return to rivers. Exit cues could also be incorporated to promote dispersal out of lakes (e.g. short sharp drop in water level followed by a gradual recession). Lakes or wetlands supporting large fish populations should not be allowed to dry out until fish have been provided adequate opportunity to move out.	Lower Murray – all PUs Lower Darling – all PUs. The Menindee Lakes, including Lake Cawndilla are an important nursery ground for golden and silver perch and contribute to basin-wide outcomes for flow pulse specialists. See NF6 for other existing and potential recruitment sites. Upper Murray River and tributaries – PUs including Lake Hume, Jingellic, Upper Murray and Dora Dora water sources.

[75] Based on hydraulic modelling of Locks 7 and 8 under different flow and weir pool level scenarios (data and analysis provided by MDBA).

Ecological objective	Important flow regime characteristics	Focus areas &/or species
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) and higher baseflows (e.g. BF2a–c in the lower Darling River) may promote spawning and subsequent recruitment by providing small-scale productivity & inundating additional spawning and feeding habitats (e.g. low-lying benches and snags). Events should occur for 14–90 days ideally in spring, or during the warmer months of September–April, at a frequency of 5–10 years in 10. Water temperatures should be >20°C. River blackfish and trout cod may spawn in lower water temperatures of >16°C, and Murray cod in >18°C. Murray cod have a narrower spawning window of September–December. For nesting species (e.g. Murray cod, trout cod & eel-tailed/freshwater catfish) preventing rapid drops in water levels (that exceed natural rates of fall) for at least 14 days after spawning is important to prevent fish nests from drying (NestS1). Since exact spawning dates are not always known, the LTWP recommends avoiding applying conservative rates of fall in flow (slower than the 20th percentile of modelled natural rates of fall) for at least 21 days starting on 1 October in all rivers and streams. For trout cod which occur in the Murray River upstream of Yarrawonga and which can spawn at lower water temperatures, slow rates of fall are recommended for a minimum of 60 days during the period 15 September–15 November. Recruitment is enhanced by a secondary flow pulse (large fresh, bankfull or overbank[76]) for dispersal & access to nursery habitat in low-lying wetland habitats. Riverine specialists prefer hydraulically complex flowing streams containing submerged structure (snags & benches) that provides cover & spawning habitat. Flow variability through the delivery of baseflows, small and large freshes, bankfull and overbank flows, (especially flows that connect anabranches and smaller creek systems LF3/4, BK1 & higher, outside of summer months[76])) enhance the availability of diverse habitat, enhances growth and condition of larvae and juveniles; and provides connectivity for dispersal between habitats.	All PUs (except Deniboota–Cadell–Moira in the Edward–Wakool system) The lower Darling River supports one of the most robust population age structures of Murray Cod in the Murray Darling Basin. However, the population is under stress due to thermal stratification issues during prolonged periods of low or no flow. Anabranches and creeks in Barmah–Millewa forest, the Edward–Wakool system and the Lower Murray provide hydraulically complex flowing habitats important for Murray cod and other riverine specialists. However, these populations breeding outcomes are compromised due to hypoxic blackwater events following extended dry periods. Strategies to protect/enhance these species and populations need to be urgently developed and implemented. These strategies need to consider the effects of climate change and investigate practical options to minimise the effects of hypoxic blackwater and stratification. Additional fast flowing and complex habitats may become available with the relaxation of constraints to the delivery of higher managed flows.

[76] Bankfull and overbank events should be avoided in summer due to the increased risk of hypoxic blackwater and carp breeding.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
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. Regular lateral connectivity with off-channel wetlands, lakes and hydraulically complex creek systems (LF3/4, BK1, OB1–10) are crucial for the recruitment of golden perch and Murray cod, and therefore to meeting the target of a 25% increase in abundance of mature fish. Re-connection of wetlands and lakes is required within 3–18 months of previous connecting events to allow juvenile and mature fish to move back into rivers. Lateral connectivity with wetlands, lakes and floodplains (LF3/4, BK1, and OB1–10) is also important for driving primary and secondary productivity that provides the food resources that native fish require to reach maturity and maintain good condition. See Objective EF4 specific flow requirements to support productivity. Longitudinal connectivity (protecting the integrity of flow pulses along entire systems, especially those flows which are returning from floodplains upstream) are important for transporting nutrients, carbon and the outputs of productivity from upstream sites to downstream recruitment sites. This includes integration with other rivers and tributaries outside the Murray and Lower Darling catchment such as the Barwon-Darling and northern rivers, Murrumbidgee River and Yanco-Billabong Creek system, and Victorian tributaries such as the Goulburn River, Ovens-King, Kiewa and Campaspe. Recommendation: Develop and implement a native fish management and recovery strategy for golden perch and Murray cod identifying drought refuge and recovery sites that are not affected by hypoxic blackwater and stratification, and identifies complementary measures required to remove barriers to flow and fish movement.	All PUs Important recruitment and/or refuge sites • Menindee Lakes, including Lake Cawndilla • lower Darling River • Barmah–Millewa Forest (including creek systems) • Edward–Wakool system (currently limited by flow constraints) • Smaller creeks such as Tuppal Creek where freshwater can be delivered via irrigation systems. • Frenchmans Creek & the Carrs–Cappits–Bunberoo creek system (requires removal of barriers to fish movement) Other potential recruitment sites • Lake Victoria (requires installation of fish passage on the Frenchmans Creek inlet and Rufus River outlet structures • Barmah and Moira Lakes (require improved wetting-drying regimes) • Edward–Wakool system creeks (requires relaxation of constraints to higher flows and some removal of barriers to fish movement) • Euston Lakes (require improved wetting-drying regimes through a greater range of weir pool (Lock 15) variation and removal of barriers) • Bengallow Creek system

Ecological objective	Important flow regime characteristics	Focus areas &/or species
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 (LF1–3), bankfull (BK1) and overbank flows (OB1–9) that provide longitudinal connectivity along rivers and lateral connectivity with wetlands, lakes and small creek systems. 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). Recommendation: Develop and implement a native fish management and recovery strategy for small-bodied floodplain specialists identifying drought refuge and recovery sites that are not affected by hypoxic blackwater and stratification.	<u>Flathead galaxias</u> in the River Murray from Hume to Barmah, all Edward Wakool PUs and in the upper Murray (Upper Murray River, Tooma, Maragle, Jingellic, Dora Dora, Hume and Albury water sources) <u>Southern pygmy perch</u> in the mid Murray River (Hume to Wakool River junction), lower Murray River (Wakool junction to SA border), Edward River (Deniliquin to Wakool junction), upper Murray River and tributaries (Upper Murray River, Indi, Swampy Plains, Jingellic, Dora Dora, and Ournie Welaregang water sources) <u>Murray hardyhead</u> in wetlands in the Lake Victoria and Frenchmans Creek PU, and Murray River wetlands (Barmah to Wakool junction) <u>Olive perchlet</u> – lower Darling River (especially Lake Wetherell), Menindee Lakes & the Lower Murray–Darling Unregulated PUs <u>Purple-spotted gudgeon</u> – Murray River (Yarrawonga to SA border)
NF8: Increase the prevalence &/or expand the population of key **moderate to long-lived riverine specialist** native fish species into new	Flow requirements of riverine specialists are outlined for NF5. Expanding populations into new areas adjacent to existing populations will be particularly dependent on dispersal flows that also promote hydraulic complexity. These include large freshes (LF1–4), bankfull (BK1) & overbank flows (OB1–10). Complementary actions such as conservation stocking &/or translocation may be required to support these watering actions.	<u>Trout cod</u> in the mid River Murray (Hume to Barham), Edward River and upper Murray (Lake Hume and Dora Dora water sources). <u>Macquarie Perch</u> in the upper Murray tributaries (Indi and Mannus water sources).

Ecological objective	Important flow regime characteristics	Focus areas &/or species
areas (within historical range)	Recommendation: Develop and implement a native fish management and recovery strategy for riverine specialists identifying drought refuge and recovery sites that are not affected by hypoxic blackwater and stratification.	Freshwater catfish (eel-tailed catfish) in the Wakool River, Edward River, lower Darling River and Murray River (Yarrawonga to SA border) Two-spined blackfish in the upper Murray River and tributaries (Indi, Swampy Plains, Tooma, Maragle, Tumbarumba, Mannus, Ournie Welaregang, Jingellic and Dora Dora water sources) Murray crayfish in the mid Murray River (Hume to Barham), and upper Murray tributaries (Swampy Plains, Tooma, Tumbarumba and Ournie Welaregang water sources)
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 that also improve hydraulic complexity. These include large freshes (LF1–4), bankfull (BK1) & overbank flows (OB1–10). Complementary measures that restore wetland habitats and remove barriers to flow and fish movement are also critical (see details in Table 22 under 'Restore Wetland Habitats').	Silver perch in the mid and Lower Murray River (Yarrawonga to SA border), Lake Victoria and Frenchman's Creek,
NF10: Increase the prevalence and/or expand the population of key moderate to long–lived diadromous native fish species into new areas	Diadromous fish species native to the Murray Darling Basin include pouched and short–headed lamprey and short-finned eel. These species undertake long distance upstream migrations (100s–1000s km) from the sea to freshwater habitats in the	Pouched and short-headed lamprey in the mid and Lower Murray River (Yarrawonga to SA border). Protection of large flow pulses from Murray tributaries including the Goulburn and Murrumbidgee rivers.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	Murray River and its tributaries in winter–spring to spawn the following spring for lamprey, and in later years for short-finned eel (Lintermans 2007; McDowall 1996)[77]. 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. Short-finned eels may remain in freshwater for up to 20 years before migrating to the sea to breed (Lintermans 2007). Large freshes (LF1), bankfull (BK1) or overbank flows are required in the River Murray in winter to early spring to cue upstream migration of lamprey from the sea to upstream spawning sites. Lamprey are likely to continue to migrate upstream throughout spring so multiple large freshes (e.g. LF2, 3) or higher flows are required during winter and spring to support. 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. This includes protecting large flow pulses from tributaries such as the Goulburn and Murrumbidgee rivers during winter and spring[78]. Diversions of flows (e.g. to Lake Victoria or major irrigation areas may disrupting migration). Very-low flows (VLF), baseflows (BF1, 2) and small and large freshes (e.g. SF1–2; LF1–4) are required during other times of year to support survival and recruitment and to allow mature fish to return to the sea.	

[77] There is currently limited understand of lamprey watering requirements in the Murray system however recent monitoring work is providing new insights. The watering requirements described here are based on Bice et al. (2012); Bice and Zampatti (2015 unpublished), McDowall (1996) and advice from NSW DPIF.

[78] In 2015, lamprey were detected migrating upstream through the SA Lower Lakes barrages during the passage of a large winter fresh originating in the Goulburn River (Bice and Zampatti, 2015). This was an environmental water delivery that was protected from diversions from source to sea.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	WATERBIRD OBJECTIVES[79]	
WB1: Maintain the number & type of waterbird species	Overbank & wetland/lake inundating flows (LF3–4, BK1, OB1–10, LLLF, MLLF, HLLF, VHLLF): to provide refuge, support feeding & breeding habitat (see Objectives WB2, 3, 4) & maintain habitat condition (Objective 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 drawdown of habitats over late summer–autumn this can extend feeding habitat available for migratory & resident shorebird species (small waders). In the Lower Murray River, weir pool raising (WP2) in spring followed by drawdown (WP1) in summer–autumn can be used to inundate low lying wetlands and floodplains to provide refuge, feeding and breeding habitat. A gradual drawdown of weir pools at 1–2 cm/day (no more than 3–4 cm/day) will maximise feeding habitat for migratory and resident shorebirds. Other alternative water delivery mechanisms (e.g. pumping, use of siphons or wetland regulators) can be used to complement higher river flows (e.g. to hold water in wetlands for longer) or during very dry, dry & moderate scenarios to provide refuge and feeding habitats. Complimentary measures: Identify restoration activities for wetlands and creek systems located on private property. Education activities and incentives to encourage private landholders to protect and enhance waterbird nesting and/or foraging habitats on their properties.	Mid–Murray – Millewa (PU2[80]), Perricoota–Koondrook (PU3), Werai and Niemur forests (PU5), The Pollack (Pollack Swamp) (PU3), Campbells Island (PU3), private property wetlands Lower Murray – Lower Murray River (PU8–12), including weir pool manipulation at Locks 7, 8, 9 and 15; NSW Chowilla floodplain (PU12), Euston Lakes (PU9), Lower Murray wetlands including Gol Gol wetland and Bottlebend Reserve (PU9), Rosenhoe Wetland, Wee Wee Creek (PU5,8), Thegoa Lagoon (PU10), Grand Junction Wetlands (PU10,17), Frenchman's Creek & associated wetlands (e.g. Carrs Cappits Bunberoo creeks, Wingillie, Lucerne Day) (PU13,11) Lower Darling – Menindee Lakes, Lake Wetherell, Talyawalka Creek, Darling Anabranch and associated floodplain lakes, especially Lake Nearie.

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

[80] PU number – refer to Figure 1 and 2 for location and name. PU report cards (maps, values and EWRs are in Part B of the LTWP)

Ecological objective	Important flow regime characteristics	Focus areas &/or species
WB2: Increase total waterbird abundance across all functional groups	Overbank & wetland/lake inundating flows (LF3–4, BK1, OB1–10, WP1–2, LLLF, MLLF, HLLF, VHLLF): as in Objective WB1 provide seasonal (spring–summer) inundation with gradual draw-down over summer into autumn to provide feeding & breeding habitat (Objective WB3, 4) & maintain the habitat condition (Objective WB5). Where possible to coordinate, these flows should be delivered to complement events in neighbouring catchments to provide benefits to waterbird populations by providing habitat across a larger area of Murray–Darling Basin. Follow-up overbank & wetland inundating flows in years following large breeding events in the Murray–Lower Darling & neighbouring catchments will also promote the survival of juvenile birds & contribute to increased waterbird populations.	As for Objective WB1
WB3: Increase opportunities for non-colonial waterbird breeding	Overbank & wetland inundating flows (OB1–3) and medium to very high level lake fills (MLLF, HLLF, VHLLF): to inundate wetland and lake habitats for more than 3 months. Spring & summer (preferably September–March) is the ideal season, with opportunistic breeding in autumn & winter. Large freshes (LF4) that inundate low-lying wetlands and riparian habitat (e.g. along the Edward and Niemur rivers) can be important for support colonial and non-colonial waterbird breeding events to completion. Breeding habitats should be inundated for at least 3 months or until fledging, which can be difficult for some site such as the Niemur Forest site. 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). Alternative water delivery mechanisms (e.g. pumping, use of siphons or wetland regulators) can be used in some areas to complement higher river flows (e.g. to extend the duration of inundation of breeding habitats).	As for Objective WB1 and WB2

Ecological objective	Important flow regime characteristics	Focus areas &/or species
WB4: Increase opportunities for colonial waterbird breeding	Overbank & wetland inundating flows (OB1–3) and medium to very high level lake fills (MLLF, HLLF, VHLLF): to inundate active colony sites & surrounding foraging habitat for 3–6 months to ensure successful completion of colonial waterbird breeding (from egg laying through to fledging including post-fledgling care) & access to key foraging habitats to enhance breeding success & the survival of young. Ideally September–March. Larger inundation events (OB4–10, HLLF, VHLLF) will support larger colonies & a greater number of breeding species with greater benefit to breeding success & increasing total abundance of waterbirds (Objectives WB2, WB3). These large overbank events are required on average 2–3 years in 10 years, with a maximum inter-event period of 5 years (ideally 4). Breeding sites may need to be topped up with smaller overbank, bankfull or large fresh flows (or via pumping or use of regulators) to ensure that breeding habitats are inundated to the completion of breeding. Small-medium wetland inundation flows (e.g. OB2 in the Mid Murray) may support smaller colonies and should occur at least 4 years in 10, but ideally 6–8 years in 10 to support not only breeding but also habitat (vegetation) condition, to keep colony sites in event-ready condition. The greatest potential to initiate and support colonial waterbird breeding is in the Mid Murray although breeding sites and opportunities to trigger events remain limited due to constraints to the managed delivery of higher flows and degraded habitat in many areas. Initiating small-scale colonial waterbird breeding, typically requires an initial small-medium overbank event for ~45 days to trigger breeding. This can be followed by 3–4 months of slightly Lower river flows (large fresh (LF4), bankfull, small overbank or utilise pumping/infrastructure) to maintain inundation of breeding sites to	**Mid Murray** ***Target sites for supporting naturally triggered colonial WB breeding*** Millewa forest (Reed Beds / Duck Lagoon, St Helena / Black Swamp), Werai forest (multiple potential sites), Niemur River, Koondrook–Perricoota (several historic breeding sites including The Pollack), Deniliquin Island Sanctuary, Campbells Island[81] ***Target sites for initiating breeding*** 5 year target (2 sites) – Reed Beds/ Duck Lagoon[82], The Pollack (Pollack Swamp)[83], St Helena/Black Swamp[84] 10 year target (3 sites) – as for 5 year target 20 year target (5 sites) – as for 5 & 10 year targets + Werai forest, Koondrook–Perricoota forest (multiple possible sites), Niemur River & Campbells Island.

[81] Large colonies of egrets and nankeen night herons observed during 1974 floods, good habitat (phragmites under river red gum), (Rick Webster, *pers. comm.* 2017)

[82] For Reed Beds/ Duck Lagoon – aim for 2 events in 5 years to meet Mid Murray target

[83] For Pollacks Swamp, most potential to initiate breeding event following a natural large flood event (Rick Webster, *pers. comm.* 2017)

[84] In Millewa forest. Site typically supports small colonies. The best chance of initiating breeding is with delivery of water across the Millewa forest floodplain, instead of regulator structures (Rick Webster, *pers.comm.* 2017). Note, current constraints to getting water into the site (see risks and constraints).

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	breeding completion. See OB2 for the Murray River at d/s Yarrawonga for initiating and supporting colonial waterbird breeding in Millewa forest, OB4 for the Murray River at Torrumbarry for Koondrook–Perricoota and Pollack Swamp (using infrastructure); and for Werai forest and Niemur River: OB1,2 followed by large freshes (LF3/4). To meet catchment (LTWP) and Basin-wide (BWS) objectives for colonial waterbird diversity and abundance, water managers should aim to initiate and support at least 2 small-scale colonial waterbird breeding events every 5 years in at least 2 sites in the Mid Murray the in the first 5 years of the plan (by 2024) and in at least 5 sites at least 3 years in 10 by 2039. See adjacent column for potential sites to achieve these targets. In the Lower Murray, managers should aim to initiate breeding in at least 3 sites, at least 3 years in 10, to meet the 10-year and 20-year targets. In the Lower Murray, weir pool raising (WP1) during spring–summer (complemented with the use wetland regulators and pumping) can potentially be used to maintain inundation of naturally-triggered colonies sites at a limited number of sites. Three potential sites have been identified for potential to initiate colonial wetlands in the Lower Murray, however habitat quality will need to be first improved.	**Lower Murray** ***Target sites for supporting naturally triggered colonial WB breeding*** Euston Lakes (Dry Lake, Lake Caringay), Gol Gol wetlands, Wee Wee Creek, Frenchman's Creek & associated wetlands (e.g. Carrs Cappits Bunberoo creek system, & Lucerne Day & Wingillie wetlands) ***Target sites for initiating breeding*** 10–20 year target (3 sites): Gol Gol wetlands (PU9) and Euston Lakes – Dry Lake and Lake Caringay (PU9)[85] *Aim to initiate and support small-scale colonies in all 3 sites for meet 10-year target.* **Lower Darling** ***Target sites for supporting naturally triggered colonial WB breeding*** Menindee Lakes, Lower Darling River (wetlands influenced by Lock 10 weir pool & wetlands, higher up system), Darling Anabranch and floodplain lakes, especially Lake Nearie)

[85] Require prior watering to improve breeding habitat.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
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 Murray–Lower Darling. These include sites provide nesting habitat consisting of river red gum, black box, river cooba, coolibah, common reed, lignum giant rush and cumbungi. Overbank & wetland inundating flows (LF3–4, BK1, OB1–4, WP2) and lake fills (LLLF, MLLF, HLLF, VHLLF) are needed to maintain the extent & condition of these vegetation communities in these discrete wetland and lake sites. This ensures that sites are in event-ready condition when medium & large events (OB1–3, MLLF, HLLF, VHLLF) initiate colonial waterbird breeding events. These flows, particularly the smaller overbank & wetland inundating flows (LF3–4, BK1, OB1–3), will also support a broader range of foraging habitats, 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.	**Mid Murray** – Millewa forest (foraging habitat for birds that breed nearby and/or in Millewa forest in previous year), Koondrook–Perricoota (20 years target with relaxed constraints), Niemur Forest, Werai forest. **Lower Murray** – Euston Lakes, Gol Gol wetlands, Wee Wee Creek, Frenchman's Creek & associated wetlands (e.g. Carrs Cappits Bunberoo creeks, Wingillie, Lucerne Day) **Lower Darling** – Menindee Lakes, Lower Darling River (wetlands influenced by Murray Lock 10 weir pool & wetlands higher up system), Darling Anabranch and floodplain lakes, including Lake Nearie.
	PRIORITY ECOSYSTEM FUNCTIONS OBJECTIVES[86]	
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, 2): 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. In some areas (e.g. Lower Darling River), higher baseflows are required in the warmer months to prevent prolonged stratification. They are required every year are especially important during dry times.	Rivers/creeks in all PUs Permanent and semi-permanent wetlands in all PUs (along major river corridors and in low-lying floodplain forests e.g. the Central Murray Forests Ramsar site: Millewa, Werai and Koondrook–Perricoota forests. Lakes &/or storages that provide important drought refuge

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

<table>
<tr><th>Ecological objective</th><th>Important flow regime characteristics</th><th>Focus areas &/or species</th></tr>
<tr><td></td><td><u>Small freshes (SF1,2)</u>: 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).

Infrastructure (irrigation escapes into river channels) can be used to inject good quality water from Lake Mulwala to create small-scale refuges in some parts of the Edward–Wakool system and Tuppal Creek during hypoxic blackwater events.

<u>Wetland connection flows (LF2–4, BK1, OB1)</u>: 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.</td><td>• Lake Wetherell, Moira Lake, Lake Victoria
• Lake Mulwala, Lake Benanee, Lake Hume

Small scale refuges in the Edward-Wakool system and Tuppal Creek.</td></tr>
<tr><td>EF2: Create quality instream & floodplain habitat</td><td>The full range of in-channel & overbank flow types are required to maintain quality instream & floodplain habitat. Variable in-channel flows (baseflows, freshes and 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 slackwater (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.

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. This should allow water to drain from the bank slowly as flow decreases, preventing mass failure of the banks. Maintaining rates of fall within natural rates 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) and targeting different peak heights for freshes between seasons and years.

<u>Wetland/overbank flows (OB1–9):</u> to provide floodplain & wetland habitat for native fish, waterbirds & other aquatic fauna.</td><td>All areas</td></tr>
</table>

Ecological objective	Important flow regime characteristics	Focus areas &/or species
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 Murray–Lower Darling, making large freshes & occasionally small overbank flows important for overcoming these man-made structures where fishways are not present. Coordination of flows throughout the Murray, Edward–Wakool and Lower Darling River systems are critical to providing long range dispersal and movement opportunities for biota. Wetland/overbank flows (LF2–4, BK1, OB1–9): to provide lateral connectivity to floodplain and wetland habitats, especially with large lake systems such as which provide nursery habitat for native fish (e.g. connect then re-connect large lakes 3–18 months later to support native fish recruitment).	All PUs • Regular connection of Lakes Cawndilla and Menindee to the Darling and Murray River is particularly important for providing nursery habitat for golden perch and subsequent downstream dispersal to the Lower Darling and Murray rivers; and for colonial nesting waterbird breeding. • With improved wetting-drying regimes and/or fish passage, other large lakes such as Moira Lake, Euston Lakes and Lake Victoria could support native fish recruitment and waterbird outcomes. • Key wetland complexes and floodplain forests, for example: wetlands along key river corridors; Central Murray Forests Ramsar site: Millewa, Werai and Koondrook–Perricoota forests; Niemur forest (colonial waterbird breeding site); Junction wetlands (Murrumbidgee–Murray), Lower Murray wetlands, NSW Chowilla floodplain.
EF3b: Provide movement & dispersal opportunities between catchments for water-dependent biota to complete lifecycles	Baseflows, freshes, bankfull and overbank flows: are important to allow the movement of fish and other biota between the Lower Murray in NSW/VIC and South Australia & allow re-colonisation & the replenishment of populations. Maintaining the integrity (shape and size) of flow events from the mid to Lower Murray are critical to provide effective dispersal and movement cues. Weir pool manipulation (Lowering) can be used to increase flow velocities in river to promote native fish migration. Large freshes in winter and early spring are particularly important for lamprey which undertake long range upstream migrations from the sea for spawning.	Lower Murray and Mid Murray PUs Diadromous fish species like lamprey undertake long range migrations from the sea for breeding. Lamprey have been detected in the Lower Murray near Mildura, and in the Mid Murray as far upstream as Yarrawonga[87], and in the Murrumbidgee River at Narrandera.

[87] DPIF (unpublished data) and Bice and Zampatti (2015)

Ecological objective	Important flow regime characteristics	Focus areas &/or species
EF4: Support instream & floodplain productivity	Large freshes (LF1–4) and Bankfull (BK1): to mobilise organic matter from stream banks, benches, anabranches and low lying wetlands and drive small pulses of productivity. For example, longer duration large freshes (LF3, 4) can drive small-scale primary productivity responses (e.g. macrophyte growth) along channel margins and in low-lying wetlands if water enters and is retained in wetlands for at least 2–3 months. Overbank flows (OB1–9): to inundate wetlands, floodplains and lakes to supporting large scale productivity, which in turns drives aquatic food webs both on the floodplain and in-stream. Primary productivity includes growth of algae, macrophytes (non-woody vegetation), biofilms & phytoplankton, which in turn drives secondary productivity (zooplankton, macroinvertebrates, fish larvae etc.). Long duration inundation (at least 2–3 months) (e.g. OB1, 2) is required for a macrophyte response (non-woody wetland vegetation), which will contribute to replenishing soil carbon stores, drive secondary productivity and provide organic matter than can be mobilised into rivers. Without such long duration inundation events, shorter duration floodplain inundation events pose the risk of depleting floodplain carbon stores.	All PUs For large scale productivity responses, need inundation of: • large floodplain forests: Barmah–Millewa, Werai, Niemur, Koondrook–Perricoota and Gunbower forests • Delivery of end-of-system flows in the Tuppal Creek and ephemeral creeks (located within the Murray Irrigation system) to provide direct benefits to the Edward, Wakool and Niemur rivers • Junction wetlands (at Murrumbidgee–Murray junction) • Menindee Lakes • Euston Lakes • Lower Murray wetlands and floodplain, including NSW Chowilla floodplain
EF5: Support mobilisation & transport of sediment, carbon & nutrients along channels, between channels & floodplains, & between catchments	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 & carbon, to drive primary productivity, or in the case of sediment, for channel maintenance (e.g. to replenish banks & benches). Large freshes, bankfull and overbank flows LF1–4, BK1, OB1–9): for transferring nutrients & carbon from the floodplain and wetlands to rivers. Coordinating flows (and protecting natural flow pulses) along the entire River Murray channel, together with flows in the Edward–Wakool, Murrumbidgee, Lower Darling and other tributaries is critical for maintaining the longitudinal and lateral transfer of nutrients, carbon and sediment. This will supply downstream areas of with the resources required to support ecological outcomes (e.g. native fish recruitment and waterbird breeding.	All PUs Particularly important to protect flow pulses: • returning from large floodplain and wetland complexes: (e.g. Barmah–Millewa, Koondrook–Perricoota, Gunbower and Werai forests, Lowbidgee floodplain in the Murrumbidgee) • from the Barwon–Darling • from Menindee Lakes • in the Lower Murray River, especially if they include contributions from the Lower Darling River (currently impacted by diversions to Lake Victoria).

Ecological objective	Important flow regime characteristics	Focus areas &/or species
EF6: Support groundwater conditions to sustain groundwater-dependent biota	Large freshes (LF1–4) & bankfull (BK1) and overbank flows (OB1–9): 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.	All areas
EF7: Increase the contribution of flows into the South Australian River Murray	The full range of flows (baseflows, freshes, bankfull and overbank flows) are required to meet South Australian EWRs for the SA Lower Murray River and floodplain, in addition to Coorong, Lower Lakes and Murray Mouth[88]. Freshes and larger flows are particular important in spring and early summer but are also required through autumn. A range of in-channel flows (10,000–45,000 ML/d) are required annually (annual to biannual for the upper end) between September–March for 60–90 days. Floodplain asset require overbank flows ideally during September–December for 30–60 days. These range from small overbank flows of 50,000 ML/d for 30 days with an average recurrence interval (ARI) of 1.6 years (60% of years), medium size overbank flows of 60,000–70,000 ML/d with an ARI of 2–2.6 years (40–50% of years), and larger overbank flows of 80,000 ML/d for 30–60 days every 3.6–7.6 years (13–27% of years). These flows will also contribute to EWRs for the Coorong, Lower Lakes and Murray Mouth, including barrage outflows to support the Coorong and Murray Mouth throughout the year, with peak barrage outflows in October–December.	River Murray and Lower Darling flows in all PUs. It's particularly important to preserve the integrity (shape, magnitude and timing) of flow pulses coming from the Lower Daring River and overbank events in Mid Murray, as these are likely to contain vital nutrients and carbon necessary to drive food webs in the SA Lower Murray, Coorong, Lower Lakes and Murray mouth. Protecting flow pulses from upstream also provides opportunity for movement and dispersal of native fish and other biota to/from the Lower Murray.

[88] SA DEWNR (2017). Long Term Environmental Watering Requirements for the South Australian River Murray Water Resource Plan Area.

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	**OTHER SPECIES[89]**	
OS1: Maintain species richness & distribution of flow-dependent frog communities	In addition to actions that allow breeding (Objective 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 low-lying off-channel wetlands (LF2–4, BK1, OB1) for refuge. Larger flows (OB2–4) to reach a greater number of wetlands to maintain frog condition and habitat, and to allow dispersal.	All PUs – all wetland/river types
OS2: Maintain successful breeding opportunities for flow-dependent frog species	Wetland inundating and overbank flows (LF2–4, BK1, OB1–4): to provide opportunities for breeding & recruitment (i.e. laying eggs & tadpole metamorphosis). Ideally every 1–2 years for 3[90] or more months. Spring–summer breeders require flows ideally from October–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.	All PUs – all wetlands/river types
OS3a: Maintain and increase number of wetland sites occupied by the threatened southern bell frog	Wetland inundating and overbank flows (LF2–4, OB1, 2): to provide opportunities for breeding & recruitment (i.e. laying eggs & tadpole metamorphosis). Ideally every 1–2 years for 3[90] or more months. Unlike other species it is believed the southern bell frog requires access to permanent water.	All PUs west of Deniliquin – MIL (Murray Irrigation area), Edward–Wakool, the Pollack area (downstream of Koondrook–Perricoota in the Mid Murray), Lower Murray downstream of Euston: all

[89] Important flow regime characteristics from Wassens (2010) and J. Spencer & J Ocock (DPIE-BC, pers. comms. 2018)
[90] DPIE-BC observations of successful breeding in private wetlands in Murray (DPIE-BC unpublished data)

Ecological objective	Important flow regime characteristics	Focus areas &/or species
	Events to support breeding need to occur in late spring–summer months (ideally ephemeral wetlands between October–February) Events to support refuge in autumn–winter (can be wetlands or rivers ideally March–August)	wetlands/river types (not Darling or Barmah–Millewa)
OS3b: Maintain and increase number of wetland sites occupied by the threatened Sloane's froglet	Wetland inundating and overbank flows (LF2–4, OB1, 2): to provide opportunities for breeding & recruitment (i.e. laying eggs & tadpole metamorphosis). Ideally every 1–2 years for 3[90] or more months. Events to support breeding need to occur in the winter months (between June–August).	Floodplain and wetland habitat in the following PUs: • River Murray: Hume to Yarrawonga • River Murray: Yarrawonga to Barmah (especially around Tocumwal)

4.4 Changes to the flow regime

The flow regime in the Murray-Lower Darling river system has changed due to river regulation, extraction of water for consumptive use and development in the catchment. Major water storages include Dartmouth Dam, Hume Dam, Yarrawonga weir, Lake Victoria storage, the Menindee Lakes storage and the weirs and locks along the Murray, lower Darling and Edward Rivers. Major storages have made it possible to store water during wet periods (winter-early spring) and release it as needed during late spring, summer and early autumn to support irrigated agriculture and other consumptive use (Thoms et al. 2000). However, the regulation of flows and water levels has adverse outcomes on flow-dependant ecosystems. Key changes to the flow regime of the MLD include (Thoms et al., 2000; Gippel and Blackman, 2002):

- constant flows for sustained periods during the irrigation season *(mid Murray River, Edward-Wakool system)*
- increased summer-autumn flows in some areas, which prevents necessary drying regimes for river banks, riparian zones and low-lying wetlands and encourages carp breeding and recruitment *(mid and upper Murray, Edward-Wakool system)*
- a reduction in the frequency and duration of small and medium size floods and large freshes in winter-spring *(whole system)*
- rapid rates of rise and fall *(mid and upper Murray River, Edward-Wakool system)*
- reduced hydrodynamic diversity in areas influenced by weir pools held at near-constant levels (or very limited variability) *(lower Murray River, lower Darling River).*
- reduced baseflows in winter and/or year round *(mid and lower Murray River, Edward-Wakool system, lower Darling River)*
- altered filling-drying regimes for floodplain wetlands *(whole system)* and large natural lake systems which are now used as storages *(Menindee Lakes, Euston Lakes, Lake Victoria).*

The degree and type of hydrological change varies depending on the location within the catchment. Key changes in each of the water management areas is summarised below.

Upper Murray WMA (NSW Murray catchment upstream of Hume Dam)

Key changes to the flow regime of the Upper Murray water management area (WMA) include:

- large daily and hourly fluctuations in flow in the Murray River upstream of Hume Dam due to hydropower operations (Figure 19);
- reduction in low flows and increased occurrence of cease-to-flow periods in several upper Murray tributaries due to surface water extraction for consumptive use, and/or inter-valley diversions as part of the Snowy Scheme.

Effects in individual planning units are described in Part B, which provides relevant results from the *NSW Murray and Lower Darling Surface WRPA Risk Assessment (NSW DPIE 2019a)*. An overview of effects in the catchment is provided here.

Average annual flows have increased overall by approximately 10% in the upper Murray River compared to modelled without development flows due to contribution of flows from the Snowy Mountains Hydroelectric Scheme (Snowy Scheme) (Thoms et al., 2000). Hydropower operations (Murray 1 and Murray 2 Power Stations) and subsequent releases from Khancoban Pondage to the Swampy Plains River and upper Murray River have resulted in a large increase (>50%) in the frequency of low flows, base flows and freshes, and a small (<20%) decrease in the frequency of higher overbank flows (NSW DPIE, 2019a). Of particular concern are the large daily and hourly variations in flow in the upper Murray and

Swampy Plains rivers (Figure 19). This variability can pose a risk to native fish breeding (especially nesting species like Murray Cod), in-channel vegetation and river bank stability.

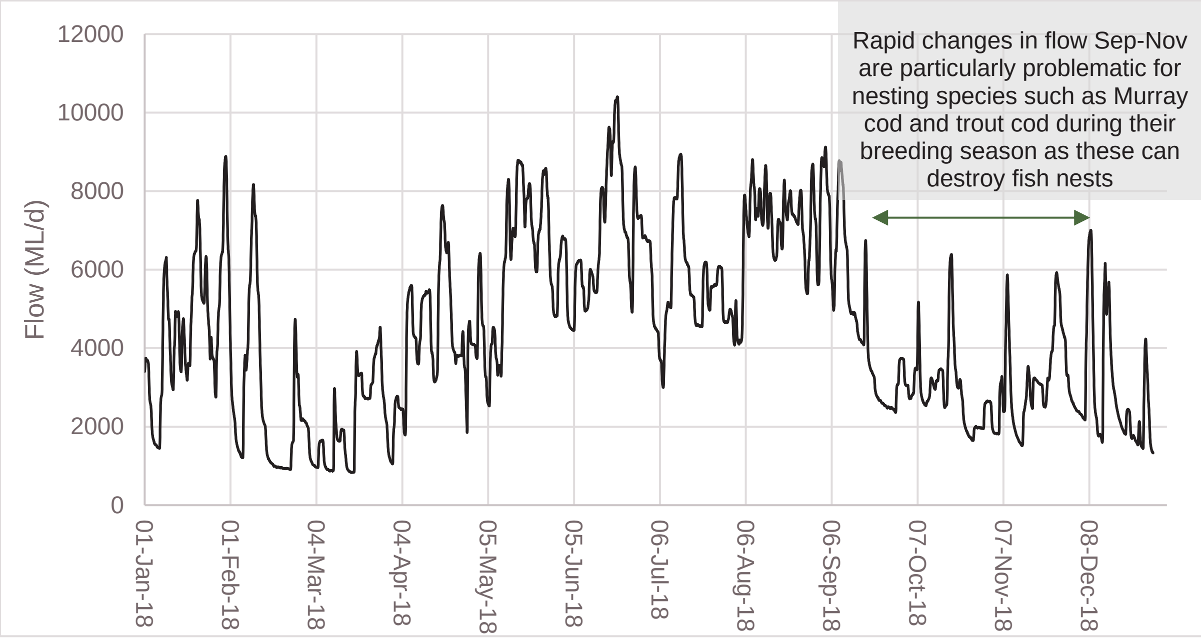

Figure 19 Observed hourly flow data for the upper Murray River at Jingellic (401201), showing large daily (often twice daily) fluctuations in flow

Major inter-basin diversion from the headwaters of the Murray River occurs from the Tooma River (295 GL/year on average) to the Murrumbidgee (NSW DPI 2012). The Tooma River has experienced a 50% increase in frequency of cease-to-flow periods and a small reduction in low flows, baseflows and freshes compared to natural conditions (NSW DPIE 2019a).

Extraction for consumptive use in upper Murray tributaries has resulted in moderate (20-50%) or large (>50%) reductions in flow flows or increases in the occurrence of cease-to-flow periods in several planning units including the Mannus, Hume and Albury water sources (NSW DPIE, 2019a).

Mid Murray WMA (including Edward-Wakool system)

Reduced average annual flows

Observed average annual flows in the middle reaches of the Murray River have declined to approximately 78% of natural (modelled without development) at downstream of Yarrawonga Weir. High irrigation demand in late spring, summer and early autumn has resulted in a reversal in the seasonality of flows in the Murray River below Hume dam (Figure 20A), and an overall reduction (or dampening) of seasonal flow variation throughout the middle reaches of the Murray River below Yarrawonga Weir (Figure 20B) and the Edward-Wakool system.

Reduced spring-winter flows

One of the most ecologically-significant changes has been the reduction in the frequency and duration of large freshes, bankfull flows and small to medium size overbank events during winter and spring. These flows are essential to supporting wetland and floodplain vegetation, native fish and waterbird populations; and importantly also primary productivity and nutrient and carbon transfer between rivers and floodplains, which drive riverine food webs.

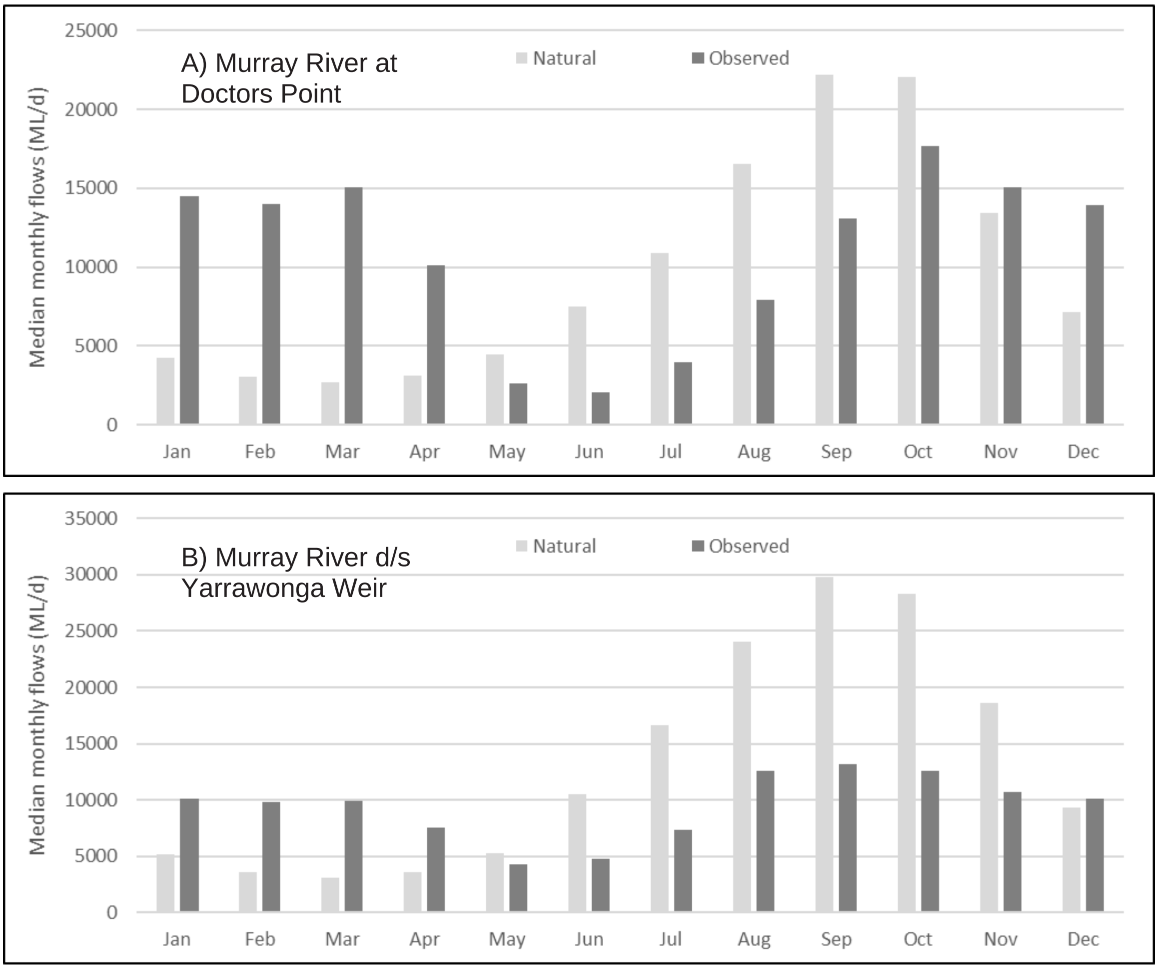

Figure 20 Median monthly flows for the mid Murray River at A) Doctors Point, B) d/s Yarrawonga Weir, for modelled 'natural' conditions (without flow regulation) and observed data

Examples of changes to higher flows in the Murray River downstream of Yarrawonga Weir include: [91]

- a 60% reduction in the frequency of small overbank events (OB3) required to maintain open grass plains and support primary productivity in Barmah-Millewa forest (frequency reduced from 67% of years to 27% of years).
- a 50% decline in the frequency of small overbank events (OB4) required to maintain the condition of river red gum, low-lying black box and wetland vegetation communities in floodplain forests, support productivity and to provide system-wide connectivity (large freshes and bankfull flows in the Edward-Wakool system) (frequencies reduced from 65% to 33% of years).
- a 35% reduction in the frequency of large freshes of suitable duration to support breeding of floodplain specialist native fish including threatened species (frequency reduced decline from 88% to 57%, current frequency is not sufficient to maintain populations of short-lived species).

[91] Change in frequency based on a comparison between frequency of events (as defined by EWRs in Part B of LTWP) under modelled natural (without development) and modelled current condition flow regimes.

The current watering frequencies and durations (which rely on natural events due to constraints on regulated flow deliveries) are not sufficient to meet the condition and recruitment requirements of these native vegetation and fish communities and so condition and populations of these communities are likely to continue to decline unless river flow constraints are relaxed to allow delivery environmental water at the required flow rates.

Winter flows have declined by more than 50% in the Murray River at Yarrawonga (Figure 20B) and by up to 90% in the Edward-Wakool system due to low irrigation demand. This can reduce condition and survival of native fish due to reduced habitat and food availability and increase predation pressure, increase expose of in-stream vegetation to cold air temperatures and reduce longitudinal connectivity.

Elevated summer-autumn flows

Higher than natural flows during summer and early autumn due to irrigation demand can prevent adequate drying regimes for river banks, riparian zones, and low-lying wetlands and floodplain forests. Continued inundation of these habitats can promote carp breeding and recruitment and prevent the establishment of water-dependant native vegetation and limit nutrient and carbon cycling processes, which in turn can limit in-stream and floodplain productivity processes (Gippel and Blackman, 2002; Thoms et al. 2000). Flows kept at near constant levels for prolonged periods reduce the diversity of instream hydraulic habitat and can exacerbate bank erosion through notching processes.

Rapid rates of fall

Rapid rates of fall can occur due to fluctuating irrigation demand, including ‘rainfall rejection’ events, and can potentially result in stranding of biota, disruption of Murray/trout cod nesting and exacerbating bank erosion through slumping processes. River Murray operations are subject to specific limits on rates of fall in the Murray River below Hume Dam and on the lower Darling River in an attempt to reduce the risk of bank slumping (MDBA 2013; 2019)). However, there are no similar guidelines in the Edward-Wakool river systems and rapid changes in flow and water level during the irrigation season remain an issue.

The EWRs for the mid Murray and Edward-Wakool system (Table 10 and Part B) attempt to address these issues to some extent by recommending annual drying regimes (BF3) following the irrigation season, nesting support flows (NestF1) and small freshes (SF2) to support nesting of riverine specialists like Murray and trout cod during spring, and recommendations on maximum rates of fall.

Lower Murray WMA

Key changes in the lower Murray River include:

- a ~50% reduction in average annual flows (57% in Lock 7-9 reach)
- reduced frequency and duration of large freshes, bankfull and small-medium overbank flows
- reduced flow flows (especially in the Lock 7-9 reach)
- numerous weirs create still-water habitats significantly reducing hydrodynamic complexity and near-constant inundation of riparian zones.

Reduced average annual flows

With progressive extraction for irrigated agriculture along the Murray River, average annual flows have decreased to 51% of natural (without-development flows) at Euston (Figure 21A) and 54% at the SA border (Gippel and Blackham 2002). A more significant decline has occurred in the Murray River between Locks 7 and 9 (downstream of Wentworth), where average annual flows are 43% of natural due to the combined effects of consumptive use upstream and large diversions to Lake Victoria: a mid-river storage used to improve the reliability of water supply to South Australia (Figure 21).

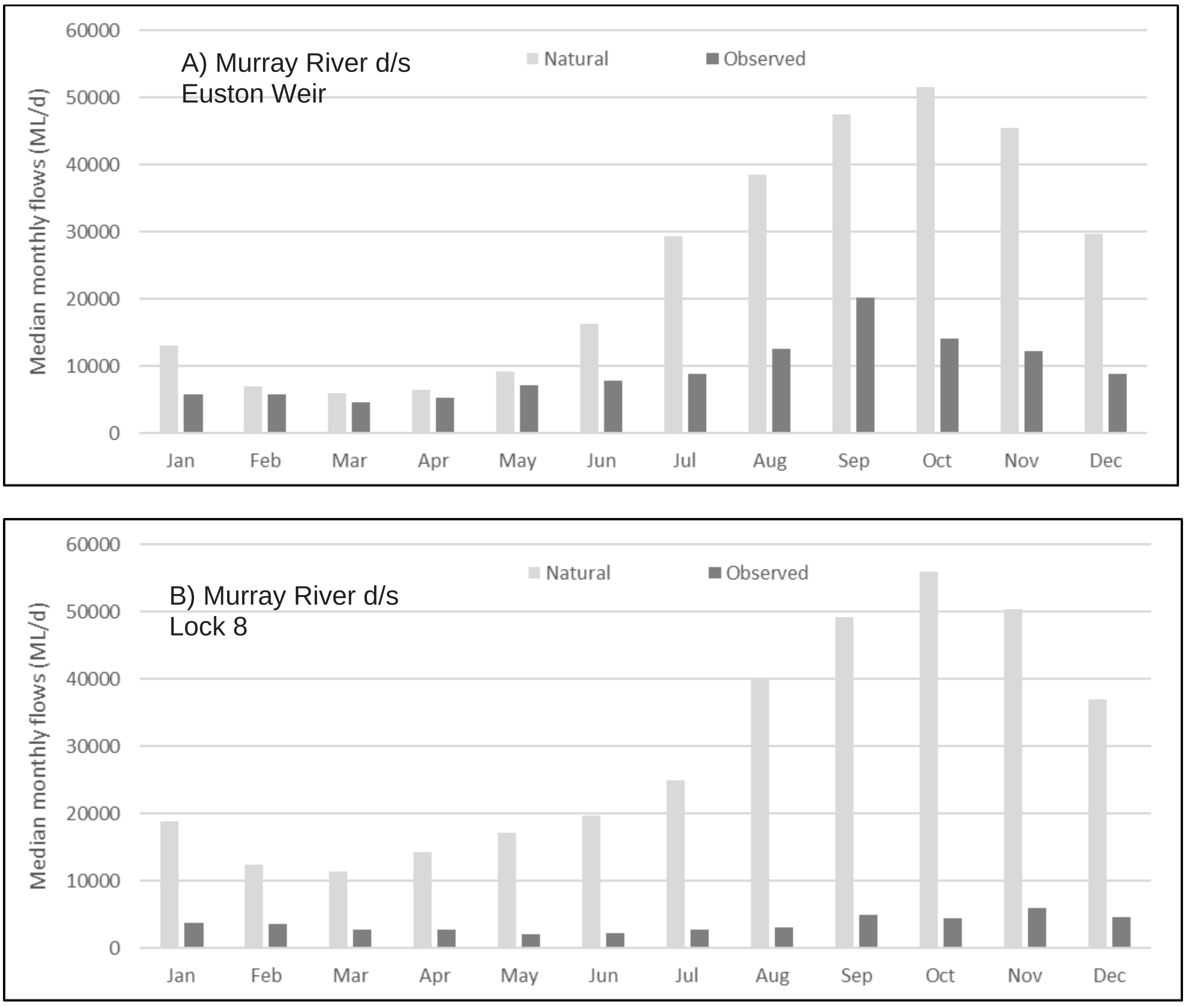

Figure 21 Median monthly flows for the lower Murray River for modelled 'natural' conditions (without flow regulation) and observed data

Reduced winter-spring-early summer high flows

As for the mid Murray River, one of the most ecological-significant changes in the lower Murray River has been the reduction in frequency and duration of large freshes, bankfull and small-medium overbank flows in winter, spring and early summer: Specific examples include:

- 35-63% reduction in large freshes to support golden perch and silver perch breeding[92]
- 48-57% reduction in small overbank flows (OB1)[93]

[92] A 35% reduction in the frequency of large freshes (>20,000 ML/d) in the Lock 7-9 reach (from almost annual events under modelled without-development conditions to ~60% of years under modelled current conditions) and a 63% reduction at Euston (from ~90% of years to ~30% of years). Large freshes are defined in EWRs in Part B of LTWP.

[93] A 57% reduction in frequency in the Lock7-9 reach and a 48% reduction in frequency at Euston (from ~60% of years under modelled without-development conditions to ~25-30% of years under modelled current conditions).

Reduced summer-autumn low flows

In the lower Murray River between Lock 7-9, low flows have also been heavily impacted, with a 60-74% decrease to late summer and autumn low flows. Median monthly flows during this time have declined from 11,500 -17,000 ML/d under natural modelled conditions to only 2100-3700 ML/d (observed) and 3500-6600 ML/d (modelled current conditions) (Figure 21B).

Effects of weirs on hydraulic diversity

The reduction in low flows is particularly significant in the lower Murray River due to the operation of numerous weirs (also commonly called *locks)* from Euston to the SA border (Locks 7, 8 , 9, 10 (Wentworth), 11 (Mildura), 12 and 15 (Euston).

The weirs are used to maintain relatively constant water levels in the river (at approximately bankfull level, called the *full supply level* (FSL)) to support ease of extraction (pumping) for irrigated agriculture and recreational uses. However, the combination of maintaining near-constant elevated water levels and greatly reduced flows entering the weir pools, results in greatly reduced hydraulic diversity (flow velocities). For example, for a flow of 4000 ML/d, 100% of the Lock 8 weir pool will have very slow velocities of less than 0.18 m/s at FSL[94]. Such conditions can reduce water quality and limit native fish movement and breeding. Increasing flow to 10,000 ML/d (a more natural summer-autumn flow magnitude) improves velocity conditions such that now 54% of the weir pool has moderate velocities of 0.18-0.3 m/s at FSL. Drawing down the weir pool to 1 m below FSL at a flow of 10,000 ML/d can improve hydraulic conditions even further by creating fast flowing habitat (greater than 0.3 m/s) in 16% of the weir pool[94].

Manipulation of weir pool levels to improve ecological outcomes in the lower Murray has occurred on a trial basis at Lock 7, 8, 9 and 15 since 2013 (NSW DoI-W 2016; CEWO 2018c). The focus of EWRs in the lower Murray is to improve baseflows year-round, provide seasonal freshes and to promote continued variability in weir pool levels.

Effects of weir pools on drying regimes

Holding near-constant and elevated water levels throughout the year in all lower Murray River weir pools means that river banks, riparian areas and low-lying wetlands do not undergo periodic drying they need to support healthy native-vegetation communities. Water-dependant vegetation is typically limited to a narrow band around the FSL. The lack of annual drying will also limit nutrient and carbon cycling and primary productivity functions.

Lower Darling WMA

The lower Darling River has one of the most heavily impacted flow regimes in the MLD with large reductions in low flows and the frequency of all categories of freshes and higher flows. Observed average annual flows have declined to 56% of natural (without development) flows and the natural pattern of flow has been erased, with (much reduced) peak flows now occurring in early summer, as opposed to two much larger flow peaks that would have occurred September and March (Figure 22). Under current conditions, flows now tend to peak in early summer, falling rapidly during late summer and remain at constant low flows until October. These changes in seasonality are significant as the Darling River historically contributed regular summer flows to the lower Murray River reaches (downstream of Wentworth).

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[94] Cross-section average velocities (MDBA unpublished data based on hydrodynamic models for Lock 7 and 8).

Reduced flows during the warmer months of September to March and the presence of many weirs has increased the frequency and severity of thermal stratification, which leads to increased risk of blue green algae outbreaks (Mitrovic et al. 2011) and hypoxia (low dissolved oxygen) conditions when weir pools de-stratify in response to small increases in flow or changes to air temperature (Ellis and Meredith 2004; NSW DoI 2017, Vertessy et al. 2019). The recent large-scale fish kill events below Menindee Weir in 2018-19 are an example of the ecological consequences of inadequate low flows (Vertessy et al. 2019).

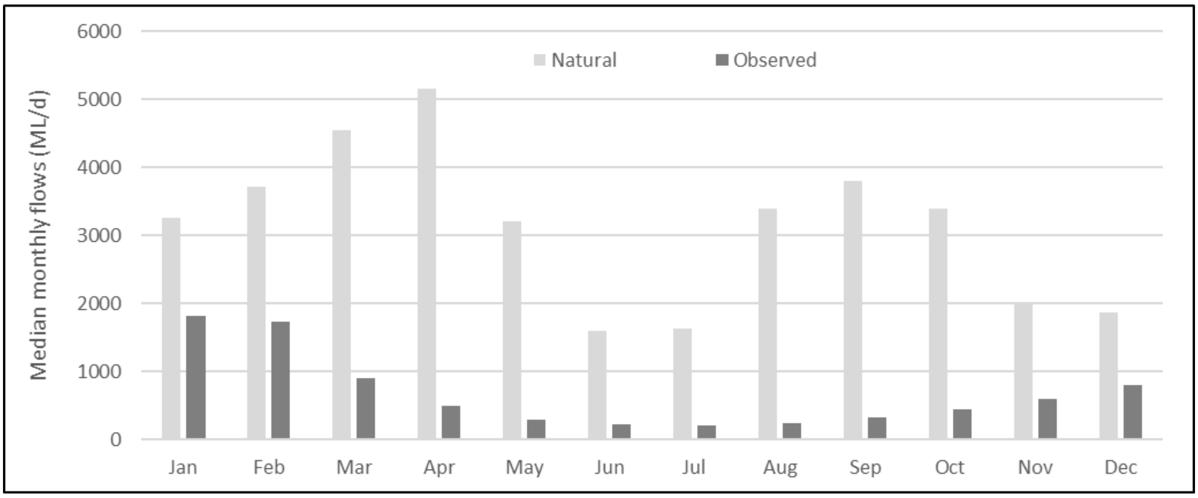

Figure 22 Median monthly flows for the lower Darling River upstream of Weir 32 for modelled 'natural' conditions (without flow regulation) and observed data

Importantly, there has been a marked decrease (37-80%[95]) in all freshes (small and large), bankfull flows and small-medium size overbank flows. Ecologically significant changes include:

- 37-80% reduction in the frequency of **small freshes** (SF1-3)
    - 50% reduction in the frequency of small freshes (SF2) of sufficient duration (60 days minimum) to support strong spawning and nesting events for Murray cod (reduced from 40% to 20% of years);
    - 80% reduction in the frequency of small freshes in autumn required to support the dispersal and condition of all native fish (to promote survival of adults and new recruits over winter) (reduced from 91% to 18% of years);
    - 37% reduction in the frequency of small freshes in summer-autumn to support the recruitment and dispersal of native fish following spring breeding (reduced from 97% to 62% of years)
- 40% reduction in the frequency of **large freshes** (LF1-3) required in late spring-summer & autumn to support dispersal of golden and silver perch recruits from Menindee Lakes (LF1), large-scale spawning of golden and silver perch in the lower Darling River (LF2) and non-woody vegetation on river banks and low-lying wetlands (LF3). Event frequency has reduced from 93-96% of years to 56-57% of years.
- 68% reduction in the **bankfull flows** (BK2) required to support connectivity with low-lying wetlands and the Darling Anabranch (reduced from 68% to 22% of years)
- 58-68% reduction in the frequency of **small overbank flows** (OB1-3) that are required to support productivity, wetland vegetation and low-lying floodplain woodlands and the dispersal, breeding and recruitment of native fish.

[95] Change in frequency based on a comparison between frequency of events (as defined by EWRs) under modelled natural (without development) and modelled current condition flow regimes.

Regulation of the Menindee Lakes system (a series of natural lakes including Menindee, Pamamaroo, Cawndilla and several smaller lakes) has led to changes in the filling and drying regimes of the lakes as illustrated for Menindee Lake over the period of 1977-2019 in Figure 23 and include:

- Higher level filling during wet periods and held full for longer
- Less variable lake levels during average and wet times (e.g. during the 1990s)
- Lakes are now drier for longer periods during dry times.

Higher than natural fill levels now support floodplain vegetation communities (river red gum, black box, lignum and coolabah woodlands) higher on the floodplain than likely under the pre-development filling regime. The reduced variability (more stable) fill levels has most led to a decline in the cover and diversity of native vegetation on lake beds and a decline in waterbird abundance and diversity (Kingsford et al., 2004).

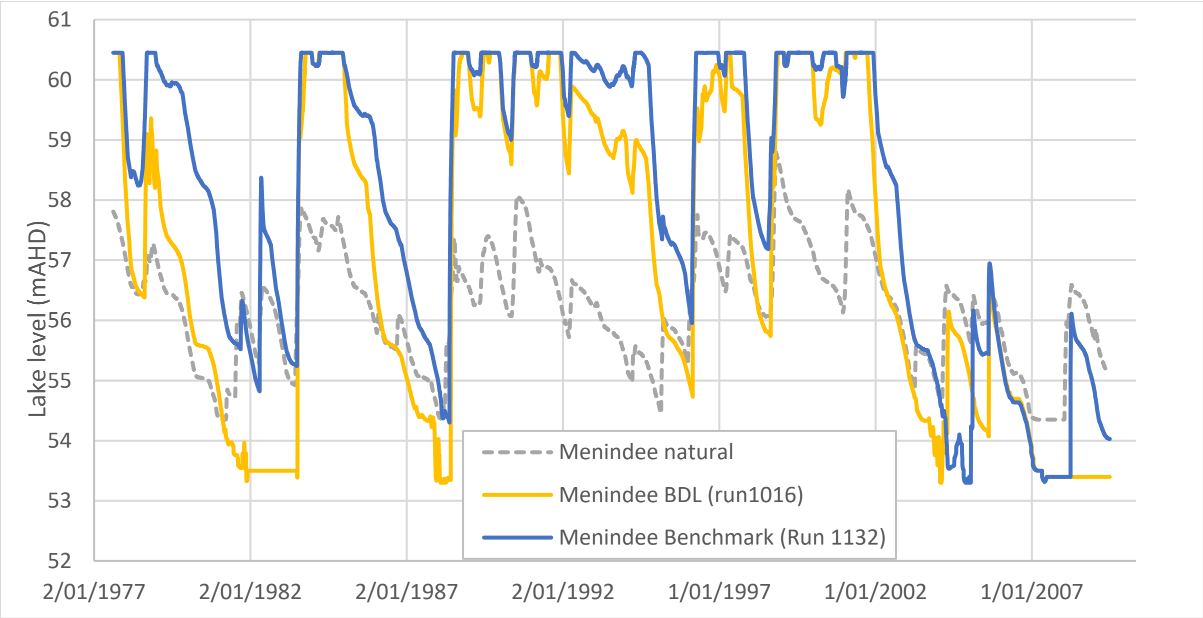

Figure 23 **Menindee Lake water level under modelled natural (without development), Benchmark (pre-Basin Plan), and BDL (post Basin Plan) between 1997 and 2009, showing changes to the filling and drying regime due to regulation**

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 under this plan. 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 *NSW Murray and Lower Darling Water Resource Plan Area Risk Assessment* (NSW DPIE, 2019a) was undertaken to inform water resource planning in the Murray–Lower Darling. It identifies risks to areas of conservation value, based on hydrological change within sub-catchments, and presents strategies outlining how those risks may be mitigated in the Murray–Lower Darling Water Resource Plan. This section complements the Murray–Lower Darling Risk Assessment and addresses the specific risks and constraints that may present in the implementation of the LTWP.

This chapter focuses on risks to meeting the EWRs of priority environmental assets and functions in the Murray–Lower Darling catchment (Table 12). It also outlines the risks and constraints that affect our capacity to achieve the ecological objectives of this LTWP (Table 13). This risk assessment has assisted with identification of appropriate investment opportunities for improving the likelihood that EWRs can be achieved in the short and long-term (Table 22).

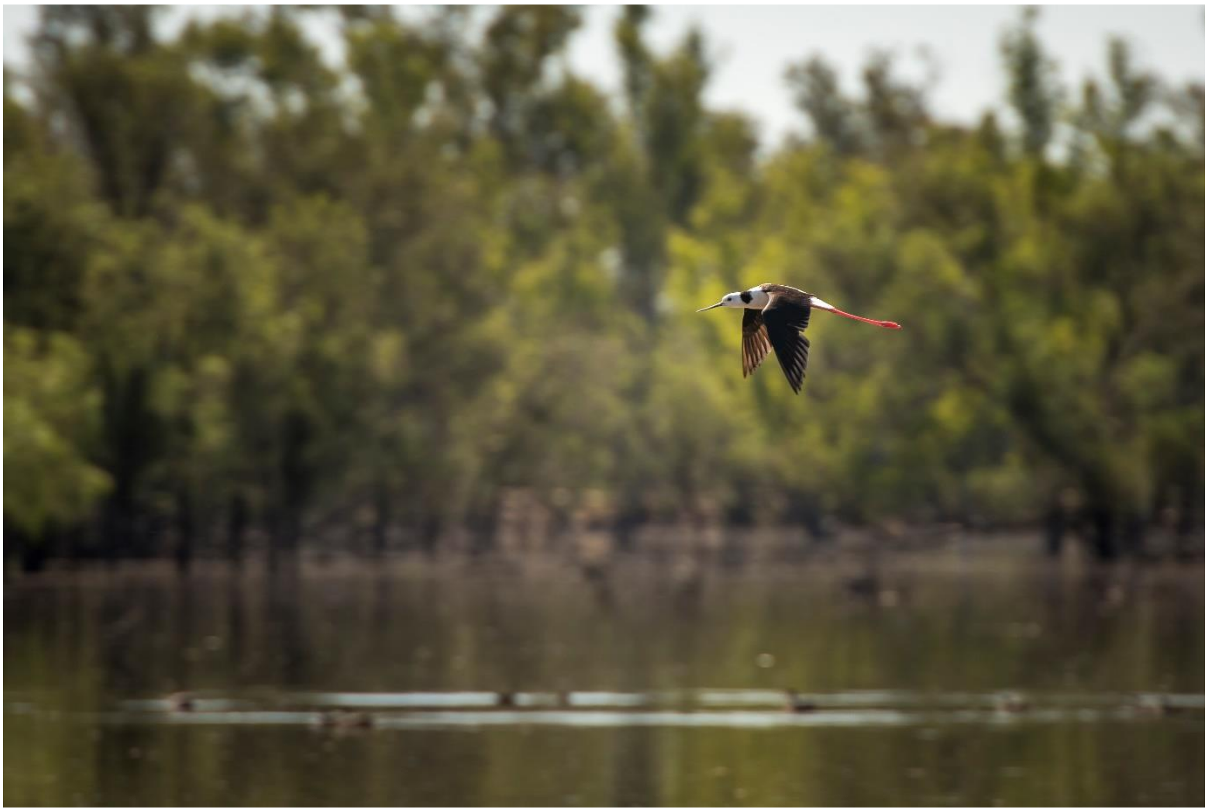

Figure 24 Black-winged stilt
Photo John Spencer

5.1 Risks and constraints to meeting EWRs

Table 12 Risks and constraints to meeting environmental water requirements and proposed management strategies to address these

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
Insufficient water for the meeting environmental needs	Total volumes of water available for the environment do not meet environmental needs. Environmental water volumes alone are insufficient to hold larger river flows (large freshes, bankfull and small overbank flows) for sufficient durations to inundate floodplain wetlands to meet native vegetation and waterbird breeding requirements e.g. Millewa and Werai forests, floodplain lakes and wetlands in the Lower Darling & Darling Anabranch systems.	**Regulated PUs (or those affected by regulated water)**	
		Allow for environmental water delivery to build on natural events through implementation of the Basin Plan Prerequisite Policy Measures (PPMs) and Constraints Management Strategy (CMS).	DPIE-Water, WaterNSW, DPIE-BC, MDBA, CEWO
		Investigate options for the strategic delivery of consumptive orders and operational water (bulk transfers between storages, inter-valley transfers and SA entitlement flows) to mimic natural flow events and contribute to meeting EWRs (requires interagency and interstate discussion).	MDBA, CEWO WaterNSW DPIE-BC, DPIE-Water, GMW
		Coordinate delivery of held (HEW) and planned (PEW) environmental water across catchments (Murray, Murrumbidgee, Goulburn, lower Darling) and in conjunction with natural events and operational water to help meet target flow rates and durations (as defined by EWRs).	MDBA, DPIE-Water WaterNSW, DPIE-BC, CEWO, GMW
		Improve the seasonal pattern of freshes through seasonally-cued HEW releases (to take advantage of higher system flows).	DPIE-BC, CEWO, TLM, MDBA, VEWH
		Ensure environmental water holdings have equal access and usage as equivalent consumptive holdings.	DPIE-Water, WaterNSW, MDBA, DPIE-BC, CEWO

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
		Unregulated PUs	
		Implementation of the *NSW Murray & Lower Darling Water Resource Plan.*	DPIE-Water
		Review low flow access rules where in-channel flows have been impacted (water sources with high or medium 'likelihood' scores in the *NSW Murray & Lower Darling WRP Risk Assessment* – see Part B for specific recommendations.	DPIE-Water
		Maintain rules restricting trade into water sources with high or medium risks (as defined by the *NSW Murray & Lower Darling WRP Risk Assessment*).	DPIE-Water
Ineffective planned environmental water rules	Ineffective PEW rules in the *Water Sharing Plan (WSP) for the NSW Murray and Lower Darling Regulated Rivers Water Sources* limit the ability to meet environmental water needs in the Murray and lower Darling Rivers. Two Environmental Water Allowances (EWAs) have never been used: i. Barmah-Millewa Overdraw Environmental Water Allowance (EWA) (***the Barmah-Millewa Overdraw)*** *– WSP clauses 26 and 28.* ii. Environmental Water Allowance (EWA) for the Lower Darling water source ***(the Lower Darling Allowance)*** *– WSP clause 31*	Review and improve the effectiveness of the **Barmah-Millewa Overdraw EWA**: • Define clear quantitative triggers for accrual of the Barmah-Millewa Overdraw EWA. The current accrual provisions under clause 28(1) of the WSP are qualitative and potentially subjective. • Ensure that the Barmah Overdraw account accrues according to the defined triggers and ensure that carryover provision under clause 28(3) are implemented. • Assign delegation of decision in making over the use of the Barmah-Millewa Overdraw EWA to the NSW Environmental Water Manager (DPIE-Biodiversity and Conservation Division), in line with current arrangements for the use of the Barmah-Millewa Allowance EWA. Clause 28(4) of the	DPIE-Water

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
		WSP currently assigns delegation over releases to the Minister. • DPIE-Water to regularly communicate the account balance to the NSW Environmental Water Manager to facilitate effective and efficient delivery of water for the environment.	
	The Lower Darling Allowance is currently only available for managing high blue green algae levels in the lower Darling River when the Menindee Lakes are in MDBA control (when lakes are moderately full or above). These rules make it impossible to use the Lower Darling Allowance to mitigate other (more common) critical water quality issues such as low dissolved oxygen (DO) levels due to inadequate flows and hot weather conditions, which can lead to weir pool stratification/destratification and subsequent large-scale fish kill events and poor water quality for riparian landholders. The Lower Darling Allowance has never been used despite many recent critical water quality incidents affecting the lower Darling River.	Revise the **Lower Darling EWA** rule in the WSP, broadening its scope of use to: • allow use to mitigate a broader range of critical water quality issues in the lower Darling River including low DO and weir pool stratification. • making the EWA available at all times (when Menindee Lakes are in either NSW or MDBA control). Lower Darling River riparian landholders and water licence holders are highly supportive of these proposed changes.	DPIE-Water
Infrastructure (e.g. roads, bridges, private crossings) & cropping activity on low-lying floodplains limits ability to deliver higher flows (large freshes, bankfull & small overbank flows).	Public and private infrastructure located on the low-lying floodplain including low-lying roads, bridges, private creek crossings, access roads, pumps & fences can lose their function during higher river flows and without appropriate mitigation measures, restrict the delivery of environmental water to meet many EWRs designed to support river, wetland and floodplain ecosystems.	Implement the Constraints Management Strategy 1. Murray River: Hume to Yarrawonga 2. Yarrawonga to Wakool Junction (including the Edward–Wakool system and Koondrook–Perricoota) including the following potential mitigation measures to allow higher flows:	DPIE-Water, MDBA, DPIE-BC

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
	Inundation of low-lying creek crossings can temporarily block stock and landholder access on private property and potentially damage pasture and crops on very low-lying parts of the floodplain. Conversely, many floodplain graziers welcome higher flows as these improve pastures and overall productivity. In many cases, current regulated flow limits in the River Murray are below official regulated water delivery limits in the Water Sharing Plan and well below published flood levels. Reasons for this include concerns raised by affected landholders and legal uncertainties regarding liability and appropriate mitigation measures. For example, in the River Murray downstream of Yarrawonga, the current flow constraint is 15,000 ML/d.	• upgrade of low-lying bridges, roads and low-level private creek crossings and access roads • provide alternative access routes where practicable • negotiate flood easements with landholders to allow required inundation of low-lying floodplains. and when deciding the new upper limit of regulated flow deliveries, include consideration of: • potential third party benefits and impacts at each flow limit option • environmental benefits (for native vegetation, waterbird, native fish and ecosystem function outcomes) and risks under each flow limit option • the risk of not achieving environmental outcomes if the lower end of the potential revised flow limits is selected.	
		Undertake trial environmental watering actions during the development of the Constraints Management Strategy to better understand the ecological benefits and third-party impacts/benefits of higher flows (these can be done at incrementally higher flows to minimise potential adverse outcomes, promote adaptive learning and management and foster relationships with landholders).	DPIE-Water, DPIE-BC, WaterNSW, MDBA, CEWO, VEWH

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
Extraction of environmental water from rivers, creeks & wetlands (Lack of formal protections for environmental water)	**All PUs**		
	For river flows, environmental water is ordered to a gauge and there is currently no formal protection of environmental water in NSW past this point to ensure that it reaches all target environmental assets. Water can be 're-regulated' by river operators and extracted from the river downstream by consumptive users. Environmental water may not be benefiting downstream catchment areas, unregulated systems or contributing to end of system flows. Specific impacts include: • Disruption of migration and dispersal of native fish and other biota (seeds, propagules) that is necessary to complete life cycles and promote dispersal to new areas. • Reduces the downstream transport of nutrients and carbon that is necessary to drive downstream food webs. • Severely limits the ability to meet downstream watering requirements (EWRs), including in-channel flows and wetland-inundating flows.	Implement Basin Plan Prerequisite Policy Measures (PPMs) in NSW to protect all held and planned environmental water delivered to: • All regulated and unregulated rivers and creeks (protection to the end-of-system i.e. to river/creek junction with the River Murray and onto the SA border). • All regulated and unregulated wetlands, lakes and floodplain areas (filled either via regulators, pumping or natural filling from river flows i.e. large freshes, bankfull or overbank flows). It is critical that environmental water is protected in unregulated rivers and wetlands for achieving ecological objectives and targets of the Basin Plan and the LTWP. It is also in the broader Public interest, as this water was purchased with public funds and the same requirement of the Water Act (2007) and Basin Plan for "*efficient use"* of environmental water should apply. Environmental water entering unregulated assets is delivered via regulated flow pathways (e.g. by natural spilling or active pumping into wetlands and unregulated creeks during regulated e-water delivery in rivers, or via irrigation networks from regulated rivers).	DPIE-Water
		Install adequate gauging to accurately quantify losses/use in off-channel sites and protect return flows (flows returning to rivers/creeks from the floodplain or wetlands).	DPIE-Water

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
		Maintain communication and relationships with landholders to maximise protection of environmental water (including if PPMs are not implemented for the case of regulated water entering unregulated environmental assets).	DPIE-BC, CEWO, MDBA, DPIE-Water, CEWO
Extraction of environmental water from rivers, creeks & wetlands (Lack of formal protections for environmental water)	**Unregulated PUs**		
	Environmental water delivered from regulated rivers to wetlands, lakes and floodplain, which tend to be in unregulated Water Sources, can be extracted by unregulated water access licence holders without any formal restrictions (with the exception of Thegoa Lagoon in the Lower Murray region which has specific WSP rules).	Revise Cease-to-Pump rules in WSPs for the a) Murray and b) Lower Murray–Darling Unregulated Water Sources, to protect environmental water delivered to unregulated creeks, wetlands, lagoons from regulated streams and water sources. An example is the current rule that prohibits extraction of environmental water from Thegoa Lagoon (in the WSP for the Lower Murray–Darling and Alluvial Unregulated Water Sources). As an interim measure, could implement temporary extraction suppression orders for specific waterways such as Tuppal Creek during environmental water delivery.	DPIE-Water, DPIE-BC
Lack of appropriate accounting arrangements &/or metering to account for loss/use in floodplain & wetland assets	Delivery of higher flows in the River Murray and Edward–Wakool system are often restricted due to a lack of appropriate metering and accounting arrangements to accurately estimate 'losses/use' in wetland and floodplain assets (i.e. the volume of water that enters a wetland/floodplain during a river flow event and does not return to a regulated river or creek). This, together with a lack of formal protection of environmental water entering wetlands and floodplains, reduces the incentive for environmental water holders to undertake larger watering actions	Develop policies that ensure that loss rates charged to environmental water holders reflect actual losses to wetlands and floodplains during individual events (as loss rates will vary depending on antecedent conditions i.e. how dry/wet the wetland or floodplain is prior to the environmental watering action). Improve the accuracy of loss estimates during environmental water deliveries by using observed flow and water level data, and the most recent verified hydraulic and/or hydrological models. Undertake regular independent reviews/auditing of loss rate estimates.	DPIE-Water, WaterNSW, MDBA

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
	as these actions fail to meet the principle of efficient and effective use of environmental water. Specific examples include: 1. The conservative fixed loss rates been applied to multi-site environmental watering events in the River Murray in recent years are fixed from year to year and are likely to overestimate real losses. This results in inefficient use of environmental water and jeopardises downstream ecological outcomes. 2. Edward River – the current regulated flow constraint of 2700 ML/d downstream of Stevens Weir is due to 'losses' into the Niemur River, Tumudgery and Reed Bed creeks and an absence of appropriate gauging to measure flows into these waterways. The bankfull capacity of the Edward River is 6,000–9,000 ML/d and higher operational flows of ~3200 ML/d in recent years have not negatively affected landholders. Flows above 2700 ML/d (large freshes) are required to meet vegetation and waterbird outcomes in the Ramsar listed wetland Werai forest but currently these EWRs cannot be met. 3. Murray River d/s Torrumbarry – regulated water deliveries including environmental water are currently restricted to 18,000 ML/d due to 'losses' into Swan Lagoon (a relatively small wetland located in the Koondrook–Perricoota TLM icon/Ramsar site that connects to the River Murray). Impacts to third parties do not occur until minor flood level of 7.3 m (41,300 ML/d).	Install appropriate gauges and/or water use meters at priority wetland, creek or floodplain sites. Improve river and floodplain inundation models including more accurate representation of environmental water demands in the lower Darling River, River Murray and Edward-Wakool system.	WaterNSW, DPIE-Water, MDBA, DPIE-BC
		Implement PPMs, in particular the protection of environmental water entering creeks, wetlands and floodplain areas during environmental water deliveries (most of these are classifies as 'unregulated' areas under the Water Sharing Plans for the Murray and Lower Darling).	MDBA, DPIE-Water, WaterNSW, DPIE-BC, GMW, CEWO
		Discuss options with environmental water holders and managers to cover losses/use in wetland and floodplain assets such as Swan Lagoon, Werai forest, and the Niemur River that would allow delivery of higher river flows than currently possible.	DPIE-BC, CEWO, MBDA, WaterNSW
Floodplain or in-channel structures that divert or block flows to wetlands & floodplain assets (e.g.	Unmanaged construction of levees, diversion channels, block banks on streams and inlet/outlet channels of wetlands and lakes; and sediment blockage of culverts, has diverted flows and caused barriers to delivering water to wetland and	Implement compliance actions to address structures that obstruct or reduce the efficiency of environmental water delivery and impede fish passage. Priority areas include:	NPWS, DPIE-Water, WaterNSW, NPWS

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
levees, diversion channels, block banks)	floodplain areas – effectively isolating and stranding these environmental assets. Examples include a private block bank obstructing flows into Coppinger's Swamp-Duck Lagoon in Moira forest (part of the Millewa forest group) with consequences for waterbird and vegetation outcomes. The block bank means that environmental water would have to be delivered at much higher flow rates in Gulpa Creek than previously necessarily, making the watering action largely unviable.	• Coolamon Creek – inlet creek to Coppingers Swamp-Duck Lagoon in Moira forest (western part of Millewa Forest group) • Edward-Wakool system • Carrs-Cappits-Bunberoo creek system on the lower Murray River floodplain – implement the proposed Locks 8-9 SDL Supply project.	
Proposed changes to the operation of the Menindee Lakes have the potential to limit or create adverse environmental outcomes	Proposed major changes to the filling and drying regime of the Menindee Lakes under the proposed Menindee Lakes Water Saving Project may have significantly limit ecological outcomes for native fish, vegetation and waterbird Lower Darling region and connected northern and southern basins. Key issues: **Menindee Lake** • Reduced variability in lake level (the lake is likely to be kept either full or empty for longer), increased periods when the lakes are dry and very fast draw down rates are likely to impact on the extent and condition of native vegetation within and fringing the lake. • Loss of waterbird breeding, feeding and refuge habitat (due to loss of vegetation as habitat and direct responses to the hydrological changes mentioned above). **Lake Cawndilla** • Loss of nursery habitat for golden perch – a reduced frequency of filling events is likely to result in fewer recruitment and dispersal	Test (and consider adopting) alternative lake operation strategies to minimise environmental impacts, acknowledging that these may result in reduced water savings. Undertake comprehensive investigations of likely ecological consequences of the Menindee Lakes Water Saving Project under different operational strategies. • Improved modelling including more accurate representation of environmental water demands in the lower Darling River and for predicting inflows to the lakes form the north. • Incorporation of climate change predictions into models (especially inflows) • Apply fish population models to estimate consequences for native fish populations in	DPIE-Water, MDBA, Department of Agriculture (federal) (DoA)

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
	opportunities for native fish, with implications for golden perch populations across the basin96, especially in the lower Darling and Murray rivers. • A reduction in filling events in consecutive years will limit opportunities for juvenile and adult fish to disperse from the lake to the Murray River via the Darling Anabranch and the Barwon-Darling system via Lake Menindee, Pamamaroo and Wetherell under some conditions96 – with potential implications on golden perch recruitment across the basin. • Extended periods between filling events during dry times (up to 7 years) is likely to exceed many ecological thresholds and may lead to loss of native vegetation cover and severe decline in condition. • Reduced frequency of connecting flows to Redbank and Tandou Creek (up to 7 years between events), and Darling Anabranch. **Lower Darling River** • The planned reduced minimum storage volumes in Menindee Lakes (only 80 GL) is likely to reduce capacity to meet minimum flows in the lower Darling River during extended dry periods, especially during the warmer months	the lower Darling River and connected southern and northern basins[96]. • Undertake detailed assessment and predictive modelling of likely consequences for native vegetation communities and waterbird breeding habitat.	

[96] There is connectivity for native fish movement between Lake Menindee, Pamamaroo and Cawndilla and the southern connected basin via the lower Darling River, Darling Anabranch and Murray River; and connectivity between Lake Wetherell, Tandure, Bijijie, Balaka and Malta with the Barwon-Darling River system upstream (Sharpe 2011). However, there is currently limited opportunity for native fish dispersal from Lake Menindee, Pamamaroo and Cawndilla upstream to the Barwon-Darling system (except for during large floods and when the lakes are full), due to the absence of adequate fish passage on lake inlet and outlet structures (Iain Ellis, DPIF pers. comm. 2019).

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
	when the risk of thermal stratification, algal blooms, low DO and fish kills is greatest. • Uncertainties in how the project is likely to affect the feasibility of meeting other flow requirements (e.g. freshes). **Darling-Anabranch** • A potential reduction in the frequency of flows to the Darling Anabranch, Redbank and Tandou creeks from Lake Cawndilla (in line with potential changes to Lake Cawndilla filling frequency). While this could be offset to some degree in the Darling Anabranch by increased connecting flows from the lower Darling River, Redbank and Tandou creeks have no alternative water source.		
Proposed changed to Lake Hume management under proposed SDL Supply Measure projects	Potential changes to the operation of Lake Hume under the proposed Sustainable Diversion Limit (SDL) Adjustment Supply Measure projects: • Enhanced Environmental Water Delivery (EEWD) project • Hume Dam airspace management and pre-release rules may result in reduced frequency and/or during of natural medium and large overbank events. These events are important for maintaining floodplain vegetation communities, waterbird breeding opportunities and driving large-scale productivity to support riverine food webs, including native fish recruitment. Less frequent floodplain inundation also increases the risk of hypoxic blackwater events when floods do occur.	Asses the proposed changes against the EWRs for the Murray River and Edward-Wakool system. Undertake predictive ecological modelling to assess likely consequences on native fish and waterbird populations and native vegetation communities. Test and consider adopting alternative lake operation strategies to minimise environmental impacts, acknowledging that these may not result in reduced water savings.	MDBA, DPIE-Water, Victorian DELWP, DoA (Federal)

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
Channel capacity sharing constraint	During the irrigation season, environmental water orders are limited due to consumptive water orders taking up most available channel capacity. This is especially an issue in the River Murray due to a number of choke points along the reach between Tocumwal and Barmah (most notably Barmah Choke). Competition over channel capacity is also an issue in the Edward-Wakool system. Environmental water deliveries in the River Murray can also be constrained during periods of bulk transfers between Lake Hume and Lake Victoria, which occur throughout the year, and particularly in spring. Fast growth in water demand in the lower Murray River due to the rapid expansion of tree-nut plantations and the Menindee Lakes Storages being off-line during dry conditions is putting increased pressure on channel capacity at Barmah Choke. It is estimated that consumptive water demand may exceed delivery capacity in spring and summer.	Negotiate arrangements for the delivery of environmental water in conjunction with operational water (consumptive water or bulk transfers) to enhance efficiency. Environmental water can cover losses/use if flows spill into floodplain creeks and wetlands – if watering these assets is seasonally appropriate and ecologically desired).	DPIE-BC, CEWO, WaterNSW, DPIE-Water
		Relax existing flow constraints in the Murray River and then deliver environmental water outside the peak irrigation demand period where possible (when there is an environmental demand at another time of year such as winter or early spring, in line with the natural flow regime). Negotiate arrangements to allow delivery of environmental, operational and consumptive water to the lower Murray River via Mulwala Canal and the Edward-Wakool system, therefore bypassing the choke at certain times (only when watering of Barmah-Millewa and Werai forests is not ecologically desired). This strategy would potentially provide enormous ecological benefits to environmental assets in the Edward-Wakool system (e.g. Niemur River and Werai forest creeks), allowing EWRs in that system to be met more effectively and efficiently. The strategy could also ease erosion pressure in river banks in key risk areas.	MDBA, DPIE-Water, WaterNSW, Murray Irrigation, DPIE-BC, CEWO
Reductions over time of channel capacity at Barmah Choke and bank erosion	Bank erosion, including erosion of natural levees, as well as sediment deposition on the riverbed over time have contributed to a gradual but continued reduction in channel capacity at Barmah Choke and other choke points along the River Murray adjacent	Consider bypassing the choke when ecologically appropriate (as per above). Consider allowing operational flows to go overbank into Barmah-Millewa forest if ecologically desirable and at times of year (winter-early spring) where the risk of hypoxic blackwater	MDBA, DPIE-Water, DPIF & WaterNSW

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
	to Barmah-Millewa forest. This has significant impacts on: • Increased competition over channel capacity (see previous risk), which reduces ability to deliver environmental water to downstream assets at ecologically critical times (spring) • Increases the occurrence of unwanted flows into Barmah-Millewa forest when the forest requires drying (summer/autumn).	is low. Environmental water holders could cover use/losses in the forest. This may be an effective may of dissipating flow energy and therefore reducing erosion pressure on river banks. Connectivity with the floodplain will also allow sediment to be transferred to the floodplain, which may reduce excess sediment deposition on the riverbed. Continue to undertake monitoring of channel morphology changes & geomorphic assessments of likely contributing factors. Undertake ecologically-appropriate remedial measures and undertake trials to determine the most effective methods. Review and control where necessary, expansion of consumptive water demand in the Lower Murray region. Undertake habitat mapping along reaches where river bank erosion is occurring to determine combined benefits of remediation works and resnagging.	
Lack of appropriate wetland regulating infrastructure or inappropriate use of existing infrastructure	Wetland regulators are not being operated to plan (in the Hume to Yarrawonga reach) due to lack of human resourcing to operate regulators and/or regulators in disrepair or requiring maintenance.	Improve wetland structure capacity to deliver water to wetlands (lower sill levels; repair or install regulators).	DPIE-BC, LLS, NPWS
		Review and update wetland regulator operation plans (bring in line with environmental watering requirements)	
		Address resourcing and maintenance issues for wetland regulators.	

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
Bulk delivery release periods limiting environmental water deliveries	Environmental water deliveries in the River Murray may be constrained to bulk delivery periods. This can restrict periods when environmental water deliveries can be made, meaning that ideal seasonal flow objectives are missed.	Deliver environmental water in conjunction with operational water (consumptive water or bulk transfers) to enhance efficiency. Environmental water cover losses/use if flows spill into wetland and floodplain assets – if watering these assets is seasonally appropriate and ecologically desired)	DPIE-BC, MDBA, CEWO, WaterNSW
Lack of (or limited) variability in weir pool water levels impacts on aquatic plants and animals by impairing ecosystem functions and reducing habitat variability for native fish	Irrigators and recreational users expect stable water levels in weirs. Operational limitations also reduce variations to weir pool height. However, the ecological condition of weir pools will improve if water levels are varied seasonally. Benefits include improved water quality and cues for native fish movement and spawning (by increasing flow velocities when weir pools are lowered) and providing a varied wetting-drying regime for wetlands, where native vegetation requires periodic drying and variable inundation to maintain condition.	Investigate options for increasing the range of weir pool raising and lowering at Locks 7, 8, 9 & 15 in the lower Murray River where weir pool manipulation already occurs.	MDBA, DPIE-BC, DPIE-Water, WaterNSW, SA Water, VEWH, Mallee CMA
		Investigate options for introducing weir pool variability at Locks 10 & 11 on the lower River Murray, including undertaking trials to understand and demonstrate environmental benefits and develop mitigation measures for reducing potential third-party impacts (requires interagency and interstate discussions).	MDBA, DPIE-BC, DPIE-Water, WaterNSW, SA Water, VEWH, Mallee CMA
		Investigate options for introducing greater weir pool variability at Stevens Weir on the Edward River (the weir pool is currently drawn down once per year in winter for maintenance).	WaterNSW, DPIE-Water, DPIE-BC
Inappropriate rate and timing of dam releases in the upper Murray River	Dam releases from Khancoban storage (part of Snowy Mountain Scheme) are driven largely by hydroelectric power demands and result in extreme variation in river levels in the upper River Murray. This can increase bank erosion and impact on aquatic biota including Murray cod, Murray crayfish and the critically endangered flathead galaxias and endangered southern pygmy perch.	Implement more natural rates of rise and fall in flow in the upper River Murray, especially during the nesting season for riverine specialist native fish (mid Sep to Nov).	DPIE-Water, WaterNSW, Snowy Hydro, MDBA, DPIE-BC
		Investigate opportunities to enable ordering of River Murray Increased Flows (RMIF) environmental water entitlements from Khancoban storage (currently only possible downstream of Hume), or alternatively shape the releases from Khancoban storage to mimic natural events.	DPIE-Water, MDBA, DPIE-BC, VEWH

Risk	Description	Potential management strategies to address risk/constraint	Potential project partners
Unenforced rules in unregulated catchment	Visible flow can be an ambiguous trigger for pump rules and compliance is difficult to enforce. There are not enough gauges in the unregulated catchment to support these rules. Limited gauging and drawdown metering in the unregulated catchment make it difficult to monitor compliance.	Consider purchasing water licences in high-risk areas (as determined by the Risk Assessment).	DPIE-BC, CEWO & DPIE-Water
		Investigate improved metering of pumps.	WaterNSW & landholders
		Investigate better gauging to help licence holders and compliance officers determine stream flow.	WaterNSW, DPIE-Water
		Consider reviewing Murray and Lower Murray-Darling unregulated and alluvial WSP rules in high-risk areas as a mechanism to ensure that sufficient water is protected for the environment.	DPIE-Water
A reduction in availability of environmental water (HEW & PEW) in future revisions of the WSP & with proposed SDL adjustment changes	Translucency, carryover, & other environmental water provisions are subject to changes resulting from 5-yearly reviews of WSP & with SDLA proposals	Ensure stakeholders are consulted in any review process. Monitoring and evidence of environmental benefit, NSW MER plan.	DPIE-BC, DPIE-Water & DPIF

Figure 25 Moira grass in seed in Millewa forest
Photo Vince Bucello

5.2 Other risks and constraints to meeting LTWP objectives

The risks and constraints to meeting the ecological objectives and targets outlined in this LTWP include factors other than those related to delivery of water to meet EWRs as described in Table 12. These may be water related, such as cold-water pollution or water quality (e.g. salinity), or consequences due to inappropriate land use practices, such as native vegetation clearing (Table 13). While managing these risks and constraints is outside the scope of this LTWP, they have been included to draw attention to their influence on river and wetland health, and to highlight the importance of linking this LTWP with other natural resources management issues.

Figure 26 Black-winged stilt in flight
John Spencer

Table 13 Risks and constraints to meeting ecological objectives in the Murray–Lower Darling catchment

Risk	Description	Potential management strategies	Potential project partners
Poor water quality	Water quality affects the ecology & survival of aquatic organisms	Implement recommendations & strategies for use of WQA detailed in the *Water Quality Management Plan* (NSW DPIE 2019c)	DPIE-Water
		Manage salinity in accordance with the *Basin Salinity Management Strategy*	DPIE-Water
		Reduce the risk from poor water quality through proposed changes to trade & access rules in the WSP	DPIE-Water
		Consider use of HEW water to prevent minor water quality issues	DPIE-BC, CEWO
		Implement land management strategies to improve water quality	LLS with landholders, Landcare, WaterNSW, DPIE-Water & other community groups
Hypoxic blackwater	Blackwater events can occur with the release of water after prolonged dry or low-flow periods. This can occur from the excessive build-up of organic material in channels & on floodplains. Can lead to low-dissolved oxygen levels & potential fish kills.	Identify high-risk areas & high-priority refuge/recovery areas	DPIE-BC, DPIE-Water, DPIF
		Use irrigation escapes to inject fresh water to natural waterways to create refuges for native fish in areas affected by hypoxic blackwater	DPIE-BC. WaterNSW, DPIF, CEWO, Murray Irrigation, LGAs
		Upgrade irrigation escapes to increase the capacity of flow into river reaches affected by hypoxic blackwater.	DPIE-BC, DPIF, Murray Irrigation & WaterNSW
		Identify & remove barriers to fish movement to increase the capacity of native fish to escape areas affected by hypoxic blackwater	DPIE-BC, DPIF, MDBA, DPIE-Water & WaterNSW
		Avoid delivering environmental water during high-risk periods, such as warm weather in late spring, summer & early autumn after very dry antecedent floodplain conditions	DPIE-BC, MDBA & WaterNSW
		Monitor dissolved oxygen for active management of water actions	WaterNSW, DPIE-Water, DPIE-BC
		Restart rivers with flow rates that reduce the risk of hypoxia, informed by water quality monitoring	WaterNSW, DPIF, MDBA and DPIE-BC

Risk	Description	Potential management strategies	Potential project partners
Cold water pollution	Cold water releases from dams can change the range & distribution of species, reduce the opportunity for effective reproduction, reduce body growth & condition, & reduces recruitment success for up to 400 km downstream (NSW DPIE WQMP, 2019c).	Identify & implement outcomes of the *New South Wales Cold Water Pollution Strategy* Releases from Lake Hume & Khancoban storages have been identified as a high risk during large discharges in summer in this strategy.	DPIE-Water, WaterNSW, MDBA
Native vegetation clearing	Native vegetation clearing has direct impacts on vegetation objectives & the availability of waterbird habitat. Changes to riparian vegetation can impact on water quality, erosion rates & instream habitat.	Work with relevant departments & organisations to identify & protect core wetland vegetation communities	DPIE-BC
		Review identification of semi-permanent & ephemeral wetland during dry cycles	DPIE-BC
		Map & identify riparian & aquatic habitat condition to inform development of formal agreements in a unified strategy Prioritise reaches for management in partnership with LLS & landholders	DPIE-BC, DPIF, LLS
Acid sulphate-soils	Several areas within Lower Murray floodplain & isolated areas in the Edward–Wakool have been found to have acid sulphate soils (MDBA 2011; NSW OEH 2013). Lowered water levels and drying of sediments at these sites could lead to the development of low pH (acidic) conditions in wetlands and waterways.	Further research to understand the risk & its impact on weir pool management.	DPIE-Water, DPIE-BC
Grazing pressure & stock access to waterways	Stock trampling & grazing riverbanks can: • reduce native vegetation cover which allows weeds to establish • reduce streambank stability	Map & identify riparian & aquatic habitat condition to inform development of formal agreements in a unified strategy Prioritise reaches for management in partnership with LLS & landholders	DPIE-BC, DPIF, LLS
		Implement grazing strategies that protect & restore wetland vegetation	LLS, landholders

Risk	Description	Potential management strategies	Potential project partners
	• damage important instream habitat • reduce water quality.	Investigate incentives to improve management of wetlands & waterways on private land	DPIE-Water, LLS & DPI Agriculture
		Communicate wetland sensitive grazing practices to graziers	DPIE-BC & LLS
Spread of pest flora species	There is potential for environmental water to spread weeds like lippia, sagittaria & water hyacinth	Map & identify riparian & aquatic habitat condition to inform development of formal agreements in a unified intra-state strategy Prioritise reaches for management in partnership with LLS, Victorian Catchment Management Authorities & landholders	DPIE-BC, NPWS, LLS & CMAs
		Maintain existing weed control programs including implementing water hyacinth control protocols & maintain spray equipment to be able to respond to outbreaks	DPIE-BC, NPWS, LLS, Local Councils
		Negotiate & implement easement agreements that recognise greater need for weed management to supplement existing weed management on private land	LLS, DPIE-BC
		Inundate wetlands for enough time to favour native wetland species growth & reduce the extent of lippia	DPIE-BC & CEWO
		Introduce periods of increased flow in rivers (e.g. weir pools) to minimise abundance & extent of weeds that thrive in stable conditions (e.g. like elodea)	DPIE-BC, MDBA, WaterNSW, CEWO
Spread of pest fauna species	Pest fauna populations may benefit from environmental water use	Investigate a carp management plan for the southern basin	DPIF, WaterNSW, DPIE-BC
		Implement the NSW Carp Control Plan (NSW DPI 2010) and strategies to manage the other Class 1 noxious fish in NSW: Redfin perch.	DPIF
		Support the development & appropriate implementation of the carp herpes virus	DPIF
		Coordinate & implement feral pig control	LLS, landholders, DPIE-BC, NPWS

Risk	Description	Potential management strategies	Potential project partners
		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.	MDBA, DPIE-BC, DPIF, WaterNSW
Excessive erosion	Rapid flow recession can cause excessive erosion & bank slumping. This can increase turbidity & reduce instream habitat quality	Protect variable flows & ecologically desirable flow recession rates	MDBA, WaterNSW
		Map & prioritise riparian habitat & erosion points for remediation at the catchment scale, with a commitment to manage risk & monitor outcomes	MDBA, WaterNSW
		Manage environmental water delivery to mimic natural flow patterns & variability (where possible)	DPIE-BC, WaterNSW, CEWO, MDBA
		Investigate methods for improving the seasonal pattern & variability of water delivery	MDBA, DPIE-BC, WaterNSW, CEWO
Instream barriers & structures	Instream structures impede natural flow & connectivity which impacts on fish	Develop a fish way/passage strategy that identifies priority barriers to fish movement in the Murray-Darling Basin & investigate funding opportunities for implementation (Thorncraft & Harris 2000).	DPIF
		Remove priority illegal barriers	DPIE-Water
		Continue to maintain existing fish ways on structures & monitor their effectiveness, including the Sea to Hume Dam program on the Murray River (Barret and Mallen-Cooper 2009).	MDBA, WaterNSW, DPIF
	Diversion of water can have significant impact on native fish by altering habitat & affecting spawning & recruitment	Develop a management plan, incentives and appropriate technology for installing screens on pumps (Boys et al. 2012)	DPIF, DPIE-Water
		Develop a native fish management and recovery plan for the southern basin focussed on improving flow, habitat & connectivity.	MDBA, DPIF, DPIE-BC, DPIE-Water

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 2017 was the hottest year on record for NSW[97], and the driest since 2006 (BOM 2018[98]). 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 Murray region (CSIRO 2008). By 2030 under the best estimate (median), the project predicts[99]:

- a 10% reduction in average annual runoff to rivers
- a 14% reduction in average surface water availability
- a 24% reduction in end-of-system flows (not taking into account delivery of held environmental water)
- a significant increase in the average period between beneficial floods and average annual flood volumes would be between 8–15% of without-development volumes under historical climate, which would have very serious consequences for the ecosystem health of the entire region.

Best available climate change predictions for the Murray–Lower Darling region indicate a significant change to climatic patterns in the future. According to the NARCLiM model[100] (scenario 2), the changes in Table 14 are predicted by 2039 and 2079.

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 Murray–Lower Darling catchment.

[97] For both mean and daytime temperatures.

[98] www.bom.gov.au/climate/current/annual/nsw/summary.shtml.

[99] Scenario C (future climate and current development) is referenced.

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

Table 14 Potential climate-related risks in the Murray–Lower Darling catchment

Potential climate change risk	Description of risk	NARCLiM projection (scenario 2)						
		Season	2020-39			2060-79		
			Murray headwaters[101]	Upper & Mid Murray[102]	Lower Murray Darling[103]	Murray headwaters	Upper & Mid Murray	Lower Murray Darling
Change in rainfall	Rainfall is projected to vary across the region with large seasonal differences. The greatest increases are predicted to occur in summer & autumn, & the greatest decreases in spring. Winter rainfall is primarily decreasing across the region.	Summer	+0.8%	+4.4%	+3.1%	+8.8%	+10.5%	+12.6%
		Autumn	+6.5%	+9.4%	+14.1%	+11.0%	+12.7%	+13.7%
		Winter	-2.6%	-2.0%	-7.2%	-4.1%	+0.2%	+4.1%
		Spring	-7.5%	-10.9%	-10.3%	-11.2%	-11.9%	-5.4%
Change in average temperature	Mean temperatures are projected to rise by 0.67ºC 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 Murray–Lower Darling region.	Summer	+0.88°C	+0.87°C	+0.9°C	+2.28°C	+2.36°C	+2.49°C
		Autumn	+0.59°C	+0.54°C	+0.59°C	+1.87°C	+1.88°C	+2.05°C
		Winter	+0.43°C	+0.37°C	+0.41°C	+1.66°C	+1.42°C	+1.64°C
		Spring	+0.69°C	+0.71°C	+0.8°C	+2.15°C	+2.11°C	+2.31°C
Change in number of hot days (maximum temperature >35°C)	Hot days are projected to increase across the region by an average of 3, 8 & 12 days per year by 2030 (going from east to west). The greatest increases are seen around Bourke & Cobar, where it is projected to experience an additional 10–20 more hot days a year. Additional hot days are primarily during summer & spring across the region.	Annual	+2.7 days	+8.0 days	+11.5 days	+8.2 days	+22.9 days	+35.1 days

[101] Murray headwaters refers to the South East and Tablelands region in the NARCLiM.

[102] Upper and Mid Murray refers to the Murray Murrumbidgee region in the NARCLiM.

[103] Lower Murray Darling refers to the Far West region in the NARCLiM.

Potential climate change risk	Description of risk	NARCLiM projection (scenario 2)						
		Season	2020-39			2060-79		
			Murray headwaters[101]	Upper & Mid Murray[102]	Lower Murray Darling[103]	Murray headwaters	Upper & Mid Murray	Lower Murray Darling
Change in number of cold nights (minimum temperature <2°C)	Cold nights are projected to decrease across the Murray–Lower Darling region by an average of 3–12 fewer nights per year by 2030 (increasing as you move east). Changes in cold nights can have considerable impacts on native ecosystems.	Annual	-11.5 nights	-7.4 nights	-3.2 nights	-35.4 nights	-21.2 nights	-9.5 nights
Bushfires Changes in number of days a year FFDI>50[104]	Overall severe fire weather is projected to have a small to moderate (0.1–1.3) increase across the region by 2030. Increased severe fire weather is during spring (the prescribed burning season) & summer (peak fire risk season) & severe fire weather is expected to remain the same in autumn & winter.	Annual	+0.1 days	+0.6 days	+1.3 days	+0.5 days	+2.0 days	+3.2 days
Hillslope erosion	Changes in erosion can have significant implications for natural assets & water quality. Removal of groundcover will increase the risk of erosion significantly.	Mean annual percent change	1.02%	1.4%	10.92%	14.46%	13.63%	29.1%
Biodiversity	Rising temperature, increased fire frequency & changing fire regimes, storm damage & potentially drought will all affect species composition & distribution							

[104] 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 to support improved river and wetland health outcomes has occurred in the Murray–Lower Darling catchment since 2005. 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 will assist in answering questions such as:

- How will the volume of water stored in Hume Dam 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 Murray and Lower Darling?
- How will changes in consumptive water use influence the use of water for the environment?

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 27 Lignum shrublands provide important breeding habitat for waterbirds
Photo: Vince Bucello

6. Water management under different water availability scenarios

6.1 Prioritisation of ecological objectives and watering in planning units that are regulated or that can be affected by regulated water

Environmental water managers and environmental water advisory groups consider a range of factors when determining where and when discretionary water for the environment should be delivered. Some of these 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 (DECCW 2011).

Planning for the management of water-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 strategies ability to contribute to environmental outcomes.

Sections 6.1.1 to 6.1.5 set out a framework to help inform and guide annual water delivery decisions depending on the water resource availability scenario (RAS) in river reaches which are regulated or affected by regulated water. Each of these sections contains three parts:

- the broad priorities to guide management under the particular scenario
- the potential management strategies for achieving these priorities
- a table identifying the priority LTWP objectives for each scenario (Tables 14 to 17). The table also outlines the flow types which would be required to support those priority objectives.

Some of the LTWP objectives are more relevant under different RAS, with objectives for population expansion taking a lesser priority in dry and very dry RAS, to objectives such as 'NF1: No loss of native fish species'. There may also be objectives that include improvement of condition or increases in extent, such as or 'NV2: Maintain or increase the extent and maintain the viability of non-woody vegetation communities occurring in wetlands and on floodplains' that are refocused to 'Maintain non-woody vegetation communities occurring in core wetlands'. The priority objectives, and if relevant, refocused objectives for very dry, dry, moderate and wet conditions are shown in Table 15 to Table 18. More information about RAS and how it is defined is outlined in Appendix B.

Figure 28 Potamogeton, an aquatic plant found in Murray River wetlands. Photo: Vince Bucello.

Water resource availability scenario: Very dry – Protect

Broad management priorities	Management strategies for achieving priorities
Avoid critical loss of species, communities & ecosystems **Maintain refuges[105]** **Avoid irretrievable damage or catastrophic events** **Avoid unnaturally prolonged dry periods between flow events[106]** **Support targeted longitudinal connectivity within catchment for functional processes & a range of flora & fauna**	Allow dry down consistent with historical wetting-drying cycles Sustain key in-channel refuge pools, instream habitat & core wetland areas[107] Provide very low flows to relieve severe unnatural prolonged dry periods & support suitable water quality Prevent two consecutive years of extreme dry to core wetland areas and streams If a critical water shortage or similar critical incident restricts the use of water for the environment, then DPIE-BC will work with the Murray–Lower Darling EWAG to prioritise environmental water needs & DPIE-Water to ensure that these needs are considered, & ensure that there is appropriate DPIE-BC representation on the Critical Water Advisory Panel (see also 6.2 – *Water management during ecologically critical water quality incidents and extreme conditions.*

Table 15 Priority objectives and flow categories in a very dry resource availability scenario

Priority objectives	Flow categories								
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank[108]	Medium overbank	Large Overbank
NF1: No loss of native fish species	X	X	X	X			Infrastructure assisted delivery to core wetlands (drought refuges)		
NV1: Maintain the extent & viability of non-woody vegetation communities occurring within channels	X	X	X	X					
NV2a: Maintain the extent & viability of non-woody vegetation communities occurring in core wetlands									
WB5: Maintain the extent & improve condition of waterbird habitats									
EF1: Protect a diversity of refugia across the landscape	X	X	X	X					
EF2: Maintain quality instream & wetland habitat	X	X	X	X					
OS1: Maintain species richness & distribution of flow-dependent frog communities	X	X	X						

[105] Key drought refuges in the MLD are listed in Section 3.4. Drought Refugia, and in Table 11 under Native Fish objective 1 (NF1: No loss of species) and Ecosystem Functions Objective 1 (EF1: Protect a diversity of refugia across the landscape).

[106] As opposed to maintaining the long-term ideal frequency of events.

[107] Alternative watering actions may be required to support floodplain habitats to prevent threatened fish species from drying out.

[108] Small freshes and small overbank flows (via infrastructure assisted delivery to specific wetlands) may be important and achievable in a very dry scenario to protect core wetland habitats and avoid critical habitat loss

Water resource availability scenario: Dry – Maintain

Broad management priorities	Management strategies for achieving priorities
Support the survival & viability of threatened species & communities **Maintain refuges** **Maintain environmental assets & ecosystem functions** **Avoid unnaturally prolonged dry periods between flow events** **Provide small to medium sized flow events that have recently had lower than ideal frequency** **Support longitudinal connectivity for functional processes & a range of flora & fauna**	Allow dry down consistent with historical wetting-drying cycles Sustain key in channel pools, instream habitat & core wetland areas[107] Provide freshes to channels & core wetlands where possible at ecologically relevant times Provide low flows to relieve severe unnatural prolonged dry periods & support suitable water quality

Table 16 Priority objectives and flow categories in a dry resource availability scenario

Priority objective	Flow categories								
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank[109]	Medium Overbank	Large Overbank /Wetland
NF1: No loss of native fish species	X	X	X	X			X		
NF2: Maintain the distribution & abundance of short to moderate-lived generalist native fish			X	X					
NF3: Maintain the distribution & abundance of short to moderate-lived floodplain specialist native fish			X	X	X	X	X		
NF4: Maintain native fish population structure for moderate to long-lived flow pulse specialist native fish			X	X	X				
NF5: Maintain native fish population structure for moderate to long-lived riverine specialist native fish			X	X	X				
NF6: Maintain the abundance of mature (harvestable sized) golden perch & Murray Cod			X	X	X				
NV1: Maintain the extent & viability of non-woody vegetation communities occurring within channels	X	X	X	X	X				
NV2a: Maintain the extent & viability of non-woody vegetation communities occurring in core wetlands					X	X	X		

[109] Small overbank flows (in most cases infrastructure-assisted delivery to core wetlands via pumping, siphons, wetland regulators or weir pool raising) may be important and achievable in a dry scenario to protect core wetland habitats and avoid critical habitat loss.

Priority objective	Flow categories								
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank[109]	Medium Overbank	Large Overbank /Wetland
NV3: Maintain the extent & condition of river red gum communities closely fringing river channels					X	X	X		
NV4a: Maintain the extent & condition of river red gum forests						X	X		
WB5: Maintain the extent & improve condition of waterbird habitats					X	X	X		
EF1: Protect a diversity of refugia across the landscape	X	X	X	X			X		
EF2: Maintain quality instream, floodplain & wetland habitat	X	X	X	X	X		X		
EF3a: Provide movement & dispersal opportunities within catchments			X	X	X				
EF4: Support instream productivity				X					
EF5: Support nutrient, carbon & sediment transport along channels				X					
EF6: Support groundwater conditions to sustain groundwater-dependent biota				X					
EF7: Increase contribution of flows to the South Australian River Murray				X	X				
OS1: Maintain species richness & distribution of flow-dependent frog communities		X	X	X			X		
OS3a: Maintain the number of wetland sites occupied by the threatened southern bell frog							X		
OS3b: Maintain the number of wetland sites occupied by the threatened Sloane's froglet							X		
OS4: Maintain water-dependent species richness		X	X	X	X		X		

Water resource availability scenario: Moderate – Recover

Broad management priorities	Management strategies for achieving priorities
Enable growth, reproduction & small-scale recruitment for a diverse range of flora & fauna **Support ideal event frequencies, prioritising EWRs that have recently has long inter-event periods or lower than ideal frequency** **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 lateral connectivity with low-lying wetlands** **Support longitudinal connectivity & end of system flows** **Set aside water for use in drier years**	Provide freshes & bankfull flows to channels where possible at ecologically relevant times[110] Improve condition of key off channel waterholes[1] Build on natural events to provide wetland & floodplain inundation at ecologically relevant times Provide flows to systems that are cut off from natural flows Consider carrying over water to support water use in drier years

Table 17 Priority objectives and flow categories in a moderate resource availability scenario

Priority objectives	Flow categories								
	Cease-to-flow	Very Low Flow	Baseflow	Small	Large Fresh	Bankfull	Small Overbank[111]	Medium overbank[112]	Large Overbank
NF1: No loss of native fish species		X	X	X	X		X		
NF2: Increase the distribution & abundance of short to moderate-lived generalist native fish			X	X	X	X	X		
NF3: Increase the distribution & abundance of short to moderate-lived floodplain specialist native fish			X	X	X	X	X		

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

[111] Managed river flows, natural events or infrastructure-assisted delivery to key wetland and floodplain assets. Note that many objectives such as native fish dispersal and recruitment, dispersal of other aquatic biota, productivity, nutrient/carbon transport and large-scale waterbird breeding and recruitment are difficult or impossible to achieve with infrastructure-assisted delivery alone. This mode of water delivery lacks the system-scale lateral and longitudinal connectivity between rivers and floodplains required to achieve many ecological objectives.

[112] Natural events or infrastructure-assisted delivery to higher-elevation wetland and floodplain assets if there has been a run of dry years leading up to the Moderate Availability Scenario year and maximum inter-event periods have been (or are close to be) exceeded. For example, it has been 4-5 years since the last medium size overbank event meaning that river red gum woodland communities and ephemeral understorey non-woody vegetation communities require watering to avoid decline in condition. See note above about the limitations of infrastructure assisted delivery.

Priority objectives			Cease-to-flow	Very Low Flow	Baseflow	Small	Large Fresh	Bankfull	Small Overbank[111]	Medium overbank[112]	Large Overbank
			Flow categories								
NF4: Improve native fish population structure for moderate to long-lived flow pulse specialist native fish					X	X	X	X	X		
NF5: Improve native fish population structure for moderate to long-lived riverine specialist native fish					X	X	X	X	X		
NF6: A 25% increase in abundance of mature (harvestable sized) golden perch & Murray Cod					X	X	X	X	X		
NF7: Increase the prevalence &/or expand the population of key short to moderate-lived floodplain specialist native fish into new areas					X	X	X	X	X		
NF8: Increase the prevalence &/or expand the population of key moderate to long-lived riverine specialist native fish into new areas					X	X	X	X	X		
NF9: Increase the prevalence &/or expand the population of key moderate to long-lived flow pulse specialist native fish into new areas					X	X	X	X	X		
NF10: Increase the prevalence &/or expand the population of key moderate to long-lived diadromous native fish species into new areas							X	X	X		
NV1: Maintain the extent & viability of non-woody vegetation communities occurring within channels					X	X	X	X			
NV2a	Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains	Wetland plants					X	X	X		
NV2b		Ephemeral understorey plants					X	X	X		
NV3: Maintain the extent & maintain or improve the condition of river red gum communities closely fringing river channels							X	X	X		
NV4a	Maintain the extent & maintain or improve the condition of native woodlands & shrublands	RRG-Forest						X	X		
NV4b		RRG-Woodlands							X	X	
NV4c		Black box							X	X	
NV4e		Lignum								X	
WB1: Maintain the number & type of waterbird species								X	X		
WB2: Increase total waterbird abundance across all functional groups								X	X		
WB3: Increase opportunities for non-colonial waterbird breeding								X	X		
WB4: Increase opportunities for colonial waterbird breeding								X	X		
WB5: Maintain the extent & improve condition of waterbird habitats							X	X	X		

Priority objectives	Flow categories							
	Cease-to-flow	Very Low Flow	Baseflow	Small	Large Fresh	Bankfull	Small Overbank[111]	Medium overbank[112]	Large Overbank
EF1: Provide & protect a diversity of refugia across the landscape			X	X	X	X	X		
EF2: Create quality instream, floodplain & wetland habitat			X	X	X	X	X		
EF3a Provide movement & dispersal opportunities within-catchments			X	X	X	X	X		
EF3b Provide movement & dispersal opportunities between catchments					X	X	X		
EF4: Support instream & floodplain wetland productivity					X	X	X		
EF5: Support nutrient & carbon transport along channels, & between channels & floodplains/wetlands					X	X	X		
EF6: Support groundwater conditions to sustain groundwater-dependent biota					X	X	X		
EF7: Increase contribution of flows to the South Australian River Murray			X	X	X	X	X		
OS1: Maintain species richness & distribution of flow-dependent frog communities			X	X	X	X	X		
OS2: Maintain successful breeding opportunities for flow-dependent frog species							X		
OS3a: Maintain & increase number of wetland sites occupied by the threatened southern bell frog							X		
OS3b: Maintain & increase number of wetland sites occupied by the threatened Sloane's froglet					X	X	X		
OS4: Maintain water-dependent species richness			X	X	X	X	X		

Water resource availability scenario: Wet – Improve

Management priorities	Management strategies for achieving priorities
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**	Build on natural events to provide wetland & floodplain inundation at ecologically relevant times[4] Protect naturally occurring floodplain inundating events & high flow connectivity with the Murray, Edward-Wakool & lower Darling river systems. Carry over water to support water use in drier years

Table 18 Priority objectives and flow categories in a wet resource availability scenario

Priority objectives	Flow categories								
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank	Medium overbank	Large Overbank
NF1: No loss of native fish species		X	X	X	X		X		
NF2: Increase the distribution & abundance of short to moderate-lived generalist native fish			X	X	X	X	X		
NF3: Increase the distribution & abundance of short to moderate-lived floodplain specialist native fish			X	X	X	X	X		
NF4: Improve native fish population structure for moderate to long-lived flow pulse specialist native fish			X	X	X	X	X		
NF5: Improve native fish population structure for moderate to long-lived riverine specialist native fish			X	X	X	X	X		
NF6: A 25% increase in abundance of mature (harvestable sized) golden perch & Murray Cod			X	X	X	X	X		
NF7: Increase the prevalence &/or expand the population of key short to moderate-lived floodplain specialist native fish into new areas			X	X	X	X	X		
NF8: Increase the prevalence &/or expand the population of key moderate to long-lived riverine specialist native fish into new areas			X	X	X	X	X		
NF9: Increase the prevalence &/or expand the population of key moderate to long-lived flow pulse specialist native fish into new areas			X	X	X	X	X		
NF10: Increase the prevalence &/or expand the population of key moderate to long-lived diadromous native fish species into new areas					X	X	X		

Priority objectives	Flow categories								
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank	Medium overbank	Large Overbank
NV1: Maintain the extent & viability of non-woody vegetation communities occurring within channels			X	X	X	X			
NV2a Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains: Wetland plants					X	X	X		
NV2b Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains: Ephemeral understorey							X	X	X
NV3: Maintain the extent & improve the condition of river red gum communities closely fringing river channels					X	X	X		
NV4a Maintain the extent & improve the condition of native woodlands & shrublands: RRG forest							X	X	
NV4b Maintain the extent & improve the condition of native woodlands & shrublands: RRG woodlands							X	X	X
NV4c Maintain the extent & improve the condition of native woodlands & shrublands: Black box							X	X	X
NV4d Maintain the extent & improve the condition of native woodlands & shrublands: Coolibah								X	X
NV4e Maintain the extent & improve the condition of native woodlands & shrublands: Lignum								X	X
WB1: Maintain the number & type of waterbird species						X	X	X	X
WB2: Increase total waterbird abundance across all functional groups							X	X	X
WB3: Increase opportunities for non-colonial waterbird breeding							X	X	X
WB4: Increase opportunities for colonial waterbird breeding							X	X	X
WB5: Maintain the extent & improve condition of waterbird habitats					X	X	X	X	X
EF1: Provide & protect a diversity of refugia across the landscape		X	X	X	X	X	X	X	X
EF2: Create quality instream, floodplain & wetland habitat		X	X	X	X	X	X	X	X
EF3a: Provide movement & dispersal opportunities within catchment				X	X	X	X	X	X
EF3b: Provide movement & dispersal opportunities between catchments					X	X	X	X	X
EF4: Support floodplain productivity							X	X	X
EF5: Support nutrient & carbon transport along channels, & between channels & floodplains/wetlands					X	X	X	X	X
EF6: Support groundwater conditions to sustain groundwater-dependent biota					X	X	X	X	X
EF7: Increase contribution of flows to the South Australian River Murray				X	X	X	X	X	X
OS1: Maintain species richness & distribution of flow-dependent frog communities						X	X	X	X
OS2: Maintain successful breeding opportunities for flow-dependent frog species						X	X	X	X

Priority objectives	Flow categories								
	Cease-to-flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank	Medium overbank	Large Overbank
OS3a: Increase number of wetland sites occupied by the threatened southern bell frog							X	X	X
OS3b: Increase number of wetland sites occupied by the threatened Sloane's froglet						X	X	X	X
OS4: Maintain water-dependent species richness			X	X	X	X	X	X	X

6.2 Water management during ecologically critical water quality incidents and extreme conditions

The quantity and quality of water are important drivers of ecological processes and contribute to the overall health of a waterway. Physical and chemical properties such as temperature, pH, electrical conductivity, algal blooms, heavy metals, pesticides, and dissolved oxygen affect the biology and ecology of aquatic plants and animals, especially when outside tolerable levels (Watson *et al.* 2009).

Insufficient water or water of poor quality can impact all water users, including water used for crops or livestock, recreational activities, and drinking. The responsibility for managing water to prevent or reduce the severity of water quality issues or during extreme conditions therefore lies with all users.

The effective management of water quality incidents relies on the timely access to monitoring information at key sites and the identification of risk factors. Whilst environmental water may be used in certain instances to provide refuge habitat, there is insufficient environmental water to avoid, mitigate or offset water quality issues in NSW rivers, nor is it the responsibility of environmental water managers to do so.

Table 19 and Table 20 describe critical water quality incidents and extreme conditions respectively, and recommended management strategies for environmental water managers. In these two instances, the management priorities of water managers are to:

1. avoid irretrievable damage or catastrophic events
2. avoid critical loss of species, communities and ecosystems
3. protect critical refuges
4. maximise the environmental benefits of all water in the system.

For a more detailed description of the roles and responsibilities for each critical incident stage, please refer to the *NSW Murray and Lower Darling Surface Water Resource Area Incident Response Guide* (NSW DPIE 2019d).

Table 19 Priorities and strategies for managing water during critical water quality incidents

Critical water quality incident description	Identifying features	Management strategies for achieving priorities
Water quality does not meet Australian and New Zealand Guidelines for Fresh and Marine Water Quality, and is causing or is likely to cause significant impact on aquatic ecosystems[113]	Weir/refuge pools are stratified Water quality sampling and analysis demonstrates unfavourable conditions: • lack of dissolved oxygen[114] • unnatural change in temperature • unnatural change in pH • unnatural change in salinity • excess suspended particulate matter[115] • elevated levels of nutrients[116] • chemical contamination[117]	DPIE-BC will work with the Murray-Lower Darling EWAG to prioritise environmental water needs and DPIE-Water and WaterNSW to ensure that these needs are considered in the management of all water Work with WaterNSW to protect, or if possible, provide baseflows and very low flows[118] to support suitable water quality in rivers and critical refuge pools[119] Sustain critical in-channel refuge pools and instream habitat Use infrastructure-assisted delivery, where possible, to create small-scale refuges of good quality water for native biota[119] Limit exceedance of maximum inter-event periods for floodplain inundating flows to reduce the risk of hypoxic blackwater events

Table 20 Priorities and strategies for managing water during extreme conditions

Extreme conditions description	Identifying features	Management strategies for achieving priorities
A critical drought and/or water shortage where only restricted town water supply, stock and domestic and other restricted high priority demands can be delivered	Very low to no natural or regulated flows resulting in disconnected pools Limited water held in storages Limited ability to deliver water for critical human needs WSP may be suspended	DPIE-BC will work with the Murray-Lower Darling EWAG to prioritise environmental water needs and DPIE-Water and WaterNSW to ensure that these needs are considered in the management of all water Sustain critical in-channel refuge pools and core wetland areas Work with WaterNSW to protect, or if possible, provide very low flows or replenishment flows[118] to relieve severe unnatural prolonged dry periods and support suitable water quality in critical refuge pools[119]

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113 Description of the types of water quality degradation, their main causes, and where they are likely to occur in the Murray-Lower Darling catchment can be found in the Murray-Lower Darling Surface Water Quality Management Plan in the WRP (DPIE-Water in prep)

114 Dissolved oxygen levels should be high enough to prevent the asphyxiation of respiring organisms, typically >4mg/L

115 Excess particulate matter may be identified through poor optical properties of waterbodies, the smothering of benthic organisms, or the reduction in photosynthesis (which will inhibit primary production)

116 May lead to nuisance growth of aquatic plants

117 Diffuse or point source pollutants may have lethal or sub-lethal effects on aquatic biota

118 As described in the relevant EWRs in the LTWP

119 Natural flows, operational water, PEW and water quality allowances (where they exist) should be used in the first instance before considering the use of HEW

6.3 Protection of ecologically important flow categories in unregulated planning units

In areas where water cannot be delivered through a regulating structure, the only means of protecting environmentally important flows is through rules in the WSPs for the *Murray Unregulated and Alluvial Water Sources* and the *Lower Murray-Darling Basin Unregulated and Alluvial Water Sources*. Table 21 sets out potential management strategies that could be implemented in the WSPs to ensure important flows are protected. Many of these strategies are consistent with the NSW macro planning approach for pools (NSW Office of Water 2011) which recommends that water access rules for in-river and off-river (wetland) pools be reviewed and alternative rules considered where moderate or high risks to instream environmental values are identified.

Part B of the LTWP identifies unregulated planning units where the WRP Risk Assessment (NSW DPIE, 2019a) has identified one or more flow categories as being at medium to high risk. The LTWP recommends specific management strategies from Table 21 to mitigate these risks in each of these planning units based on the level of risk, which flow categories are at risk and characteristics of extractive water use or hydropower operations.

In areas where flows are affected by the Snowy Mountain Scheme (Upper Murray, Tooma and Swampy Plains water source planning units), environmental water entitlements cannot be delivered under existing arrangements and there are no relevant WSP rules. Protecting environmentally important flows can occur through rules in the Snowy Water License which regulates Snowy Hydro's operation of the Snowy Mountain Scheme, however these rules are currently limited in their scale and scope and do not apply to the upper Murray, Tooma or lower Swampy Plains rivers. Table 19 sets out some additional strategies to protect environmentally important flows in these rivers.

Table 21 Potential management strategies to protect ecologically important flows in unregulated planning units

Potential management strategies
• Investigate opportunities to reduce extraction pressure on in-stream flows in water sources with moderate to high levels of impact within five years (consistent with the NSW macro planning approach for pools, NOW 2011). Measures to be considered include the following:
○ Consider reviewing existing rules to ensure that visible flow is maintained downstream of extraction points.
○ Where a cease-to-pump (CtP) rule currently exists, consider reviewing the threshold.
○ Where no CtP rule currently exists, consider introducing a CtP rule (relating to a flow or water level gauge)
○ Consider implementing a commence-to-pump threshold that is higher than the cease-to-pump (CtP) threshold.
○ Consider installing water level gauges at or near extraction sites
○ Consider installing river flow gauges on ungauged streams with extraction sites
○ Consider rostering landholder water access
○ 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 WSPs for the *Murray Unregulated and Alluvial Water Sources* and the *Lower Murray-Darling Basin Unregulated and Alluvial 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.

Potential management strategies
• 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 (PPMs) which provide for delivered environmental water to be protected. It is also recommended by the Matthews reports (2017a, b).
• For water access licences on lagoons (wetlands) 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.
• For upper Murray catchment planning units affected by hydropower releases from the Snowy Scheme, work collaboratively with Snowy Hydro and DPIE-Water to investigate opportunities to: ○ implement more natural rates of rise & fall in flow downstream of storages on the upper Murray, lower Swampy Plains and Tooma rivers (especially during the nesting season for riverine specialist native fish (mid Sep to Nov) in the upper Murray River); ○ enable ordering of River Murray Increased Flows (RMIF) environmental water entitlements directly from Khancoban Pondage (currently only possible to order downstream of Hume Dam); or at least shape the releases from Khancoban to mimic natural events, where practicable.

7. Going forward

7.1 Cooperative arrangements

River operations to benefit the environment

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 13) 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 operational, consumptive or stock and domestic deliveries to achieve better flow regimes for the environment
- optimise water releases from Hume and Khancoban Dams to mimic natural rates of rise and fall
- consider environmental needs in the management of weir pools.

Despite the advantages of coordinated use of held and planned environmental water, there is insufficient water available from these sources alone to meet the water needs of the environment. Coordinating deliveries of held environmental water 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 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 many EWRs, 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 DPIE-BC, DPIE-Water, WaterNSW and MDBA River Operations 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 arrangements

Managing water for the environment at the catchment-scale requires cooperation between stakeholders. Such cooperative arrangements ensure that all water in the system can be managed in a coordinated way that maximises environmental outcomes, and that the receiving environment is accessible and supported by appropriate management.

Water for the environment in the NSW Murray–Lower Darling is managed cooperatively by DPIE-BC and DPIE-Water in NSW, together with CEWO, MDBA (River operations and The Living Murray Program), the Victorian Environmental Water Holder (VEWH) and the South Australian Department of Environment and Water (SA DEW).

Complementary natural resource management

To achieve the LTWP's 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 water-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 and community groups that ensure adequate stewardship of environmental assets are essential to the success of this LTWP. A priority action from this LTWP is to secure and formalise the continuity of these arrangements with relevant landholders and agencies.

Cooperative investment opportunities

A number of significant investment priorities have been identified in the Murray–Lower Darling catchment (Table 22). 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, DPIE will seek opportunities to build links and partnerships to support implementation of projects that will contribute to the ecological objectives of the LTWP.

Figure 29 Wetland in the Lower Murray
Photo: John Spencer

Table 22 Investment opportunities to improve environmental outcomes from water management in the Murray–Lower Darling catchment

Investment opportunity	Description	Potential project partners
Engagement with Traditional Owners	Traditional Owners hold unique knowledge about the values and requirements of the Murray-Lower Darling. 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.	DPIE
Measures to address flow constraints **(as envisaged by the Constraints Management Strategy MDBA 2013)**	Upgrade low level bridges, roads and private creek crossings and negotiate management agreements with private landholders, including in the Mid Murray and Edward–Wakool systems to increase the regulated flow limits at key gauges along the Murray River from Hume Dam to the Wakool River junction (current limits are 25,000 ML/d at Doctors Point and 15,000 ML/d at d/s Yarrawonga Weir). This will allow environmental water managers to meet large fresh, bankfull & small overbank environmental watering requirements, to support native vegetation condition in wetlands and low-lying floodplains; native fish dispersal, breeding and recruitment; waterbird condition and breeding; frog breeding and important ecosystem functions such as primary productivity, and lateral and longitudinal connectivity.	DPIE-Water, MDBA, landholders, LLS
Restore wetland habitats	Undertake a range of measures to restore the habitat of river-connected wetlands to provide critical breeding and recruitment habitat for native fish (especially floodplain specialists). Restoration requires: • improving wetland-river connectivity (upgrade of regulators, removal of block banks, lowering of sills) • carp control through installation of carp screen on inlet/outlets and drying of wetlands to remove or limit carp prior to restoration • restoration of native wetland vegetation (requires prior remove of carp, possible transplantation and appropriate watering regime) • development of appropriate watering regimes and management plans for operating and maintaining wetland infrastructure. Priority sites • Wetlands along the Murray River from Hume to Yarrawonga – this reach has some of the largest and best condition wetlands in the southern connected basin although many are in a degraded condition. The last reported locations of threatened floodplain specialist native fish (flathead galaxias and pygmy perch) occur in this reach. • Edward–Wakool system – e.g. Mutton Gut Lagoon, Moonya Lagoon, Merran Creek	DPIF, LLS, Murray–Lower Darling Wetlands Working Group

<table>
<tr><th>Investment opportunity</th><th>Description</th><th>Potential project partners</th></tr>
<tr><td></td><td>Lower Murray – Euston Lakes (potential waterbird breeding and fish recruitment site), Wee Wee Creek, Murrumbidgee–Murray Junction Wetlands & the Lock 7 to 9 floodplain, including the Carrs-Cappits-Bunberoo creek system.</td><td></td></tr>
<tr><td>Remove or upgrade low level weirs</td><td>Continue ‘Assessment to Barriers’ program to identify low head weirs that create barriers and blockages to flow and fish passage. Remove or upgrade weirs to allow fish passage and support longitudinal connectivity of flow.

Priority weirs include: Widgee Weir (upper Wakool River), weirs on Bookit and Merribit creeks, weirs on Tumudgery and Reed Beds creeks in the Edward–Niemur river system, 183 Dam on the Darling Anabranch</td><td>WaterNSW, DPIF</td></tr>
<tr><td rowspan="3">Upgrade regulators to improve flow connectivity and fish passage

Examples include:</td><td>Millewa forest regulators

Upgrade regulators to automatic lay flat gates to improve operational efficiency and fish passage. Lower the commence-to-flow threshold and clear sediment build up. Currently these regulators are manually operated undershot gates, which are a risk to small fish. Some upgrades already covered by the proposed SDL supply measure project for Millewa forest but other regulators upstream of Picnic point are not.</td><td>WaterNSW</td></tr>
<tr><td>Niemur offtake regulator

Replace the existing Niemur offtake regulator on the Edward River with a contemporary structure to allow more efficient and effective delivery of baseflows and freshes to the Niemur River. The existing commence-to-flow threshold of ~700 ML/d (Edward River d/s Stevens Weir) means that baseflows (BF1) in the Murray River (4000 ML/d) and Edward River (~600 ML/d) typically do not connect through to the Niemur River. The sill of the Niemur offtake regulator should be lowered to stream bed level to allow connectivity at flows of 800 ML/d at Stevens Weir.</td><td>WaterNSW</td></tr>
<tr><td>Lake Victoria inlet and outlet regulators

Identification of the most appropriate structures and installation of fishways at the Lake Victoria inlet regulator on Frenchmans Creek and the Lake Victoria outlet regulator on the Rufus River – to facilitate fish passage between the Murray River and Lake Victoria and Frenchmans Creek floodplain system. The proposed fishways will also complement the upgrade of structures along the Carrs, Cappitts and Bunberoo Creeks by improving fish passage and increasing availability of floodplain nursery areas. Priority riparian and floodplain vegetation communities are also influenced by flow rates within Frenchmans Creek.</td><td>WaterNSW, SA Water, MDBA</td></tr>
</table>

Investment opportunity	Description	Potential project partners
	Back Creek (connects to Colligen Creek in the Edward–Wakool system) Upgrade of temporary regulator to a permanent structure in Back Creek would exclude high summer flows, reduce the amount of time creek is dry and ensure annual inundation.	WaterNSW
Remove block banks and other barriers to flow and fish passage **Examples include:**	Undertake audit of floodplain structures & develop appropriate compliance and mitigation programs	DPIE-BC, DPIE-Water
	Jimaringle and Cockran Creeks system Remove block-banks, modify restrictive culverts and install new escape outlets throughout the Jimaringle Cockran Creeks system to enable more efficient and effective delivery of environmental water, particularly in the middle section, which is currently isolated from Colligen Creek or backup flows from the Niemur River. Improved management of flows will assist in reinstating wetting and drying cycles and lead to positive outcomes for instream and riparian vegetation communities and fauna communities. Regular flows throughout the system will also assist with management of highly saline groundwater intrusions and acid sulphate soils in priority areas.	DPIE, WaterNSW
	Tuppal Creek Complete Stage 2 of the Tuppal Creek Restoration Project by replacing block-banks and restrictive culverts with fish friendly structures to enable more efficient and effective delivery of water for the environment. Increasing the flow capacity and removing barriers will assist to improve the creeks health, promote food productivity and provide habitat for wildlife including native fish.	DPIE
	Carrs, Cappits and Bunberoo Creeks (connected to Frenchmans Creek and lower Murray River) Upgrade or remove existing in-channel structures to improve flow connectivity, fish passage and reinstate wetting and drying phases for ephemeral streams and adjoining wetlands located on the Ta-Ru Lands floodplain (formerly the Moorna State Forest, which was recently handed back to its traditional owners, the Barkindji people). Flow diversions from the Murray River through Frenchmans Creek to Lake Victoria provide good opportunities to divert water into the creeks and wetlands more frequently and efficiently, which will enable connectivity between the two system, facilitating carbon and nutrient exchange processes, providing fast flowing habitat for native fish and improving floodplain vegetation communities.	WaterNSW, Ta-Ru Lands Board of Management, DPIE-Water, MDBA, SA Water

Investment opportunity	Description	Potential project partners
	Other priority sites • Private property wetlands • Wee Wee Creek near the Murray–Wakool river junction • Coppingers Swamp (Millewa Forest)	
Improve deliverability of flows to ephemeral creeks	Install new escape outlets on existing irrigation infrastructure to allow delivery of environmental water into ephemeral creeks. Priority sites include Jimaringle, Cockrans, Gwynnes (JCG) creeks and Yarrein Creek.	Murray Irrigation, WaterNSW
Habitat mapping of river sites targeted for recovery	Undertake habitat mapping and hydraulic modelling of key rivers and streams to better understand environmental watering requirements and therefore maximise ecological outcomes of watering. Habitat mapping involves bathymetric surveys and land-based geomorphic surveys of river banks and other important in-channel features such as benches, bars, snags and lateral channels connecting to wetlands. This data can be used to determine commence-to-fill thresholds for wetlands and in-channel benches. The inundation of these features is critical to ecological outcomes such as fish recruitment and primary productivity. The survey data can also be used build hydraulic models of representative river reaches, which can be used to understand flow hydraulics, e.g. what flows are required to achieve fast velocities to trigger native fish movement and breeding or to maximise the availability of slackwater (zones of slow flowing water at channel margins) at critical times for feeding and recruitment of native fish and other aquatic fauna.	DPIF, CEWO, DPIE, MDBA
Investigate improved flow regime in the upper Murray River above Lake Hume	Flows in the Murray River upstream of Lake Hume are highly impacted by dam releases from Khancoban Pondage, which is managed for hydropower generation as part of the Snowy Hydropower Scheme. Key changes to the flow regime include extreme variability in flows, rapid rates of rise and fall and a reduction in the frequency of higher flows. Consider reviewing timing and frequency of releases from Khancoban pondage to reduce flow variability and improve environmental outcomes. For example, consider implementing limits on rates of rise and fall at key Murray River gauges (Murray at Bringenbong and Murray at Jingellic) to reduce impacts on Murray cod nesting, reduce the risk of bank erosion, negative impacts on in-channel vegetation and stranding of biota.	DPIE-Water, Snowy Hydro
Increase the number of gauges in key locations	Install or upgrade existing gauges key unregulated watercourses in upper Murray and unregulated streams in Mid Murray. In unregulated systems where no gauges exist, commence-to-pump rules are often unable to specify flow rates, which is important to protect critical low & baseflows. Gauges should be installed to allow better flow monitoring in these locations.	DPIE-Water, WaterNSW

Investment opportunity	Description	Potential project partners
Improve understanding of climate change impacts, thresholds & adaptive management strategies	Potential changes in weather, bushfires & erosion due to climate change are outlined in Table 14. This task involves assessing the potential impact of these changes on the environmental assets of the Murray–Lower Darling WRPA, identifying management adaptations to respond to change & developing indicators to trigger responses.	DPIF, NPWS, DPIE-Water, MDBA
Improve protection of important native vegetation communities from clearing	Native vegetation clearing is a major threat to the Murray–Lower Darling catchment's resilience. The protection of native vegetation requires good knowledge, the cooperation of various stakeholders, and multiple different projects, which include: • habitat mapping to identify riparian and aquatic habitat condition and prioritise reaches for management actions in partnership with LLS and landholders, to develop formal agreements and unified strategies • work with relevant state and federal government departments and other organisations to identify and protect core wetland vegetation communities • implement grazing strategies required to protect and restore wetland vegetation, bank stability and adequate water quality in collaboration with LLS and landholders • provide incentives to landholders to improve management of wetlands on private land • commence wetland restoration activities.	LLS, NPWS, CEWO, DPI, landholders
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: • 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.	Murray–Lower Darling Wetlands Working Group, LLS, NPWS, CEWO, DPIE-Water, DPIF, landholders, Biodiversity Conservation Trust
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 and addressing priority barriers to fish passage in the catchment • the implementation of pump screening methods to prevent entrainment (the entrapment of one substance by another substance) of native fish and eggs • works to achieve instream habitat improvement including re-snagging and aquatic revegetation (re-snagging especially in lower Murray River weir pools)	DPIF, LLS

Investment opportunity	Description	Potential project partners
	• instream habitat mapping to help identify high-risk and priority refuge areas • development and implementation of a carp management strategy • reintroduction, translocation and stocking of threatened fish species in key locations.	
Reduce the spread of pest plant and animal species	See also strategies identified in Table 13 • ensure ongoing investment into the control of lippia, sagittaria & water hyacinth and other invasive plant species across the catchment • prioritise reaches for weed management with Local Land Services, NPWS, Victorian Catchment Management Authorities and landholders • implement priority pest species management actions	LLS, landholders, land managers, NPWS
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 and floodplain creek systems, 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.	DPIE, DPI Fisheries
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.	DPIE
Knowledge gaps-vegetation mapping	Improved vegetation mapping of riparian and lower floodplain areas of the Murray-Lower Darling catchment would assist in management of these areas and for tracking progress against of LTWP targets for native vegetation. - Particular knowledge gaps exist for non-woody vegetation and lignum shrublands (all PUs) - Extent, classification (plant community type) and condition of native vegetation on the lower Murray and Darling river floodplains, Darling Anabranch floodplain and in and around Menindee Lakes.	LLS, DPIE

7.2 Measuring progress

Monitoring, evaluating and reporting (MER) and adaptive management are integral parts of the environmental water management process that inform planning and operational decisions. Monitoring how water moves through the system and how the environment responds to watering events informs ongoing improvements to water management. This information will also assist in progressing adaptive management of environmental water and inform revisions of this LTWP every five years.

Monitoring and evaluating environmental water management in the Murray–Lower Darling catchment draws on contributions from Australian and NSW Government agencies, as well as university and other research institutions.

The DPIE-BC Environmental Water Monitoring and Evaluation Program (MER Program) provides the structure within which the various monitoring activities come together to provide a broad evaluation of how the environment is responding to environmental water management. The MER program has three core outcomes: (i) measurement of LTWP outcomes (ii) improved decision making for environmental water planning and delivery, and (iii) improved institutional arrangements. To do this, the DPIE MER Program will:

- collate and adopt relevant environmental watering and wetland management objectives, including those within LTWPs
- establish a program that will evaluate progress towards achieving outcomes defined within LTWPs
- meet DPIEs obligations for monitoring as stated in high level plans, including the Basin Plan
- develop a strategic plan to address information and monitoring gaps or short-falls
- support continual improvement of DPIE operations through designing an appropriate monitoring program for the provision of high-quality, scientifically-robust information
- collaborate with water delivery partners (particularly the CEWO), MDBA, DPIE-Water, wetland managers, Victorian water managers, other agencies and researchers to value-add to monitoring outcomes and minimise duplication in monitoring efforts
- create increased government and community confidence, awareness and support for environmental water management through increased transparency, community engagement and improved reporting of environmental water outcomes and management
- streamline reporting requirements under WRPs, LTWPs, Schedule 12 of the Basin Plan and the National Partnership Agreement.

The DPIE-BC MER Program is also integrated with DPIE-Water and DPIF MER programs to create a unified approach to delivering Basin Plan and NSW evaluation and reporting requirements. The NSW approach has capitalised on existing MER by retaining the best available scientific knowledge, evidence and analyses to develop this new cohesive program, ensuring credibility, transparency and usefulness of findings.

The NSW 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 built on in a cost-effective and coordinated manner
- DPIEs 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 integrated MER activities for surface water monitoring in each catchment
- monitoring methods manuals that describe research themes (e.g. fish, hydrology, vegetation, water quality, macroinvertebrates, waterbirds). Once developed, these manuals will contain specific information relating to survey, data handling and analysis techniques, conceptual models, the location of survey sites and cooperative research arrangements.

The following principles are used as a foundation for developing this integrated MER Program:

- uses 'SMART' (Specific, Measurable, Achievable, Realistic, Time-bound) objectives
- relies on an agreed program logic
- uses best available knowledge and multiple lines of evidence
- emphasis collaboration and builds on existing programs to improve efficiency and reduce duplication in effort
- offers open access to information
- recognises the influence of externalities.

7.4 Review and update

This LTWP brings together the best available information from a range of 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.

Additional reviews may also be triggered by:

- accreditation or amendment to the WSP or WRP for the Murray–Lower Darling catchment
- revision of the BWS that materially affects this LTWP
- an SDL adjustment
- new information arising from evaluating responses to environmental watering
- new knowledge about the ecology of the Murray–Lower Darling catchment that is relevant to environmental watering
- improved understanding of the effects of climate change and its impacts on the Murray–Lower Darling catchment and inclusion of climate change in Basin Plan processes
- 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 23 Ecological objectives for priority environmental asset in PUs that are regulated or that can be affected by regulated water

	Code	Ecological objective	Mid Murray				Edward-Wakool			Lower Murray						Menindee Lakes		Lower Darling River & Darling Anabranch			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Native fish 	NF1	No loss of native fish species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NF2	Increase the distribution & abundance of short to moderate-lived generalist native fish species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NF3	Increase the distribution & abundance of short to moderate-lived floodplain specialist native fish species		•							•		•								
	NF4	Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NF5	Improve native fish population structure for moderate to long-lived riverine specialist native fish species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NF6	A 25% increase in abundance of mature (harvestable sized) golden perch & Murray cod	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	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)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•
	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)	•	•	•		•		•		•										
	NF9	Increase the prevalence &/or expand the population of key moderate to long-lived flow pulse specialists native fish species into new areas (within historical range)		•	•	•	•	•	•	•	•	•	•	•	•						
	NF10	Increase the prevalence &/or expand the population of key moderate to long-lived diadromous native fish species into new areas		•	•	•				•	•	•	•	•							
Waterbirds 	WB1	Maintain the number & type of waterbird present	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	WB2	Increase total waterbird abundance		•	•		•			•	•	•	•	•	•	•	•	•	•	•	•
	WB3	Increase breeding activity in non-colonial nesting waterbirds		•	•		•				•	•	•	•	•	•	•				•
	WB4	Increase opportunities for colonial waterbird breeding events		•	•		•				•				•	•	•				•
	WB5	Maintain the extent and improve condition of waterbird habitats	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Vegetation 	NV1	Maintain the extent & viability of non-woody vegetation communities occurring within or closely fringing river channels	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NV2a	Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains (semi-permanent, intermittent, temporal & ephemeral wetlands)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

	Code	Ecological objective	Mid Murray				Edward-Wakool			Lower Murray						Menindee Lakes		Lower Darling River & Darling Anabranch			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	NV2b	Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains (ephemeral understorey vegetation within forests, woodland & open floodplain areas)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NV3	Maintain the extent & maintain or improve the condition of river red gum communities closely fringing river channels	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NV4a	Maintain the extent & maintain or improve the condition of river red gum forest	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NV4b	Maintain the extent & maintain or improve the condition of river red gum woodland	•	•	•	•	•	•	•							•					
	NV4c	Maintain the extent & maintain or improve the condition of black box woodland	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NV4d	Maintain the extent & maintain or improve the condition of coolibah woodland														•	•				
	NV4e	Maintain the extent & maintain or improve the condition of lignum shrubland			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Ecosystem functions	EF1	Provide & protect a diversity of refugia across the landscape	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF2	Create quality instream, floodplain & wetland habitat	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF3a	Provide movement & dispersal opportunities within catchments for water-dependent biota to complete lifecycles	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF3b	Provide movement & dispersal opportunities between catchments for water-dependent biota to complete lifecycles								•	•	•	•	•	•	•	•	•	•	•	•
	EF4	Support instream & floodplain productivity	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF5	Support nutrient, carbon & sediment transport along channels, & exchange between channels & floodplains/wetlands	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF6	Support groundwater conditions to sustain groundwater dependent biota	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF7	Increase NSW Murray-Lower Darling contributions to the South Australian Murray	•	•	•	•				•	•	•	•	•	•	•	•	•	•	•	•
Other species 	OS1	Maintain species richness of flow-dependent frog communities	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	OS2	Maintain successful breeding opportunities for flow-dependent frog species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	OS3a	Maintain & increase number of wetland sites occupied by the threatened southern bell frog		•		•	•	•	•	•	•	•	•	•	•						
	OS3b	Maintain & increase number of wetland sites occupied by the threatened Sloane's froglet	•	•																	
	OS4	Maintain water-dependant species richness	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Table 24 Ecological objectives for priority environmental asset in unregulated planning units

	Code	Ecological objective	Upper Murray (Murray source to Hume dam)												Mid Murray and Edward-Wakool					Lower Murray Darling
			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Native fish 	NF1	No loss of native fish species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NF2	Increase the distribution & abundance of short to moderate-lived generalist native fish species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NF3	Increase the distribution & abundance of short to moderate-lived floodplain specialist native fish species									•	•								
	NF4	Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species		•						•		•	•					•		•
	NF5	Improve native fish population structure for moderate to long-lived riverine specialist native fish species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
	NF6	A 25% increase in abundance of mature (harvestable sized) golden perch & Murray cod		•		•	•	•	•	•	•	•	•	•				•		•
	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)	•	•	•	•	•				•	•	•	•	•					•
	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)	•	•	•	•	•	•	•	•	•	•	•							
	NF9	Increase the prevalence &/or expand the population of key moderate to long-lived flow pulse specialists native fish species into new areas (within historical range)																		
	NF10	Increase the prevalence &/or expand the population of key moderate to long-lived diadromous native fish species into new areas																		
Waterbirds 	WB1	Maintain the number & type of waterbird present																		
	WB2	Increase total waterbird abundance																		
	WB3	Increase breeding activity in non-colonial nesting waterbirds																		
	WB4	Increase opportunities for colonial waterbird breeding events																		
	WB5	Maintain the extent & improve condition of waterbird habitats																		
Vegetation 	NV1	Maintain the extent & viability of non-woody vegetation communities occurring within or closely fringing river channels	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
	NV2a	Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains (semi-permanent, intermittent, temporal & ephemeral wetland)	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	
	NV2b	Maintain the extent & viability of non-woody vegetation communities occurring in wetlands & on floodplains (ephemeral understorey vegetation within forests, woodland & open floodplain areas)	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	

	Code	Ecological objective	Upper Murray (Murray source to Hume dam)												Mid Murray and Edward-Wakool					Lower Murray Darling
			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
	NV3	Maintain the extent & maintain or improve the condition of river red gum communities closely fringing river channels	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	NV4a	Maintain the extent & maintain or improve the condition of river red gum forest		•	•	•				•	•	•	•	•	•		•	•	•	•
	NV4b	Maintain the extent & maintain or improve the condition of river red gum woodland	•	•	•	•	•	•	•		•	•	•	•		•	•	•	•	•
	NV4c	Maintain the extent & maintain or improve the condition of black box woodland															•	•	•	•
	NV4d	Maintain the extent & maintain or improve the condition of coolibah woodland																		•
	NV4e	Maintain the extent & maintain or improve the condition of lignum shrubland												•		•	•	•	•	•
	EF1	Provide & protect a diversity of refugia across the landscape	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF2	Create quality instream, floodplain & wetland habitat	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF3a	Provide movement & dispersal opportunities within catchments for water-dependent biota to complete lifecycles	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
Ecosystem functions	EF3b	Provide movement & dispersal opportunities between catchments for water-dependent biota to complete lifecycles																•		•
	EF4	Support instream & floodplain productivity	•	•	•	•	•	•	•	•	•	•	•	•						
	EF5	Support nutrient, carbon & sediment transport along channels, & exchange between channels & floodplains/wetlands	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF6	Support groundwater conditions to sustain groundwater dependent biota	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	EF7	Increase the contribution of flows into the South Australian lower Murray River																		
	OS1	Maintain species richness of flow-dependent frog communities	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Other species	OS2	Maintain successful breeding opportunities for flow-dependent frog species	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	OS3a	Maintain & increase number of wetland sites occupied by the threatened southern bell frog																		
	OS3b	Maintain & increase number of wetland sites occupied by the threatened Sloane's froglet																		
	OS4	Maintain water-dependant species richness	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Appendix B. Resource availability scenario

Guidelines for the method to determine priorities for applying environmental water[120]

The assessment of the RAS occurs throughout the water year. The critical information for this assessment is the water availability and the condition of the environment (antecedent conditions). These can be determined with reference to existing data. These data are 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 either: 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 25):
   - 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 25):
   - 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 water resource plan area using all of the historical climate condition data that are available (in Table 25 this is the surface water availability percentile)

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

Table 25 Default matrix for determining the Resource Availability Scenario

Surface water availability	Antecedent conditions				
	Very dry (0–15%)	Dry (16–45%)	Medium (46–60%)	Wet (61–85%)	Very wet (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

[120] As outlined by the MDBA at www.mdba.gov.au/publications/policies-guidelines/guidelines-method-determine-priorities-applying-environmental-water