DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

Lachlan Long Term Water Plan

Part A: Lachlan catchment

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Cover photo: Ibis chicks in nests in Booligal Wetlands, Vince Bucello

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Acknowledgement of Traditional Owners

The NSW Department of Planning, Industry and Environment pays its respect to the Traditional Owners of the Murray-Darling Basin and their Nations. 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 Lachlan catchment, the Department of Planning, Industry and Environment pays its respects to the Traditional Owners – the Nari Nari, Ngiyampaa, Wiradjuri and Yita Yita Nations – past, present and emerging, as well as those of other Nations for whom this river is significant. We look forward to developing new partnerships and 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 **Nardoo at Booligal Wetlands**
Photo: V Bucello/Midstate Video

Abbreviations

AHIMS	Aboriginal Heritage Information Management System
ASL	Above Sea Level
Basin Plan	Murray-Darling Basin Plan 2012
BCT	Biodiversity Conservation Trust
BF	Baseflow
BK	Bankfull
BWS	Basin-wide environmental watering strategy
CAG	Customer Advisory Group
CAMBA	China–Australia Migratory Bird Agreement
CEWO	Commonwealth Environmental Water Office
CF	Cease-to-flow
DBH	Diameter at breast height
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DPIE	NSW Department of Planning, Industry and Environment
DPIE–BC	NSW Department of Planning, Industry and Environment – Biodiversity and Conservation Division
DOIE–EES	NSW Department of Planning, Industry and Environment – Environment, Energy and Science
DPIE–Water	NSW Department of Planning, Industry and Environment – Water
DPIF	NSW Department of Primary Industries Fisheries
EEC	Endangered ecological community
EWA	Environmental water allowance
EWAG	Environmental Water Advisory Group
EWR	Environmental water requirement
FFDI	Forest Fire Danger Index
GCM	Global Climate Model
GDE	Groundwater-dependent ecosystem
GL/yr	gigalitres per year
ha	hectares
HEW	Held environmental water
JAMBA	Japan–Australia Migratory Bird Agreement
LALC	Local Aboriginal Land Council
LF	Large fresh
LLS	Local Land Services (NSW)
LTWP	Long Term Water Plan
m	metres
m/s	metres per second
MDBA	Murray-Darling Basin Authority

MER	Monitoring, evaluation and reporting
mg/L	milligrams per litre
ML/d	megalitre per day
NPWS	NSW National Parks and Wildlife Services
NRAR	Natural Resources Access Regulator
NSW	New South Wales
OB	Overbank
PCT	Plant community type
PEW	Planned environmental water
RAS	Resource availability scenario
RCM	Regional Climate Model
Risk Assessment	Risk assessment for the Lachlan Surface Water Resource Plan Area
ROKAMBA	Republic of Korea–Australia Migratory Bird Agreement
RRG	River red gum
SDL	Sustainable diversion limit
SF	Small fresh
VF	Very low flow
WL	Wetland inundating flow
WQA	Water quality allowance
WQMP	Water quality management plan
WRP	Water resource plan
WRPA	Water resource plan area
WSP	Water sharing plan

Glossary

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

Cease-to-pump (access rule in WSP)	Pumping is not permitted: • from in-channel pools when the water level is lower than its full capacity • from natural off-river pools when the water level is lower than its full capacity • from pump sites when there is no visible flow. These rules apply unless there is a commence to pump access rule that specifies a higher flow rate that licence holders can begin pumping.
Cold water pollution	The artificial lowering of water temperature that occurs downstream of dams, particularly during warmer months when stratification is more likely to occur. The impact of cold water pollution can extend for hundreds of kilometres along the river from the point of release.
Constraints	The physical or operational constraints that affect the delivery of water from storages to extraction or diversion points. Constraints may include structures such as bridges that can be affected by higher flows, the volume of water that can be carried through the river channel, or scheduling of downstream water deliveries from storage.
Consumptive water	Water that is removed from available supplies without return to a water resource system (such as water removed from a river for agriculture).
Cultural water dependent asset	A place that has social, spiritual and cultural value based on its cultural significance to Aboriginal people. Related to the water resource.
Cultural water dependent value	An object, plant, animal, spiritual connection or use that is dependent on water and has value based on its cultural significance to Aboriginal people.
Discharge	The amount of water moving through a river system, most commonly expressed in megalitres per day (ML/d).
Dissolved Organic Carbon (DOC)	A measurement of the amount of carbon from organic matter that is soluble in water. DOC is transported by water from floodplains to river systems and is a basic building block available to bacteria and algae that are food for microscopic animals that are in turn consumed by fish larvae, small bodied fish species, yabbies and shrimp. DOC is essential for building the primary food webs in rivers and ultimately generates a food source for large bodied fish like Murray cod and golden perch and predators such as waterbirds.
Environmental asset	The physical features that make up an ecosystem and meet one or more of the assessment indicators for any of the five criteria specified in Schedule 8 of the Basin Plan.
Ecosystem 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. Identified ecosystem functions must also meet one or more of the assessment indicators for any of the four criteria specified in Schedule 9 of the Basin Plan.
Ecological objective	Objective for the protection and/or restoration of an environmental asset or ecosystem function. Objectives are set for all priority environmental assets and priority ecosystem functions, and have regard to the outcomes described in the Basin-wide environmental watering strategy.
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) and are able to demonstrate progress towards the objectives and the outcomes described in the Basin-wide environmental watering strategy.
Ecological value	An object, plant or animal which has value based on its ecological significance.

Ecosystem	A biological community of interacting organisms and their physical environment. It includes all the living things in that community, interacting with their non-living environment (weather, earth, sun, soil, climate and atmosphere) and with each other.
Environmental water	Water for the environment. It serves a multitude of benefits to not only the environment, but communities, industry and society. It includes water held in reservoirs (held environmental water) or protected from extraction from waterways (planned environmental water) for the purpose of meeting the water requirements of water dependent ecosystems.
Environmental water requirement (EWR)	An environmental water requirement (EWR, singular) describes the characteristics of a flow event (e.g. magnitude, duration, timing, frequency, and maximum dry period) within a particular flow category (ego small fresh), that are required for that event to achieve a specified ecological objective or set of objectives (e.g. to support fish spawning and in-channel vegetation). There may be multiple EWRs defined within a flow category, and numerous EWRs across multiple flow categories within a Planning Unit. Achievement of each of the EWRs will be required to achieve the full set of ecological objectives for a Planning Unit. The water required to support the completion of all elements of a lifecycle of an organism or group of organisms (taxonomic or spatial), consistent with the objective/target, measured at the most appropriate gauge. It includes all water in the system including natural inflows, held environmental water and planned environmental water.
Flow category	The type of flow in a river defined by its magnitude (e.g. bankfull).
Flow regime	The pattern of flows in a waterway over time that will influence the response and persistence of plants, animals and their ecosystems.
Freshes	Temporary in-channel increased flow in response to rainfall or release from water storages.
Groundwater	Water that is located below the earth’s surface in soil pore spaces and in the fractures of rock formations. Groundwater is recharged from, and eventually flows to, the surface naturally.
Held environmental water (HEW)	Water available under a water access right, a water delivery right, or an irrigation right for the purposes of achieving environmental outcomes (including water that is specified in a water access right to be for environmental use).
Hydrograph	A graph showing the rate of flow and/or water level over time past a specific point in a river. The rate of flow is typically expressed in megalitres per day (ML/d).
Hydrological connectivity	The link of natural aquatic environments.
Hydrology	The occurrence, distribution and movement of water.
Hypoxic Blackwater	Occurs when dissolved oxygen (DO) levels fall below the level needed to sustain native fish and other water dependent species. Bacteria that feed on dissolved organic carbon use oxygen in the water. When they multiply rapidly their rate of oxygen consumption can exceed the rate at which oxygen can be dissolved in the water. As a result, oxygen levels fall and a hypoxic (low oxygen) condition occurs. Dissolved oxygen is measured in milligrams per litre (mg/L). Generally native fish begin to stress when DO levels fall below 4 mg/L. Fish mortality occurs when DO levels are less than 2 mg/L.

Large fresh (LF)	High-magnitude flow pulse that remains in-channel. These flows may engage flood runners with the main channel and inundate low-lying wetlands. They connect most in-channel habitats and provide partial longitudinal connectivity, as some low-level weirs and other in-channel barriers may be drowned out.
Lateral connectivity	The flow linking rivers channels and the floodplain.
Longitudinal connectivity	The consistent downstream flow along the length of a river.
Long Term Water Plan (LTWP)	A component of the Murray–Darling Basin Plan. Long Term Water Plans give effect to the Basin-wide environmental watering strategy (MDBA 2014) relevant for each river system and will guide the management of water over the longer term. These plans will identify the environmental assets that are dependent on water for their persistence, and match that need to the water available to be managed for or delivered to them. The plan will set objectives, targets and watering requirements for key plants, waterbirds, fish and ecosystem functions. 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 (PEW)	Water that is committed or preserved by the Basin Plan, a water resource plan or a plan made under state water management law for fundamental ecosystem health or other specified environmental purposes. This water cannot be taken or used for any other purpose.
Planning Unit	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 environmental asset	A place of particular ecological significance that is water dependent, meets one or more of the assessment indicators for any of the five criteria specified in Schedule 8 in the Basin Plan, and can be managed with environmental water. This includes planned and held environmental water.
Priority ecosystem function	Ecosystem functions that meets one or more of the assessment indicators for any of the four criteria specified in Schedule 9 of the Basin Plan and 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.
Refuge pool	Sections of river channel or waterholes that are deep relative to the rest of the channel which retain water for longer periods of time can provide refuge for aquatic biota during periods of no flow. Refugial waterholes and lakes can also be present in floodplain areas. Not only do these features provide refugial habitat & nursery sites for aquatic life, they are important sinks for nutrients & DOC cycling within the riverine environment.
Refugium	An area in which a population of plants or animals can survive through a period of decreased water availability. Plural is refugia.
Registered cultural asset	A cultural water-dependent asset that is registered in the Aboriginal Heritage Information Management System (AHIMS).

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.
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. These flows can improve DO saturation and reduce stratification in pools.
Water quality management plan (WQMP)	A document prepared by state authorities and accredited by the Commonwealth under the Basin Plan. It forms part of a water resource plan and 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. It forms part of a water resource plan.
Water dependent	An ecosystem or species that depends on periodic or sustained inundation, waterlogging or significant inputs of water for natural functioning and survival.
Wetland inundation flow (WL)	Flows that fill wetlands at flow rates below bankfull or via regulating structures over weeks or sometimes months (i.e. longer than a typical fresh/pulse), or flows that are required to inundate wetlands in areas

where there are very shallow channels or no discernible channels exist (e.g. terminal wetlands).

Summary

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

Over the past 200 years, the natural flow regimes of many rivers, wetlands and floodplains in New South Wales (NSW) have been altered by dams, weirs, floodplain development, and water regulation and extraction. In the case of the Lachlan, the frequency, duration and timing of cease-to-flow periods, low flows and small freshes have experienced the greatest alteration, and the magnitude of large freshes and small overbank flows have been diminished by extraction.

The NSW Government's first Lachlan 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 Lachlan. The LTWP identifies water management strategies for maintaining and improving the long-term health of the Lachlan's riverine and floodplain environmental assets and the ecosystem 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 delivered in the future. It will help water managers and advisory groups, such as the Lachlan Environmental Water Advisory Group (EWAG), provide advice about where, when and how water can be used to achieve agreed long-term ecological objectives. The LTWP also looks at all sources of water and how these can be managed to support environmental outcomes in the catchment.

Background to Long Term Water Plans

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

The *Basin-wide Environmental Watering Strategy* (BWS) (MDBA 2014) and LTWPs are central features of this framework. The BWS establishes long-term environmental outcomes and targets for the Basin and its catchments. LTWPs, which apply to water resource plan areas (WRPA) (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 Lachlan Long Term Water Plan

The Lachlan LTWP is one of nine plans being developed by the NSW Department of Planning, Industry and Environment, Biodiversity and Conservation Division (DPIE–BC) to cover the NSW portion of the Murray-Darling Basin. Development of the LTWP has involved five main steps:

1. undertaking a comprehensive **stocktake** of water dependent native fish, birds and plant species and the river processes that underpin a healthy river system across the catchment to identify priority environmental assets and priority ecosystem functions.

2. determining specific and quantifiable **objectives and targets** for the priority assets and functions in the Lachlan catchment.
3. 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.
4. identifying potential **management strategies** to meet environmental water requirements.
5. 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 10 chapters in two parts, with accompanying appendices.

Environmental values of the Lachlan catchment

The Lachlan catchment supports a range of water dependent ecosystems, including instream aquatic habitats, riparian forests, and floodplain watercourses, woodlands and wetlands. The aquatic ecological community in the natural drainage system of the lower Lachlan River is listed as an endangered ecological community (EEC) in NSW. The lowland Lachlan River EEC provides a wide range of habitats for fish and invertebrates, including pools, runs or riffles, backwaters and billabongs, in-stream woody habitat, and aquatic plants. The Lachlan River floodplain also provides a mosaic of habitat types, including permanent and temporary wetlands, and terrestrial habitats (NSW DPI 2006).

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

Extensive local, scientific and, where possible, traditional knowledge about the Lachlan 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 Lachlan's environmental values closely aligns with material in the NSW Department of Planning, Industry and Environment's *Risk assessment for the Lachlan Surface Water Resource Plan Area* (NSW DPIE–Water 2019c).

Water for the environment

The Lachlan LTWP contains ecological objectives and targets for priority environmental assets and ecosystem functions in the Lachlan catchment. Priorities are defined in the Basin Plan 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, river connectivity, ecosystem functions, frogs and ecosystem functions. Objectives and targets for improving connectivity along the catchment, between rivers and floodplain areas, and with the Lachlan are also included because lateral and longitudinal connectivity is vital to achieving Basin-wide outcomes. 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 can be expected from implementation of the Basin Plan in the rivers, wetlands, floodplains and watercourses of the Lachlan 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 Lachlan LTWP

Broad outcomes	Overarching objectives	Example uses of water for the environment to achieve LTWP outcomes and objectives
To maintain the diversity and improve the population of native fish in the catchment	Increase native fish distribution and abundance, and ensure stable population structures	• Provide improved conditions for native fish recruitment and dispersal in the lower Lachlan River and wetlands and Merrowie Creek • Replenish refuge waterholes for native fish
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 and black box communities, lignum shrublands and non-woody wetland vegetation such as common reed and phragmites	• Improve the extent and condition of vegetation in core wetland areas of the Lachlan, including the Great Cumbung Swamp • Improve the condition of river red gum closely fringing river channels
To maintain the diversity of waterbird species and increase their numbers across the catchment	Restore habitat for waterbirds to contribute to recovery of waterbird populations across the Murray-Darling Basin	• Support the successful completion of colonial nesting waterbird breeding • Provide foraging habitat for waterbirds
• To maintain and protect a variety of wetland habitats and support the movement of nutrients throughout the river system	Various objectives relating to instream and floodplain refuge and habitat, supporting productivity and the lifecycles of water dependent biota, and connecting riverine and floodplain systems.	• Restart flows after cease-to-flow conditions in the lower river to reduce the risk of hypoxic blackwater and fish kills • Contribute to improved flows in Lake Brewster and the effluent creeks in the lower Lachlan
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 and platypus and support successful breeding.	• Ensure in-channel flows are within the natural rate of rise and fall to protect platypus burrows and protect feeding and breeding habitats • 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). These include addressing cold water pollution caused by water releases from Wyangala Dam, providing incentives to landholders to conserve riparian, wetland and floodplain vegetation and screening irrigation pumps to protect fish.

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 Lachlan catchment to:

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

Review and update of the Long Term Water Plan

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

- accreditation or amendment to the WSP or WRP for the Lachlan 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 Lachlan catchment that is relevant to environmental watering
- improved understanding of climate change and its impacts on the Lachlan catchment, EWRs and water management
- changes to the river operating environment or the removal of barriers that affect watering strategies
- material changes to river and wetland health, not considered within this LTWP.

Figure 2 The Lachlan River from the air
Photo: P Packard/DPIE

1. Introduction

The Lachlan River in central western NSW, drains a catchment of 8,470,000 hectares (Lachlan CMA n.d.). It has an overall length of approximately 1450 kilometres, flowing from the Great Dividing Range near Goulburn, where elevations reach 1200 metres above sea level (ASL), to the lower Lachlan wetlands including the Great Cumbung Swamp and the Booligal Wetlands (≤80 metres ASL). Major tributary rivers include the Belubula and Abercrombie Rivers, and distributary creeks include Willandra, Middle, Merrowie, Merrimajeel and Muggabah Creeks. The Lachlan River is generally a terminal system and a tributary to the Murrumbidgee River only during periods of higher flows.

The Lachlan River is one of the most naturally variable river systems in Australia. The river is influenced by both northern and southern weather systems, resulting in generally uniform distribution of rainfall throughout the year, but with significant annual variability. There is also a distinct east-west rainfall gradient with most rain falling on the eastern slopes (Barma Water Resources et al. 2011).

Stream flows in the catchment are regulated by Wyangala Dam below the junction of the Lachlan and Abercrombie Rivers and Carcoar Dam on the Belubula River, while Lake Brewster and Lake Cargelligo are *en route* storages for maintaining a regulated flow in the lower Lachlan.

There are eight wetlands in the Lachlan catchment that are listed in the Directory of Important Wetlands in Australia, including the Booligal Wetlands, Lachlan Swamp and Great Cumbung Swamp (Department of Environment and Energy 2018). An additional nine wetlands are identified as regionally significant (Lachlan CMA n.d.). The aquatic ecological community in the natural drainage system of the lower Lachlan River is also listed as an endangered ecological community (EEC) in NSW (NSW DPI 2006).

The Great Cumbung and Baconian swamps remain in a relatively natural although highly stressed condition, representing good examples of terminal reed swamps and associated floodplain vegetation. The Great Cumbung Swamp together with the Lowbidgee wetlands supports one of the largest stands of river red gum in NSW (estimated to be between 14,000 and 20,000 hectares). The Great Cumbung Swamp is approximately 50,000 hectares in size, of which approximately 4000 hectares supports Phragmites reed beds, although their area has been reduced because of altered flows. The Booligal Wetlands support some of the largest areas of lignum in the State.

The region also contains diverse water dependent ecosystems that support threatened and iconic native fish (e.g. olive perchlet, Murray cod) and migratory waterbirds (e.g. straw-necked ibis, Australasian bittern).

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

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

1.1 Approach to developing the Lachlan Long Term Water Plan

The Lachlan LTWP applies to the Lachlan Surface-water water resource plan area (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 Murray-Darling Basin Plan (Basin Plan) (MDBA 2012).

The Lachlan LTWP is the product of best available information and engagement with water managers, natural resource managers, environmental water holders, First Nations community members and the EWAG. 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 Lachlan LTWP has involved six main steps:

1. undertaking a comprehensive stocktake of water dependent environmental assets and ecosystem functions across the Lachlan catchment to identify native fish, water dependent bird, flood-dependent frog species, vegetation species, and river processes that underpin a healthy river system
2. determining specific and quantifiable objectives and targets for the key species and functions in the Lachlan catchment
3. 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
4. identifying the risks and constraints to meeting the long-term water requirements of priority environmental assets and ecosystem function
5. identifying potential management strategies for guiding water management decisions and investment into the future
6. complementary measures such as cooperative water management and investment opportunities.

Figure 3 **Lake Ita**
Photo: P Packard/DPIE

1.2 Implementing the Lachlan Long Term Water Plan

Implementation of the LTWP requires strong partnerships and coordination between land managers, water users and the community. The LTWP supports future coordination efforts by:

- guiding annual water management deliberations and planning by DPIE–BC
- 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 contribute to the outcomes sought by this LTWP
- building broad community understanding of river and wetland health issues.

1.3 The Long Term Water Plan document structure

The Lachlan LTWP is presented in 10 chapters with accompanying appendices. It is divided into Part A and Part B.

Part A: Lachlan catchment scale information

- **Chapter 1** explains the background, purpose and structure of the LTWP.
- **Chapters 2** and **3** identify the Lachlan's water dependent environmental assets, values and ecosystem functions. They also outline the environmental outcomes expected from implementation of the LTWP with ecological objectives and targets.
- **Chapter 4** provides the environmental water requirements (EWRs) that are needed to achieve the 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 Lachlan LTWP. It also recommends management strategies for addressing these.
- **Chapter 6** identifies strategies for the management of water under different water resource availability scenarios, extreme events and critical water quality incidents.
- **Chapter 7** describes potential cooperative arrangements between government agencies and private landholders and prioritised investment opportunities to achieve the ecological objectives described in this LTWP.

Part B: Lachlan planning unit scale information

- **Chapter 1** explains the need and logic for splitting the Lachlan catchment into different planning units.
- **Chapters 2** and **3** present the LTWP at the planning unit scale. This includes a summary of the priority environmental assets and values the planning unit supports, specific EWRs with flow rates attributed to specific gauges, and an evaluation of the impact of water resource development on local hydrology.

1.4 Planning units

The planning units shown in Figure 4 are referred to in most chapters. The planning units typically align with the regulated (Zone A) and unregulated (Zone B) river reaches. Planning unit boundaries in Zone A (planning units (1–16) were delineated to reflect how storage and diversion infrastructure can be used to manage water for environmental outcomes. In some instances, Zone A planning unit boundaries include unregulated areas that are downstream regulated areas because they are affected by regulated water deliveries. Planning unit boundaries in Zone B (planning units 17-39) align with the Water Source boundaries in the *Lachlan Surface Water Resource Plan* (NSW DPIE–Water 2019d).

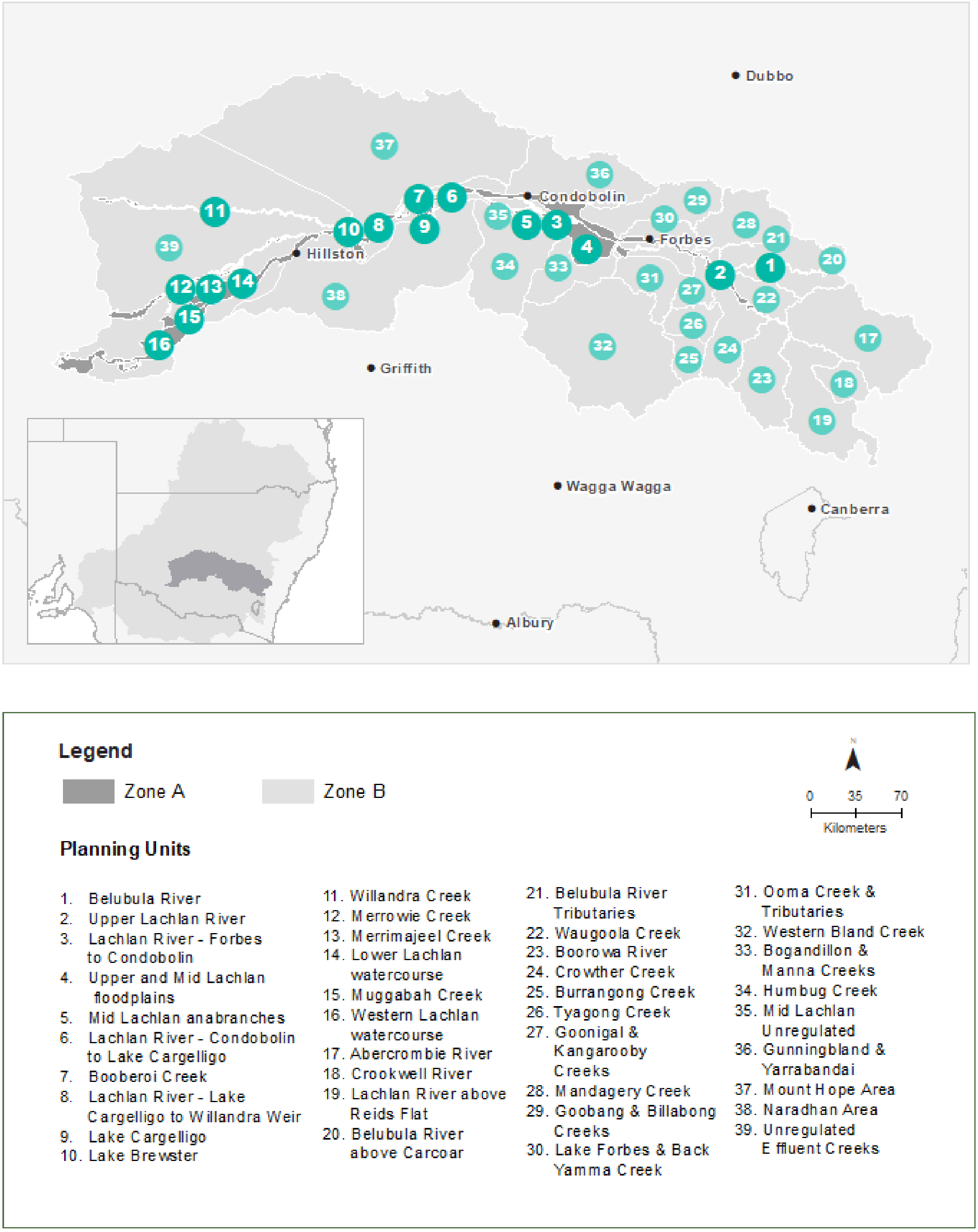

Figure 4 The Lachlan catchment showing the division of planning units into Zone A and Zone B in the Long Term Water Plan

2. Environmental assets: Lachlan catchment

The Lachlan 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 Lachlan 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, or can support threatened species, threatened ecological communities or significant biodiversity.

The Lachlan's water dependent ecosystems, which are comprised of waterbodies, water dependent vegetation, and the water-dependent fauna they support were assessed against Schedule 8. Significant Aboriginal cultural water dependent areas that are registered in the Aboriginal Heritage Information Management System (AHIMS) were also included as water dependent assets in the LTWP. This identified areas such as Aboriginal ceremony and dreaming sites, fish traps, scar trees, and water holes throughout the Lachlan catchment. Querying the AHIMS system is not intended to substitute for consultation about sites. However, it is used to demonstrate the presence and variety of sites registered in the Lachlan WRPA. Results of the analysis are presented in Figure 5.

Priority environmental assets in LTWPs are the assets that have been identified using Schedule 8 criteria that can be managed through:

- NSW's planned environmental water (PEW)
- NSW's and CEWO's held environmental water (HEW)
- implementation of the *Water Sharing Plan for the Lachlan Regulated and Unregulated Rivers Surface Water Sources* and the *Water Sharing Plan for the Belubula Regulated River Water Source* rules and compliance with water access licences (WAL).

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 Lachlan LTWP are mapped and listed in the relevant planning units in Part B, Chapters 2 and 3.

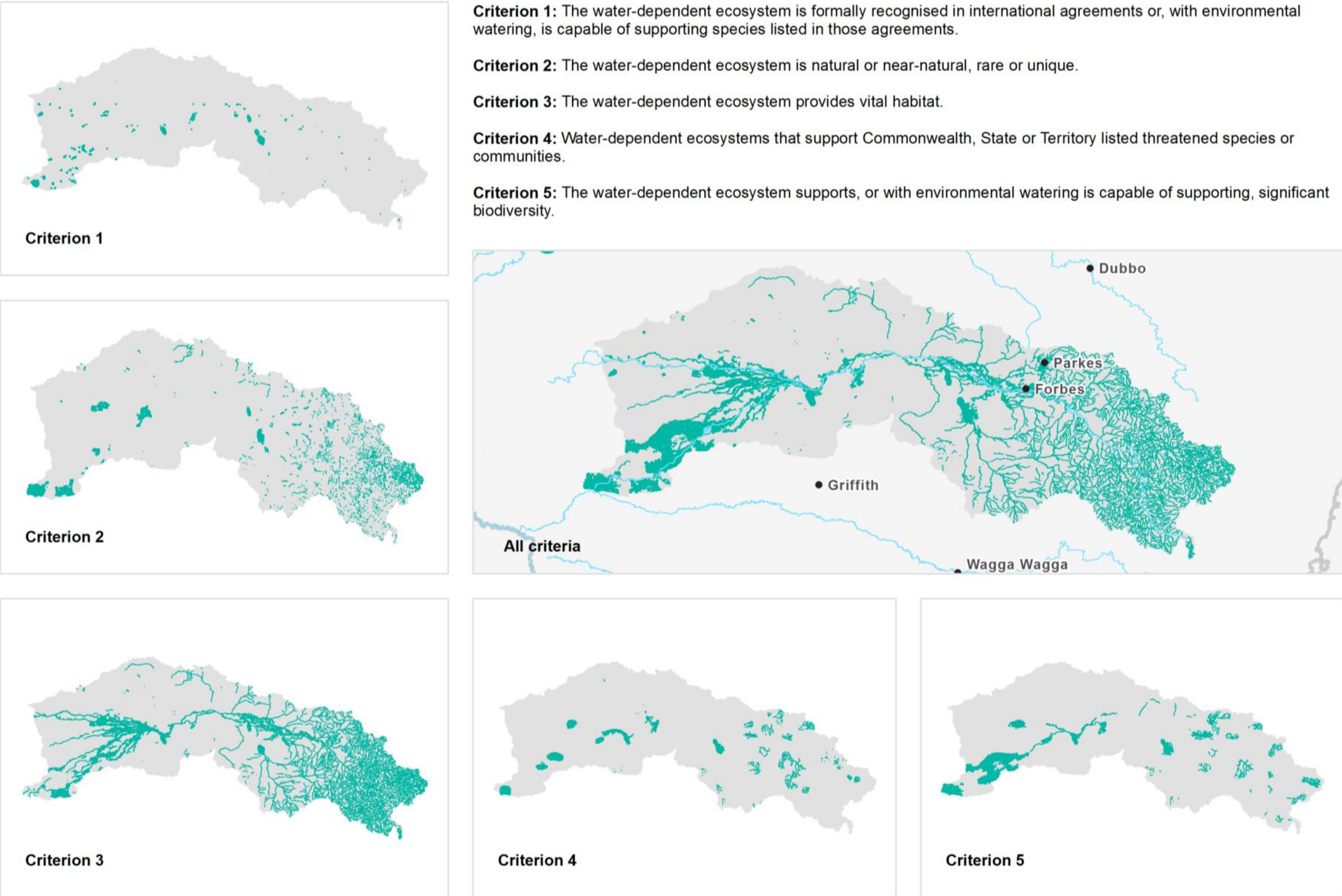

Figure 5 The five criteria for the identification of water-dependent environmental assets applied to the Lachlan catchment

3. Ecological objectives and targets

Ecological objectives and targets have been established for priority environmental assets in the Lachlan catchment (Chapters 3.1–3.5). Consistent with the *Basin-wide Watering Strategy* (BWS) (with the exception of frogs and Aboriginal cultural values and uses), the objectives are grouped into five themes: native vegetation, waterbirds, native fish, frogs, and priority ecosystem functions. Each theme is a good indicator of river system health and is responsive to flow. The water requirements of these indicator, functional groups of species, or ecosystem functions within each theme are representative of those needed by many other water dependent species, such as turtles, water-dependent bats, platypus, and water rats.

The Lachlan's ecological objectives are 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, 10 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 strategies outlined in the LTWP. If the targets are achieved, this will indicate that the environment is responding positively to water management strategies. Failure to meet targets should trigger re-assessment of the flow regime and whether the LTWP is being implemented as intended. It is important to note that the 20-year targets in the LTWP assume the relaxation or removal of constraints to allow more flexibility in water delivery.

Implementation of the LTWP can contribute to Aboriginal cultural objectives (Chapter 3.6). Objectives and outcomes[1] for the water-dependent values and uses of the Nari Nari, Ngiyampaa and Wiradjuri Nations are described in the relevant reports on culturally appropriate First Nations consultation as part of the WRP development.

The ecological objectives for the Lachlan's priority environmental assets as they relate to individual planning units are listed in Appendix A.

3.1 Native fish values and objectives

The expected native fish community in the Lachlan catchment consists of 20 native finfish species and seven crustaceans (NSW Department of Primary Industries Aquatic Ecosystem Research Database, from records collected between 1994 and 2017). There are several listed threatened species either expected to occur or that have a historical distribution within the catchment, including purple-spotted gudgeon, silver perch, Murray cod, Macquarie perch, trout cod, southern pygmy perch, flathead galaxias, freshwater catfish, olive perchlet and a small gastropod, Hanley's river snail (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 (Davies et al. 2012; Mallen-Cooper & Zampatti 2015). Overall, the fish community in the Lachlan is in poor to very poor health. Some reaches within creek systems such as Booberoi Creek are considered to be in fair condition (Ellis et al. 2018; NSW DPI 2016).

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 & Zampatti 2015). Fish population structure is closely tied to the frequency of successful breeding events and enhanced recruitment (Ellis et al. 2018).

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[1] as determined during targeted consultation for *The Report on culturally appropriate First Nations consultation with Gomeroi Nation*

Objectives and targets for native fish in the Lachlan catchment focus on increasing distribution and abundance. Targeted management should achieve a stable population structure with representation of young-of-year, juvenile and adult-life-history stages (Table 2 & Appendix A). These objectives can be achieved by providing a variety of flows across the entire spectrum (from low flows through to bankfull and overbank flow events) that meet the EWRs for each fish species group.

The Lachlan has been identified as capable of expanding the range of six threatened fish species (MDBA 2014). These are the Macquarie perch, trout cod, southern pygmy perch, olive perchlet, purple-spotted gudgeon and flathead galaxias. It is expected that range extensions for these species will be achievable in specific planning units across the Lachlan catchment that support the habitat and flow requirements of these species in both regulated and unregulated sections. Alternative watering actions (e.g. pumping) may be required to support floodplain to ensure no loss of species and range extensions for some species.

Figure 6 (From left to right) Freshwater catfish, olive perchlet, and purple-spotted gudgeon
Photo: G Schmida

Table 2 Native fish (NF) ecological objectives and targets

<table>
<tr><th colspan="2" rowspan="2">Objectives</th><th rowspan="2">Target fish species</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="2">NF1</td><td rowspan="2">No loss of native fish species</td><td rowspan="2">All recorded fish species</td><td colspan="3">All known species detected annually</td></tr>
<tr><td>–</td><td colspan="2">Fish community status improved by one category compared to 2014 assessment</td></tr>
<tr><td>NF2</td><td>Increase the distribution and abundance of short to moderate-lived generalist native fish species</td><td>Australian smelt, carp gudgeon, flat-headed gudgeon, bony herring, Murray-Darling rainbowfish, unspecked hardyhead</td><td colspan="3" rowspan="2">Increased distribution and abundance of short to moderate-lived species compared to 2014 assessment
No more than one year without detection of immature fish (short-lived)
No more than two years without detection of immature fish (moderate-lived species)</td></tr>
<tr><td>NF3</td><td>Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish species</td><td>Southern pygmy perch, Murray hardyhead, olive perchlet[2], flathead galaxias, purple-spotted gudgeon[3]</td></tr>
<tr><td>NF4</td><td>Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species</td><td>Golden perch, silver perch, spangled perch</td><td colspan="3" rowspan="2">Juvenile and adult fish detected annually
No more than two consecutive years without recruitment in moderate-lived species
No more than four consecutive years without recruitment in long-lived species</td></tr>
<tr><td rowspan="2">NF5</td><td rowspan="2">Improve native fish population structure for moderate to long-lived riverine specialist native fish species</td><td rowspan="2">Murray cod, river blackfish, Macquarie perch, freshwater catfish, purple-spotted gudgeon, olive perchlet</td></tr>
<tr><td>Minimum of 1 significant recruitment event in 5 years[4]</td><td>Minimum of 2 significant recruitment events in 10 years</td><td>Minimum of 4 significant recruitment events in 20 years</td></tr>
</table>

[2] Olive perchlet may be considered either floodplain specialist or riverine (lentic) depending on geographical location.
[3] Purple-spotted gudgeon may be considered either floodplain specialist or riverine (lentic) depending on geographical location.
[4] Young-of-year comprise more than 30% of the population.

Objectives		Target fish species	Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
NF6	A 25% increase in abundance of mature (harvestable sized) golden perch and Murray cod	Golden perch, Murray cod	Length-frequency distributions include size classes of legal take size for golden perch and Murray cod 25% increase in abundance of mature golden perch and Murray cod		
NF7	Increase the prevalence and/or expand the population of key short to moderate-lived floodplain specialist native fish species into new areas (within historical range)	Flathead galaxias, southern pygmy perch, olive perchlet	Adults detected annually in specified planning units No more than 1 year without detection of immature fish in specified planning units (short-lived) No more than 2 years without detection of immature fish in specified planning units (moderate-lived species)		
			-	Increased distribution and abundance in specified planning units	
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, olive perchlet	Adults detected annually in specified planning units No more than 2 years without detection of immature fish in specified planning units (moderate-lived species) No more than 4 years without detection of immature fish in specified planning units (long-lived species)		
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	-	Increased distribution and abundance in specified planning units	

3.2 Native vegetation values and objectives

The Lachlan catchment supports a wide range of vegetation communities reflecting a diverse geography. Extensive dry sclerophyll forest can be found in the upper reaches of the Lachlan River, transitioning to open grassy woodlands in the lower slopes and plains, of which large areas have been lost to clearing (Green et al. 2011). The western portion of the Lachlan catchment supports extensive areas of floodplain woodlands and wetlands, dominated by river red gum with grassy understorey that occur along the river and the effluent creeks (Green et al. 2011). A total of 471,000 hectares of wetlands are mapped within the Lachlan catchment. Of these, 95% are floodplain wetlands and 5% are freshwater lakes (Kingsford et al. 2003 cited in Green et al. 2011).

The distributary effluents (Willandra, Merrowie, Merrimajeel and Muggabah creeks) that characterise the Lower Lachlan are lined by black box and lignum while the floodplain woodlands are dominated by black box with a grassy understorey (Green et al. 2011). There are approximately 130,000 hectares of black box woodland communities in the Lachlan catchment. Along these effluent channels where flooding is more frequent, approximately 20,000 hectares of lignum shrublands have developed within the Lachlan catchment (Green et al. 2011).

The Booligal Wetlands are an area of braided channels and depressions that are inundated with moderate to large floods and support some of the most extensive areas of lignum in NSW (Armstrong et al. 2009). Stands of river red gum and river cooba can also be found in this area (Armstrong et al. 2009).

The largest stands of river red gum in the Lachlan catchment surround the terminal reed bed of the Lachlan River known as the Great Cumbung Swamp. Together with the adjoining Lowbidgee Wetlands, it forms one of the largest areas of river red gum in NSW (Green et al. 2011). There is up to 110,000 hectares of river red gum forest and woodland within the actively managed floodplain of the Lachlan catchment, of which approximately 42,000 hectares are found in the riparian zone. Deflation basin wetlands, such as Murrumbidgil Swamp, Lake Ita, Lake Tarwong, Lake Bullogal, Peppermint Swamp and Baconian Swamp are known to support a large proportion of river red gum woodlands in the Lachlan.

The Great Cumbung Swamp is also known for supporting one of the largest areas of common reed in NSW. Non-woody wetlands occur throughout the Lachlan catchment with 1500 hectares of common reed, 17,500 hectares of freshwater sedgeland and 5000 hectares of cane grass swamp. The floodplain woodlands grade into significant expanses of chenopod shrubland with increasing distance from the rivers and creeks (Green et al. 2011).

Over time, regulation of flow in the Lachlan River has decreased the amount of water reaching the wetlands, detrimentally affecting flood-dependent vegetation such as river red gums (Armstrong et al. 2009). While it may not be possible to expand woodland communities due to surrounding agricultural development, the objectives of this plan aim to ensure adequate water is available to maintain their current extent and improve their health over the long-term as a minimum.

Catchment-wide objectives for lignum shrubland and non-woody wetland vegetation communities are also to maintain or increase where possible, their extent and improve condition. Promoting vegetative growth alone will not support the long-term sustainability of vegetation communities, particularly those of short-lived species such as sedges and rushes. The objectives for the maintenance of these species include targets for regular seed setting to ensure ongoing population viability. Specific targets have been set for the main vegetation types described in the BWS. However, rather than focusing on outcomes for single species, objectives have been set for the plant community types (PCTs) to which species belong. Table 3 describes the ecological objectives for native vegetation in the Lachlan water resources plan area.

Table 3 Native vegetation (NV) ecological objectives and targets

<table>
<tr><th colspan="3" rowspan="2">Objectives</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>NV1</td><td colspan="2">Maintain the extent and viability of non-woody vegetation communities occurring within channels</td><td colspan="3">Increase the cover of non-woody, inundation-dependent vegetation within or closely fringing river channels following inundation events</td></tr>
<tr><td rowspan="2">NV2</td><td colspan="2" rowspan="2">Maintain or increase the extent and maintain the viability of non-woody vegetation communities occurring in wetlands and on floodplains</td><td colspan="3">Over a 5 year rolling period, phragmites and cumbungi to flower and set seed at least 2 years in 5</td></tr>
<tr><td colspan="2">Maintain the total area of non-woody wetland vegetation communities occurring within the regulated flow paths</td><td>Increase the total area of non-woody wetland vegetation by 10% occurring within actively managed flow paths</td></tr>
<tr><td rowspan="2">NV3</td><td colspan="2" rowspan="2">Maintain the extent and improve the condition of river red gum communities closely fringing river channels</td><td colspan="3">Maintain the 2016 mapped extent[5] of river red gum woodland communities closely fringing river channels</td></tr>
<tr><td colspan="2">Over a 5 year rolling period:
• maintain the extent and proportion of river red gum communities closely fringing river channels that are in moderate or good condition
• no further decline in the condition of river red gum communities closely fringing river channels that are in poor or degraded condition</td><td>Over a 5 year rolling period:
• increase the proportion of river red gum communities closely fringing river channels that are in moderate or good condition
• improve the condition score of river red gum communities closely fringing river channels that are in poor, degraded or severely degraded condition by at least one condition score</td></tr>
<tr><td>NV4b</td><td rowspan="2">Maintain or increase the extent and maintain or improve the condition of native woodland and shrubland communities on floodplains</td><td>River red gum woodland</td><td colspan="3">Maintain the 2016 mapped extent of river red gum woodland and black box woodland communities</td></tr>
<tr><td>NV4c</td><td>Black box woodland</td><td colspan="2">Over a 5 year rolling period:
• maintain the extent and proportion of woodlands and shrublands in moderate or good condition
• no further decline in the condition of woodlands and</td><td>Over a 5 year rolling period:
• increase the proportion of woodlands and shrublands in moderate or good condition
• improve the condition score of woodlands and shrublands in poor, degraded or severely degraded condition by at least one condition score</td></tr>
</table>

[5] Extent based on compiled native vegetation plant community type (PCT) mapping of the NSW Lachlan catchment. Map compiled by DPIE from best available PCT mapping as at 2016.

Objectives			Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
			shrublands in poor or degraded condition • increase the abundance of woodland seedlings and saplings in degraded river red gum woodlands on the managed floodplain		• Support successful recruitment of trees in the long-term by increasing in the abundance of young adult trees (10–30 cm DBH) compared to the previous 10 year period
NV4e		Lignum shrublands	Maintain the 2016 mapped extent of lignum shrubland and nitre goosefoot communities		Increase the total area of lignum shrublands and nitre goosefoot by 10% occurring within actively managed flow paths

Figure 7 Milfoil at Booligal Wetlands
Photo: V Bucello/Midstate Video

3.3 Waterbird values and objectives

Floodplain wetlands in the Lachlan catchment are recognised as nationally important (Environment Australia 2001), providing important feeding and breeding habitat for a range of waterbird species. Records from the early 1990s onwards indicate that at least 80 waterbird species have been recorded in Lachlan wetlands, including 10 threatened species and 16 migratory species recognised on international migratory bird agreements (Spencer et al. 2018a). Field surveys by Maher (1990) during extensive natural flooding from 1989–1990 documented many breeding sites across the Great Cumbung Swamp, the large reedbed complex at the end of the Lachlan system. Maher (1990) cited early records from 1900 of significant colonies of magpie geese and straw-necked ibis in this region.

The Lower Lachlan also has many river red gum swamps, including Murrumbidgil Swamp, which provide important feeding and breeding habitat for a range of waterbird species (Maher 1984). Upstream, the Booligal Wetlands are also recognised as important habitat for waterbirds, providing some of the best and most important breeding locations in Australia (Magrath 1992). This large lignum swamp, which is fed by the Merrimajeel and Muggabah creeks, and in periods of high flow Merrowie Creek, is one of the most important breeding habitats for colonial nesting waterbirds in the Basin (Brandis 2010). Recent monitoring has shown that Booligal Swamp continues to support a large number of waterbird species and very large ibis colonies during large flood events (Kingsford et al. 2013; Brandis & Lyon 2016). Wetlands in the Mid Lachlan region including Lake Cowal and Lake Brewster also provide significant habitat for waterbirds. Lake Brewster can support Australian pelicans nesting in large numbers (Brandis 2010).

Colonial nesting waterbird species including ibis, spoonbills, egrets, pelicans, cormorants and herons can nest in large numbers in inundated wetland habitats. Opportunities for large-scale colonial nesting waterbird breeding events have declined in the Lachlan catchment with reduced flows reaching the end of the system (Hillman et al. 2003; Driver et al. 2005). Waterbird species need flows to inundate their feeding and breeding habitat. Where breeding is initiated, the water depth and extent in colony sites and surrounding habitats needs to be maintained so birds can complete their breeding cycles, which includes laying eggs, raising and fledging their young until they are independent adult birds. Some colonial nesting waterbird breeding species, such as the straw-necked ibis, are particularly sensitive to falling water levels in their colony sites and surrounding habitats, which can cause adults to abandon their nests (Carrick 1962; Brandis et al. 2011). For many colonial nesting waterbird species, breeding is initiated once the extent of inundated floodplain habitat reaches a certain magnitude, with the overall size of the breeding response determined by the extent of inundation. Larger and longer overbank events are associated with a greater number of colonies overall and the presence of large colonies (>5000 nests) (Spencer 2017).

Recent surveys of the Lower and Mid Lachlan wetlands during widespread natural flooding demonstrated that wetland areas still provide significant breeding and feeding habitat for colonial nesting waterbird species and a range of non-colonial waterbird species (Brandis & Lyon 2016; Kingsford et al. 2017; Spencer et al. 2018a). There were at least six separate colonies in the Mid Lachlan and nine sites in the Lower Lachlan wetland region in 2016–17. The largest colonies were recorded at Lake Brewster where more than 7000 pelican nests were recorded over two nesting events between November 2016 and July 2017 (Spencer et al. 2018a). Downstream in Booligal Swamp more than 100,000 ibis nests were active in spring 2016 (Brandis & Lyon 2016).

Key objectives of the Lachlan LTWP (Table 4) are to maintain the number of waterbird species and support waterbird population recovery in the Lachlan, to contribute to increasing waterbird total abundance across the Basin. Sites in the Lower Lachlan and Mid Lachlan wetlands, including the Great Cumbung Swamp, Booligal Wetlands, Lake Cowal and Lake Brewster, are identified as four of 33 waterbird sites in the Basin for maintaining waterbird species richness, and increasing abundance and breeding activity (MDBA 2014).

Inundation levels required to trigger large-scale colonial nesting waterbird breeding are primarily achieved through larger natural flood events in the Lachlan, or can in some sites be replicated through managed water deliveries. Therefore, the focus of waterbird objectives in this LTWP is to support these large breeding events when they occur by extending the duration and extent of natural flooding to allow birds to complete their nesting cycles.

Increasing opportunities for waterbirds to breed will occur through the maintenance and improvement of the health of key waterbird nesting and foraging habitats. This can be achieved by the delivery of targeted flows to key sites. The management of water levels in Lake Brewster, including following natural flooding, has provided breeding opportunities for Australian pelicans over successive years in the 2011–13 and 2016–18 period (Spencer 2017; Spencer et al. 2018a).

The targeted delivery of environmental water to the Lower Lachlan and Mid Lachlan wetland regions during years of dry to moderate water availability can also provide foraging opportunities for a diverse range of waterbird species. Where flows are synchronised with spring watering in the neighbouring Murrumbidgee catchment this can provide greater foraging opportunities for waterbirds, including migratory shorebird species.

Figure 8 Chicks at Moon Moon swamp
Photo: V Bucello/Midstate Video

Table 4 Waterbird (WB) ecological objectives and targets

Objectives		Targets		
		5 years (2024)	10 years (2029)	20 years[6] (2039)
WB1	Maintain the number and type of waterbird species	Maintain a 5-year rolling average of 33 or more waterbird species across the 5 functional groups in the Mid Lachlan		
		-	Identify at least 73 waterbird species in the Mid Lachlan in a 10-year period	At least 78 waterbird species observed in the Mid Lachlan in a 20-year period
		Maintain a 5-year rolling period of 27 or more waterbird species across the 5 functional groups in the Lower Lachlan		
		-	Identify at least 46 waterbird species in the Lower Lachlan in a 10-year period	At least 56 waterbird species observed in the Lower Lachlan in a 20-year period
WB2	Increase total waterbird abundance across all functional groups	Total abundance of the 5 functional groups maintained in the Mid and Lower Lachlan compared to the 5-year 2012–16 period	Total waterbird abundance increased by 20–25% in the Mid and Lower Lachlan compared to the 5-year 2012–16 period, with increases in all functional groups	Maintain or increase total waterbird abundance in the Mid and Lower Lachlan compared to the 10-year target, with increases in all functional groups
WB3	Increase opportunities for non-colonial nesting waterbird breeding	Total abundance of non-colonial waterbirds in the Mid Lachlan maintained and breeding recorded in at least 7 non-colonial waterbird species compared to the 5-year 2012–16 baseline period	Total abundance of non-colonial waterbirds in the Mid Lachlan maintained and breeding recorded in at least 7 non-colonial waterbird species compared to the 5-year 2012–16 baseline period	Maintain or increase total abundance of non-colonial waterbirds in the Mid Lachlan compared to the 10-year target, with breeding detected in at least 7 non-colonial waterbird species
		Total abundance of non-colonial waterbirds in the Lower Lachlan maintained and breeding recorded in at least 3 non-colonial waterbird species compared to the 5-year 2012–16 baseline period	Total abundance of non-colonial waterbirds in the Lower Lachlan maintained and breeding recorded in at least 3 non-colonial waterbird species compared to the 5-year 2012–16 baseline period	Maintain or increase total abundance of non-colonial waterbirds in the Lower Lachlan compared to the 10-year target, with breeding detected in at least 3 non-colonial waterbird species

[6] 20-year targets will be further refined following additional data collection in the first five years of implementation of the plan.

<table>
<tr><th colspan="2" rowspan="2">Objectives</th><th colspan="3">Targets</th></tr>
<tr><th>5 years (2024)</th><th>10 years (2029)</th><th>20 years[6] (2039)</th></tr>
<tr><td rowspan="2">WB4</td><td rowspan="2">Increase opportunities for colonial nesting waterbird breeding</td><td colspan="3">Support active waterbird colonies in the Mid and Lower Lachlan by maintaining the water depth and duration of flooding (as required) to support breeding through to completion (from egg laying through to fledging including post-fledgling care) and maintain duration of flooding in key foraging habitats to enhance breeding success and the survival of young</td></tr>
<tr><td>In line with natural cues initiate and support small-scale colonial nesting waterbird breeding in the Lower Lachlan in 2 colony sites in 2 of 5 years</td><td>In line with natural cues initiate and support small-scale colonial nesting waterbird breeding in the Lower Lachlan in 5 colony sites in 3 of 10 years</td><td>In line with natural cues, initiate and support small-scale colonial nesting waterbird breeding in the Lower Lachlan in 5 colony sites in 3 of 10 years</td></tr>
<tr><td rowspan="3">WB5</td><td rowspan="3">Maintain the extent and improve condition of waterbird habitats</td><td colspan="3">Maintain extent and improve condition of nesting vegetation, including lignum, river cooba and river red gum in known colonial breeding locations in the Mid Lachlan</td></tr>
<tr><td colspan="3">Maintain extent and improve condition of nesting vegetation, including common reed, lignum, cumbungi, river cooba and river red gum in known colonial breeding locations in the Lower Lachlan</td></tr>
<tr><td colspan="3">Maintain or increase extent and improve condition of waterbird foraging and breeding locations in the Mid and Lower Lachlan (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 Lachlan 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, gravel beds, instream benches, snags, aquatic vegetation and riparian vegetation are available to the catchment's aquatic species. Restoring lateral and longitudinal connectivity amongst these features is fundamental to supporting many of the priority ecosystem functions in the Lachlan. For example, improved hydrological connectivity along river systems and between rivers and their riparian corridors and floodplain is pivotal to moving nutrients, carbon and sediments, enhancing productivity, allowing organisms to disperse and improving water quality (MDBA 2014). Ecological objectives for priority ecosystem functions are described in Table 5.

Drought refugia

Refugia can occur within the main river channels, as instream pools, or in off-channel habitat where water persists after disconnection from the channel, such as in billabongs and anabranches. The refugia can contain different types of habitat, such as 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. 2010). Refugia should be the highest priority for protection, especially during drought.

Quality instream habitat

The physical form of instream habitats, including the location of riparian and instream vegetation, channel shape and bed sediment, is influenced by river flow (Bunn & Arthington 2002). For example, fresh and bankfull flows with sufficient velocity are required to maintain pool depth and riffles by scouring out bed material and initiating material transportation downstream (Davie & Mitrovic 2014). Changes to the rates of rise and fall of river levels can also impact on the quality of instream habitat.

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).

Instream and floodplain productivity

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

River flow management can be used to increase carbon and nutrient sources in-channel by increasing the frequency of floodplain inundation. Re-wetting patches (e.g. river channels, channel benches, floodplains) following drying provides a pulse of terrestrial carbon available for potential use by consumers (Lanhans & Tockner 2006) and the flow of water enhances the physical breakdown of leaves, branches and other terrestrial detritus (Mora-Gomez et al. 2015). Furthermore, mimicking the natural flooding and drying regimes in wetlands is likely to conserve and enhance macroinvertebrate assemblages (NOW 2012).

Sediment, carbon and nutrient exchange

The frequency of flows that connect rivers with their floodplain has been substantially reduced in the Lachlan catchment because water volumes 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 (Baldwin et al. 2016). Consequently, the amount of dissolved organic carbon entering the main channels is reduced because of less frequent wetting of benches, flood runners and floodplains (Westhorpe et al. 2010). Longitudinal connectivity is equally important and fulfils the important environmental function of transporting nutrients and sediments between environments (MDBA 2014).

Groundwater dependent biota

While this LTWP is primarily focused on the management of surface water, the Lower Lachlan Groundwater Source plays an important ecological role in supporting terrestrial and aquatic ecosystems, particularly during extended dry periods where groundwater can be critical for maintaining refuges. The dominant groundwater recharge process for the Lower Lachlan Alluvium occurs through leakage from the Lachlan River and its various tributaries and anabranches, and infiltration from rainfall and irrigation activity (NSW DPI 2017). To continue to support groundwater dependent ecosystems (GDEs) in the Lachlan, objectives in the LTWP relate to maintaining the mapped extent of groundwater dependent vegetation communities and groundwater levels within their long-term natural ranges.

Table 5 Priority ecosystem function (EF) objectives and targets

Objectives			Description and key contributing processes	Targets		
				5 years (2024)	10 years (2029)	20 years (2039)
EF1	Provide and protect a diversity of refugia across the landscape		Water depth and quality in pools (in-channel), core wetlands and lakes Condition of vegetation in core wetlands and riparian zones	Very low flows (VF1) and baseflows (BF1) and wetland inundations flows (WL1) are provided at target magnitudes and durations as specified in planning unit EWRs Cease-to-flow periods do not exceed maximum durations as specified in planning unit EWRs Adequate water depth is maintained in key refuge pools during dry times Maintain dissolved oxygen >4 mg/L in key refuge pools (approximately 50% saturation in 25°C water)		
EF2	Create quality instream, floodplain and wetland habitat		Regulation of dissolved oxygen, salinity and water temperature Flow variability and hydrodynamic diversity Provision of diverse wetted areas Appropriate wetting and drying cycles Geomorphic (erosion/deposition) processes that create and maintain diverse physical habitats Appropriate rates of fall to avoid excessive bank erosion Control of woody-vegetation encroachment into river channels and wetlands	Rates of rise and fall do not fall outside the 5th and 95th percentiles of natural rates during regulated water deliveries Period for which instream freshes are held at constant level (± 5%) does not exceed natural durations At least 1 overbank/wetland inundating event 9 years in 10 in relevant planning units At least 3 fresh events per year to inundate in-channel habitat in relevant planning units		
EF3a	Provide movement and dispersal opportunities for water dependent biota to	within catchments	Dispersal of eggs, larvae, propagules and seeds downstream and into off-channel habitats Migration to fulfil life-history requirements Foraging of aquatic species	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 and above, and wetland inundating flows) Provide longitudinal connectivity and integrity of flows to end-of-system, including flow pulses (regulated, natural or augmented natural)		

Objectives		Description and key contributing processes	Targets		
			5 years (2024)	10 years (2029)	20 years (2039)
EF3b	complete lifecycles and disperse into new habitats between catchments	Recolonisation following disturbance	The long-term average frequency of 2 connecting events in 10 years between Lachlan and Murrumbidgee.		
EF4	Support instream and floodplain productivity	Aquatic primary productivity (algae, macrophytes, biofilms, phytoplankton) Terrestrial primary productivity (vegetation) Aquatic secondary productivity (zooplankton, macroinvertebrates, fish larvae, adult fish) Decomposition of organic matter	Maintain or increase the proportion of wetland and 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 Enhance riverine productivity to support increased food availability for aquatic food webs by increasing the supply of autochthonous and allochthonous carbon and nutrients		
			No decline in key native fish species condition metrics Maintain the abundance and distribution of decapod crustaceans	Improve key native fish species condition metrics Improve the abundance and distribution of decapod crustaceans	
EF5	Support nutrient, carbon and sediment transport along channels, and between channels and floodplains/wetlands	Sediment delivery to downstream reaches and to/from anabranches, floodplains and wetlands Mobilisation of carbon and nutrients from in-channel surfaces (e.g. benches/banks), floodplains and wetlands and transport to downstream reaches and off-channel habitats Dilution of carbon and nutrients that have returned to rivers	Maintain nutrient and carbon (DOC) pulses at multiple locations along a channel during freshes, bankfull and overbank events Increase lateral connectivity with anabranches, low-lying wetlands and floodplains, as specified in EWRs for large freshes, bankfull events, wetland inundating flows and overbank flows Maintain extent and condition of floodplain vegetation Maintain soil nitrogen, phosphorus and carbon levels at long-term natural levels		
EF6	Support groundwater conditions to sustain groundwater dependent biota	Groundwater recharge and discharge Dilution of saline/acidic groundwater Salt export from the Murray-Darling Basin	Maintain the 2016 mapped extent of groundwater dependent vegetation communities Maintain groundwater levels within the natural range of variability over the long-term		

Figure 9 Endangered river snails in the Murray-Darling Basin
Photo: M Miles/DPIF

3.5 Other species values and objectives

The variety of water-dependent ecosystems in the Lachlan 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 (Table 6). Frogs are an important food source for waterbirds, fish and reptiles. Flow-dependent frogs have similar watering requirements to waterbirds for breeding, however, they are not highly mobile, so they require refuge between watering events. As such, the inclusion of flow-dependent frog objectives places greater emphasis on the need to maintain refuge (including permanent waterbodies for some species) in the floodplain.

Historical frog surveys throughout the Lower Lachlan are limited, but a large-scale, post flood survey in 2012–2013 identified eight frog species in the region (Amos 2017) and follow up surveys in 2015–16 identified four species (Dyer et al. 2016). Of these records, five species are considered ‘flow-dependent’ and present in sufficient numbers to form an appropriate baseline dataset for setting LTWP objectives. While the threatened southern bell frog was detected in the 2012–13 surveys this was only at one site in the Lower Lachlan region (Amos 2017; Amos et al. 2013) and it was not detected again during targeted area surveys in 2013–2014 (Amos et al. 2014) or the 2015–16 surveys (Dyer et al. 2016). The 2012–16 baseline period incorporates available datasets for the five water years (Amos et al. 2014; Amos 2017; Dyer et al. 2016). Many of the survey sites supported breeding with evidence of tadpoles and metamorphs from giant banjo frogs, spotted marsh frog and the barking marsh frog (Amos 2017; Dyer et al. 2016).

Table 6 Frog and other water-dependent species (OS) ecological objectives and targets

Objectives		Targets		
		5 years (2024)	10 years (2029)	20 years (2039)
OS1	Maintain species richness and distribution of flow-dependent frog communities	Detect all 5 flow-dependent frog species[7] known from the Lower Lachlan area based on comprehensive surveys over the 2012–16 period		
OS2	Maintain successful[8] breeding opportunities for flow-dependent frog species	Maintain proportion of wetlands sites where breeding activity[9] of flow-dependent frog species is detected in the Lower Lachlan area compared to the 2012–16 period		
OS4[10]	Maintain water-dependent species richness	Over the long term (20 years) no reduction in the number and range of water-dependent species that are found throughout the catchment. Maintain the current range of platypus across the Lachlan catchment[11]. Evidence of platypus burrows and successful breeding detected.		

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).

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

The floodplain wetlands and waterways of the Lachlan WRPA are central to its Traditional Owners, the Nari Nari, Ngiyampaa, Wiradjuri and Yita Yita people, who have longstanding and continuing ties to Country, the waterways and life sustained by it.

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[7] Species include eastern sign-bearing froglet, barking marsh frog, spotted grass frog, Peron's tree frog and giant banjo frog. Southern bell frogs are not included in the OS1 list of flow-dependent frog species. While there are records for the Lower Lachlan (Amos et al. 2013), they are not thought to be currently viable populations. This will be reviewed in future LTWP revisions.

[8] 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.

[9] We consider male frog callings, tadpoles detected and/or recently metamorphosed juvenile frogs as evidence of breeding activity. Where there are recently metamorphosed juvenile frogs this is evidence of potential recruitment of new individuals into the adult breeding population.

[10] OS3 refers to objectives relating to southern bell frogs, which are not relevant in Lachlan catchment.

[11] Refer to Part B of the Lachlan LTWP for relevant planning units where platypus have been recorded.

Consultation with these Nations on cultural values and objectives related to water-dependant ecosystems and management of water more broadly is ongoing. This includes the MDBA Aboriginal Partnership Program, and relevant reports on culturally appropriate First Nations consultation that are developed by DPIE-Water as part of the WRP process[12]. These reports present the objectives and outcomes for the management of water, based on their water-dependent values and uses.

In order to achieve these objectives and outcomes, continued collaboration is needed between government and non-government agencies, landholders, and First Nations people in the Lachlan. DPIE–BC will continue to consult with these Nations during implementation of the LTWP.

Figure 10 Booberoi Creek elder, NBAN and Lachlan EWAG member Peter Harris harvesting cumbungi for traditional string making in the upper Booberoi Creek, assisted by DPIE water manager, Jo Lenehan.
Photo: M Carnegie/Lake Cowal Foundation

[12] At the time of publication, reports on culturally appropriate First Nations consultation (as part of the NSW surface water resource plans) have been completed for the Nari Nari and Ngiyampaa Nations (NSW DPIE–Water 2019e, f)

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 produce flooding and drying patterns. Flow regimes govern river channel and wetland formation, their configuration and connectivity with the floodplain. Flow regimes prompt key ecological processes such as nutrient cycling and energy flow, breeding and migration, and dispersal of plants and animals.

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, overbank and wetland 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 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 11 and Table 7). Flow rates for flow categories at sites across the Lachlan catchment are shown in Table 9.

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

Meeting the full life-history needs of an aquatic organism (plant or animal) 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 2–4 weeks in early spring to support nesting. Once the fish reaches maturity (1–3 years) it may require a 'bankfull' fast-flowing river in combination with 'overbank' flows to trigger dispersal and migration.

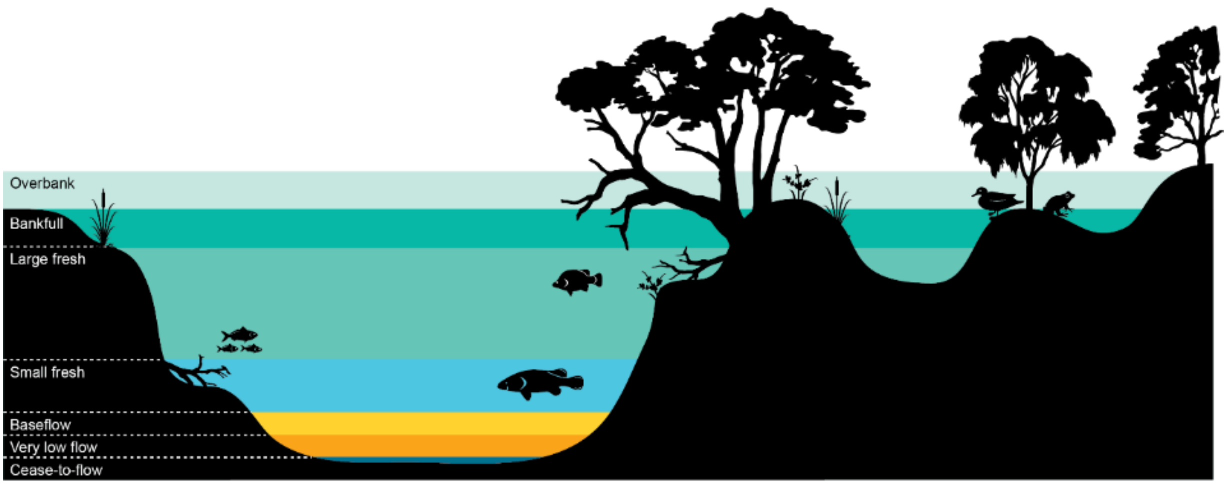

Figure 11 A simplified conceptual model of the role of each flow category

Table 7 Description of the role of each flow category

Flow category	Description
Overbank / Wetland inundation flow (OB / WL)	Both overbank and wetland inundation flows provide broad scale lateral connectivity with floodplain and wetlands. They support nutrient, carbon and sediment cycling between the floodplain and channel, and promote large-scale productivity. Overbank flows are used to describe flows when they are above bankfull. Wetland inundation flows (not shown in Figure 11) are used to describe: 1. flows that fill wetlands via regulating structures below bankfull over weeks or sometimes months (i.e. longer than a typical fresh/pulse), or 2. flows that are required to inundate wetlands in areas where there are very shallow channels or no discernible channels exist (e.g. terminal wetlands).
Bankfull flow (BK)	Inundates all in-channel habitats and connects many low-lying wetlands. They provide partial or full longitudinal connectivity and drown out of most small in-channel barriers (e.g. small weirs).
Large fresh (pulse) (LF)	Inundates benches, snags and inundation-tolerant vegetation higher in the channel. They support productivity and transfer of nutrients, carbon and sediment. They also provide fast-flowing habitat and may connect wetlands and anabranches with low commence-to-flow thresholds.
Small fresh (pulse) (SF)	Improves longitudinal connectivity. They inundate lower banks, bars, snags and in-channel vegetation, and can flush pools and stimulate productivity/food webs. They can provide a trigger for aquatic animal movement and breeding.
Baseflow (BF)	Provides connectivity between pools and riffles and along channels. They provide sufficient depth for fish movement along reaches.
Very low flow (VF)	Minimum flow in a channel that prevents a cease to flow. They provide connectivity between some pools.
Cease-to-flow (CF)	Partial or total drying of the channel. The stream contracts to a series of disconnected pools and there is no surface flow.

4.1 Developing environmental watering requirements to support ecological objectives

Development of EWRs for LTWPs draws 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 are 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 Table 8 for full description of EWR terms). Complete EWRs for each planning unit the Lachlan, including flow rates and total volumes, can be found in Part B.

A summary of flow rates for flow categories at sites along the Lachlan are shown in Table 9. The timing, duration and frequency components of EWRs, grouped by flow category, for all biota and functions in the Lachlan 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 11-15.

Table 8 Definition of terms and guide for interpreting environmental water requirements

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

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

Figure 12 The Lachlan River at Oxley
Photo: P Packard/DPIE

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 Lachlan catchment (Figure 13). 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, unless otherwise stated) for flow categories in the Zone A planning units in the Lachlan catchment

Planning unit	Gauge	Low flows		Freshes			Wetland inundation flows		Overbank flows	
		Very low flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small	Large	Small	Large
Belubula River	412033	10–30	30–70	70–655	655–5,000	5,000–6,000			6,000–8,000	8,000–14,000 +
Upper Lachlan River	412002	50–160	160–420	420–5,600	5,600–30,600	30,600–47,800			47,800–85,500	85,500–135,000 +
Lachlan River (Forbes to Condobolin)	412004	50–165	165–600	600–8,500	8,500–13,000	13,000–13,900			13,900–45,000	45,000–65,000 +
Lachlan River (Condobolin to Lake Cargelligo)	412011	10–30	30–165	165–6,300	6,300–8,600	8,600			8,600–15,000	15,000–23,000 +
Lachlan River (Lake Cargelligo to Willandra Weir)	412038	30–115	115–280	280–2,200	2,200–3,500	3,500			3,500–11,300	11,300–20,000 +
Lower Lachlan watercourse	412039	20–100	100–280	280–1,600	1,600–4,000	4,000–5,000	2,800 (>10–30 days)	2,800 (>30 days)	5,000–7,000	7,000–8,000 +
Western Lachlan watercourse	412005	10–50	50–150	150–650	650–2,000	2,000–2,700	650–1,200 (>30–60 days)	1,200 + (>60 days)	2,700–4,000	4,000–5,000 +
Upper and Mid Lachlan floodplain	412036							15,000 +		
	412004								21,600–45,000	45,000–65,000 +
Mid Lachlan anabranches	412188		10–30	30–80		80–100				
	412046		10–30	30–120	120–200	200–250				
	412016		40–70	70–200	200–300	300–350				
	412004								13,900–45,000	45,000–65,000 +
Booberoi Creek	412189		30–60	60–120	120–175	175–200			200 +	
	412011					8,000–9,000			11,000–15,000	15,000–23,000 +
Lake Cargelligo	412107						storage >65% full			
Willandra Creek	412012		50–70	70–250	250–300	300–500			500–1,500	1,500–2,500 +
	412042						150 (>30–50 days)	150 (>50 days)		

Planning unit	Gauge	Low flows		Freshes			Wetland inundation flows		Overbank flows	
		Very low flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small	Large	Small	Large
Merrowie Creek	412163			120–200	200–250	250–400	150 (>30–60 days)	150 (>60 days)		
	412038								3,000–8,000	8,000–10,000 +
Merrimajeel Creek	412005						300–850 (>30–60 days)	850–1,200 + (>60 days)	2,500–4,000	4,000–5,000 +
Muggabah Creek	412005						300–850 (>30–60 days)	850–1,200 + (>60 days)	2,500–4,000	4,000–5,000 +

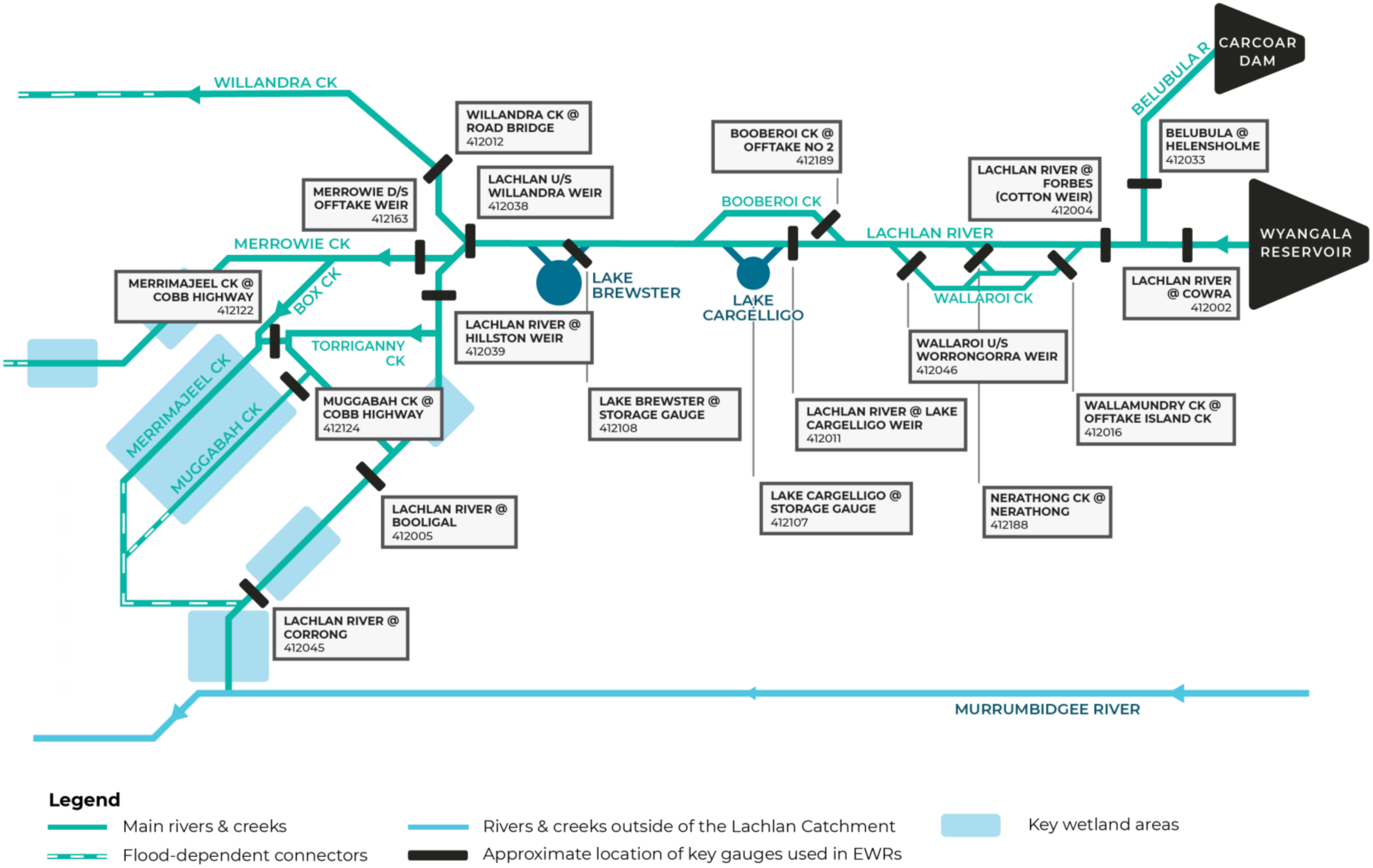

Figure 13 Schematic diagram of the main watercourses and streamflow gauges in the Lachlan catchment

4.3 Catchment scale environmental water requirements

Table 10 Catchment-scale environmental water requirements and the ecological objectives they support[13]

Flow category and EWR code		Ecological objectives	Timing	Minimum duration	Frequency (LTA frequency)	Maximum inter-event period	Additional water requirements
Cease-to-flow	CF1	Native Fish: NF1 - Survival (all species) Ecosystem Functions: EF1, 2 - refuge habitat Native Vegetation: NV1	In line with historical low flow season	In line with natural, unless key refuges threatened	No greater than natural	N/A	When restarting flows, ensure a slow rate of rise and fall (in line with natural) to reduce the risks of harmful water-quality impacts, such as de-oxygenated refuge pools. Ideally there would be no cease-to-flow periods between August to June to accommodate the platypus reproductive cycle, including juvenile dispersal, in known platypus breeding habitat.
Very-low flow	VF1	Native Fish: NF1 - Survival and condition (all species) Ecosystem Functions: EF1, 2 - refuge habitat	Any time	In line with natural	No less than natural	N/A	
Baseflow	BF1	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9 - condition and movement Native Vegetation: NV1, 2 - in-channel and wetland non-woody Ecosystem Functions: EF1, 2, 3a Other Species: OS4 – platypus foraging and movement	Any time	In line with natural	No less than natural	1 year	Minimum depth of 0.3 m to allow native fish passage Flow magnitude should be varied during events to avoid bank notching (within daily limits for rates of rise and/or fall)
	BF2	Native Fish: NF1, 2, 5, 6, 8, 9 - **Recruitment (riverine specialists, generalists)** Ecosystem Functions: EF1, 2, 3a	September to March	In line with natural	5–10 years in 10	2 years	

13 See Table 9 for definitions and explanatory text

Flow category and EWR code		Ecological objectives	Timing	Minimum duration	Frequency (LTA frequency)	Maximum inter-event period	Additional water requirements
Small fresh	SF1	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9 - Dispersal/condition (all species) Native Vegetation: NV1 - in-channel Ecosystem Functions: EF1, 2, 3a, 5 Other species: OS4	October to April (but can occur any time)	10 days	Annual	1 year	Minimum depth of 0.5 metres to allow movement of large native fish >20°C from Oct to April (for native fish); >16°C for river blackfish >18°C from Sept to Dec for Murray cod Flow magnitude should be varied during event to avoid bank notching (within daily limits for rates of rise and/or fall) Rate of fall: No faster than 5th percentile of natural
	SF2	Native Fish: NF1, 2, 5, 6, 8 - **Spawning (river specialists, generalists)** Native Vegetation: NV1 - in-channel Ecosystem Functions: EF1, 2, 3a, 5 Other species: OS4	October to April	14 days	5–10 years in 10 (75%)	2 years	
	SF3[14]	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9 - Dispersal/condition (all species) Native Vegetation: NV1, 2 - in-channel Ecosystem Functions: EF1, 2, 3a, 5	August to February (but can occur any time)	6 days	5–10 years in 10 (75%)	2 years	
Large fresh	LF1	Native Fish: NF1, 2, 4, 5, 6, 8, 9 - dispersal/condition (all species) Native Vegetation: NV1 - in-channel Ecosystem Functions: EF2, 3a, 4, 5, 6 Other Species - OS1, 2, 4	July to September (but can occur any time)	5days	5–10 years in 10 (75%)	2 years	Minimum depth of 2 metres to cover instream features and trigger response from native fish Ideal foraging habitat for platypus is 1-3 metres

[14] Only relevant in Lachlan River (Forbes to Condobolin) planning unit

Flow category and EWR code		Ecological objectives	Timing	Minimum duration	Frequency (LTA frequency)	Maximum inter-event period	Additional water requirements
	LF2	Native Fish: NF1, 4, 6, 9 - **spawning (flow pulse specialist fish)** Native Vegetation: NV1 - in-channel Ecosystem Functions: EF2, 3a, 4, 5, 6 Other Species: OS1, 2	October to April	5 days	3–5 years in 10 (40%)	4 years	Flow ideally 0.3 to 0.4 m/s (depending on channel form) to trigger native fish movement Flow magnitude should be varied during longer duration events to avoid bank notching (within daily limits for rates of rise and/or fall) Rate of rise and fall: No faster than 5th percentile of natural Ideally flow should be complete before the end of August and the upper limit of the flow should be 1 metre below bankfull to support the creation of suitable burrows for platypus breeding in planning units where platypus are present Higher magnitude large fresh flows will often result in overbank flows and wetland inundation in downstream planning units
	LF3[14]	Native Fish: NF1, 2, 4, 5, 6, 8, 9 - dispersal/condition (all species) Native Vegetation: NV1, 2 Ecosystem Functions: EF2, 3a, 4, 5, 6 Other Species - OS1, 2	August to February (but can occur any time)	7 days	3–5 years in 10 (40%)	4 years	
Bankfull	BK1	Native Vegetation: NV1, 2, 3 - in-channel & fringing, wetland Ecosystem Functions: EF1, 2, 3, 4, 5, 6 - channel maintenance, lateral/longitudinal connectivity Other Species – OS4	August to February (but can occur any time)	In line with natural	In line with natural	N/A	Rate of fall: No faster than 5th percentile of natural Ideally flow should be complete before the end of August and the upper limit of the flow should be 1 metre below bankfull to support the creation of suitable burrows for platypus breeding in planning units where platypus are present

Flow category and EWR code		Ecological objectives	Timing	Minimum duration	Frequency (LTA frequency)	Maximum inter-event period	Additional water requirements
Small wetland inundation	WL1	Native Fish: NF1, 3, 7 - **Spawning (floodplain specialist fish)** Native Vegetation: NV1, 2 - **non-woody wetland maintenance and condition** Waterbirds: WB1, 2, 3, 4, 5 - survival and habitat, potential small scale breeding Ecosystem Functions: EF1, 2, 3, 4, 5, 6 - connectivity, **productivity** Other Species: OS1, 2	September to March (but can occur any time)	2–8 months of asset inundation	7–8 years in 10 (75%)	2 years	Rate of fall: No faster than 5th percentile of natural Ideally 2–4 weeks after SF2 or LF2
	WL2	Native Fish: NF1, 3, 7 Native Vegetation: NV1, 2, 4b, 4e - **lignum condition** Waterbirds: WB1, 2, 3, 4, 5 - survival, habitat and potential breeding Ecosystem Functions: EF2, 3, 5, 6 - connectivity, **productivity** Other Species: OS1, 2	October to April	2–6 months of asset inundation	5–7 years in 10 (60%)	3 years	Rate of fall: No faster than 5th percentile of natural
Large wetland inundation	WL3	Native Fish: NF1, 3, 7 - **dispersal & condition (all species)** Native Vegetation: NV1, 2, 4b, 4e - **lignum maintenance** Waterbirds: WB1, 2, 3, 4, 5 - survival, habitat and breeding Ecosystem Functions: EF2, 3a, 4, 5, 6 - connectivity (possibly between catchments), productivity Other Species: OS1, 2	August to February (but can occur any time)	2–3 months of asset inundation	3–5 years in 10 (40%)	4 years	>22°C Rate of fall: No faster than 5th percentile of natural Ideally 2–4 weeks after SF2 or LF2

Flow category and EWR code		Ecological objectives	Timing	Minimum duration	Frequency (LTA frequency)	Maximum inter-event period	Additional water requirements
	WL4	Native Vegetation: NV1, 2, 4b, 4c, 4e Waterbirds: WB1, 2, 3, 4, 5 - survival, habitat and breeding Ecosystem Functions: EF2, 3a, 3b, 4, 5, 6 - connectivity, productivity Other Species: OS1, 2	Any time	2-3 months of asset inundation	2–3 years in 10 (25%)	5 years	Rate of fall: No faster than 5th percentile of natural
Small overbank	OB1	Native Fish: NF1, 3, 7 Native Vegetation: NV3, 4a, 4c - in-channel, fringing, wetland; **lignum condition** Waterbirds: WB1, 2, 5 - survival and habitat Ecosystem Functions: EF1, 2, 3, 5, 6, 7 - connectivity, **productivity** Other Species: OS1, 2	September to March (but can occur any time)	2–8 months of asset inundation	7–8 years in 10 (75%)	2 years	Rate of fall: No faster than 5th percentile of natural
	OB2	Native Fish: NF1, 3, 7 - **Spawning (floodplain specialist fish)** Native Vegetation: NV4a, 4b, 4c - **RRG maintenance; black box/lignum condition** Waterbirds: WB1, 2, 3, 5 - survival, habitat and potential breeding (non-colonial) Ecosystem Functions: EF2, 3, 4, 5, 6 - connectivity, **productivity** Other Species: OS1, 2	October to April	10 days 2–6 months of asset inundation	4–7 years in 10 (55%)	3 years	Rate of fall: No faster than 5th percentile of natural Ideally 2–4 weeks after SF2 or LF2

Flow category and EWR code		Ecological objectives	Timing	Minimum duration	Frequency (LTA frequency)	Maximum inter-event period	Additional water requirements
	OB3	Native Fish: NF1, 2, 3, 4, 5, 6, 7, 8, 9 - **dispersal & condition (all species)** Native Vegetation: NV4a - RRG woodland condition Waterbirds: WB5 - habitat Ecosystem Functions: EF2, 3, 5 - lateral connectivity, **productivity** Other Species: OS1, 2	August to February (but can occur any time)	5 days 2-3 months of asset inundation	3–5 years in 10 (40%)	4 years	>22°C Rate of fall: No faster than 5th percentile of natural Ideally 2–4 weeks after SF2 or LF2
Large overbank	OB4	Native Fish: NF3 Native Vegetation: NV4b, 4c - **black box & lignum maintenance** Waterbirds: WB1, 2, 3, 4, 5 - **breeding (colonial and non-colonial) and habitat** Ecosystem Functions: EF2, 3, 4, 5, 6 - lateral connectivity, **productivity,** between catchment connectivity Other Species: OS1, 2	September to May (but can occur any time)	3–8 months of asset inundation	2–3 years in 10 (25%)	5 years	Rate of fall: No faster than 5th percentile of natural
	OB5	Native Fish: NF3 Native Vegetation: NV4b Waterbirds: WB1, 2, 3, 4, 5 - breeding (colonial and non-colonial) and habitat Ecosystem Functions: EF2, 3, 4, 5, 6 - lateral connectivity, productivity, **between catchment connectivity** Other Species: OS1, 2	Any time	1–6 months of asset inundation	1 year in 10 (10%)	10 years	Rate of fall: No faster than 5th percentile of natural

Table 11 Important flow regime characteristics needed to deliver native fish objectives

NATIVE FISH OBJECTIVES[15]

Ecological objective	EWR code	Important flow regime characteristics
NF1: No loss of native fish species	CF1	Cease-to-flow periods of durations that are not longer than the persistence of water of sufficient volume and quality in key larger river pool refuges is vital for survival of native fish populations. Alternative watering actions (e.g. pumping) may be required to support floodplain habitats under very dry, dry and moderate scenarios to ensure no loss of species (e.g. to prevent wetlands with threatened fish species from drying out).
	VF1; BF1	Very low flows and baseflows are required for the survival and maintenance of native fish condition as these flows maintain adequate water quality (dissolved oxygen, salinity and temperature) in refuge pools and sufficient flow depth along the whole channel to allow fish movement [at least 0.3 m above cease-to-flow for small and moderate bodied fish (Gippel 2013; O'Conner et al. 2015)].
	BF2	A baseflow preferably between September and March with an annual or biannual frequency is required to enhance recruitment outcomes.
	SF1	Small freshes (at least 0.5 m above cease-to-flow) supports movement and dispersal opportunities for large bodied fish (Fairfull & Witheridge 2003; Gippel 2013; O'Conner et al. 2015).
	LF1	A large fresh of at least five days duration and occurring ideally between July and September (but can occur at any time) is required to promote dispersal and pre-spawning condition for all native fish species five to 10 years in 10. The large fresh should trigger some primary productivity that will provide food resources and hence improve fish condition prior to the spring/summer spawning season. Flow velocities of >0.3 m/s are ideal to trigger fish movement.
	WL4; OB3	A small overbank and wetland inundating flows, ideally from August to February, for at least five days and occurring two to three years in 10 years (with a maximum inter-event period of five years) is also required to support condition and movement/dispersal outcomes of all native fish groups. Larger flows that inundate off-stream habitat can also promote growth and recruitment through increased floodplain productivity and habitat availability. Larger flows that connect low-lying wetlands provide important habitat to support strong survivorship and growth of juveniles.

[15] Important flow regime characteristics for all native fish objectives are based on NSW DPI 2015b and Ellis et al. 2018.

NATIVE FISH OBJECTIVES[15]

Ecological objective	EWR code	Important flow regime characteristics
NF2: Increase the distribution and abundance of **short to moderate-lived generalist** native fish species	CF1; VF1; BF1-2; SF1; LF1; WL4; OB3	In addition to the flows listed above for all native fish species (see NF1 objective), other important aspects of the flow regime for generalists are listed below.
	SF2	Regular (ideally annual) spawning and recruitment events are required for the persistence of short-lived species. Although generalist species can spawn independent of flow events, spawning is enhanced by small freshes during the warmer months of October to April. Events should occur five to 10 years in 10 years with a minimum event duration of 14 days for egg development and hatching. Providing multiple freshes during the spawning season provides flexibility in species response and opportunities for multiple spawning events.
	LF2	Large freshes occurring two to three weeks after spawning will enhance recruitment of larvae and juveniles by aiding dispersal and access to habitat and suitable prey. Larger flows that inundate off-stream habitat can also promote growth and recruitment (i.e. increased floodplain productivity and habitat availability).
NF3: Increase the distribution and abundance of **short to moderate-lived floodplain specialist** native fish species	CF1; VF1; BF1-2; SF1; LF1; WL4; OB3	In addition to the flows listed above for all native fish species (see NF1 objective), other important aspects of the flow regime for floodplain specialists are listed below.
	WL3; OB2	Overbank and wetland inundating flows during the warmer months of October to April provide spawning habitat and floodplain productivity benefits to support fish growth. Overbank and wetland flows should inundate floodplain habitats for at least 10 days to allow for egg development and occur at least five years in 10, with a maximum inter-event period of four years. This period will depend on the persistence of floodplain habitats and time between reconnection to mainstem waterways. Flows should be of a long enough duration to support isolated populations. Water temperatures should be above 22°C.
	LF1-3; BK1; WL1-4; OB1-5	Recruitment is enhanced by subsequent flows events 2–4 weeks after spawning flows. Most floodplain specialist species require spawning and recruitment every one to two years for population survival.

NATIVE FISH OBJECTIVES[15]

Ecological objective	EWR code	Important flow regime characteristics
NF4: Improve native fish population structure for **moderate to long-lived flow pulse specialist** native fish species	CF1; VF1; BF1-2; SF1; LF1; WL4; OB3	In addition to the flows listed above for all native fish species (see NF1 objective), other important aspects of the flow regime for flow pulse specialists are listed below.
	LF2	Spawning of flow pulse specialists is triggered by a rapid rise or fall in flow (relative to natural rates) between spring and summer when temperatures are greater than 17°C. In lowland systems, spawning responses are enhanced by substantial flow depths of at least 2 metres to cover in-stream features and high flow velocities of greater than 0.3 m/s. A large fresh between October to April for a minimum of five days and a rapid rate of rise should meet these spawning requirements. This is needed three to five years in 10 with a maximum inter-event period of four years. Integrity of flow events need to be maintained over long distances (10s to 100s of km) to maximise the capacity for in-stream spawning, downstream dispersal by drifting eggs and larvae and movements by adults and juveniles.
NF5: Improve native fish population structure for **moderate to long-lived riverine specialist** native fish species	CF1; VF1; BF1-2; SF1; LF1; WL4; OB3	In addition to the flows listed above for all native fish species (see NF1 objective), other important aspects of the flow regime for riverine specialists are listed below.
	SF2	Spawning of riverine specialists usually occurs annually, independent of flow, however spawning may be enhanced by a small fresh between October and April to promote ecosystem productivity and inundate additional spawning habitat. Event duration should be a minimum of 14 days with an average frequency of five to 10 years in 10 and maximum inter-event period of two years. Water temperatures should be >20°C. River blackfish may spawn in lower water temperatures of >16°C and Murray cod in >18°C. Murray cod have a narrower spawning window of September to December. For nesting species (e.g. Murray cod and freshwater catfish) preventing rapid drops water levels (that exceed natural rates of fall) during, and for a minimum of 14 days after, spawning is important for preventing fish nests from drying.

NATIVE FISH OBJECTIVES[15]

Ecological objective	EWR code	Important flow regime characteristics
	SF1-2; LF1-2; BK1; WL1-4; OB1-5	Overall, riverine specialists prefer hydraulically complex flowing streams containing submerged structure (snags and benches) that provides cover and spawning habitat. Flow variability through the delivery of small and large freshes, bankfull and overbank flows enhance the availability of diverse habitat, enhances growth and condition of larvae and juveniles and provides connectivity for dispersal between habitats. Recruitment is also enhanced by a larger secondary flow pulse for dispersal and access to nursery habitat in low-lying wetland habitats.
NF6: A 25% increase in abundance of mature (harvestable sized) golden perch and Murray cod	All flows	The flow requirement of golden perch (flow pulse specialist) and Murray cod (riverine specialist) are outlined above under NF4 and NF5, respectively. An increase in mature (harvestable size) fish is strongly dependant on recruitment success and supporting improved population structure.
	BF1-2	Baseflows support the maintenance of populations.
	SF2; LF1-2; WL4; OB3	Recruitment for both species benefits from fresh events and larger flows that inundate ephemeral wetlands. Such large events provide dispersal opportunities and access to sheltered and productive nursery habitat.
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)	CF1; VF1; BF1-2; SF1; LF1-3; BK1; WL4; OB2-3	In addition to the flows listed above for floodplain specialists species (see NF3 objective), important aspects of the flow regime for increasing their prevalence and/or expanding their population are listed below.
	LF1; LF3; WL4; OB3	Expanding populations into new areas will be particularly dependant on dispersal flows, particularly large freshes and overbank and wetland inundating flows. Complementary actions such as conservation stocking and/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 and moderate scenarios to ensure no loss of species for floodplain specialists (e.g. to prevent wetlands with threatened fish species from drying out).
NF8: Increase the prevalence and/or expand the population of key **moderate to long-lived riverine specialist** native fish species into new areas (within historical range)	CF1; VF1; BF1-2; SF1-2; LF1-2; BK1; WL4; OB3	In addition to the flows listed above for riverine specialists species (see NF5 objective), important aspects of the flow regime for increasing their prevalence and/or expanding their population are listed below.

NATIVE FISH OBJECTIVES[15]

Ecological objective	EWR code	Important flow regime characteristics
	LF1; WL4; OB3	Expanding populations into new areas will be particularly dependant on dispersal flows, particularly large freshes and overbank and wetland inundating flows. Complementary actions such as conservation stocking and/or translocation may be required to support these watering actions.
NF9: Increase the prevalence and/or expand the population of key **moderate to long-lived flow pulse specialists** native fish species into new areas (within historical range)	CF1; VF1; BF1-2; SF1; LF1-2; WL4; OB3	In addition to the flows listed above for flow pulse specialists species (see NF4 objective), important aspects of the flow regime for increasing their prevalence and/or expanding their population are listed below.
	LF1; WL4; OB3	Expanding populations into new areas will be particularly dependant on dispersal flows, particularly large freshes (LF1) and overbank and wetland inundating flows (OB3, WL4). Complementary actions such as conservation stocking and/or translocation may be required to support these watering actions.

Table 12 Important flow regime characteristics needed to deliver native vegetation objectives

NATIVE VEGETATION OBJECTIVES[16]

Ecological objective	EWR code	Important flow regime characteristics
NV1: Maintain the extent and viability of non-woody vegetation communities occurring within and closely fringing channels	CF1	Non-woody, inundation tolerant plants occurring on the channel bed, banks, bars and benches require regular wetting and drying to complete life cycles. Prolonged submergence of some amphibious species (e.g. especially if there are continuous high flows during the irrigation season) may have detrimental impacts on survival. [17]
	SF1-2	Small freshes in summer and autumn are important for replenishing soil moisture in river banks to ensure survival and maintenance.

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

[17] Increased cover of non-woody, inundation tolerant vegetation on banks is likely to stabilise bank material and therefore reduce the risk of excessive bank erosion.

NATIVE VEGETATION OBJECTIVES[16]

Ecological objective	EWR code	Important flow regime characteristics
	LF1-3; BK1	Inundation of banks during late winter and early spring by freshes and bankfull flows is required to replenish soil moisture to promote growth during spring. Prolonged submergence of some amphibious species (e.g. especially if there are continuous high flows during the irrigation season) may have detrimental impacts on survival. Variable size and duration of flows including baseflows, variable size freshes and bankfull flows throughout the year will promote diverse communities. Regular inundation will also encourage a dominance of native species over exotic species, as the latter tend to be less tolerant of inundation (Catford et al. 2011). Increased cover of non-woody, inundation tolerant vegetation on banks is likely to stabilise bank material and therefore reduce the risk of excessive bank erosion.
NV2: Maintain the extent and viability of non-woody vegetation communities occurring in wetlands and on floodplains	LF1-3; BK1	Large freshes and bankfull flows will support non-woody wetland vegetation in some low-lying wetlands with low commence to flow thresholds.
	WL1-4; OB1-5	Overbank and wetland inundating flows that inundate wetlands and floodplains for two to eight months between August and April are required to support non-woody, inundation tolerant vegetation.
	WL1-2; OB1	Small but frequent overbank and wetland inundating events will be important for maintaining the extent and viability of these species. The required duration and frequency varies widely by species. Highly water-dependant, amphibious species such as water couch, spike-rush, and cumbungi require inundation for five to eight months, eight to 10 years in 10. The maximum period between events is two years.
	WL4; OB3-4	Larger overbank and wetland inundating flows will support amphibious damp species such as floodplain herbs, grasses and sedges that require less frequent (three to 10 years in 10) and shorter duration (two to four months) inundation.
NV3: Maintain the extent and maintain or improve the condition of river red gum and river cooba communities closely fringing river channels	LF1-3; BK1	Large freshes and bankfull flows that recharge alluvial aquifers and soil moisture in the riparian zone are also important for maintaining deep rooted vegetation between inundation events. The general condition of riparian vegetation will benefit from inundation or groundwater recharge anytime of the year, with an ideal frequency of inundation of four to 10 years in 10 to maintain good condition.
	BK1; WL3-4; OB1-5	River red gum and river cooba fringing river channels will be supported by a range of flows including, most importantly, bankfull flows, which inundate the tops of banks, overbank flows and larger wetland inundating flows that inundate the fringing riparian zone.

NATIVE VEGETATION OBJECTIVES[16]

Ecological objective		EWR code	Important flow regime characteristics
NV4: Maintain the extent and maintain or improve the condition of native woodland and shrubland communities on floodplains	River red gum woodland	WL3; OB2	Maintaining the condition of river red gum woodlands on the floodplain requires overbank flows that inundate vegetation for between two and seven months during September to February. For river red gum communities located on lower parts of the floodplain, inundation needs to occur four to 10 years in 10 years with a maximum period between events of three years.
		WL4; OB3	Maintenance of river red gum communities located higher on the floodplain requires larger overbank and wetland inundating events but these can occur less frequently: on average three to five years in 10 years, with a maximum inter-event period of five years. Regeneration of river red gum communities will require additional, shorter duration (one to two months) inundation during August to November. These events would ideally occur the year following a maintenance flow to support the survival of seedlings from the previous year in areas where recruitment is desired.
	Lignum shrubland	WL3-4; OB1-2	Maintenance of lignum shrublands requires inundation by overbank or wetland inundating flows for three to seven months at a frequency of five to 10 years in 10 and a maximum period between events of five years. Regeneration requires more frequent inundation (ideally annual), for one to 12 months between August and March (September to February for vegetative expansion).
		WL3; OB2	Overbank and wetland inundating events that occur more frequently will support regeneration and maintenance of lignum on lower parts of the floodplain.
		WL4; OB4-5	Large overbank events and wetland inundating events will support maintenance of lignum located higher on the floodplain.
	Black box woodland	OB4-5	Large overbank flows are required to maintain and improve condition of black box woodland communities, which tend to be located on higher parts of the floodplain. Maintenance requires inundation for two to six months, at a frequency of two to four years in 10 years and a maximum period between events of five years. Greater than five years interval may result in a reduction in condition.
		OB2	Regeneration and improvement of condition will require additional inundation for one to two months on an annual basis (maximum inter event period of two years).

Table 13 Important flow regime characteristics needed to deliver waterbird objectives

WATERBIRD OBJECTIVES[18]

Ecological objective	EWR code	Important flow regime characteristics
WB1: Maintain the number and type of waterbird species	WL1-4; OB1-5	Maintaining waterbird species richness in the mid and lower Lachlan wetlands will require a range of small, medium and large overbank and wetland inundating flows to support feeding and breeding habitat (see WB2, 3, 4 objectives) and maintain habitat condition (see WB5 objective). Overbank and wetland inundating flows, preferably delivered in spring–summer, that inundate a mosaic of floodplain habitats including non-woody floodplain vegetation, open shallow waterbodies and deep lakes and lagoons will provide feeding habitat for a range of waterbird species including open water foragers, herbivores, emergent vegetation dependent species, large waders, wetland generalists and 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 and resident shorebird species (small waders).
WB2: Increase total waterbird abundance across all functional groups	WL1-4; OB1-5	As in WB1 provide seasonal (spring–summer) flooding with gradual drawdown over summer into autumn to provide feeding habitat for waterbird species and maintain the condition of waterbird breeding and feeding habitats. Increasing total waterbird abundance will also rely on maintaining (and in some cases) improving the condition of key native vegetation types that provide breeding and foraging habitats. Overbank and wetland inundating flows are critical to maintaining the extent and condition of these breeding habitats (see WB5 objective).
	WL1-3; OB1-2	Small and medium overbank and wetland inundating events (OB1, 2, WL1–3) will support survival of waterbirds, provide foraging habitat and may support small scale non-colonial waterbird breeding. Where possible to coordinate, overbank flows (OB1, 2, WL2–4) should be delivered at the same time as neighbouring catchments to provide benefits to waterbird populations by providing habitat across a larger area of the Murray-Darling Basin.
	WL2-3; OB1-2	Follow-up overbank and wetland inundating flows (OB1, 2, WL2–3) in years following large breeding events in the Murrumbidgee catchment will also promote the survival of juvenile birds and contribute to increased waterbird populations.

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

WATERBIRD OBJECTIVES[18]

Ecological objective	EWR code	Important flow regime characteristics
	WL4; OB4-5	Increasing waterbird abundance in the Lachlan area will require increased breeding opportunities for both colonial and non-colonial waterbirds in the wetlands across the Murray-Darling Basin. This can be enhanced through supporting large overbank and wetland inundating flows from September to March with inundation duration maintained into May for colonies that commence in March.
	OB4-5	For active colony sites extend the duration of large overbank flows to extend the duration of inundation in colony sites and maintain adequate water depths under nesting birds. Overbank events need to be of sufficient duration (3–6 months, species dependant) to ensure successful completion of colonial waterbird breeding (including from egg laying through to fledging including post-fledgling care) and access to key foraging habitats to enhance breeding success and the survival of young.
WB3: Increase opportunities for non-colonial waterbird breeding	OB2; OB4; OB5	Providing opportunities for non-colonial waterbird breeding will include the provision of seasonal flows (September to March) to inundate floodplain habitats for more than 2–3 months. Spring and summer is the ideal season, with opportunistic breeding in autumn and winter.
	WL3-4; OB2; OB4; OB5	Habitat availability for non-colonial species will increase with increasing magnitude (both extent and duration of inundation) of overbank and wetland inundating flows. Providing opportunities for breeding in non-colonial species and contributing to increased numbers of non-colonial species will also rely on maintaining (and in some cases) improving the condition of key native vegetation types that provide breeding and foraging habitats (see WB5 objective).
WB4: Increase opportunities for colonial waterbird breeding.	OB4-5	Supporting breeding in active waterbird colonies in the Lachlan requires large overbank flows during September to March. The minimum duration of inundation of active colony sites and surrounding foraging habitat is three to four months to ensure successful completion of colonial waterbird breeding (from egg laying through to fledging including post-fledgling care) and access to key foraging habitats to enhance breeding success and the survival of young. These large overbank events are required on average two to three years in 10 years, with a maximum inter-event period of five years. They will support larger colonies and a greater number of breeding species (non-colonial and colonial species) with greater benefit to breeding success and increasing total abundance of waterbirds (wee WB2 and WB3 objectives).

WATERBIRD OBJECTIVES[18]

Ecological objective	EWR code	Important flow regime characteristics
WB5: Maintain the extent and improve condition of waterbird habitats	WL1-4; OB1-5	Waterbirds depend on a wide variety of breeding and foraging habitats, which are maintained through a range of overbank and wetland inundating flows. Colonial waterbird species are dependent on relatively few sites across the major wetlands of the Murray Darling Basin. These include sites that provide nesting habitat consisting of river red gum, river cooba, belah, lignum and/or cumbungi.
	WL2-4; OB1-5	Overbank and wetland inundating flows will also support a broader range of foraging habitats in the Lachlan, including spike-rush sedgelands, marsh grasslands, lignum shrublands, open lagoons and lakes. The required duration and frequency of overbank flows to support these vegetation types are outlined under the native vegetation objectives.
	WL2-3; OB1-2	Overbank flows of sufficient duration are needed to maintain the extent and condition of these vegetation communities in these discrete wetland sites. This ensures that sites are in event-ready condition
	OB4-5	Large overbank events (OB4,5) are required to initiate large scale colonial waterbird breeding events.

Table 14 Important flow regime characteristics needed to deliver priority ecosystem function objectives

PRIORITY ECOSYSTEM FUNCTIONS OBJECTIVES[19]

Ecological objective	EWR code	Important flow regime characteristics
EF1: Provide and protect a diversity of refugia across the landscape.	CF1	Cease-to-flow periods of durations that are not longer than the persistence of water of sufficient volume and quality in key larger river pool refuges is vital for survival of native plants and animals.
	VF1; BF1-2	Very low flows and baseflows are required to maintain in-channel pools as refugia for native fish and other biota. These flows need to be of sufficient magnitude to prevent stratification of pools that can lead to de-oxygenation of the water column and subsequent fish deaths. They are required every year for most of the year (no less than natural) and are especially important during dry times.
	SF1-3	When restarting flows after a cease-to-flow event, larger magnitude flows may be required to prevent detrimental water quality outcomes (as poor quality water from the bottom of pools is mixed through the water column).

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

PRIORITY ECOSYSTEM FUNCTIONS OBJECTIVES[19]

Ecological objective	EWR code	Important flow regime characteristics
	WL1-4; OB1-5	Core wetland areas in the Lachlan can hold water for many months to years and provide an important refuge for waterbirds and other aquatic fauna during dry times. Regular overbank and wetland inundating flows are required to maintain the condition of wetland and vegetation in the Lachlan floodplain and wetlands to ensure they can function as refuges during dry times.
EF2: Create quality instream and floodplain and wetland habitat	All flows	The full range of in-channel and overbank flows are required to maintain quality instream and floodplain habitat. Variable in-channel flows (baseflows – bankfull flows) will provide a diversity of physical and hydraulic habitats. With increasing magnitude of flows, greater areas of the channel are inundated (e.g. benches, bars, snags and banks at different elevations in the channel). Bank notching can be avoided by varying flows (avoiding holding flows constant for too many consecutive days) and targeting different peak heights for freshes. To protect banks from excessive erosion it is important to maintain rates of fall that do not exceed natural rates of fall for ALL regulated deliveries. Slow rates of fall allow water to drain from the bank slowly, preventing mass failure of the banks.
	BF1-2; SF1-3	Baseflows and small freshes provide areas of slackwater (slow flowing) habitat. Small freshes are also important for flushing fine sediment from pools, de-stratifying pools and maintaining geomorphic features such as benches and bars. Maintaining slow rates of fall is particularly important when flows are in the lower third of the channel, to protect the 'toe' of the bank, which supports the rest of the bank above.
	LF1-3; BK1	Large freshes provide deeper and faster flowing habitats. Bankfull flows are important for geomorphic maintenance of all channel features. Large freshes are also important for flushing fine sediment from pools, de-stratifying pools and maintaining geomorphic features such as benches and bars.
	WL1-4; OB1-5	Overbank and wetland inundating flows (OB1–5, WL1–4) are required to provide essential floodplain and wetland habitat for native fish, waterbirds and other aquatic fauna.
EF3: Provide movement and dispersal opportunities within and between catchments for water dependent biota to within catchment	BF1-2; SF1-3	Providing longitudinal connectivity is critical for migration, recolonisation following disturbance events, allowing species to cross shallow areas, and dispersal of larvae to downstream habitats. In-channel flows of adequate depth and duration (baseflows and freshes) are important to allow for the movement of aquatic and riparian fauna and flora along rivers and creeks. For example, flows of at least 0.3 m are needed to allow medium sized native fish to move along a channel.

PRIORITY ECOSYSTEM FUNCTIONS OBJECTIVES[19]

Ecological objective		EWR code	Important flow regime characteristics
complete lifecycles and disperse into new habitats.		LF1-3; BK1; WL1-4; OB1-5	Physical barriers, such as dams and weirs, have introduced additional barriers throughout the Lachlan, make large freshes, bankfull flows, and occasionally small overbank flows important for overcoming these man-made structures where fishways are not present.
	between catchments	OB5	End of system flows from the Lachlan occasionally connects with the Murrumbidgee, when it is also experiencing high flows, providing dispersal opportunities for native fish, mainly floodplain specialists.
EF4: Support instream and floodplain productivity		LF1-3; BK1; WL1	Large freshes bankfull flows and small wetland inundating flows may drive small pulses of productivity.
		WL2-4; OB1-5	Overbank and wetland inundating flows that inundate the floodplain for several months are the most critical flow categories for supporting large scale productivity, which in turns drives aquatic food webs both on the floodplain and in-stream. Primary productivity includes growth of algae, macrophyte, biofilms and phytoplankton, which in turn drives secondary productivity (zooplankton, macroinvertebrates, fish larvae etc.).
EF5: Support nutrient, carbon and sediment transport along channels, and between channels and floodplains/wetlands.		SF1-3; LF1-3; BK	Freshes and bankfull flows are important for mobilising organic matter and sediment from in-channel surfaces (e.g. leaf litter that has accumulated on bars, benches and 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 and carbon, to drive primary productivity, or in the case of sediment, for channel maintenance (e.g. to replenish banks and benches).
		WL1-4; OB1-5	Overbank and wetland inundating flows are essential for transferring nutrients and carbon from the floodplain to the channel.
EF6: Support groundwater conditions to sustain groundwater dependent biota.		LF1-3; BK1; WL1-4; OB1-5	Large freshes, bankfull flows, overbank, and wetland inundating flows will contribute to recharging shallow groundwater aquifers in areas where there is a surface-groundwater connection. This recharge can reduce the salinity of shallow aquifers and raise water tables, providing critical soil moisture for deep-rooted vegetation in the riparian zone and on low-lying floodplains.

Table 15 Important flow regime characteristics needed to deliver frog and other species objectives

OTHER SPECIES OBJECTIVES

Ecological objective	EWR code	Important flow regime characteristics
OS1: Maintain species richness and distribution of flow-dependent frog communities	CF1	The duration of cease-to-flow events should not persist longer than what occurred naturally to protect sufficient water volumes and quality in key larger river pool refuges.
	VF1; BF1-2	Very low flows and baseflows can help maintain adequate water quantity and quality (dissolved oxygen, salinity and temperature) in refuge pools.
	WL1; OB1	Wetland inundating events and small overbanks maintain core wetlands, including off-channel waterholes for refuge.
	WL2-4; OB2-5	larger flows maintain frog condition and habitat, allow dispersal, and support breeding.
OS2: Maintain successful breeding opportunities for flow-dependent frog species.	WL1-4; OB1-5	Wetland inundating events and overbank flows provide opportunities for breeding and recruitment (i.e. laying eggs and tadpole metamorphosis). To support successful breeding opportunities, these flows should ideally occur every one to two years and inundate their habitat for six or more months (with a minimum of four months). Spring–summer breeders require flows ideally from October to March, while species with more flexible breeding are likely to benefit from flows arriving between July to April. A gradual rise and fall is likely to improve recruitment outcomes.
OS4: Maintain water-dependent species richness[20]	VF1; BF1; SF1-2	Low flows and riffle areas should be maintained between June to August to support foraging areas and movement between pools, which are their preferred habitat. Platypus prefer to feed in water that is 1-3 metres deep (Serena & Williams 2010).
	LF1; BK1	Large freshes and bankfull flows should ideally finish before the end of August to encourage female platypus to choose burrows higher on the river bank. If these higher flows occur between September to February or for extended periods they can flood platypus burrows and reduce the availability of benthic invertebrates, therefore reducing breeding success (Scott & Grant 1997).

4.4 Changes to the flow regime

The flow regime in the Lachlan has changed due to regulation and development in the catchment. The degree and type of change varies depending on the location within the catchment.

Consumptive use is responsible for diverting 33% of the Lachlan River, however the total capacity of the major storages in the Lachlan catchment exceeds the natural average annual

[20] Most of the other flows are able to support the majority of other water-dependent species, however platypus have been found to have a few specific flow requirements to fulfil their life history.

flow (Hillman et al. 2003). The flow categories most impacted by storage and diversions are cease-to-flow periods, low flows and small freshes. Larger events are gradually less impacted as you get further away from Wyangala Dam, mainly due to the flows contributed by tributaries and because water extraction is a small portion of the larger flows. Importantly, the timing of delivering significant flows servicing irrigation demand has also been changed from natural seasonality (Hillman et al. 2003).

Zone A planning units

Flow regimes in the rivers, creeks and wetlands downstream of Wyangala and Carcoar dams are affected by:

- the capture and subsequent active release of water from Wyangala Dam that support agricultural production
- the re-capture and active release of water from Lake Cargelligo and Lake Brewster at times that support agricultural production and for flood mitigation
- the redistribution of flows by weir infrastructure under river management and operations
- the extraction or diversion of flows out of rivers and creeks under basic landholder rights or licenced extractions (regulated Stock & Domestic, High Security, General Security)
- river and creek channel works (straightening deepening, increased or decreasing connections) and floodplain works (channels, levees, etc.).

These regulation and management actions have had the following impacts on flow regimes.

Regulated Lachlan River upstream of Forbes

The Zone A planning units upstream of Forbes are heavily influenced by Wyangala Dam operations and their impacts. This seasonality of flows is profoundly modified in this section of river (Hillman & Brierley 2002) due to delivery of irrigation orders. It is also highly susceptible to impact by a fast rising and falling river level and thermal influences from the dam supply.

Proximity to dam operations leaves this reach susceptible to the main impacts of regulation. The low-flow regime has been significantly altered, as periods of flow below 200 ML/d have been reduced from 27 percent to only two percent (Hillman & Brierley 2002). Additionally, the impact of the dam has been to remove small to medium floods and freshes, between 3,000 ML/d and 25,000 ML/d (Hillman & Brierley 2002).

Consequences of this loss of flow variation include infestation with carp, a decline in native fish, and increase in algal bloom risk (Hillman et al. 2003).

Lachlan River and anabranches from Forbes to Willandra Weir

This zone of the Lachlan system is responsible for the majority of water extraction for irrigation.

The in-channel environment is also heavily modified to maintain the efficiency of water delivery. Weirs and other barriers impact fish passage and bulk water diversions can impact fish populations.

The Lachlan anabranches, and main channel to a lesser extent, receive a longer, steady base flow with less variation than natural conditions. As such, conditions are favourable for invasive fish species and the encroachment of cumbungi beyond its natural extent. While this is a reflection of the changes that have also occurred in the river's main channel, the departure from natural condition is more significant in the anabranch creeks.

Water quality risks for both blue-green algae and hypoxic black water are exacerbated by these altered flow conditions

Lake Cargelligo and Lake Brewster

These lakes have experienced increased periods of inundation and wetting as a result of river regulation. These assets have developed new ecological characteristics and values, however conditions also render them prone to blue green algae and enables them to support pest fish species.

Wetlands downstream of Willandra Weir

The extensive wetlands at the end of the Lachlan system have been affected in health and extent by the cumulative effects of consumption along the length of the river (Hillman et al. 2003). At the Great Cumbung Swamp, typically low flow rates have been reduced further, due to the removal of flows greater than 50 ML/d (Hillman & Brierley 2002).

The area from Hillston to Whealbah experiences high irrigation demand. This means that bulk water is delivered and removed quickly from the system, which can lead to large, rapid changes in water level, inconsistent with the geomorphology. This localised hydrological regime impacts bank stability, water quality, fish and stream metabolism.

Again, the conditions for hypoxic blackwater, blue-green algae and invasive species are more favourable under this altered regime.

Lower Lachlan and effluent creeks

In the lower Lachlan and many of the effluent creeks, the impact of reduced water volume and flow rates are more significant than seasonality, which has a less pronounced effect than in the upper catchment (Hillman & Brierley 2002). Flows reach the Murrumbidgee River in only 15–20% of years but they have reduced significantly; average annual flows have declined from 234 GL/yr to 120 GL/yr at Oxley (Hillman & Brierley 2002).

In addition to the impacts listed for the lowland wetlands above, the main river channel is choked by silt and woody debris, so that insufficient flows are achieved for stock and domestic purposes. (Hillman & Brierley 2002).

Figure 14 **Lachlan Riverine Working Group at Booberoi Creek**
Photo: L Thurtell/DPIE

Zone B planning units

The main impact to flow regimes in Zone B planning units is from extraction for basic landholder rights, unregulated licenced extractions together with weirs, levees and other works (including unlicensed structures). While total extractions on these systems are lower, the effects on these parts of the flow regime can be significant.

The impact of this development through most systems in Zone B has been to:

- increase the duration of cease-to-flow periods
- reduce pool persistence duration in some cases and cause extended periods of pooling in others
- reduce low flows
- reduce small fresh flows in some rivers and creeks

Flows in these systems are almost entirely dependent on natural rainfall events and are not manageable except by some small-scale structures such as small weirs and in-stream (licenced) dams. The main tool available to maintaining or improving flow regimes is through protection of environmental water which flows from Zone A (HEW and PEW). Other rules in the WSP will also support ecologically important flow categories by defining when water can be taken, outlining the limits to extraction, and on trading into these planning units. Management recommendations to support important flows in Zone B are described in Chapter 6 and recommendations for specific planning units are described in Part B, Chapter 3.

5. Risks, constraints and strategies

The Lachlan LTWP is focused on managing water for the environment to deliver ecological objectives 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 *Risk Assessment for the Lachlan Water Resource Plan Area* (NSW DPIE–Water 2019b) was undertaken to inform water resource planning in the Lachlan. 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 Lachlan Water Resource Plan. This chapter complements that risk assessment and addresses the specific risks and constraints that may affect the implementation of the LTWP.

This chapter focuses on risks to meeting the EWRs of priority environmental assets and functions in the Lachlan catchment (Table 16). It also outlines the risks and constraints that affect our capacity to achieve the ecological objectives of this LTWP (Table 17).

This risk assessment has assisted with identifying investment opportunities for improving the likelihood that EWRs can be achieved in the short and long-term (Table 26).

Figure 15 **Merrimajeel Creek**
Photo: V Bucello/Midstate Video

5.1 Risks and constraints to meeting EWRs

Table 16 Risks and constraints to meeting environmental water requirements in the Lachlan catchment and strategies for managing them

Risk	Description	Potential management strategies	Potential project partners
Insufficient water for the environment	Total volumes of water available for the environment do not meet environmental need.	**Zone A planning units**	
		Improve the seasonal pattern of freshes through seasonally-cued HEW releases	DPIE–BC and CEWO
		Allow for environmental water delivery to build on natural events	WaterNSW, DPIE–BC and DPIE–Water
		Investigate options for the strategic delivery of irrigation orders to mimic natural flow events (requires interagency discussion)	WaterNSW, DPIE–BC, EWAG, CAG and DPIE–Water
		Zone B planning units	
		Implementation of the Lachlan Water Resource Plan	DPIE–Water
		Maintain rules restricting trade into water sources with high or medium risks (as defined by the Lachlan WRP Risk Assessment)	DPIE–Water
		Consider implementing daily extraction limits to protect any altered ecologically important flow categories	DPIE–Water
		Review low flow access rules where in-channel flows have been impacted since development	DPIE–Water
Unprotected tributary inflows	There are currently no rules to protect tributary inflow events (e.g. Belubula)	Use planned water accounts to strategically protect tributary inflows	DPIE–BC
		Investigate opportunities to establish rules in the Lachlan Water Sharing Plan to protect important tributary inflows	DPIE–Water

Risk	Description	Potential management strategies	Potential project partners
Water take during environmental water delivery and natural flow events	Losses as discrepancies in volumes of environmental water from all flow deliveries (ordered or natural events) **Note**: The likelihood of water loss is related to the pressure for consumptive water and a perceived lack of monitoring and/or enforcement of water extraction.	WSP rules, an effective gauging network and accounting should combat large discrepancies in monitored environmental water	WaterNSW and DPIE–Water
		Establish an appropriate communication strategy to inform relevant stakeholders of environmental water deliveries	DPIE–BC and WaterNSW
		Refer to the Natural Resources Access Regulator *Water Compliance Policy and Strategy*	NRAR
Floodplain structures and barriers	Unmanaged construction (e.g. levees, diversion channels, sediment blockage of culverts) has diverted flows and caused barriers to delivering water to wetland and floodplain areas.	Investigate opportunities to complete a *Lachlan Valley Floodplain Management Plan*	DPIE–Water
		Undertake comprehensive review of works and structures in the Great Cumbung Swamp	DPIE–Water and NRAR
		Implement compliance or remediation actions where needed to maximise the benefit of bankfull and overbank flows	NRAR
Insufficient channel capacity	Channels that are choked by silt and non-woody debris can impede deliveries (e.g. Merrimajeel Creek)	Reinstate more natural variability of flows to reduce bank slumping, notching, increased erosion and siltation	DPIE–BC, CEWO and WaterNSW
		Investigate works and land management options to increase ability to deliver environmental flows in the lower Lachlan effluent creeks	DPIE–BC, CEWO and LLS
Channel capacity sharing constraint	During irrigation season high environmental flows targeting certain key floodplain wetland areas are limited due to consumptive water orders taking up available channel capacity in the lower river.	Formalise previously used channel sharing arrangements	DPIE–BC and WaterNSW
		Investigate implementing a market based mechanism for sharing channel capacity when there are competing demands.	DPIE–Water, DPIE–BC, and WaterNSW
		Continue to participate with WaterNSW and irrigators in sharing and planning for deliveries when this channel sharing capacity constraint may occur.	DPIE–BC, CEWO and WaterNSW

Risk	Description	Potential management strategies	Potential project partners
Inappropriate regulator design	Lachlan River flows above 2,400 ML/d at Willandra Weir commences flows into Willandra Creek even with the creek regulator fully shut. Any environmental flow targeting assets below Willandra Weir means there will be some “losses” into Willandra Creek.	Investigate measures to improve water management options at Willandra Weir. Possibly upgrade regulator or weir pool.	WaterNSW, DPIE–BC, CEWO and DPIE–Water
Bulk delivery release periods limiting environmental water deliveries	During years of low irrigation orders and low natural flows (dry conditions) deliveries in rivers and creeks may be constrained to bulk delivery periods. This can restrict periods when environmental water deliveries can be made.	Proactively plan for delivery of environmental water during years that bulk delivery is not implemented, to maximise ecological objectives	DPIE–BC
		Work with river operators to inform the timing, rate and duration of consumptive water deliveries to achieve better environmental outcomes	WaterNSW and DPIE–BC
Decreased release capacity	At each storage, release capacities decrease as storage levels drop. This is due to the availability of different release mechanisms and some inefficiencies	Investigate options for increasing the maximum delivery rates from storages to meet EWRs at a variety of storage capacities.	DPIE–BC, DPIE–Water and WaterNSW
	In-stream fresh flow releases from Wyangala Dam are often constrained in flow rate to accommodate the requirement of the hydro plant to maximise releases through their facility. The hydro plant has a capacity of approximately 3,000 ML/d	Investigate opportunities to increase deliveries from Wyangala beyond the flow rates acceptable to the hydro plant. This includes clarifying the arrangements for competing priorities in release rates	DPIE–BC, WaterNSW and DPIE–Water

Risk	Description	Potential management strategies	Potential project partners
	If Brewster or Cargelligo are affected by blue-green algae then they cannot be used to deliver flows to the Lachlan. This can quarantine the Brewster EWA and prevent its use, subjecting it to evaporative losses. A resulting greater proportion of environmental water use from Wyangala leads to the WQA being debited for losses. The use of EWA from Wyangala reduces the efficacy of watering events due to increased lead times, flattening of the hydrograph in the lower river, and losses.	Supplement flows from BGA-affected storages (with shandying) with environmental flows from Wyangala Dam Investigate opportunities to access Brewster EWA from Wyangala Dam subject to transmission adjustments When conditions are favourable, utilise environmental water to undertake risk mitigation activities within Lake Brewster to maintain water quality, which can contribute to keeping the storage online	DPIE–BC and WaterNSW
Inappropriate rate of dam releases	Dam releases occur from Wyangala Dam as efficiently as possible, meaning river levels rise and fall rapidly. This can increase erosion rates, cause stream banks to collapse and impact on the life cycles of native plants and animals.	Implement more natural flow patterns to benefit the ecology of the river. This can be achieved by adopting a more natural rate of reduction in releases from Wyangala Dam after flow events, and providing variability in flow rates during long delivery periods Management techniques or environmental water could be employed to achieve this [21]	DPIE–Water, DPIE–BC, CEWO and WaterNSW
		Investigate whether bulk water deliveries can be released from Wyangala Dam at a flow rates that mimic natural flow conditions[22]	DPIE–BC, CEWO, –DPIE–Water, WaterNSW and water users

[21] Investigate whether the risk associated with the reduced frequency of freshes during late spring and summer can be mitigated by delivering bulk water in patterns that mimic natural flow conditions. The ability to implement this strategy will vary between years and seasons and must be consistent with the need for efficient and timely water delivery. Discussions would need to be undertaken between DPIE and the CAG at the start of the irrigation planning season, to examine whether delivery patterns can be varied without impacting on water security and efficiency.

[22] The ability to implement this strategy will vary between years and seasons and must be consistent with the need for efficient and timely water delivery. Discussions will need to be undertaken between DPIE–BC and other water users at the start of the irrigation planning season, to examine whether delivery patterns can be varied without impacting on water security and efficiency.

Risk	Description	Potential management strategies	Potential project partners
Inappropriate timing of dam releases	Irrigation water is released from Wyangala and Carcoar dams as efficiently as possible and counter to natural seasonal flow patterns. This has an impact on the life cycles of native plants and animals	Optimise water releases for multiple benefits	DPIE–Water, DPIE–BC and WaterNSW
Lack of protection for environmental flows	*Water Sharing Plan for the Lachlan Regulated and Unregulated River Water Source* and the *Water Sharing Plan for the Belubula Regulated River Water Source* inadequately deals with protection of environmental flows in unregulated reaches Environmental water is ordered to a gauge and there is no protection of environmental water past this point to ensure that it reaches all target assets Environmental water may not be benefiting downstream catchment areas, unregulated systems or contributing to end of system flows	Communicate to Lachlan community the whole-of-system management approach to help improve understanding of the importance of protecting environmental return flows	DPIE–BC, WaterNSW and DPIE–Water
		Installation of adequate gauging to more accurately quantify and protect return flows (relates to Booberoi Creek anabranch to the Lachlan River)	DPIE–Water
		Utilise remote surveillance tools, such as satellite, to track flows through the system and monitor compliance with water access licence conditions	DPIE–Water and NRAR
		Investigate mechanisms in the Lachlan WSP to protect environmental water deliveries (HEW and PEW) from extraction (e.g. in Merrimajeel, Muggabah and Merrowie Creeks), including from floodplain harvesting	DPIE–BC and DPIE–Water
		Maintain relationships with landholders and formalise agreements that protect environmental water delivery to its intended location	DPIE–Water, DPIE–BC
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	Consider purchasing water licences in high-risk areas (as determined by the Risk Assessment)	DPIE–BC, CEWO and DPIE–Water
		Investigate improved metering of pumps	DPIE–Water, WaterNSW and Landholders

Risk	Description	Potential management strategies	Potential project partners
	in the unregulated catchment to support these rules. Limited gauging and drawdown metering in the unregulated catchment makes it difficult to monitor compliance.	Investigate better gauging to help licence holders and compliance officers determine stream flow	DPIE–BC, DPIE–Water, WaterNSW and CEWO
		Consider reviewing Lachlan unregulated and alluvial WSP rules in high-risk areas as a mechanism to ensure that sufficient water is protected for the environment	DPIE–Water
Reduced water available for the environment from farm dam interception	The Murray-Darling Basin Sustainable Yields project (CSIRO date) estimated a growth rate of 0.6% for the entire Basin, which would equate to a reduction of inflows of 1.3-1.6% to streams as a result of farm dam interception in the Lachlan. This impact is most apparent to low flows in the Belubula and Crookwell Rivers, and to all flows in the Abercrombie River.	Require farm dams with a capacity above the maximum harvestable right dam capacity to be licensed and comply with extraction limits (SDL)	DPIE–Water and NRAR
		Proposed amendments to the Lachlan and Belubula WSPs to better protect impacted flow components	DPIE–BC and DPIE–Water
Unwanted impacts from environmental water deliveries	May include inundation of crops, disruption to access and inundation of stock and infrastructure for overbank environmental flows.	Improve stakeholder education and resources to increase understanding of floodplain inundation patterns	LLS
		Investigate opportunities to complete a *Lachlan Valley Floodplain Management Plan*	DPIE–BC, DPIF and DPIE–Water
		Communicate intended flow deliveries and provide regular updated information for landholders to understand and determine their own flooding risk of farming on the floodplain	DPIE–BC and CEWO
		Investigate improving crossings and provide access, and programs to reduce cropping land used in lowest flow paths and floodplains	DPIE–BC and CEWO
A reduction of volumes and availability of	Translucency, carryover, and other environmental water provisions are	Ensure stakeholders are consulted in any review process for the Lachlan WSP	DPIE–Water

Risk	Description	Potential management strategies	Potential project partners
environmental water (HEW and PEW) in future revisions of the WSP	subject to changes resulting from 5-yearly reviews of WSP.	Monitoring and evidence of environmental water requirements benefits through implementation of the NSW MER plan.	DPIE–BC, DPIE–Water and DPIF
Lack of variability in weir pool depth 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 height. However, the ecological condition of weir pools will improve if water levels are variable.	Investigate options for optimising management of weir pools, considering environmental benefits and informed by science	DPIE–BC, DPIF, DPIE–Water and WaterNSW

Figure 16 Monitoring flows in the river
Photo: M Carnegie/Lake Cowal Foundation

5.2 Non-flow related risks and constraints to meeting LTWP objectives

The risks and constraints to meeting the ecological objectives include non-flow related external factors that could potentially impact on achieving the objectives outlined in this plan (Table 17). These may be water related, such as cold-water pollution downstream of Wyangala and Carcoar dams; or consequences of inappropriate land use practices, such as the reduction of groundcover over large areas in upper catchments, and the clearing of native vegetation. While managing these risks and constraints is outside the scope of this LTWP, they have been included to draw attention their influence on river and wetland health, and to highlight the importance of linking this LTWP with natural resource management.

Table 17 Risks and constraints to meeting ecological objectives in the Lachlan catchment

Risk	Description	Potential management strategies	Potential project partners
Poor water quality	Water quality affects the ecology and survival of aquatic organisms	Implement recommendations and strategies for use of WQA detailed in the *Water Quality Management Plan and the Incident response guide* (NSW DPIE–Water 2019a and d)	DPIE–Water with the Critical Water Advisory Panel and the Regional Algal Coordinating Committee
		Manage salinity in accordance with the *Basin Salinity Management Strategy*	DPIE–Water
		Reduce the risk from poor water quality through proposed changes to trade and access rules in the WSP	DPIE–Water
		Consider use of HEW water to prevent minor water quality issues when PEW or WQA is not available.	DPIE–BC
		Implement land management strategies to improve water quality	LLS with Landholders, Landcare, WaterNSW, DPIE–Water and other community groups
Hypoxic events	Hypoxic events can occur with the release of water after dry or low-flow periods (including flood events), heatwaves, or as a result of algal blooms. This can occur from the build-up of organic material in channels and on floodplains or higher than normal temperatures for long periods. Can lead to low-dissolved oxygen levels and potential fish kills.	Map high-risk areas and high-priority refuge areas	DPIE–BC, DPIE–Water and DPIF
		Implement recommendations and strategies for use of WQA detailed in the *Water Quality Management Plan and the Incident response guide* (NSW DPIE–Water 2019a and d) before a major algal bloom outbreak	DPIE–Water with the Critical Water Advisory Panel, and WaterNSW
		Consider delivering HEW to key areas during high-risk periods, such as warm weather in late spring and summer	DPIE–BC
		Monitor dissolved oxygen for active management of water actions	DPIE–Water
		Provide flow regimes that avoid extended dry or very low-flow periods	DPIE–BC and DPIE–Water

Risk	Description	Potential management strategies	Potential project partners
		Restart rivers with flow rates that reduce the risk of hypoxic blackwater, informed by water quality monitoring	DPIE–BC and WaterNSW
Native vegetation clearing and/or degradation	Native vegetation clearing has direct impacts on vegetation objectives and the availability of waterbird habitat. Changes to riparian vegetation can impact on water quality, erosion rates and instream habitat.	Work with relevant departments and organisations to identify and protect core wetland vegetation communities	DPIE–BC
		Review identification of semi-permanent and ephemeral wetland during dry cycles	DPIE–BC
		Map and identify riparian and aquatic habitat condition to inform development of formal agreements in a unified strategy Prioritise reaches for management in partnership with Local Land Services and landholders	DPIE–BC, DPIF and LLS
Acid sulphate-soils	Several areas surrounding the Lachlan and Lake Cargelligo weir pools have been found to have acid sulphate soils (Wallace 2010). Lowered waters in these pools could lead to releases from soil.	Further research to understand the risk and its impact on weir pool management	DPIE–Water and DPIE–BC
Grazing pressure and stock access to waterways	Stock trampling and grazing riverbanks can: • reduce native vegetation cover which allows weeds to establish • reduce streambank stability • damage important instream habitat • reduce water quality.	Map and identify riparian and aquatic habitat condition to inform development of formal agreements in a unified strategy Prioritise reaches for management in partnership with Local Land Services and landholders	DPIE–BC, DPIF and LLS
		Implement grazing strategies that protect and restore wetland vegetation	LLS and Landholders
		Investigate incentives to improve management of wetlands on private land	LLS and DPI Agriculture
		Communicate wetland sensitive grazing practices to graziers	DPIE–BC and LLS

Risk	Description	Potential management strategies	Potential project partners
Spread of pest flora species	There is potential for environmental water to spread weeds like lippia. The spread of amphibian chytrid fungus is a potential risk to frog species	Map and identify riparian and aquatic habitat condition to inform development of formal agreements in a unified strategy Prioritise reaches for management in partnership with Local Land Services and landholders	DPIE–BC and LLS
		Maintain existing weed control programs including implementing water hyacinth control protocols and maintain spray equipment to be able to respond to outbreaks	DPIE–BC, LLS and Local Council
		Implement recommendations in the DPIE–EES statement of intent, the hygiene protocol for the control of disease in frogs, and the Commonwealth threat abatement plan to reduce spread of amphibian chytrid fungus	DPIE–EES and CEWO
		Negotiate and implement easement agreements that recognise greater need for weed management to supplement existing weed management on private land	DPIE–BC and LLS
		Inundate wetlands for enough time to favour native wetland species growth and reduce the extent of lippia	DPIE–BC
Spread of pest fauna species	Pest fauna populations may benefit from environmental water use	Investigate a carp management plan for the Lachlan catchment	DPIF, WaterNSW, DPIE–BC and Fisheries Research and Development Corporation
		Refer to strategies from NSW Department of Primary Industries, Fisheries	DPIF
		Support the development and implementation of the carp herpes virus	DPIE–BC
		Coordinate and implement feral pig and other terrestrial vertebrate pest control, including the use of aerial culling.	LLS, Landholders, DPIE–BC and 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	DPIE–BC, DPIF and WaterNSW
Excessive erosion	Rapid flow recession can cause excessive erosion and bank slumping. This can increase turbidity and reduce instream habitat quality.	Protect variable flows and ecologically desirable flow recession rates	DPIE–BC and WaterNSW
		Map and prioritise riparian habitat and erosion points for rehabilitation at the catchment scale, with a commitment to manage risk and monitor outcomes	DPIE–BC, DPIF and WaterNSW
		Manage environmental waters to mimic natural flow patterns and variability (where possible)	DPIE–BC, DOI–W, WaterNSW, CEWO
		Investigate methods for improving the seasonal pattern and variability of water delivery	DPIE–BC, WaterNSW, CEWO
Instream barriers and structures	Instream structures impede natural flow and connectivity which impacts on fish.	Refer to strategies from NSW Department of Primary Industries, Fisheries, in line with the requirements of the *Fisheries Management Act 1994*	DPIF
		Identify, investigate and remove priority illegal barriers	DOI–W
		Develop and implement operational protocols for weirs and regulators	WaterNSW
		Review conditions for licensed structures	DPIE–Water
	Diversion of water can have significant impact on native fish by altering habitat and affecting spawning and recruitment.	Refer to NSW Department of Primary Industries, Fisheries management plan for screens on pumps	DPIF, LLS, Industry groups and DOI–W
		Develop a connectivity plan Investigate a Lachlan catchment connectivity plan focussed on improving habitat connectivity	DPIE–BC, DPIF and DOI–W

5.3 Climate change

Climate change is a key long-term risk to river, wetland and floodplain health. It will exacerbate the natural seasonal variability that exists in NSW, making it more difficult to manage our landscapes and ecosystems and the human activities that depend on them. Average temperatures have been steadily rising since the 1950s. The decade from 2001 to 2010 was the hottest on record, while 2019 was the hottest year in NSW (DECCW 2011, BOM 2019). 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 Lachlan region (CSIRO 2008). The best estimates for 2030[23] predicts:

- a 10% reduction in average annual runoff to rivers in the Lachlan catchment
- a 13% reduction in end-of-system flows
- an increase of 24% in the average period between winter–spring inflows to the Booligal Wetlands and Great Cumbung Swamp, resulting in fewer bird breeding events.

Best available climate change predictions for the Lachlan catchment indicate a significant change to climatic patterns in the future. According to the NARCLiM model[24] (scenario 2), the changes in Table 18 are predicted by 2030 and 2070.

There are uncertainties with these climate change predictions, and the predicted changes are unlikely to 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 Lachlan catchment.

Figure 17 Water moving through the Great Cumbung Swamp
Photo: P Packard/DPIE

[23] Assuming the current levels of development within the catchment.
[24] 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 18 Potential climate-related risks in the Lachlan catchment

Potential climate change risk	Description of risk	NARCLiM projection (scenario 2)						
			2020-39			2060-79		
			Upper Lachlan[25]	Central Lachlan[26]	Lower Lachlan[27]	Upper Lachlan	Central Lachlan	Lower Lachlan
Change in rainfall	Rainfall is projected to vary across the region, with the greatest increases predicted to occur during autumn and the greatest decreases during summer. Winter rainfall is primarily decreasing across the region.	Summer	+0.8%	-1.1%	+4.4%	+8.8%	+13.2%	+10.5%
		Autumn	+6.5%	+14.7%	+9.4%	+11.0%	+13.5%	+12.7%
		Winter	-2.6%	-4.2%	-2.0%	-4.1%	+5.4%	0.2%
		Spring	-7.5%	-7.6%	-10.9%	-11.2%	-5.8%	-11.9%
Change in average temperature	Mean temperatures are projected to rise by 0.7ºC 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 Lachlan regions.	Summer	+0.88°C	+0.95°C	+0.87°C	+2.28°C	+2.44°C	+2.36°C
		Autumn	+0.59°C	+0.65°C	+0.54°C	+1.87°C	+2.04°C	+1.88°C
		Winter	+0.43°C	+0.40°C	+0.37°C	+1.66°C	+1.65°C	+1.42°C
		Spring	+0.69°C	+0.80°C	+0.71°C	+2.15°C	+2.30°C	+2.11°C
Change in number of hot days (maximum temperature >35°C)	Hots days are projected to increase across the region by an average of 9 days per year by 2030. The greatest increases are seen around Nyngan during summer which is projected to experience an additional 10–20 days per year. There is little change in the Central Tablelands around Bathurst.	Annual	+2.7	+9.1	+8.0	+8.2	+27.0	+22.9
Change in number of cold nights (minimum temperature <2°C)	Cold nights are projected to decrease across the region by an average of 8 fewer nights per year by 2030. The Lachlan region is projected to experience 10–20 fewer cold nights per year. Changes in cold nights can have considerable impacts on native ecosystems.	Annual	-11.5	-7.7	-7.4	-35.4	-22.5	-21.2

[25] Upper Lachlan refers to the South east and tablelands region in the NARCLiM
[26] Central Lachlan refers to the Central west and Orana region in the NARCLiM
[27] Lower Lachlan refers to the Murray Murrumbidgee region in the NARCLiM

Potential climate change risk	**Description of risk**	**NARCLiM projection** (scenario 2)						
			2020-39			**2060-79**		
			Upper Lachlan[25]	Central Lachlan[26]	Lower Lachlan[27]	Upper Lachlan	Central Lachlan	Lower Lachlan
Bushfires Changes in number of days a year FFDI>50[28]	Severe fire weather is projected to increase across the region by 2030 during summer and spring. Declines are projected during Autumn due to increases in rainfall. There is little change during winter. These increases are being seen during the peak prescribed burning season (spring) and peak fire risk season (summer). Overall severe fire weather is projected to have a small increase across the region by 2030.However increased severed fire weather is during spring (the prescribed burning season) and summer (peak fire risk season). Conversely declines in severe fire weather are expected in autumn due to increases in rainfall.	Annual	+0.1	+0.5	+0.6	+0.5	+1.3	+2.0
Hillslope erosion	Changes in erosion can have significant implications for natural assets and water quality. Removal of groundcover will increase the risk of erosion significantly.	Mean percent change	1.0%	4.6%	1.4%	14.5%	20.0%	13.6%
Biodiversity	Rising temperature, increased fire frequency and changing fire regimes, storm damage and potentially drought will all affect species composition							

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

Strategies for mitigating climate-related risks

Environmental water management and the proactive release of water from Wyangala Dam and Carcoar Dam to support improved river and wetland health outcomes has occurred in the Lachlan catchment since 2005 and 2012 respectively. The climate has been variable during this time, with the region experiencing extreme drought and flooding. Environmental water managers have become experienced in dealing with these highly variable conditions, using management practices and responses established over time based on real-world experience and collaboration.

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

- How will the volume of water stored in Wyangala and Carcoar dams and Lake Brewster and Cargelligo 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 Lachlan?

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

Figure 18 **Pelicans in the Lachlan**
Photo: M Carnegie/Lake Cowal Foundation

6. Water management priorities and strategies

6.1 Prioritisation of ecological objectives and watering in Zone A

Environmental water managers and EWAGs consider a range of factors when determining how discretionary water for the environment should be managed. Some of these considerations include the current condition of the plants and animals, the recent connectivity history 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 strategy's ability to contribute to environmental outcomes.

This chapter sets out a framework to help inform annual water management decisions depending on the water resource availability scenario (RAS) in river reaches which are regulated or affected by regulated water. Each of these chapters contains three parts:

1. the broad priorities to guide management under the particular scenario
2. the potential management strategies for achieving these priorities
3. tables identifying the priority LTWP objectives for each scenario and target flow categories (marked with an X) (Table 19-22).

Some of the wording of the LTWP objectives has been adjusted to highlight the most relevant aspect of the objective under the scenario. For example, a LTWP objective that over 20 years seeks 'improvement' may only seek to 'maintain' under a dry scenario[29]. Some of the objectives have been combined for better presentation. The full list of objectives can be found in Chapter 3. More information about RAS and how it is defined is outlined in Appendix B.

[29] Some of the objectives have been summarised to assist with presentation. The full set of objectives can be found in Chapter 3.

Water resource availability scenario: Very dry – Protect

	Broad management priorities	Management strategies for achieving priorities
Very Dry	Avoid critical loss of species, communities and ecosystems Maintain refuges Avoid irretrievable damage or catastrophic events Avoid unnaturally prolonged dry periods between flow events Support targeted longitudinal connectivity within catchment for functional processes and a range of flora and fauna Prevent two consecutive years of extreme dry to core wetland areas	Allow dry down consistent with historical wetting-drying cycles Sustain key in-channel pools, instream habitat and core wetland areas Provide very low flows to relieve severe unnatural prolonged dry periods and support suitable water quality Ensure sufficient volumes are allocated to re-start the river following prolonged cease-to-flow events Limit exceedance of maximum inter-event periods for smaller flows as opposed to maintaining the long-term ideal frequency of events If a critical water shortage or similar critical incident restricts the use of water for the environment, then DPIE–BC will work with the Lachlan EWAG to prioritise environmental water needs and DPIE–Water to ensure that these needs are considered, and ensure that there is appropriate DPIE–BC representation on the Critical Water Advisory Panel

Table 19 Priority objectives and flow categories in a very dry RAS

Priority objectives	Flow categories							
	Cease to Flow	Very Low Flow	Baseflow	Small Fresh[20]	Large Fresh	Bankfull	Small Overbank /Wetland[30]	Large Overbank /Wetland
NF1: No loss of native fish species	X	X	X	X			X	
NV1: Maintain the extent and viability of non-woody vegetation communities occurring within channels	X	X	X	X			X	
NV2: Maintain the extent and viability of non-woody vegetation communities occurring in core wetlands			X				X	
WB1: Maintain the number and type of waterbird species							X	
WB2: Maintain total waterbird abundance across all functional groups							X	
WB5: Maintain the extent and improve condition of waterbird habitats							X	
EF1: Protect a diversity of refugia across the landscape	X	X	X	X			X	
EF2: Maintain quality instream and wetland habitat	X	X	X				X	
EF3: Provide movement and dispersal opportunities within catchments			X				X	
OS1: Maintain species richness and distribution of flow-dependent frog species							X	
OS2: Maintain successful breeding opportunities for flow-dependent frog species							X	

[30] Small freshes and WL1 flows 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
Dry	Support the survival and viability of threatened species and communities Maintain refuges Maintain environmental assets and ecosystem functions Avoid unnaturally prolonged dry periods between flow events Support longitudinal connectivity for functional processes and a range of flora and fauna	Allow dry down consistent with historical wetting-drying cycles Sustain key in channel pools, instream habitat and core wetland areas Provide freshes to channels and core wetlands where possible at ecologically relevant times Avoid exceeding maximum inter-event periods and provide events which have recently had lower than ideal frequency Provide low flows to relieve severe unnatural prolonged dry periods and support suitable water quality Protect tributary inflows

Table 20 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 /Wetland[31]	Large Overbank /Wetland
NF1: No loss of native fish species	X	X	X	X			X	
NF2: Maintain the distribution and abundance of short to moderate-lived generalist native fish			X	X				
NF3: Maintain the distribution and abundance of short to moderate-lived floodplain specialist native fish			X	X				
NF4: Maintain native fish population structure for moderate to long-lived flow pulse specialist native fish			X	X				
NF5: Maintain native fish population structure for moderate to long-lived riverine specialist native fish			X	X				
NF6: Maintain the abundance of mature (harvestable sized) golden perch and Murray Cod			X	X				
NV1: Maintain the extent and viability of non-woody vegetation communities occurring within channels	X	X	X	X				
NV2: Maintain the extent and viability of non-woody vegetation communities occurring in core wetlands							X	
WB1: Maintain the number and type of waterbird species							X	
WB2: Maintain total waterbird abundance across all functional groups							X	

[31] Small WL1 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 /Wetland[31]	Large Overbank /Wetland
WB5: Maintain the extent and improve condition of waterbird habitats							X	
EF1: Protect a diversity of refugia across the landscape	X	X	X	X				
EF2: Maintain quality instream, floodplain and wetland habitat	X	X	X	X				
EF3: Provide movement and dispersal opportunities within catchments			X	X				
EF5: Support nutrient, carbon and sediment transport along channels				X				
OS1: Maintain species richness and distribution of flow-dependent frog communities							X	
OS2: Maintain successful breeding opportunities for flow-dependent frog species							X	

Water resource availability scenario: Moderate – Recover

	Broad management priorities	Management strategies for achieving priorities
Moderate	Enable growth, reproduction and small-scale recruitment for a diverse range of flora and fauna Promote low-lying floodplain-river connectivity Seek to meet ideal event frequencies Support medium flow river and floodplain functional processes Support longitudinal connectivity within and between catchments for functional processes and a range of flora and fauna Support low flow lateral connectivity and end of system flows Set aside water for use in drier years	Provide freshes and bankfull flows to channels where possible at ecologically relevant times[32] Improve condition of key off channel waterholes[19] Build on natural events to provide wetland and floodplain inundation at ecologically relevant times Provide flows to systems that are otherwise cut off from natural flows Prioritise EWRs that are approaching their maximum inter-event period or lower than ideal frequency Consider carrying over water to support water use in drier years

[32] Includes water deliveries for the purpose of extending duration of flows/inundation (as opposed to magnitude) to support waterbird colonies if they establish and need intervention

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

Priority objectives	Flow categories							
	Cease to Flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank /Wetland	Large Overbank /Wetland
NF1: No loss of native fish species	X	X	X	X	X		X	
NF2: Increase the distribution and abundance of short to moderate-lived generalist native fish			X	X	X			
NF3: Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish			X	X	X		X	
NF4: Improve native fish population structure for moderate to long-lived flow pulse specialist native fish			X	X	X			
NF5: Improve native fish population structure for moderate to long-lived riverine specialist native fish			X	X	X			
NF6: A 25% increase in abundance of mature (harvestable sized) golden perch and Murray Cod			X	X	X			
NF7: Increase the prevalence and/or expand the population of key short to moderate-lived floodplain specialist native fish into new areas			X	X	X		X	
NF8: Increase the prevalence and/or expand the population of key moderate to long-lived riverine specialist native fish into new areas			X	X	X		X	
NF9: Increase the prevalence and/or expand the population of key moderate to long-lived flow pulse specialists native fish into new areas			X	X	X		X	
NV1: Maintain the extent and viability of non-woody vegetation communities occurring within channels	X	X	X	X	X	X	X	
NV2: Maintain the extent and viability of non-woody vegetation communities occurring in wetlands and on floodplains						X	X	
NV3: Maintain the extent and maintain or improve the condition of river red gum communities closely fringing river channels					X	X	X	
NV4b: Maintain the extent and maintain or improve the condition of native woodlands and shrublands							X	
NV4c: Maintain the extent and maintain or improve the condition of native woodlands and shrublands							X	
NV4e: Maintain the extent and maintain or improve the condition of native woodlands and shrublands							X	
WB1: Maintain the number and 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	
WB4: Increase opportunities for colonial waterbird breeding							X	
WB5: Maintain the extent and improve condition of waterbird habitats						X	X	
EF1: Provide and protect a diversity of refugia across the landscape	X	X	X	X	X	X	X	

Priority objectives	Flow categories							
	Cease to Flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank /Wetland	Large Overbank /Wetland
EF2: Create quality instream, floodplain and wetland habitat	X	X	X	X	X	X	X	
EF3: Provide movement and dispersal opportunities within and between catchments			X	X	X	X	X	
EF4: Support instream and floodplain wetland productivity					X	X	X	
EF5: Support nutrient, carbon and sediment transport across the catchment				X	X	X	X	
EF6: Support groundwater conditions to sustain groundwater dependent biota					X	X	X	
OS1: Maintain species richness and distribution of flow-dependent frog communities					X	X	X	
OS2: Maintain successful breeding opportunities for flow-dependent frog species					X	X	X	

Water resource availability scenario: Wet – Improve

	Management priorities	Management strategies for achieving priorities
Wet	Enable growth, reproduction and large-scale recruitment for a diverse range of flora and fauna Support longitudinal connectivity within and between catchments for functional processes and a range of flora and fauna Support high flow lateral connectivity and end of system flows Set aside water for use in drier years	Build on natural events to provide wetland and floodplain inundation at ecologically relevant times[22] Protect naturally occurring floodplain wetland inundating events and high flow connectivity with the Murrumbidgee Provide flows to systems that are otherwise cut off from natural flows Where possible, provide events that are well below their maximum inter-flow event period to improve resilience during dry periods Carry over water to support water use in drier years

Table 22 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 /Wetland	Large Overbank /Wetland
NF1: No loss of native fish species	X	X	X	X	X		X	X
NF2: Increase the distribution and abundance of short to moderate-lived generalist native fish			X	X	X			X
NF3: Increase the distribution and 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
NF5: Improve native fish population structure for moderate to long-lived riverine specialist native fish			X	X	X			X
NF6: A 25% increase in abundance of mature (harvestable sized) golden perch and Murray Cod			X	X	X			X
NF7: Increase the prevalence and/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 and/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 and/or expand the population of key moderate to long-lived flow pulse specialists native fish into new areas			X	X	X		X	X
NV1: Maintain the extent and viability of non-woody vegetation communities occurring within channels	X	X	X	X	X	X		
NV2: Maintain the extent and viability of non-woody vegetation communities occurring in wetlands and on floodplains						X	X	X
NV3: Maintain the extent and improve the condition of river red gum communities closely fringing river channels					X	X	X	
NV4b: Maintain the extent and improve							X	X
NV4c: the condition of native woodlands							X	X
NV4e: and shrublands							X	X
WB1: Maintain the number and type of waterbird species						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
WB4: Increase opportunities for colonial waterbird breeding							X	X
WB5: Maintain the extent and improve condition of waterbird habitats					X	X	X	X
EF1: Provide and protect a diversity of refugia across the landscape	X	X	X	X	X	X	X	

Priority objectives	Flow categories							
	Cease to Flow	Very Low Flow	Baseflow	Small Fresh	Large Fresh	Bankfull	Small Overbank /Wetland	Large Overbank /Wetland
EF2: Create quality instream, floodplain and wetland habitat	X	X	X	X	X	X	X	X
EF3: Provide movement and dispersal opportunities within and between catchments			X	X	X	X	X	X
EF4: Support instream and floodplain wetland productivity					X	X	X	X
EF5: Support nutrient, carbon and sediment transport across the catchment				X	X	X	X	X
EF6: Support groundwater conditions to sustain groundwater dependent biota					X	X	X	X
OS1: Maintain species richness and distribution of flow-dependent frog communities					X	X	X	X
OS2: Maintain successful breeding opportunities for flow-dependent frog species					X	X	X	X

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

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. The *NSW Extreme Events Policy* (NSW DoI 2018) provides a framework for making decisions during extreme events. It is designed to facilitate early intervention and delay the need to suspend certain water sharing arrangements.

Tables 23 and 24 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 Incident response guide for the *Lachlan Surface Water Incident Response Guide* (DPIE–Water 2019a).

Figure 19 Sunset at Lake Cowal
Photo: M Carnegie/Lake Cowal Foundation

Table 23 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 develop priority environmental water needs in consultation with the Lachlan EWAG, 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[38] to relieve severe unnatural prolonged dry periods and support suitable water quality in critical refuge pools[39]

Table 24 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[33]	Weir/refuge pools are stratified Water quality sampling and analysis demonstrates unfavourable conditions: • lack of dissolved oxygen[34] • unnatural change in temperature • unnatural change in pH • unnatural change in salinity • excess suspended particulate matter[35] • elevated levels of nutrients[36] • chemical contamination[37]	DPIE–BC will develop priority environmental water needs in consultation with the Lachlan EWAG, 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[38] to support suitable water quality in rivers and critical refuge pools[39] 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[39] Limit exceedance of maximum inter-event periods for floodplain inundating flows to reduce the risk of hypoxic blackwater events

6.3 Protection of ecologically important flow categories in Zone B

In areas where water cannot be delivered through a regulating structure (Zone B), the only means of protecting environmentally important flows is through rules in the *Water Sharing Plan for the Lachlan Unregulated River Water*. Table 25 sets out potential management strategies that could be implemented in the WSPs to ensure important flows are protected during very dry through to wet times. Many of these strategies are consistent with the NSW macro planning approach for pools (NOW 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. In order for any of

[33] Description of the types of water quality degradation, their main causes, and where they are likely to occur in the Lachlan catchment can be found in the *Water quality management plan for the Lachlan Water Resource Plan Area* (DPIE-Water 2019d)
[34] Dissolved oxygen levels should be high enough to prevent the asphyxiation of respiring organisms, typically >4mg/L
[35] 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)
[36] May lead to nuisance growth of aquatic plants
[37] Diffuse or point source pollutants may have lethal or sub-lethal effects on aquatic biota
[38] As described in the relevant EWRs in the LTWP
[39] 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

these strategies to be successful, adequate compliance measures need to be in place, and in some areas, improved water metering and gauging is also required.

Part B of the LTWP identifies unregulated planning units where the *Risk Assessment for the Lachlan Water Resource Plan Area* (NSW DPIE–Water 2019b) has identified one or more flow categories as being at medium to high risk. The LTWP recommends specific management strategies from Table 25 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.

Table 25 Potential management strategies to protect ecologically important flows in Zone B

Flow category	Potential management strategies	Most relevant resource availability scenarios
Cease-to-flow	Consider rostering landholder water access during low flow months or when flows begin to approach the cease-to-pump flow rate Consider reviewing cease-to-pump rules to reduce the length of cease-to-flow periods Consider implementing a first flush rule to ensure cease-to-flow periods are broken at ecologically relevant times and with events of sufficient magnitude to avoid adverse water quality incidents	Very dry Dry
Low flows and baseflows	Consider rostering landholder water access during low flow months or when flows begin to approach the cease-to-pump flow rate. Consider reviewing cease-to-pump rules to better protect low flows and baseflows, especially during dry times or ecologically important months	Very Dry Dry
Freshes	Consider implementing a first flush rule to protect freshes at ecologically relevant times Consider implementing extraction limits[40, 24]	Very dry Dry Moderate

[40] Individual daily extraction limits or total daily extraction limits for a particular flow class may be considered to reduce extraction pressure on ecologically important flow categories

Flow category	Potential management strategies	Most relevant resource availability scenarios
Entire flow regime, including overbank and wetland inundating flows	Consider targeted water access licence purchases from willing sellers where flows are acutely impacted. Ensure compliance with water access licence conditions[41] Consider implementing extraction limits.[23, 24] Ensure protection of planned environmental water and consider protection of held environmental water that originates from regulated planning units[24,42] Maintain no trade into water source rules in the WSP Monitor for changes in land use, floodplain harvesting, and water demand and review access rules if current usage is high or if the pattern changes	All weather scenarios

[41] Potentially requires improved water metering and gauging in certain areas
[42] Requires adequate compliance measures and potentially requires improved water metering and gauging in certain areas

7. Going forward

7.1 Cooperative arrangements

River operations to benefit the environment

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 ecological objectives can be achieved. The risks and constraints to achieving EWRs (Table 16) described in this LTWP identifies some river management practices that are currently limiting or impacting on the ability to achieve ecological objectives. The LTWP identifies the following strategies to maximise the benefit of all water in the system:

- investigate options for the delivery of irrigation orders to more closely mimic natural flow events.
- establish better channel sharing arrangements by permitting environmental water to build on consumptive or stock and domestic deliveries to achieve better flow regimes for the environment.
- optimise water releases from Wyangala and Carcoar dams to mimic natural rates of 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 environmental water requirements, 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 and WaterNSW to assist in shaping consumptive deliveries to more closely reflect natural flow patterns and strike a balance between operational efficiency and ecological objectives.

Cooperative water management 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 NSW is managed cooperatively by three government agencies: DPIE–BC, CEWO and DPIE–Water. Together these agencies manage NSW and Commonwealth held environmental water portfolios (DPIE–BC and CEWO), and the WSP's that provide planned environmental water throughout the system (DPIE–Water).

This management is supported by the water rule set – the Water Sharing Plan as part of the Water Resources Plan, development and managed by DPIE–Water with implementation of river operations under licence to WaterNSW. DPIF is also integral to several processes, like fish passage and in-stream structures compliance.

Agencies should consider a multi-agency, intergovernmental working group to collaboratively scope and to develop an ongoing program to implement the LTWP for the Lachlan.

Complementary natural resource management

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

Complementary management of 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.

Figure 20 **Giant banjo frog at Eurugabah Creek**
Photo: C Amos/DPIE

Cooperative investment opportunities

A few significant investment priorities have been identified in the Lachlan catchment (Table 26). Identification of key project partners, funding opportunities and subsequent implementation of projects to address these priorities would contribute significantly to the ecological objectives 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.

Table 26 Investment opportunities to improve environmental outcomes from water management in the Lachlan catchment

Investment opportunity	Description	Potential project partners
Wyangala Dam cold water pollution mitigation	The outlet tower on Wyangala Dam is constructed with two fixed level in-takes that draw colder water from the bottom of the lake that thermally stratifies from spring to autumn. Cold water impacts have been recorded more than 400 km downstream of the dam (Lugg 1999). Restoration to near natural river water temperatures will provide native fish species the environmental cues they require to spawn and reproduce.	WaterNSW, CEWO
Measures to address flow constraints in the Lachlan catchment	The current commence to flow for Willandra Creek is a significant impediment to delivery of water for the environment in the lower Lachlan. The Willandra Creek commence to flow is lower than the pre-development level (approximately 2,400 ML/d versus 8,000 ML/d). A proportion of any high flows managed below Lake Brewster for ecological purposes further downstream spills into the Willandra. This may result in commence to fill for important assets in the lower Lachlan not being met and the Willandra may receive too much water and result in negative environmental or social outcomes. Construction of outflow regulator on Murrumbidgil Swamp would enable water levels in the swamp to be held within the target depth and period to support ecological recovery of this DIWA red gum woodland wetland.	WaterNSW, CEWO, Landholders
Improve protection of important native vegetation communities from clearing	If not correctly managed, native vegetation clearing could be a threat to the Lachlan 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 that protect and restore wetland vegetation, bank stability and adequate water quality in collaboration with Local Land Services and landholders • provide incentives to landholders to improve management of wetlands on private land • commence wetland restoration activities in key assets, in partnership with private landholders.	LLS, NPWS, CEWO, Landholders

Investment opportunity	Description	Potential project partners
Increase engagement capacity	Approximately 95% of Lachlan Wetlands are located on private land. The ongoing direct support of landholders is essential to any system-level efforts to arrest the decline and restore wetlands in the Lachlan catchment. By increasing engagement with the people who live and work in the Lachlan catchment, we will increase the communities' understanding, appreciation and involvement in protecting the catchment's freshwater ecosystem. More importantly, we also increase our knowledge and understanding of the catchment, which will ultimately lead to a better LTWP in the future.	NBAN, Land council, Traditional Owners, Local council, LLS, Landholders, general community
Identifying cultural assets and capacity building for First Nations people	Many of the ecological values across the Lachlan catchment have cultural value and significance to First Nations people and Traditional Owners. Better engagement, opportunities for co-learning and sharing knowledge (including of contemporary water management and cultural values and uses) will provide benefits to local communities and management of water for the environment. Increased engagement with First Nation people will help identify the co-benefits that water for the environment can deliver relative to water dependent cultural uses and values.	First Nations people, CEWO, MDBA, NBAN, LALC
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 • investigation of key pumps to be screened to prevent entrainment (the entrapment of one substance by another substance) of native fish and eggs • works to achieve instream habitat improvement • instream habitat mapping to help identify high-risk and priority refuge areas • support and implementation any outcomes from the National Carp Control Plan • reintroduction, translocation and stocking of threatened fish species in key locations	DPIF, LLS, CEWO
Reduce the spread of pest plant and animal species	There is potential for environmental water to spread weeds, such as lippia. Projects should be put in place to increase the re-establishment of native plants. Pest animal populations may benefit from environmental water use and the Lachlan requires the control of various pest species such as pigs and carp. Some strategies are to: • ensure ongoing investment into the control of lippia and other invasive plant species across the catchment • prioritise reaches for weed management with Local Land Services and landholders • implement priority pest species management actions.	LLS, Landholders, Land managers, NPWS
Addressing gaps in the water quality network	Currently, there are gaps in the NSW water quality network in the Lachlan. A functional water quality monitoring network will help mitigate against future detrimental water quality events.	MDBA

Figure 21 Monitoring in the Lachlan
Photo: M Carnegie/Lake Cowal Foundation

7.2 Measuring progress

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

Monitoring and evaluating environmental water management in the Lachlan WRPA draws on contributions from Australian and NSW Government agencies, universities, other research organisations, non-government organisations, individuals and land managers.

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

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

The NSW MER Framework, which includes NSW Fisheries Basin Plan Environmental Outcomes Monitoring program and DPIE MER program, provides the structure within which various NSW-led monitoring activities are brought together for:

- tracking progress towards stated LTWP and WSP outcomes
- improved decision making for environmental water planning and operations (supporting adaptive management).

To do this, the 2018 NSW MER Framework, aim to:

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

The detail of the monitoring to be undertaken under the DPIE MER program is being finalised and is dependent on the level of available funding.

Monitoring progress reports are made available following each watering year.

7.3 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 Lachlan catchment
- revision of the BWS that materially affects this LTWP
- a sustainable diversion limit adjustment
- new information arising from evaluating responses to environmental watering
- new knowledge about the ecology of the Lachlan catchment that is relevant to environmental watering
- improved understanding of the effects of climate change and its impacts on the Lachlan 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.

Figure 22 Royal spoonbills
Photo: M Todd

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Appendix A. Ecological objectives relevant to each planning unit

Table 27 Ecological objectives for priority environmental asset in the Zone A planning units

	Code	Ecological objective	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Native fish	NF1	No loss of native fish species	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NF2	Increase the distribution and abundance of short to moderate-lived generalist native fish species	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
	NF3	Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish species	X	X	X	X	X	X		X		X	X	X	X	X		X
	NF4	Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species		X	X			X		X		X		X		X		X
	NF5	Improve native fish population structure for moderate to long-lived riverine specialist native fish species	X	X	X	X	X	X		X		X	X	X		X		X
	NF6	A 25% increase in abundance of mature (harvestable sized) Golden Perch and Murray Cod		X	X	X	X	X		X		X	X	X		X		X
	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)			X	X	X	X		X		X	X	X	X	X		X
	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)		X	X	X	X	X		X		X	X	X		X		X
	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)																X
Waterbirds	WB1	Maintain the number and type of waterbird present			X	X	X	X	X	X	X	X		X	X	X	X	X
	WB2	Increase total waterbird abundance			X	X	X	X	X	X	X	X		X	X	X	X	X
	WB3	Increase breeding activity in non-colonial nesting waterbirds			X	X	X	X	X	X	X	X		X	X	X	X	X
	WB4	Increase opportunities for colonial waterbird breeding events			X	X	X	X	X	X	X	X		X	X	X	X	X
	WB5	Maintain the extent and improve condition of waterbird habitats			X	X	X	X	X	X	X	X		X	X	X	X	X
Vegetation	NV1	Maintain the extent and viability of non-woody vegetation communities occurring within channels	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV2	Maintain the extent and viability of non-woody vegetation communities occurring in wetlands and on floodplains		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV3	Maintain the extent and maintain or improve the condition of river red gum communities closely fringing river channels	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV4a	Maintain the extent and maintain or improve the condition of river red gum woodland	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV4b	Maintain the extent and maintain or improve the condition of black box woodland					X	X	X	X	X	X	X	X	X	X	X	X
	NV4c	Maintain the extent and maintain or improve the condition of lignum shrubland						X	X	X	X	X	X	X	X	X	X	X
	EF1	Provide and protect a diversity of refugia across the landscape	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Code	Ecological objective	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ecosystem functions	EF2	Create quality instream, floodplain and wetland habitat	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF3	Provide movement and dispersal opportunities within and between catchments for water dependent biota to complete lifecycles and disperse into new habitats	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF4	Support instream and floodplain productivity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF5	Support nutrient, carbon and sediment transport along channels, and between channels and floodplains/wetlands	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF6	Support groundwater conditions to sustain groundwater dependent biota	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other Species	OS1	Maintain species richness and distribution of flow-dependent frog communities			X	X	X	X	X	X	X	X		X	X	X	X	X
	OS2	Maintain successful breeding opportunities for flow-dependent frog species			X	X	X	X	X	X	X	X		X	X	X	X	X
	OS4	Maintain water-dependent species richness	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 28 Ecological objectives for priority environmental asset in the Zone B planning units

	Code	Ecological objective	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Native fish	NF1	No loss of native fish species	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NF2	Increase the distribution and abundance of short to moderate-lived generalist native fish species	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X
	NF3	Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish species	X	X	X		X		X				X	X	X		X	X	X	X	X	X			X
	NF4	Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species																			X				X
	NF5	Improve native fish population structure for moderate to long-lived riverine specialist native fish species	X		X		X	X	X	X	X		X	X	X		X	X	X		X				X
	NF6	A 25% increase in abundance of mature (harvestable sized) golden perch and Murray Cod																	X		X				X
	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)	X	X	X				X						X		X	X	X	X	X	X			X
	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)	X		X													X	X		X				X
	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)																							
Waterbirds	WB1	Maintain the number and type of waterbird present																	X		X				
	WB2	Increase total waterbird abundance.																	X		X				
	WB3	Increase breeding activity in non-colonial nesting waterbirds																	X		X				
	WB4	Increase opportunities for colonial waterbird breeding events																	X		X				
	WB5	Maintain the extent and improve condition of waterbird habitats																	X		X				
Vegetation	NV1	Maintain the extent and viability of non-woody vegetation communities occurring within channels	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV2	Maintain the extent and viability of non-woody vegetation communities occurring in wetlands and on floodplains										X	X		X	X	X	X	X	X	X	X	X	X	X
	NV3	Maintain the extent and maintain or improve the condition of river red gum communities closely fringing river channels	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV4a	Maintain the extent and maintain or improve the condition of river red gum woodland	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	NV4b	Maintain the extent and maintain or improve the condition of black box woodland											X			X			X	X	X	X	X	X	X

	Code	Ecological objective	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	NV4c	Maintain the extent and maintain or improve the condition of lignum shrubland																	X	X	X		X	X	X
Ecosystem functions	EF1	Provide and protect a diversity of refugia across the landscape	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF2	Create quality instream, floodplain and wetland habitat	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF3	Provide movement and dispersal opportunities within and between catchments for water dependent biota to complete lifecycles and disperse into new habitats	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF4	Support instream and floodplain productivity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF5	Support nutrient, carbon and sediment transport along channels, and between channels and floodplains/wetlands	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	EF6	Support groundwater conditions to sustain groundwater dependent biota	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other Species	OS1	Maintain species richness and distribution of flow-dependent frog communities																	X		X				
	OS2	Maintain successful breeding opportunities for flow-dependent frog species																	X		X				
	OS4	Maintain water-dependent species richness	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Appendix B. Resource availability scenario

Guidelines for the method to determine priorities for applying environmental water[43]

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

To determine the RAS, the following steps are followed:

a. determine the antecedent conditions for a given water resource plan area by (the 'X' axis of the matrix in Table 29):
   - 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 29):
   - 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 29, this is the surface water availability percentile)

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

Table 29 Default matrix for determining the RAS

Surface water availability	Antecedent conditions				
	Very dry (0–15%)	Dry (16–45%)	Medium (46–60%)	Wet[44] (61–85%)	Very wet22 (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

[43] As outlined by the Murray-Darling Basin Authority in https://www.mdba.gov.au/publications/policies-guidelines/guidelines-method-determine-priorities-applying-environmental-water.

[44] Wet and Very wet RAS are combined in this LTWP because the management strategies are the same.