



Basin-scale evaluation of 2019–20 Commonwealth environmental water: Synthesis

Commonwealth Environmental Water Office (CEWO):
Monitoring, Evaluation and Research Program

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Acknowledgement of Country

The Flow-MER research team acknowledges the Traditional Owners of the lands and waters of Australia, and in particular the Traditional Owners of the lands and waters of the Murray–Darling Basin. The river and its tributaries are known by many names including; Millewa (Ngarrindjeri name for the main Murray channel in South Australia), Baarka (Barkindji; Darling River, inland New South Wales (NSW)), Warring (Taungurung; Goulburn River, Victoria), Kolety (Wamba Wamba; Edwards River, inland NSW), Kalari (Wiradjuri; Lachlan River, inland NSW), Murrumbidjeri (Wiradjuri; Murrumbidgee River, inland NSW) and Guwayda (Kamilaroi; Gwydir River, northern NSW), amongst others. While the European names will be used here, the authors recognise the important associations and history of the Indigenous names for rivers and streams in the Murray Darling Basin. We express our respect for Elders, past present and emerging amongst the Nations of the Murray–Darling Basin.

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OVERVIEW OF FLOW-MER

Flow-MER is the Commonwealth Environmental Water Office’s (CEWO) Monitoring, Evaluation and Research Program. Its objective is to monitor and evaluate the ecological responses to the delivery of Commonwealth environmental water in the Murray–Darling Basin. It provides the CEWO with evidence to inform our understanding of how water for the environment is helping maintain, protect, and restore the ecosystems and native species across the Basin. This work will support environmental water managers, demonstrate outcomes, inform adaptive management and fulfil the legislative requirements associated with managing Commonwealth-owned environmental water.

The Program runs from 2019 to 2022 and consists of 2 components: monitoring and research in 7 Selected Areas (Selected Area projects); and Basin-scale evaluation and research (the Basin-scale project) (Figure 1). The Basin-scale project is led by CSIRO in partnership with the University of Canberra, and collaborating with Charles Sturt University, Deakin University, University of New England, South Australian Research & Development Institute, Arthur Rylah Institute, NSW Department of Planning, Industry and Environment, Australian River Restoration Centre and Brooks Ecology & Technology.

It builds on work undertaken through the Long Term Intervention Monitoring (LTIM) (2014–2019) and Environmental Water Knowledge and Research (EWKR) (2014–2019) projects.

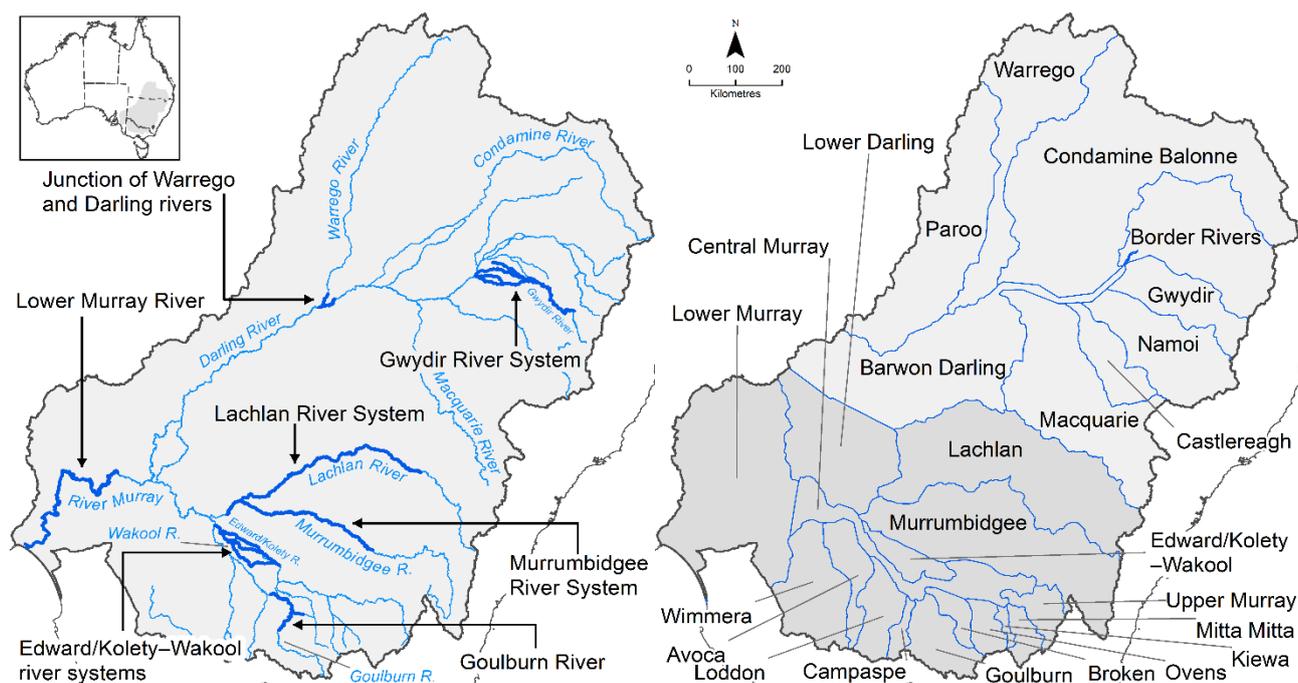


Figure 1 The 7 Selected Areas and 25 valleys established for long-term monitoring of the effects of environmental watering under the LTIM Project and Flow-MER Program (2014–15 to present)

The Flow-MER evaluation adopts an adaptive management framework to acknowledge the need for collectively building the information, networks, capacity and knowledge required to manage environmental water at Basin scale. While knowledge of ecological response to instream flow and inundation has advanced significantly in recent years, substantive challenges remain in understanding the similarities and differences in species’ response across time and space, as well as the interaction between species at a community and ecosystem scale.

The Basin-scale evaluation is being undertaken across 6 Basin Themes (Figure 2) based on ecological indicators developed for the LTIM Project and described in the Environmental Water Outcomes Framework. It is undertaken in conjunction with the Selected Area projects, which provide data, research and knowledge for ecological outcomes

within the 7 Selected Areas. The Basin-scale evaluation integrates across Selected Areas, themes, datasets, approaches and different types of knowledge.



Figure 2 Basin-scale Project evaluation reports on Commonwealth environmental water outcomes for the 6 Basin Themes as well as a high-level Basin-scale synthesis

The evaluation is informed by Basin-scale research projects, stakeholder engagement and communication, including Indigenous engagement, visualisation and modelling, as well as the 7 Selected Area projects

About the Basin-scale evaluation

Water delivery and outcomes data provided by CEWO is used in conjunction with monitoring data provided by the 7 Selected Areas and other publicly available data to undertake the Basin-scale evaluation. The research and evaluation content is structured into 6 disciplinary themes. Technical reports for each of the 6 themes are available from the CEWO website.

The evaluation aims to address theme specific questions in relation to how Commonwealth environmental water contributed to, supported, or influenced environmental outcomes. Commonwealth environmental water is often delivered in conjunction with other environmental water holdings, and non-environmental water releases (such as for irrigation or during high-flow events). The evaluation consequently draws on available information to estimate (where possible) the specific contribution of Commonwealth environmental water to particular environmental outcomes. The way in which this contribution is assessed varies between the 6 themes depending on the data and tools currently available:

- modelling to estimate and compare outcomes both with and without Commonwealth environmental water (counterfactual modelling) – Hydrology (instream); Fish (multi-year evaluation)
- identification of ecological response in locations that received Commonwealth environmental water (potentially in conjunction with other sources of environmental water or non-environmental water), and where feasible, comparison with areas that did not receive Commonwealth environmental water – Ecosystem Diversity, Species Diversity, Vegetation
- use of flow and water quality metrics to infer likely outcomes – Hydrology (inundation); Food Webs and Water Quality
- synthesis of findings across Selected Areas – Fish (annual); Vegetation; Food Webs and Water Quality.

KEY MESSAGES

Strategic management of Commonwealth environmental water by the Commonwealth Environmental Water Holder (CEWH) is key to achieving Murray-Darling *Basin Plan 2012* objectives. The 3-year Basin-scale Flow-MER Program evaluates the ecological responses to the delivery of Commonwealth environmental water to support legislative requirements under the Basin Plan, inform adaptive management, and support environmental water managers. This evaluation reports on Basin-scale outcomes from Commonwealth environmental water for the most recent water year (2019–2020) and cumulative outcomes since the beginning of the program in 2014. It assesses the contribution of Commonwealth environmental water to Basin Plan objectives, and provides considerations for adaptive management.

The most recent water year, 2019–20

- Low rainfall resulted in below average flows across the Basin and very low (or no) flows for prolonged periods in rivers in the north of the Basin.
- Against this climatic background, 1,195 GL of Commonwealth environmental water was used to supplement instream flows and wetland inundation, as well as improve connectivity along river systems. Periods of very low (or no) flow were substantially reduced in the southern Basin by the use of environmental water. Commonwealth environmental water had limited impact on very low flows in the northern Basin due to a combination of dry conditions restricting allocations, small entitlements held, and fewer available strategies for active management.
- Flow volumes delivered to the Coorong, Lower Lakes and Murray Mouth using Commonwealth environmental water did not meet Basin plan objectives. These volumes did however keep the water level in Lake Alexandrina above 0.4 m Australian Height Datum (Basin Plan objective 8.06).
- Commonwealth environmental water was the only water that passed through the barrages in South Australia, exporting 624,000 tonnes of salt and maintaining low river salinity in South Australia by diluting salt in the Lower Murray River channel. While less than the Basin Plan salt export objective (9.09) of 2 million tonnes per year, Commonwealth environmental water exported salt from the Basin and limited nett salt import to the Coorong.
- Commonwealth environmental water was delivered to 15,591 km of river length and, in coordination with other sources of water, inundated 177,260 ha of lakes and wetlands and 13,844 ha of floodplain. These actions support Basin Plan objective (8.06) in contributing to the protection and restoration of hydrological connectivity between and within water-dependent ecosystems. Of the 67 aquatic ecosystem types (Australian National Aquatic Ecosystems) found in the Basin, 48 (or 72%) received Commonwealth environmental water.
- Commonwealth environmental water was delivered to 8 Ramsar areas¹, contributing to the inundation of 114,854 ha of wetland habitat and thereby supporting these significant ecosystems and their biodiversity.

¹ Listed under the Convention on Wetlands of International Importance (the Ramsar Convention, 1971) (<https://www.environment.gov.au/water/wetlands/ramsar>)

- Commonwealth environmental water contributed to the inundation of areas containing rare and threatened plant species, and plants with traditional Indigenous uses. Higher richness of plant communities was observed in areas receiving environmental water compared with those that did not. For this watering year, 25% of taxa were only observed where environmental water was used.
- Due to dry conditions, Commonwealth environmental water primarily supported habitat and movement of native fish rather than breeding activity, although recruitment was observed in some locations for some species. Sixty-five waterbird species, 18 frog species and 3 turtle species were positively influenced by Commonwealth environmental water, including 19 EPBC Act-listed migratory bird species, 36 threatened bird species and several vulnerable frog species.

Multiple water years, 2014–20

- Over the 6 years, Commonwealth environmental water has contributed to Basin Plan objectives (8.05, 8.06, 8.07, 9.08, 9.09, and 9.14) through restoration of key aspects of the flow regime, full and partial wetland inundation (including Ramsar areas) and enhanced lateral and longitudinal connectivity. Environmental water has supported representative ecosystems, biodiversity and ecosystem function.
- The 6-year period was characterised by variable conditions, with some of the wettest years on record in parts of the Basin and some of the most intense drought conditions recorded. Overall, drought conditions and low flows dominated.
- Over the 6 years, 9,510 GL of water was delivered via 666 watering actions. Adaptive management principles were applied to optimising water delivery for environmental outcomes, benefitting from knowledge gained through monitoring of outcomes from previous watering actions.
- Commonwealth environmental water accounted for between 64 and 100% of total salt export to the Southern Ocean and was used on multiple occasions to prevent or reduce the impacts of anoxic blackwater.
- There was greater diversity and cover of submerged, amphibious and damp-loving plant species as a result of environmental water delivery. More than 700 plant species were observed at monitoring sites between 2014 and 2020. Almost 40% of these are species that have only occurred at sites that received environmental water.
- Drought conditions during the period resulted in few high flow events that provide important habitat food resources and support recruitment of native fish. Commonwealth environmental water supported low flows that enhanced recruitment of Australian smelt and body condition for golden perch, Murray cod and common carp (introduced).
- Targeted watering actions were used to support major waterbird breeding events where natural flows would not have persisted long enough to allow juveniles to leave the nest. Flows were used in a similar way to support fish larval feeding and movement into the juvenile life stage.
- Commonwealth environmental water improves ecological condition of ecosystems and in so doing increases resilience to the effects of stressors such as non-native species and climate change.

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KEY TERMS

Term	Description
ANAE	Australian National Aquatic Ecosystems is a classification framework which allows groupings of similar ecosystems into a series of classes.
Counterfactual	In the context of this work, the conditions that would have existed in the Murray–Darling Basin if the Murray–Darling Basin Plan had not been implemented. This would incorporate hydrological change due to abstractions and impoundments, and the effects of variability in rainfall, but would not include recovery of water for environmental flows
Ecosystem	A biological community of interacting organisms and their environment, including the physical characteristics (habitat) and transformations of materials and movements of energy (ecosystem functions) that support them
Ecological community	The living organisms that are present in a place. The community can be described by the number of species (diversity), the number of individuals present (abundance), the physical arrangement of those species (structure) and the distribution of individuals across species (composition)
Ecological condition	Condition is an assessment of the presence of ecological communities and processes that would represent the undisturbed state of an ecosystem. Poor condition may indicate individual plants or animals in poor condition, degradation of key ecological processes or loss of species
Ecosystem diversity	The range of aquatic ecosystem types that are affected by Commonwealth environmental water (as defined in the Foundation Report for this project)
Ecosystem functions	Movements of energy and transformations of materials in an ecosystem e.g. denitrification, feeding, respiration
Energetics	The movement of energy between parts of an ecosystem, including processes such as photosynthesis, feeding links, decomposition and respiration
Environmental counterfactual	Building on the concept of the hydrological counterfactual, the environmental counterfactual seeks to model what the condition of environmental assets would have been had the Basin Plan not been enacted
Evapotranspiration	The process by which water is transferred to the atmosphere by transpiration from plants. This can be measured directly or from satellite imagery. It is a measure of plant water stress.
Food webs	A map of the movement of energy between organisms in an ecosystem, usually as feeding links
Hydrology	river flow and wetland water regimes with and without Commonwealth environmental water (as defined in the Foundation Report for this project)
Meta-populations	A group of populations which are connected by movements of individuals. Population models can be connected together to represent the effects of individual movement on local population dynamics
Population modelling	Quantitative population models use data on reproduction, survival, growth, immigration and emigration to develop mathematical models allowing predictions of whether a population will grow or shrink
Recruitment	Describes the movement of an individual from one life history stage to another e.g. from larvae to juvenile, or from sub adult to adult
Refugia	An area of habitat where a species or group of species can be sheltered from the effects of stressful conditions. These refugia may be short term or may have persisted for millennia. Refuges are a critical component of resilience.
Remote sensing	The process of collecting data at a distance via satellite imagery or aerial imagery of various types from drones or other aircraft
Resilience	An ecosystems' stability and capability of tolerating disturbance (resistance) and restoring itself (recovery)
Scaling	In an ecological context scaling represents the ability to predict ecological values into the future (temporal scaling) at unmonitored locations (extrapolating) or over larger areas than sampled (scaling up)

Term	Description
Species Diversity	The number and relative abundance of species found in a particular location. Sometimes referred to as biodiversity
Stream metabolism	The movement of energy into (via photosynthesis), through (by feeding links) and out of (via respiration) a food web. In this project continuous monitoring of oxygen concentrations across day/night cycles is used to model rates of gross primary production (carbon uptake) and ecosystem respiration (carbon release as CO ₂)
Vegetation diversity	The number and relative abundance of plant species found in a particular location. Water quality – the concentrations of biologically important materials in natural waters, e.g. dissolved oxygen, pH, nitrate, phosphorus, salts
Vegetation diversity	The number and relative abundance of plant species found in a particular location. Water quality – the concentrations of biologically important materials in natural waters, e.g. dissolved oxygen, pH, nitrate, phosphorus, salts
Water quality	The concentrations of biologically important materials in natural waters, e.g. dissolved oxygen, pH, nitrate, phosphorus, salts.

Abbreviations and acronyms

Term	Description
2019–20	Water year 1 July 2019 to 30 June 2020
2014–20	Water years 1 July 2014 to 30 June 2020
CEWH	Commonwealth Environmental Water Holder
CEWO	Commonwealth Environmental Water Office
EWKR	Environmental Water Knowledge and Research
LTIM	Long-term Intervention Monitoring
MER	Monitoring, Evaluation and Research
the Basin	the Murray–Darling Basin

1 INTRODUCTION

Australia's rivers, floodplains and wetlands are unique and diverse ecosystems that support a range of plant and animal communities. Rivers, floodplains and wetlands provide food and habitat for a wide variety of species, often within otherwise dry landscapes. Floodplains and wetlands also provide organic matter to rivers, contributing important resources which underpin ecosystem functions such as the processing of carbon and other nutrients. These functions in turn support the plants and animals which constitute river, floodplain and wetland ecosystems.

A combination of land clearing, grazing and water-use have fundamentally changed the nature and condition of ecosystems across the Murray–Darling Basin (the Basin). There has been widespread loss of plant and animal communities and what remains is often in poor condition. For the period 2008–2010, the Sustainable Rivers Audit assessed the condition of riverine ecosystems as very poor to moderate across the majority of modified rivers in the Basin². In contrast, many unregulated rivers were assessed as being in better condition.

Commonwealth environmental water is delivered to rivers and wetlands across the Basin to supplement existing flows and support water-dependent ecosystems. Wetting and drying affects species' recruitment, growth and persistence. River, floodplain and wetland ecosystems are particularly sensitive to changes in flows and watering regimes, and the composition and structure of plant and animal communities is strongly influenced by both short- and long-term flow conditions.

1.1 Evaluating the outcomes from environmental water

The Commonwealth Environmental Water Office (CEWO) invests in the Monitoring, Evaluation and Research Program (Flow-MER) to provide data, knowledge, tools, and processes for evaluating ecological responses to Commonwealth environmental water in the Basin. Building on work undertaken through the Long-Term Intervention Monitoring (LTIM, 2015–2019) and Environmental Water Knowledge and Research (EWKR, 2014–2019) projects, Flow-MER supports monitoring, evaluation and research in seven Selected Areas (Figure 1.1). The Basin-scale project provides the CEWO with evidence to inform our understanding of how water for the environment is helping maintain, protect, and restore the ecosystems and native species across the Basin. This work will support environmental water managers, demonstrate outcomes, inform adaptive management and fulfil the legislative requirements associated with managing Commonwealth-owned environmental water.

This report summarises Basin-scale findings from the evaluation of environmental outcomes from the delivery of Commonwealth environmental water in 2019–20 and for the period that monitoring of environmental water outcomes has been in place (2014–20). This evaluation is a high-level assessment of the outcomes from using Commonwealth environmental water based on a combination of measured, modelled and inferred responses. The findings in this report complement the findings from targeted intervention monitoring (for specific watering events) and broadscale ecological monitoring that takes into account all environmental conditions (irrespective of the application of environmental water).

² MDBA (2012) Sustainable Rivers Audit 2: The ecological health of rivers in the Murray–Darling Basin at the end of the Millennium Drought (2008–2010). Murray–Darling Basin Authority, Canberra, Australia

1.2 About the Basin-scale evaluation

The Basin-scale evaluation was undertaken across 6 Basin Outcomes (themes) based on ecological indicators developed for the LTIM project and described in the Environmental Water Outcomes Framework³. Table A.1 depicts the relationship between the Basin Outcomes and reporting on Basin Plan objectives. We used data obtained from evaluation of environmental water outcomes within the 7 Selected Areas supplemented by other publicly available data. A technical report is available for each theme evaluation⁴.

- This Basin-scale evaluation reports on the outcomes of Commonwealth environmental water for 2019–20 against 4 objectives of the Basin Plan: biodiversity, ecological function, water quality and resilience.
- The evaluation is reported at the whole-of-Basin scale including, in some cases, valleys where environmental outcomes from Commonwealth environmental water are not actively monitored.
- Key evaluation questions for each Basin Theme contribute to addressing the objectives of the Basin Plan.
- Cumulative outcomes are reported for the 6 years of monitoring to date (2014–20).

The evaluation addresses theme-specific questions in relation to how Commonwealth environmental water contributed to, supported, or influenced environmental outcomes. The way in which this contribution is assessed varies between the 6 themes, depending on the data and tools currently available:

- modelling is used to estimate and compare outcomes both with and without Commonwealth environmental water
- identification of ecological responses, by monitoring key variables, in locations that received Commonwealth environmental water (potentially in conjunction with other sources of environmental water or non-environmental water), and where feasible, comparison with areas that did not receive Commonwealth environmental water
- use of flow and water quality metrics to infer other, un-monitored outcomes
- synthesis of findings across Selected Areas and across years.

Flow-MER adopts an adaptive management framework to collectively build the information, networks, capacity and knowledge required to manage environmental water at Basin scale. While knowledge of environmental water outcomes has advanced significantly in recent years, substantive challenges remain in understanding outcomes across time and space, particularly at a Basin scale.

EVALUATION OF THE CONTRIBUTION OF COMMONWEALTH ENVIRONMENTAL WATER TO BASIN PLAN OBJECTIVES

Biodiversity – to protect and restore water dependent ecosystems (Section 8.05)

- What did Commonwealth environmental water contribute to ecosystem diversity?
- What did Commonwealth environmental water contribute to species diversity?
- What did Commonwealth environmental water contribute to community diversity?
- What was the contribution to Ramsar wetlands In the Murray–Darling Basin?

³ <https://www.environment.gov.au/water/cewo/publications/environmental-water-outcomes-framework>

⁴ Reports available from CEWO website

Ecosystem function – to protect and restore ecosystem function (Section 8.06)

- What did Commonwealth environmental water contribute to restoration of the hydrological regime?
- What did Commonwealth environmental water contribute to ecosystem respiration and primary productivity?

Resilience – to ensure water-dependent ecosystems are resilient to climate change and other risks and threats (Section 8.07)

- What does the evaluation show in relation to reliance to climate change and other risks and threats?

Water quality – to maintain water quality and meet salt export, salinity and dissolved oxygen targets (Sections 9.08, 9.09, 9.14)

- What was the contribution to maintaining water quality and to meet dissolved oxygen, salinity and salt export targets?

2 HYDROLOGY

AT A GLANCE

- Rainfall over the last 6 years (2014–2020) was lower than the longer-term (20 year) average – and surface water inflows across the Basin were lower than the longer-term (20 year) average
- In the 2019–20 year, Commonwealth environmental water was provided to 15,591 km of watercourses. 1,195 GL of Commonwealth environmental water was provided to rivers, wetlands and floodplains across 17 valleys; when reuse is accounted for, the 125 Commonwealth watering actions delivered the equivalent of 1,705 GL
- Flow volumes over the last 6 years (2014–2020) were lower than the longer-term (20 year) average throughout most of the Basin, with the exception of the Upper Murray Valley. Over the 6 years, 9,510 GL of water was delivered in 666 Commonwealth watering actions
- Base flows were below targets in the northern Basin for prolonged periods during 2019–20 whilst excessive periods of below-threshold base flows were largely avoided in the southern Basin, due to contributions of Commonwealth environmental water
- Lateral connectivity was improved between rivers and floodplains in 2019–20; 177,260 ha of lakes and wetlands and 13,844 ha of floodplain were inundated
- Longitudinal connectivity outcomes, assessed as increased flow volumes (2019–20) at Louth and in the Murray River at the SA border, were achieved using Commonwealth environmental water
- At the Coorong, Lower Lakes and Murray Mouth, whilst target flow volumes were not achieved in 2019–20, water level thresholds in the Lower Lakes were maintained
- Commonwealth environmental water was delivered to 8 Ramsar areas in 2019–20, inundating 114,856 hectares of wetland habitat. Between 2014 and 2020, 10 Ramsar wetlands have been inundated, totalling 730,863 hectares of wetland habitat.

2.1 Climate

The first 2 years of the 6-water years (2014–20) of Basin-scale monitoring and evaluation were particularly dry in the southern Basin, with rainfall among the lowest on record (Figure 2.1).

In 2016–17, there were wetter conditions in the southern Basin and along the headwaters of some northern Basin tributaries. Conditions returned to dry across the whole Basin over the period 2017–20 (Figure 2.1). The northern Basin experienced an intense drought through the first half of 2019–20, with well-below average rainfall from August to December 2019. In contrast, rainfall was above average in early 2020.

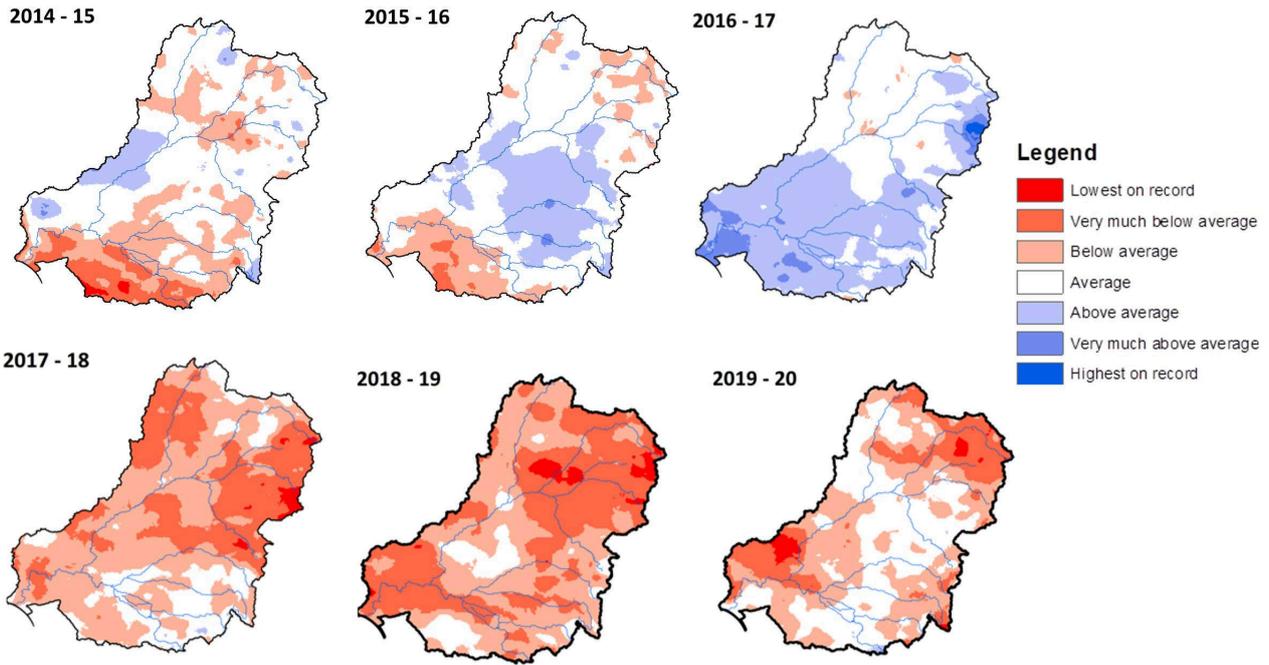


Figure 2.1 Annual rainfall deciles over the 6-year monitoring period
 Source: Bureau of Meteorology

2.2 Surface water

Total surface water inflows in the Basin in 2019–20 totalled 15,867 gigalitres (GL). Basin storages recorded net inflows of approximately 1,954 GL. This is below the average for the past 20 years (Figure 2.2).

Flow volumes were particularly low in the northern tributaries of the Warrego, Gwydir, Namoi and Macquarie Rivers and throughout the Barwon-Darling River. Across the southern Basin, flow volumes were typically higher than the average for the past 20 years at upstream sites, whilst flow volumes at sites further downstream were very low (Figure 2.2, Figure 2.3).

The Warrego River experienced a large inundation event in 2019–20, connecting the Warrego and Darling Rivers for over 4 months, inundating over 11,500 ha of the Western Floodplain and connecting the floodplain to the Darling River for the first time since 2012.

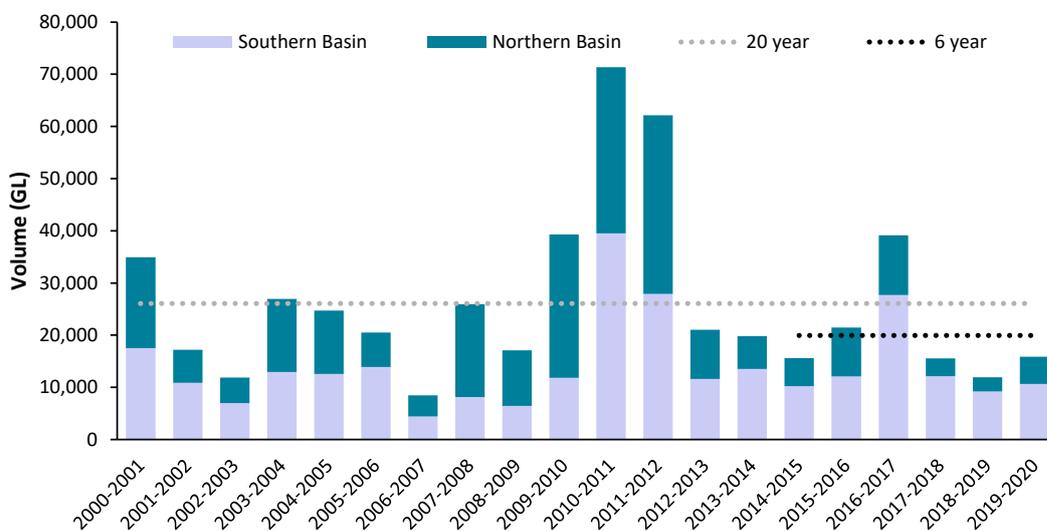


Figure 2.2 Annual surface water inflows in the Murray–Darling Basin showing 6-year and 20 year averages
 Data source: BoM National Water Account

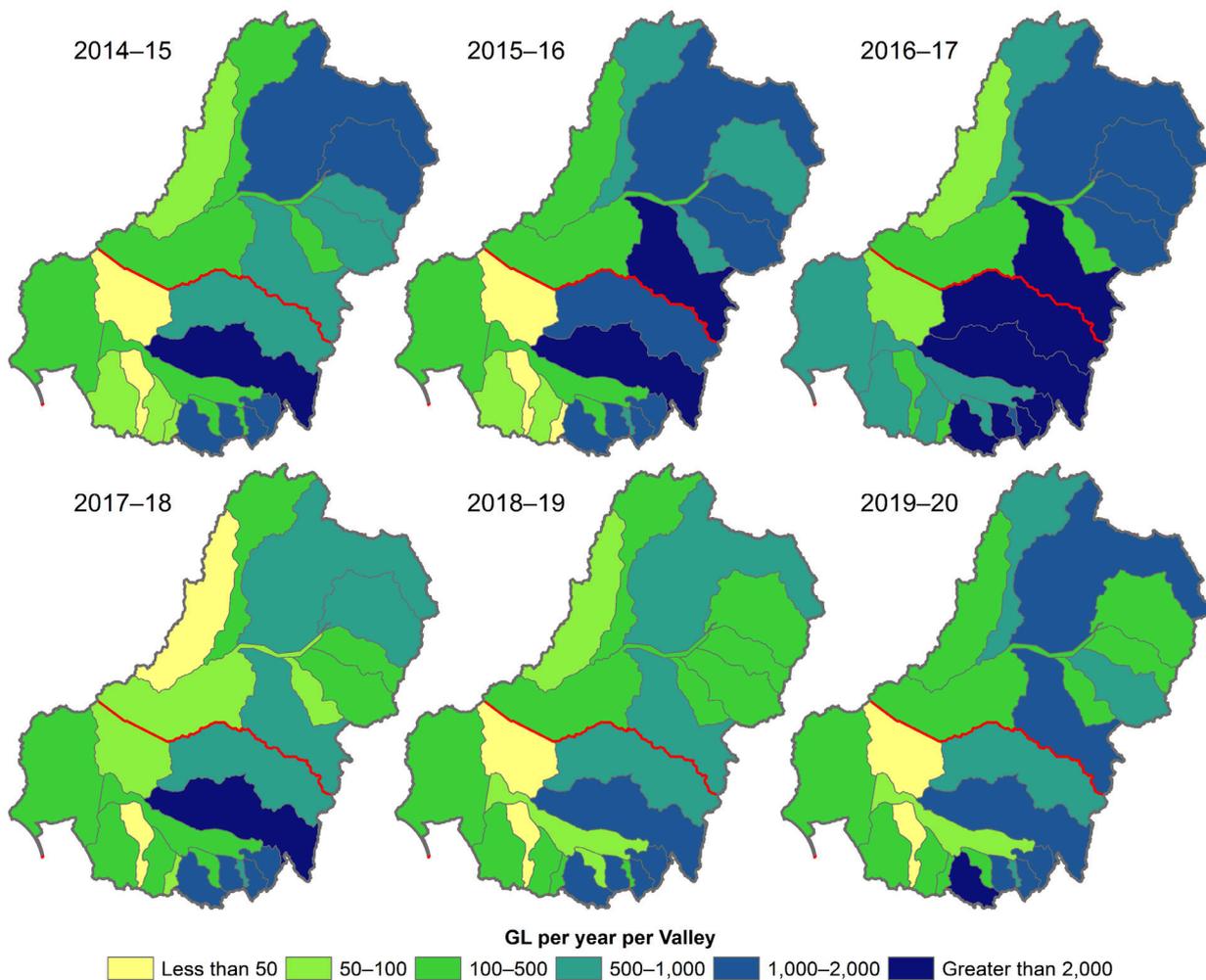


Figure 2.3 Maps of annual surface water inflows in the Murray–Darling Basin for 2014–20 with north-south divide in red
Source: BoM National Water Account

2.3 Delivery of Commonwealth environmental water

Environmental water is strategically used throughout the year by the Commonwealth Environmental Water Holder to protect and restore hydrological connectivity within and between water-dependent ecosystems (Basin Plan 8.06). This involves connecting river reaches during dry times and connecting the river to the floodplain during wetter periods. The hydrological component of the evaluation considered the impact of Commonwealth environmental water delivery on flow, including low flows (base flows), flow increases in the river channel (freshes), floodplain inundation and upstream-downstream (longitudinal) connectivity.

2.3.1 Water year 2019–20

In 2019–20, 1,195 GL of Commonwealth environmental water was provided to rivers, wetlands and floodplains across 17 valleys of the Basin. Some environmental water was also available for reuse, resulting in a total of 125 watering actions and the equivalent use of 1,705 GL. This amount represented <8% of total 2019–20 inflows to the Basin.

In 2019–20, most Commonwealth environmental water was delivered in-channel (53 actions, 94% by volume) providing base flows and freshes to 15,591 km of river. These releases support biodiversity and ecosystem processes at in-channel pools and benches.

The majority of Commonwealth environmental water in 2019–20 was delivered in the southern Basin, totalling 944 GL. Two large flow events occurred in the southern Basin in winter and early spring 2019. Most

Commonwealth environmental water was delivered in the southern Basin through releases from dams during July to August 2019, September 2019 to mid-January 2020, and April to June 2020.

Northern Basin rivers received 251 GL of Commonwealth environmental water in 2019–20. Commonwealth environmental water was delivered to revitalise permanent waterholes following dry conditions during the spring and early summer of 2019. The majority of Commonwealth environmental water was delivered as a large pulse in early 2020, in the Condamine Balonne, Border Rivers and Warrego valleys.

17 valleys received Commonwealth environmental water in 2019–20; 45% of the volume was delivered in the Lower Murray (767 GL), 14% in the Central Murray (261 GL), 14% in the Goulburn (316 GL), 10% in the Condamine Balonne (167 GL) and 8% in the Murrumbidgee (48 GL). The remaining valleys received less than 10% combined of the Commonwealth environmental water delivered in 2019–20 (Figure 2.4). A total of 72 environmental watering actions were delivered to wetlands (65 actions, 3% of total volume) or a combination of rivers and wetlands (7 actions, 3% of total volume) (Figure 2.4).

The large contribution of Commonwealth environmental water to the Lower Murray is due to the combined end-of-system flows to the Murray Mouth and Lower Lakes, and to the Coorong estuarine ecosystem.

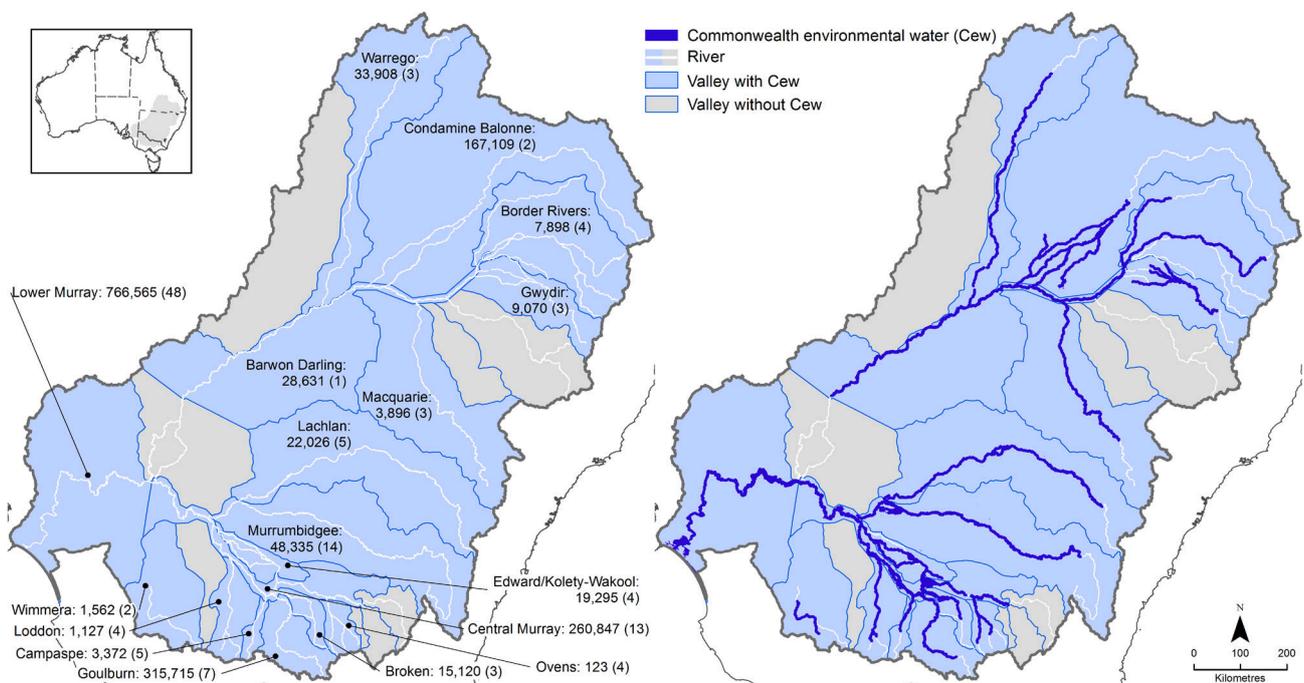


Figure 2.4 Volume (GL) of water and number of watering actions (in brackets) delivered and the area inundated by Commonwealth environmental water, 2019–20

Values shown are number of ANAE ecosystem types water was delivered to with (in brackets) the percentage of valley total ecosystem diversity which was managed with environmental water

2.3.2 Water years 2014–20

Over 6 years from 2014–20, 9,510 GL of Commonwealth environmental water was delivered in 666 environmental watering actions. Over the 6-year period, 45% of the volume was delivered in the Lower Murray, 14% in the Central Murray, 14% in the Goulburn and 8% in the Murrumbidgee. The remaining valleys received <4% of the volume of Commonwealth environmental water. Larger environmental water entitlements are held and delivered in the southern than in the northern Basin, accompanied by a wider range of options for active water management.

Commonwealth environmental water contributed to total volumes across all river valleys, except the Ovens, Border Rivers and upper Murray River, where proportions were less than 10%. In some years,

Commonwealth environmental water comprised around 50% or more of the total volume in the lower reaches of the Gwydir, lower Macquarie, lower Lachlan, Loddon, Darling Anabranch and lower Murray.

Watering actions typically targeted Basin Plan and *Basin-wide environmental watering strategy*⁵ environmental outcomes for vegetation, fish and water birds. Actions also supported base flows and longitudinal river connectivity to support in-stream ecosystem processes and water quality objectives, including mitigation of blackwater events and management of algal blooms (Figure 2.5).

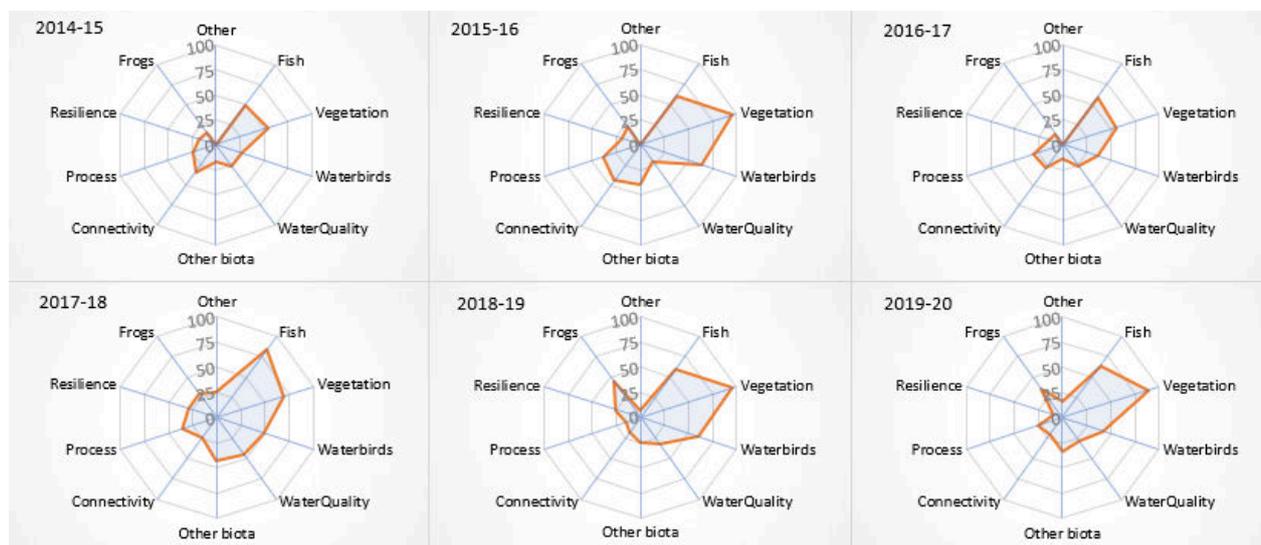


Figure 2.5 Relative volumes of Commonwealth environmental water targeted to specific expected outcomes, 2014–20

2.4 Restoring flows

ECOSYSTEM FUNCTION – TO PROTECT AND RESTORE ECOSYSTEM FUNCTION

- What did Commonwealth environmental water contribute to restoration of the hydrological regime?

The Basin Plan⁶ requires the protection and restoration of hydrologic connectivity within and between water-dependent ecosystems, including:

- longitudinally along watercourses
- laterally between watercourses and their floodplains (and associated wetlands) and
- vertically between the surface and subsurface.

This evaluation considers the impact of environmental water releases on restoration of flows, including low flows (base flows), flow increases in the river channel (freshes), floodplain inundation and longitudinal and lateral connectivity (depicted in Figure 2.6).

⁵ MDBA (2019) Basin-wide environmental watering strategy. Second edition, revised February 2020. Murray–Darling Basin Authority, Canberra

⁶ Section 8.06 Protection and restoration of ecosystem functions of water-dependent ecosystems

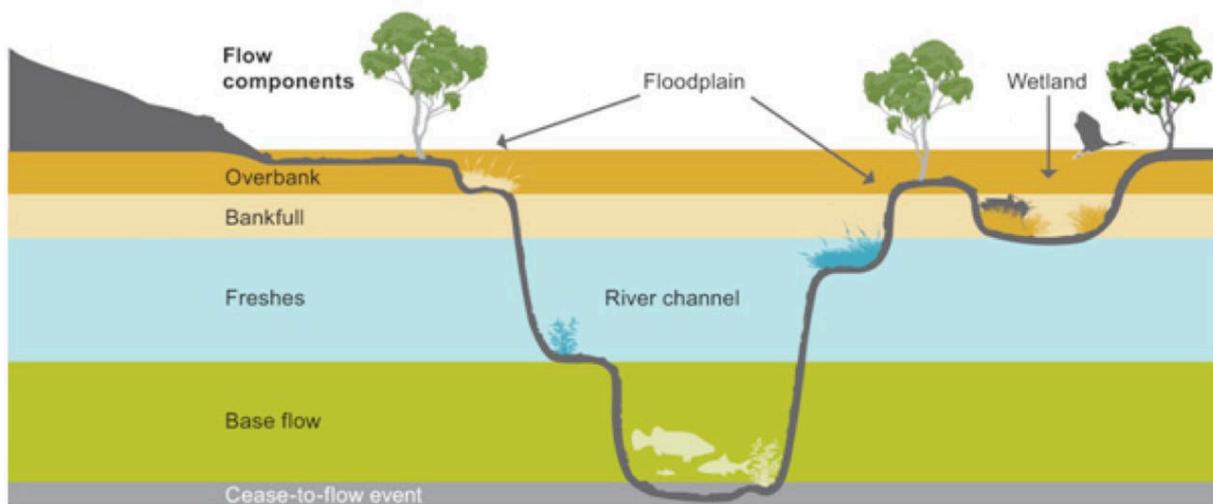


Figure 2.6 Conceptual diagram indicating threshold water levels for key flow components, including flow freshes and base flows

Source: MDBA 2011⁷

In 2019–20, much of the Basin experienced severe dry conditions and environmental watering actions were undertaken within the context of low to very low water availability. Watering objectives focused on the maintenance of refuge habitats and key habitats for biodiversity, and maintaining hydrologic connectivity.

Despite a very dry start to 2019–20, Commonwealth environmental water was delivered to 15,591 km of river length (33.5% of the river length which occurs on the managed floodplain). Commonwealth environmental water was delivered primarily in-stream to provide, base flows (25 actions) and freshes (17 actions plus 9 combined with base flows). 65 actions were delivered to restore overbank flows (2 actions plus another 2 combined with base flows and freshes) and lateral connectivity to wetlands (with another 7 actions providing water for both wetlands and in-channel flows).

Over the 2014–20 period, 9,510 GL of Commonwealth environmental water was delivered to provide base flows (44% of volume), freshes (40% of volume), wetlands (8% of volume), overbank deliveries (7% of volume), and bankfull flows (<1% of volume) (Table 2.1).

Table 2.1 Contribution of Commonwealth environmental water (GL) to flow components, and number and volume of water actions, 2014–20

Some water actions contribute to multiple flow components with primary flow component tabled

	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20
Flow component						
Baseflows	713.73	1073.81	838.16	354.25	700.89	590.62
Freshes (combined)	238.35	222.71	786.54	1513.25	236.87	807.62
Wetland	240.38	112.43	97.37	68.40	171.76	72.86
Overbank	0.00	276.75	39.17	3.24	53.54	233.49
Bankfull	1.25	0.00	56.43	6.11	0.00	0.00
Total	1193.72	1685.70	1817.67	1945.25	1163.05	1704.60

⁷ MDBA (2011) The proposed 'environmentally sustainable level of take' for surface water of the Murray–Darling Basin: Methods and outcomes. Murray–Darling Basin Authority. MDBA Publication No. 226/11 <https://www.mdba.gov.au/sites/default/files/pubs/eslt-mdba-report.pdf>

	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20
Number of water actions						
Fish	50	61	58	83	60	64
Vegetation	55	96	56	69	96	90
Biodiversity*	34	68	36	57	68	61
Water quality	27	21	26	45	33	29
Volume of water actions (GL)						
Fish	1,082	1,551	1,659	1,835	1,071	1,081
Vegetation	704	1,567	1,360	1,780	476	738
Other*	272	1,239	854	822	248	296
Water quality	749	935	1,229	1,059	703	902

*waterbirds, frogs, turtles, platypus and rakali (native water rat)

2.4.1 Base flows

591 GL of Commonwealth environmental water was delivered across the Basin in 2019–20 to maintain base flows. These are flows that maintain longitudinal connectivity and flow in river systems so that they do not become dry or isolated pools.

Base flows were below target levels in the northern Basin for prolonged periods during 2019–20. Low rainfall across much of the Basin contributed to very low to no-flows. Extended periods of low flows were particularly severe in the Barwon-Darling, Gwydir, Macquarie and Namoi.

Excessive periods of below-threshold base flows were largely avoided in the southern Basin, due to contributions of Commonwealth environmental water to the Lower Murray, Edward-Wakool, Goulburn, Broken, Murrumbidgee and Lachlan valleys. In the southern Basin, 2019–20 saw improvements to base flows in the Lachlan, Murrumbidgee, and central Murray valleys. Low flow conditions also improved dramatically in the upper reaches of the Loddon, Campaspe and Goulburn rivers.

2.4.2 Freshes

Freshes are small in-channel events which replenish pools and are important for managing water quality risks (e.g. algal blooms), allowing fish to move between refugia and supporting the persistence and resilience of in-channel refuge pools.

In 2019–20, 808 GL of Commonwealth environmental water was delivered as freshes, primarily in the Murray Rivers and its southern tributaries. While the frequency of freshes has been consistently low in the northern Basin over recent years, particularly in the Peel, Namoi and Border Rivers, all valleys received a contribution of Commonwealth environmental water as freshes in 2019–20.

Across the Basin, more than 50% of rivers experienced high flows during 2019–20, with the exception of the lower Murray which was the only valley to have experienced no high flows since 2016–17.

2.4.3 Overbank flows

Overbank flows occur when there is movement of water between the channel and floodplain (lateral hydrological connectivity). In 2019–20, 233 GL of Commonwealth environmental water was delivered to floodplains and floodplain wetlands in 8 of the 25 valleys of the Basin, totalling 177,260 ha of inundation of lakes and wetlands and 13,844 ha of inundation of floodplains (Figure 2.7). This contribution was less than 50% of the area inundated by Commonwealth environmental water in previous years due to dry conditions;

primarily, 2019–20 watering actions were delivered as freshes to meet in-channel objectives relating to water quality and connectivity.

Over 2014–20, Commonwealth environmental water contributed to the inundation of over 367,909 ha of wetlands, lakes and floodplains in the Central Murray, Border Rivers, Broken, Condamine Balonne, Gwydir, Lachlan, Lower Murray (excluding the Lower Lakes), Macquarie, Murrumbidgee, Warrego, Lower Darling, Edward Wakool and Ovens valleys. Some floodplains in the Gwydir, Murrumbidgee, Lachlan, Central and Lower Murray and Macquarie valleys were inundated nearly every year.

In 2019–20, flows to support lateral connectivity were important for maintaining floodplain ecosystems such as the Macquarie Marshes and the Great Cumbung Swamp at the terminus of the Lachlan River.

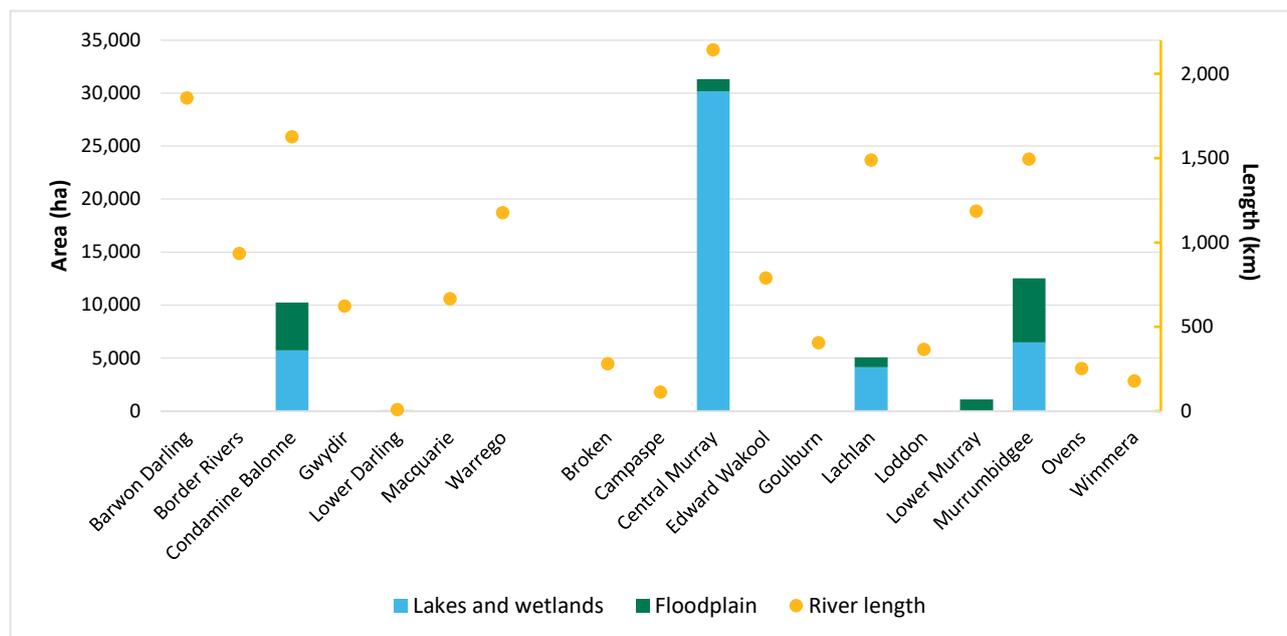


Figure 2.7 Area of lakes and wetlands, and floodplain inundated and length of river receiving Commonwealth environmental water, 2019–20 *excludes Lower Lakes

2.4.4 Connectivity along rivers

Lower reaches of river valleys are particularly vulnerable to water withdrawals from upstream, with a risk of flows declining to severely low levels during dry periods. The Lower Lakes, Coorong and Murray Mouth are dependent on freshwater flows that deliver longitudinal hydrological connectivity from upstream.

In 2019–20, Commonwealth environmental water supported 15,591 km of river length (Figure 2.7). Commonwealth environmental water delivered baseflows or freshes that improved longitudinal connectivity in most valleys. Commonwealth environmental water contributed to flow volume targets for the Coorong, Lower Lakes and Murray Mouth (Table 2.2). *Basin-wide environmental watering strategy* targets⁸ were not met in 2019–20, but Commonwealth environmental water delivered flows to the Coorong, Lower Lakes and Murray Mouth that were above minimum volumes and water levels at Lake Alexandrina remained above the 0.4 m Basin Plan target.

⁸ Basin-wide environmental watering strategy expected outcomes — Barrage flows being greater than 2,000 GL/year on a 3-year rolling average basis for 95% of the time, with a 2-year minimum of 600 GL at any time and 0.4m AHD target threshold for water levels in Lake Alexandrina

Table 2.2 Contribution of Commonwealth environmental water to Barrage releases

	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
CEW contribution (GL)	453	736	811	755	377	685
CEW contribution (% of Barrage releases)	45.9%	100%	12.4%	88.8%	100%	100%
Total Barrage release (GL)	986	736	6,558	851	377	685

FLOWS AND NATIVE FISH

Flows underpin native fish ecology

Flow-MER evaluation shows that Commonwealth environmental water provides a range of benefits to native fish populations and supporting of critical life-history processes such as recruitment, body condition and population abundance. Fish responses to Commonwealth environmental water differ among species, years, hydrological components, and monitoring sites.

In 2019–20, dry and low flow conditions continued across the Basin. Commonwealth environmental water flows facilitated hydrological connectivity and fish movement for several species such as golden perch in rivers and pouched and shortheaded lamprey between the ocean, Coorong Estuary and Murray River. Commonwealth environmental water also supported wetland inundation for maintaining refuge habitat for native fish. Such wetland inundation provided habitat for many small-bodied native fish, such as Australian smelt and the nationally threatened Murray hardyhead.

The benefits of baseflows are important during extended drought conditions to meet the water needs of native fish. Commonwealth environmental water contributed to increased baseflows and, to a lesser extent, small freshes throughout the period, benefiting native fish. Modelling shows that Commonwealth environmental water contributed to juvenile survival, fish body condition and abundance of Murray cod, golden perch, Australian smelt and bony herring. Though fish responses to Commonwealth environmental water differed among species, years, and monitoring sites.

RESEARCH: Flow, movement and fish population dynamics in the Murray–Darling Basin

Fish populations are connected to one another via movement of individuals along river systems. Research in the Flow-MER program focuses on Fish movements and Fish populations. Fish movements are likely to be an important part of resilience and recovery from disturbance events such as blackwater events. Understanding fish movement allows managers to manage for fish passage, support important refugia for migrating fish and to understand the potential for large scale fish movements to provide resilience for populations. Research builds on earlier work to evaluate flow triggers for local and regional scale fish movement among fish species and regions in the Basin.

2.4.5 Ramsar wetlands

In 2019–20, Commonwealth environmental water was delivered to 8 Ramsar areas⁹ inundating a total area of 114,854 ha. Most Commonwealth environmental water provided for biodiversity outcomes was delivered on floodplains, including Ramsar areas. In 2014–20, Commonwealth environmental water has inundated over 730,000 ha across 10 Ramsar areas with the aid of other environmental water (Table 2.3).

⁹ Listed under the Convention on Wetlands of International Importance (the Ramsar Convention, 1971) (<https://www.environment.gov.au/water/wetlands/ramsar>)

Table 2.3 Areas of Ramsar sites inundated (hectares) by Commonwealth environmental water, 2014–20

Ramsar area	2014-15	2015-16	2016-17	2017-18	2018-19	2019–20	Total
Banrock Station Wetland Complex	10	339	0	213	68	42	672
Barmah Forest	0	7,294	0	6,947	7,549	1,746	23,536
Coorong, and Lakes Alexandrina and Albert Wetland	105,929	113,637	110,112	99,717	104,856	105,972	640,223
Fivebough and Tuckerbil Swamps	0	0	0	144	337	103	584
Gwydir Wetlands: Gingham & Lower Gwydir (Big Leather) Watercourses	573	211	341	523	476	0	2,124
Hattah-Kulkyne Lakes	965	932	0	842	0	116	2855
Macquarie Marshes	3,963	49,53	7,456	7,596	5,556	-	29,524
Narran Lake Nature Reserve	0	0	716	0	0	4,330	5,046
NSW Central Murray State Forests	0	5,018	0	4,809	5,725	1,598	17,150
Riverland	36	2,927	118	3,267	1,854	947	9,149
Total	111,476	135,311	118,743	124,058	126,421	114,854	730,863

RESEARCH: FLOW ECOLOGY

Understanding interactions between watering and ecological responses

While our knowledge of the relationship between water and ecological responses is improving, there remain gaps in monitoring ecological changes to Commonwealth environmental water in the Basin. Research is being undertaken in the Flow-MER program to understand responses to flow and to quantify expected outcomes for key indicators. This will enable extrapolation to unmonitored sites and reporting of outcomes at Basin scale. These predictive models will evaluate change to ecological outcomes, considering with and without environmental water.

3 OUTCOMES 2019–20

OUTCOMES AT A GLANCE, 2019–20

WATER QUALITY

- Commonwealth environmental water was important for decreasing the likelihood of low dissolved oxygen by increasing water mixing and oxygen exchange at the surface
- 624 k-tonnes of salt export to the ocean was due entirely to Commonwealth environmental water.

GROUNDCOVER PLANTS

- 25% of taxa were only recorded at sample points that received environmental water
- 15 plant species with traditional Indigenous uses were only recorded at sample points that received environmental water. Of these, 6 are classed as either submerged, amphibious or damp-loving species that are dependent on the provision of water
- 3 rare and threatened plant species were only recorded at sample points that received environmental water which is considered important for their ongoing persistence
- Environmental water was important for maintaining the presence of submerged, amphibious and water dependent species in the Basin.

NATIVE FISH

- Under dry conditions, Commonwealth environmental water was delivered to enhance native fish populations by improving habitat, providing cues for movement and maintaining refuge habitat in wetlands
- There was continued recovery of Murray cod populations from the 2016–17 post-flood blackwater event, evidenced by increased adult abundances and/or successful recruitment in some monitored areas
- While contribution to Murray cod recruitment is unknown, Commonwealth environmental water contributions to natural spring-time pulses may increase the extent and duration of flowing water habitat. This may increase the area of spawning habitat, enhance productivity and thus enhance survival of early life stages
- Golden perch spawning and recruitment was limited in the monitored areas despite water delivery targeting this specific response. Nevertheless, there was evidence of Golden perch spawning in the Murrumbidgee River and recruitment in the Warrego River. There was also evidence of spawning of Silver perch in the Goulburn River. The contribution of Commonwealth environmental water to these fish responses are unknown.
- Commonwealth environmental water delivery facilitated hydrological connectivity and fish movement for several species at varying degrees including golden perch, pouched and short-headed lamprey. Wetland inundation provided additional habitat for many small-bodied native fish, such as Australian smelt and the nationally threatened species Murray hardyhead.

OTHER FAUNA

- Commonwealth environmental water influenced the habitats of 65 waterbird species, 18 frog species and 3 turtle species across 7 valleys
- Commonwealth environmental water influenced the habitat of 19 EPBC Act¹⁰-listed migratory species and contributed to sustaining threatened species by supporting breeding by Australasian bittern, habitats for the regent parrot and maintaining foraging habitats for 36 threatened waterbird species
- Commonwealth environmental water triggered breeding and recruitment of the vulnerable southern bell frog, along with Peron's tree frog, barking and spotted marsh frog, inland banjo frog, and eastern banjo frogs.

3.1 Biodiversity outcomes 2019–20

BIODIVERSITY – TO PROTECT AND RESTORE WATER DEPENDENT ECOSYSTEMS

Key evaluation questions for biodiversity:

- What did Commonwealth environmental water contribute to ecosystem diversity?
- What did Commonwealth environmental water contribute to species diversity?
- What did Commonwealth environmental water contribute to community diversity?

Many water-dependent species and ecosystems found in Australia are adapted to and require specific cycles of high flow and periods of drying. Important reproduction and movement cues are often tightly linked to the water regime. In a climate of increasing pressures on water resources, environmental watering can play a crucial role in maintaining species, communities and ecosystem diversity. This section describes the importance of Commonwealth environmental watering for maintaining these ecosystems and the biodiversity that depends on them.

The expansion and contraction of wet areas across floodplain habitats is typically linked to rainfall high up in the valley. Local rainfall has little impact on the availability of wetland habitats in semi-arid areas. Water-dependent plants and animals respond strongly to peaks in inundation driven by high river flows. When delivered to floodplain wetlands and creeklines, environmental water directly benefits riverine, wetland and floodplain plants, water-dependent mammals, invertebrates, fish, water birds, turtles and wetland lizards and snakes. For example, many floodplain frogs have life-cycle stages that are dependent on water and will only breed when wetlands are inundated.

The Basin historically supported a unique and vibrant fish community with a diverse array of sizes and species of native fish. Since European settlement, the distribution and abundance of native species has declined and over half are now listed as threatened or of conservation concern. Freshwater fish are important indicators of ecosystem health and have critical life history processes linked to hydrology and influenced by hydraulics. They are affected by flow both directly through cues to migration and breeding and indirectly through effects on water quality and habitat and competition and predation.

Waterbirds are a key component of biodiversity in the Basin with over 65 species supported, including 19 species listed under the EPBC Act. The high proportion of listed species, and ongoing population declines make waterbirds a priority for environmental watering, particularly in floodplain and wetland habitats, typically targeting breeding sites, breeding events, foraging habitats and food sources.

¹⁰ Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*

The evaluation also examines the contribution of Commonwealth environmental water to the diversity and condition of non-woody vegetation, including aquatic macrophytes, herbs, sedges and rushes, across the Basin. Vegetation diversity is considered through all phases of the flow regime that are relevant to riparian, wetland or floodplain ecosystems (dry, base flows, freshes, bank-full and overbank flows). Changes in flow regimes are likely to significantly impact vegetation diversity across multiple scales, from the local presence and abundance of plant species to landscape-scale vegetation community composition and structure.

During 2019–20, 296 GL of environmental water was delivered, including a Commonwealth environmental water contribution of 287 GL, for outcome specifically relating to biodiversity. A further 738 GL of Commonwealth environmental water was delivered for vegetation outcomes and a further 1,081 GL was delivered for fish outcomes.

3.1.1 Ecosystem diversity

Using the Australian National Aquatic Ecosystem (ANAE) classification system, 67 ecosystem types have been identified and mapped in the Basin.

- **Commonwealth environmental water support of representative ecosystems.** Over 95% of ecosystem types in the Basin are represented on the managed floodplain – the area where Commonwealth environmental watering is possible – with many wetland and floodplain ecosystems occurring in similar proportions to the rest of the Basin. Despite dry conditions in 2019–20, 13,844 ha of floodplain were inundated and 177,260 ha of floodplain wetlands received Commonwealth environmental water. Collectively 83% (57) of the ecosystem types present in the Basin were supported by Commonwealth water.
- **Commonwealth environmental water contribution to ecosystem diversity.** Over 50% of the ecosystem types in the Lower Murray, Central Murray, Barwon-Darling, Border Rivers, Murrumbidgee and Ovens river valleys received Commonwealth environmental water (Figure 2.4). In another 12 valleys, between 20% and 50% of the ecosystem types received Commonwealth environmental water. There were no water management actions in the remaining 7 valleys.
- **Commonwealth environmental water support of representative floodplain ecosystems.** Commonwealth environmental water inundated 11% of permanent floodplain lakes including: 5,200 ha of the Narran Lakes; 52% of tall marshes on the managed floodplain including 561 ha of the Great Cumbung Swamp; and 46% of temporary River red gum floodplain swamps including 1,746 ha of Barmah Forest Ramsar site. This contribution substantially supports and maintains these ecosystems during dry periods.

3.1.2 Species diversity – fish

- **Improving Murray cod populations.** There was continued recovery of Murray cod populations in 2019–20 from losses that occurred following a large blackwater event in 2016–17. Increased numbers of adults and/or recruitment were observed in the Goulburn River, Lower Murray River and the Lachlan and Edward/Kolety–Wakool River systems. Despite difficulty in demonstrating direct causal links, it is highly likely that Commonwealth environmental water substantially increased the extent and duration of inundation of habitat, potentially enhancing spawning habitat area, productivity and the survival of early life stages.
- **Golden perch populations.** Spawning and recruitment of golden perch was limited in monitored areas in 2019–20 with the exception of the Murrumbidgee and Warrego rivers. Commonwealth environmental water contribution to these fish responses is unknown. Golden perch recruit primarily during major flows or flood events, so these findings may reflect low flows and prevalent drought conditions across the Basin.

- **Commonwealth environmental water provided flows and habitat for native fish.** Commonwealth environmental water facilitated hydrological connectivity and fish movement for several species, such as golden perch, pouched lamprey and short-headed lamprey. Wetland inundation with Commonwealth environmental water provided additional habitat for many small-bodied native fish such as Australian smelt and the nationally threatened Murray hardhead.

3.1.3 Species diversity – groundcover plants

- **Commonwealth environmental water support for groundcover plants.** 738 GL of Commonwealth environmental water was delivered for vegetation outcomes. Without this water, over 50% of floodplain-wetland monitoring locations would have experienced drier water regimes. 304 native groundcover plant species were recorded across wetland and riverine ecosystems. 50 floodplain-wetland plants, and 62 riverine plants were only recorded at locations that received environmental water. This includes submerged, amphibious and damp-loving species that require inundation or damp soil following flow recession.
- **Commonwealth environmental water support for plants with traditional Indigenous uses.** 23 culturally significant groundcover plant species received Commonwealth environmental water in 2019–20. Of these, 15 were only recorded at locations that received environmental water. Of these, 9 were either submerged, amphibious or damp-loving species that are likely to be dependent on water to be present in the landscape.
- **Commonwealth environmental water support for threatened species.** 3 listed species of groundcover plants were only recorded at locations that received environmental water. Based on these observations, it is likely that environmental water is contributing to their ongoing persistence in the landscape.

RESEARCH: NON-WOODY PLANT RESPONSES

Developing condition benchmarks for non-woody vegetation

Research is underway to improve our understanding of how to use Commonwealth environmental water to achieve outcomes for non-woody vegetation. This research is characterising the condition of non-woody vegetation and will develop a method for evaluating the condition of non-woody vegetation and applying this method to determine how non-woody vegetation responds to environmental water.



Figure 3.1 The many faces of non-woody wetland and floodplain vegetation and non-woody plant communities in the southern Basin

Photo credit: Cherie Campbell, University of Canberra

PLANTS WITH TRADITIONAL INDIGENOUS USES

Case study: The response of plants with Indigenous uses to the use of environmental water

The Basin is home to a large number of plants which have traditional Indigenous uses. While not specifically targeted because of their significance to Indigenous people, the use of Commonwealth environmental water to support groundcover vegetation has supported these species. From 2014–20, 69 significant plant species with established Indigenous uses have been recorded in monitored areas, and 15 have only been found where environmental water has been provided. In 2019–20, environmental water made a significant contribution to maintaining the cover of two such species; nardoo and old man weed.

- **Nardoo** (*Marsilea* spp.) is an important food plant occurring across inland floodplains of Australia. It is observed to occur most frequently at sites that have been flooded within the past 6 months. Both cover and abundance decline markedly with more than 12 months since flooding.
- **Old man weed** (*Centipeda* spp.) is an important medicinal plant, that also occurs across the inland floodplains of Australia. It is observed most frequently at sites that have been flooded in the past three to six months and presence and abundance declines with more than 12 months since flooding.
- **Cumbungi** (*Typha* spp.) has a range of cultural uses including as a fibre, food and ceremonial plant. It is typically found in areas that are regularly flooded and is most likely to occur where it has been flooded in the past 3 months. In 2019–20, environmental water was not used to support Cumbungi, however, between 2014 and 2020, environmental water has provided suitable hydrological conditions for Cumbungi on multiple occasions.

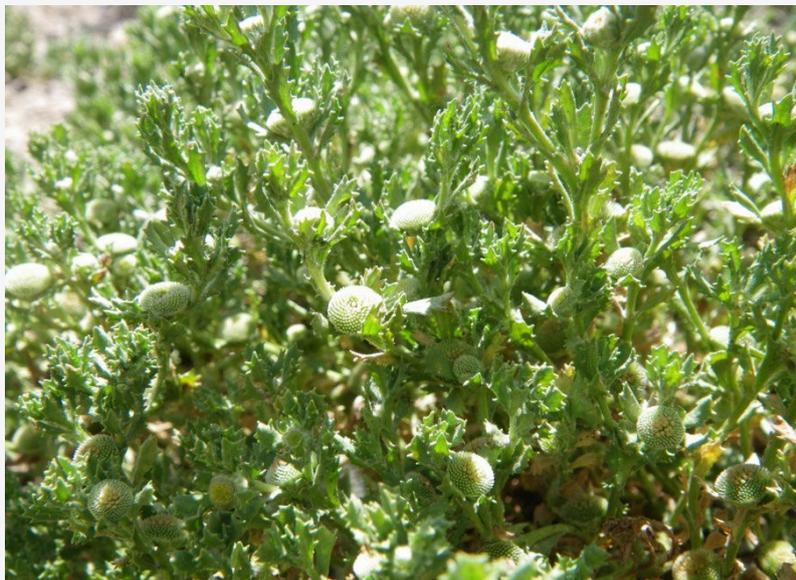


Figure 3.2 *Centipeda cunninghamii* (Old Man Weed) in flower on the Darling Anabranch. This plant is significant to many Aboriginal nations for its medicinal properties

Photo credit: Deb Bogenhuber

3.1.4 Species diversity – waterbirds

- **Commonwealth environmental water support for waterbirds.** 283 GL of Commonwealth environmental water was delivered in actions that sought outcomes, either in part or in full, for waterbirds. Whilst very dry conditions in 2019–20 reduced bird abundance and available habitat, Commonwealth environmental

water supported locally high ecological productivity. In the Lower Murray and Murrumbidgee over 30,000 individuals were observed, representing 65 species of waterbirds and 5 raptor species observed.

- **Commonwealth environmental water support for threatened water birds.** Commonwealth environmental water supported the life cycles of listed threatened species, including regent parrot, Australasian bittern and Latham's snipe, and 36 waterbird species of conservation significance. Of these, 34 are listed as threatened under state or commonwealth legislation and 21 are listed in the EPBC Act migratory waterbird list and/or international treaties¹².

3.1.5 Species diversity – turtles, snakes and frogs

- **Commonwealth environmental water support for turtles, snakes and frogs.** Commonwealth environmental water supported 18 frog and 3 turtle species across 3 valleys (where monitoring has been undertaken). This included 3 threatened species – the broad-shelled turtle, platypus, and southern bell frog
- **Commonwealth environmental water support for frog breeding.** Commonwealth environmental water triggered breeding and recruitment of frog species including the southern bell frog, Peron's tree frog, barking and spotted marsh frog, the inland banjo frog and eastern banjo frog
- **Commonwealth environmental water support for southern bell frog populations.** Due to dry conditions in 2019–20, the overall volume of Commonwealth environmental water delivered for frog outcomes (88 GL) was lower than in previous years and was focussed on maintaining refuge habitats. Successful recruitment of southern bell frogs was reported across the Murrumbidgee River System and the Central and Lower Murray rivers.

3.1.6 Diversity of ecological community assemblages

- **Commonwealth environmental water provided flows and habitat for native fish.** 1,081 GL of Commonwealth environmental water was delivered for fish outcomes, primarily hydrological connectivity for fish movement for several species such as golden perch, pouched and short-headed lamprey. Wetland inundation with Commonwealth environmental water provided additional habitat for many small-bodied native fish such as Australian smelt and the nationally threatened Murray hardyhead.
- **Commonwealth environmental water support for vegetation communities.** 738 GL of Commonwealth environmental water was delivered to achieve vegetation outcomes across the Basin. These actions are important in sustaining vegetation communities that include submerged, amphibious or damp-loving species which contribute to maintaining riverine and wetland-floodplain ecosystem types in the Basin.
- **Commonwealth environmental water contribution to riverine vegetation.** Management of environmental water more than doubled the total cover of plant species observed within river channels in the Basin. This suggests that the active management of environmental water was important for supporting instream and riverbank vegetation that contributes to bank stability.
- **Commonwealth environmental water contribution to floodplain and wetland vegetation.** The use of Commonwealth environmental water was important for maintaining the diversity of floodplain-wetland vegetation communities in the Basin and has been important in sustaining vegetation communities that include submerged, amphibious and damp-loving species.

¹² International treaties referred to are the Bonn Convention, JAMBA, CAMBA and ROKAMBA

TREES AND SHRUBS

Remote sensing trends and temporal condition responses of woody vegetation to environmental water

Remote sensing research is improving the understanding of how native trees and shrubs respond to water and water availability (including environmental watering) at the local, regional and Basin scales. Water requirement thresholds are being identified to inform environmental flow management.

Monitoring the condition of trees and shrubs is challenging because of the large scales involved and a lack of simple condition metrics. Research will also develop condition metrics which allow an assessment of the effects of environmental watering on vegetation communities.

3.2 Ecosystem function outcomes 2019–20

ECOSYSTEM FUNCTION – TO PROTECT AND RESTORE ECOSYSTEM FUNCTION

The evaluation question for ecosystem function was:

- What did Commonwealth environmental water contribute to protecting and restoring energy, carbon and nutrient dynamics, primary production and respiration?

Healthy populations of native fish, vegetation and waterbirds are reliant on a range of ecosystem functions based on productive and diverse food webs and ecological communities. **Food webs** provide a useful way to think about life in rivers and wetlands. The energy that drives riverine food webs is a fundamental requirement for all plants and animals. Without energy they have no capacity for growth or reproduction.

Food webs describe the pathways along which energy is transferred, and the strength and direction of these pathways are sensitive to impacts from changes to river flows and their landscapes. Although complex, food web studies can identify critical parts of an ecosystem that influence energy production and transfer, that in turn influence population size and structure of our iconic native fish and waterbirds.

Stream metabolism measures the production and consumption of oxygen by the key ecological processes of photosynthesis and respiration. Healthy aquatic ecosystems need both processes to generate new biomass, which becomes food for organisms higher up the food chain, and to break down plant and animal detritus to recycle nutrients to enable growth to occur.

In 2019–20, There were 29 Commonwealth environmental water actions targeted ecological outcomes for water quality, food webs, stream metabolism and productivity, and river function. In total, 20 watering actions were delivered to 6 of the 7 Selected Areas; there were no watering actions targeting water quality and food webs in the Murrumbidgee River.

- **Commonwealth environmental water contributes to ecosystem respiration.** Where terrestrial carbon from litter is mobilised from floodplains and benches to the river channel during a fresh or overbank flow, there is an increase in ecosystem respiration. The magnitude of response depends on the type of flow. For example, bankfull or overbank flows may mobilise large quantities of litter, while smaller freshes may deliver small quantities of litter to the river from in-channel features (benches, bars).
- **Small changes in primary production and ecosystem respiration occurred in response to Commonwealth environmental water.** Changes to rates of gross primary production and ecosystem respiration in response to Commonwealth environmental water in 2019–20 were generally small and largely followed seasonal trends. However, volumetric increases in water in rivers during Commonwealth environmental watering

actions led to an increase in the total amount of organic carbon produced and consumed per day within riverine ecosystems.

- **Terrestrial organic carbon is important.** Connection to backwaters and other off-channel habitats, such as floodplains and wetlands, is important for increasing productivity. Monitored areas were typically net sinks of carbon. This highlights the importance of terrestrial organic carbon from channel and floodplain connectivity as the dominant energy source in these systems.
- **Changing nutrient concentrations and turbidity did not substantially impact stream metabolism.** Nutrients did not have a strong influence on rates of stream metabolism, with variable changes in concentrations in response to Commonwealth environmental water. Similarly, increases in turbidity had a minimal and inconsistent influence on rates of primary production and ecosystem respiration.
- **Responses in stream metabolism to environmental flows are context-specific.** A valley-scale case study of the Southern Spring Flow in 2020 demonstrated that metabolic responses to flows vary spatially. Failure to detect a metabolic response to flow at the site or area scales does not necessarily mean that flow has not influenced stream metabolism elsewhere. The case study showed that incorporation of terrestrial carbon from floodplains into riverine food webs was rapid and highlights the dynamic nature of metabolic responses to flow and spatial shifts between autotrophy and heterotrophy.

EVALUATING ECOSYSTEM FUNCTION: METABOLIC FINGERPRINTS

The Ecosystem Energetics research project is working to develop tools for visualising and interpreting productivity data to enable its application to adaptive management and evaluation. Metabolic fingerprints are an emerging evaluation tool for comparing and visualising patterns of stream metabolism across rivers or across years within the same river. Understanding metabolic response to flow are important because they define the energy available to fuel riverine food webs.

A significant challenge when interpreting responses of stream metabolism to environmental flows is determining what is 'desirable' and 'undesirable' productivity. For example, a large overbank flow event has the potential to liberate large quantities of carbon from floodplains that can generate increases in heterotrophic in-channel productivity (measured as ecosystem respiration). However, such large responses may be undesirable if they occur in concert with small responses in primary production, potentially leading to blackwater events, where more oxygen is consumed from the water column than is produced, which can deplete oxygen below levels required by aquatic animals.

The fingerprint approach enables us to identify whether metabolic responses to a flow condition are within the typical metabolic regime or if they are atypical for a site. Atypical metabolic conditions could include exceptionally high gross primary production and ecosystem respiration with high energy throughput or undesirable states such as algal blooms and blackwater.

Metabolic fingerprints produced for this evaluation represent 14,029 daily records of gross primary production and ecosystem respiration from 2014 to 2020, one of the largest riverine metabolic datasets available globally. The metabolic fingerprint represents the entire distribution of daily estimates that are observed for a river, summarised into kernel density plots that allow easy visualization of both peak and median metabolic rates, and variance in the ratio between primary production and ecosystem respiration.

A valley-scale case study of the Southern Spring Flow 2020¹² found that metabolic responses were highly context specific, e.g. the inability to detect a metabolic flow response at the site or Selected Area

¹² Water for the environment was released from Hume Dam from September to December 2019 and in 2020 to support targeted wetlands and river channels from the mid-Murray to the Lower Lakes and Coorong. The release was coordinated with environmental releases from the Goulburn River, and natural and operational flows. The purpose of the Southern Spring Flow releases was to stimulate ecosystem productivity along the whole length of the Murray River, from Yarrowonga to the Coorong.

scale does not necessarily mean that a response did not occur elsewhere in the river system. Rapid incorporation of terrestrial carbon from floodplains into riverine food webs highlights the dynamic nature of metabolic responses to flow and spatial shifts between autotrophy and heterotrophy.

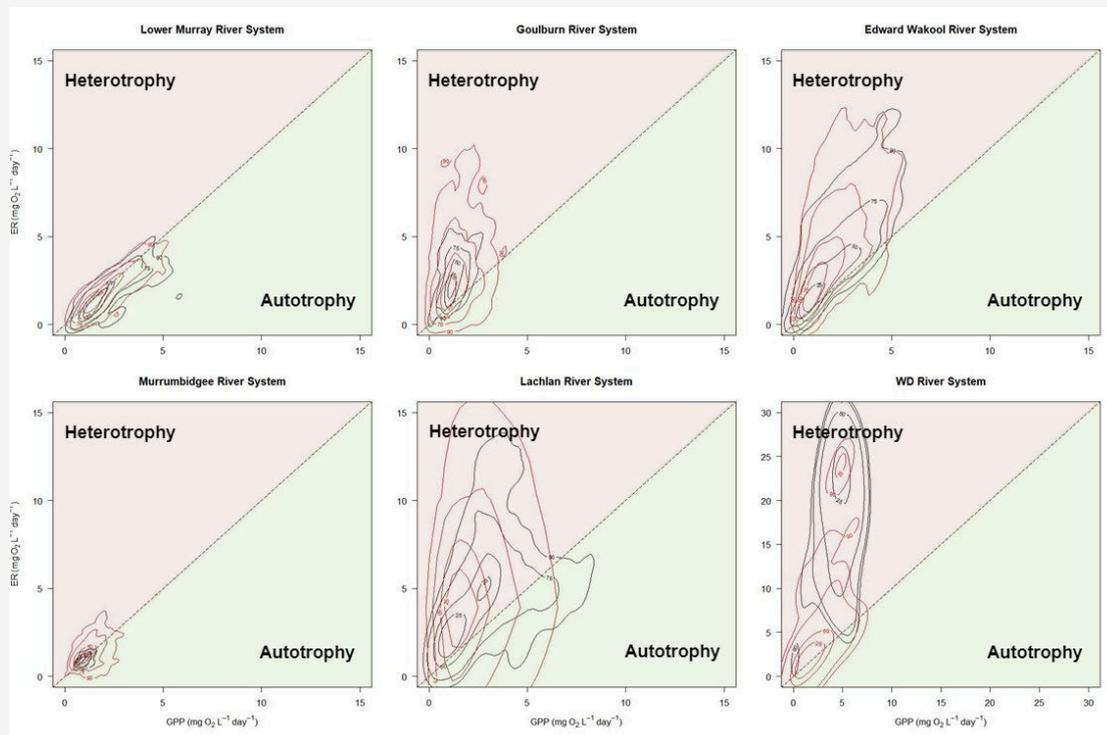


Figure 3.3 Cumulative 2014–2020 metabolic fingerprints for each Selected Area (red lines) overlaid with the 2019–20 metabolic fingerprint (black lines)

Note different scale for the Junction of the Warrego and Darling rivers plot (WD River System). Kernels represent the bivariate probability distribution estimated to contain the top 25, 50, 75, and 90% of the gross primary production (GPP, x-axis) and ecosystem respiration (ER, y-axis) data points. Points that occur above the dotted line have GPP:ER ratios <1 and indicate when the ecosystem is consuming more carbon than it is producing (heterotrophy). For points that fall below the line GPP:ER is >1 the ecosystem is producing more carbon than it is consuming (autotrophy).

RESEARCH: ECOSYSTEM ENERGETICS

Developing an environmental water energetics response model

It is now well understood that environmental water can be used as a cue to trigger native fish breeding. However, it now seems likely that some flow conditions may favour larvae both physically and in terms of what food resources are available.

This research is developing an energetics response model to predict the trophic carrying capacity of rivers and wetlands in response to environmental water delivery. A bioenergetic model for how food webs respond to flow will initially focus on refuge habitats, then extend to wetlands and flowing water habitats. The research is designed to improve the certainty of scientific predictions for ecological outcomes.

3.3 Water quality outcomes 2019–20

WATER QUALITY – TO MEET WATER QUALITY, SALINITY AND DISSOLVED OXYGEN TARGETS

The evaluation question for water quality was:

- What was the contribution to maintaining water quality and to meet dissolved oxygen, salinity and salt export targets?

Healthy populations of native fish, vegetation and waterbirds are reliant on a range of ecosystem functions being maintained and restored. Achieving water quality objectives also supports the Basin Plan objectives of improving the life cycle completion of key plants and animals and meeting the needs of plants and animals.

Water quality describes the chemical, physical, and biological characteristics of water and its suitability for environmental uses. Water quality is a key indicator of aquatic ecosystem health, and flow plays an important role in the maintenance of water quality in rivers.

A range of parameters can be measured as indicators of water quality in river systems and many form water quality targets in the Basin Plan. Water quality responds to changes in flow, and it can be a significant influence on the outcome of a watering action targeting fish and waterbirds. For example, dissolved oxygen can be influenced by flow through changes in water volume and turbulence, and through indirect processes such as rates of bacterial metabolism and photosynthesis. This, in turn, will directly influence the suitability of water quality for aquatic organisms, such as fish. Nutrients and organic matter concentrations may be influenced by flow, either by dilution or through inputs associated with water contacting parts of the channel or floodplain which were previously dry, and which have stores of nutrients and carbon in plant materials and the soil.

Water quality objectives, and associated watering actions, often exist to prevent or reduce the impact of poor water quality (low dissolved oxygen, high salinity or algal blooms) on ecosystems, plants and animals.

3.3.1 Dissolved oxygen levels

The Basin Plan target for dissolved oxygen is to maintain a value of at least 50% saturation, which equates to a dissolved oxygen concentration of approximately 4 to 5 mg/L. In 2019–20, Commonwealth environmental water was important for decreasing the likelihood of low dissolved oxygen by increasing water mixing and oxygen exchange at the surface.

3.3.2 Salinity export

The Basin Plan salt export objective (9.09) aims to ensure adequate removal of salt from the Murray River system into the Southern Ocean, and this has been set at 2 million tonnes per year.

- **624 k-tonnes of salt was exported due to Commonwealth environmental water.** Commonwealth environmental water was the only water that passed through the barrages in South Australia, highlighting its importance for maintaining water quality and salinity regimes (Table 3.1). All salt export resulted from these flows and without them, this salt would have accumulated in Basin river systems.
- **Commonwealth environmental water maintained low river salinity in South Australia** by diluting salt in the Lower Murray River channel. In dry years such as 2019–20, Commonwealth environmental water is important for maintaining salt export from the Basin and limiting nett salt import to the Coorong.

Table 3.1 Modelled salt export (tonnes) through the barrages to the Coorong estuary and through the Murray Mouth into the Southern Ocean 2019–20 (taken from Ye et al. 2021)

Modelled scenario	Barrages (tonnes)	Murray Mouth (tonnes)
All water	623,999	-335,926
Without Commonwealth environmental water	0	-2,332,963

4 OUTCOMES 2014–20

OUTCOMES AT A GLANCE – 2014 TO 2020

WATER QUALITY

- Commonwealth environmental water accounted for between 64% and 100% of total salt export to the Southern Ocean
- Commonwealth environmental water decreased the likelihood of low dissolved oxygen by increasing water mixing and oxygen exchange at the surface.

GROUNDCOVER PLANTS

- Of the more than 700 taxa recorded at monitoring locations since 2014, almost 40% are species that have only occurred at sample points that have received environmental water. This includes submerged (4), amphibious (46) and damp-loving species (50) that are unlikely to persist in the absence of water
- The delivery of Commonwealth environmental water has produced distinct hydrological regimes across the Basin. There is greater diversity and cover of submerged, amphibious and damp-loving species at monitoring locations which have wetter water regimes due to environmental water. Without Commonwealth environmental water, many locations across the Basin would have experienced drier water regimes and it is likely this would have resulted in the near absence of submerged species and substantially less diversity and cover of amphibious and damp-loving species.

NATIVE FISH

- Drought conditions existed through much of 2014–20 and low flows dominated. One high flow event (overbank) occurred in 2016–17. It was an unregulated natural flow event that led to post-flooding blackwater hypoxia and resulted in fish deaths in most monitored areas
- Large freshes and overbank flows are important for providing habitat, food resources and cues for movement and spawning. Due to dry conditions, Commonwealth environmental water contributions to large freshes and overbank flows in monitored areas was limited and this constrained expected fish outcomes
- Commonwealth environmental water benefited native fish through the provision of baseflows and freshes. Small freshes benefited recruitment of Australian smelt in all monitoring areas. Spawning of golden perch was limited, likely reflecting dry conditions; when spawning occurred it was more likely with Commonwealth environmental water though findings differed greatly across monitoring areas and years
- Commonwealth environmental water increased body condition in golden perch, Murray cod, and common carp (non-native), due primarily to the provision of small freshes which increase connectivity and therefore access to habitat and food resources.

OTHER FAUNA

- Commonwealth environmental water has supported habitats of 103 waterbird species and breeding and recruitment of a wide range of species, including, but not limited to, straw necked, white and glossy ibis, royal and yellow spoonbills, cormorants, darters, grebes and several species of duck

- Commonwealth environmental water supported broad-shelled turtles (endangered in South Australia) and created nursery habitats that supported hatchling Macquarie, long necked and broad shelled turtles
- Commonwealth environmental water supported habitats and populations of threatened species, including 41 waterbird species, one frog (southern bell frog), one woodland bird (regent parrot), one turtle (broad-shelled turtle) and one snake (grey snake)
- Commonwealth environmental water supported habitats and populations of 23 EPBC Act-listed migratory species

4.1 Biodiversity outcomes 2014–20

BIODIVERSITY – TO PROTECT AND RESTORE WATER DEPENDENT ECOSYSTEMS

The key evaluation questions for biodiversity were:

- What did Commonwealth environmental water contribute to ecosystem diversity?
- What did Commonwealth environmental water contribute to species diversity?
- What did Commonwealth environmental water contribute to community diversity?

This evaluation reports on outcomes from Commonwealth environmental water for 2014–20 and assesses the contribution of Commonwealth environmental water to Basin Plan objectives.

From 2014 to 2020, a total of 9,510 GL of Commonwealth environmental water has been delivered in the Basin. Many of the 666 actions have multiple objectives relating to biodiversity, with 376 actions targeting 8,279 GL for fish, 462 actions involving 6,625 GL for vegetation and 324 actions involving 3,731 GL with objectives for waterbirds, frogs, turtles, platypus and rakali (Table 2.1).

4.1.1 Ecosystem diversity

- Commonwealth environmental water contribution to ecosystem diversity:
 - evaluation of watering frequencies among ecosystem types shows that in the 6 years from 2014–20 Commonwealth environmental water been delivered to 85% of the ecosystem types found in the Basin
 - ecosystems that did not receive Commonwealth environmental water were either very wet systems (bog and fens, paperbark swamps, and springs) that likely do not require additional water, saline systems, or are geographically isolated from the managed floodplain
 - evaluation of watering frequencies over the 6 years showed that Commonwealth environmental water was spread widely across different individual wetlands within each ecosystem type
 - repeat watering occurred mostly in permanent systems (e.g. permanent emergent tall marsh, permanent grass marshes) or in temporary River Red Gum and woodland swamps close to rivers.
- From 2014–20, Commonwealth environmental water supported wetland and floodplain ecosystems as follows:
 - inundation of 26,853 ha of permanent and temporary lakes
 - inundation of 104,162 ha of palustrine wetlands from 20 ecosystem types
 - 23% of the palustrine wetland area of the managed floodplain has been supported at least once
 - inundation of 108,852 ha of 12 different floodplain ecosystems
 - 7.5% of the managed floodplain has been inundated (but only 2% of total Basin floodplains)

- 62,725 ha (58%) of the area inundated was river red gum forest and woodland floodplains
- flows were delivered to 28,426 km of river and stream channels, of which 91% were lowland rivers
- inundation of 104,275 ha of Lake Alexandrina and Lake Albert and their fringing wetlands
- inundation of 23,767 ha of estuarine habitat in the Coorong and Murray Mouth in all 6 years.
- Commonwealth environmental water contributed to several unique watering events:
 - increased filling of lakes in 2017–18 when Lake Victoria was filled
 - watering of lignum floodplains during water delivery to Narran lakes in 2015–16 and 2019–20
 - increased inundation of river cooba floodplain associated with floodplain watering of the Gwydir Wetlands in 2016–17 and 2017–18.

4.1.2 Species diversity – fish

- 13 native fish species were detected at monitored sites during the 6-year period
 - The number of native species did not differ greatly among years
 - Golden perch, Murray cod, common carp, and carp gudgeons were common at monitoring locations
 - Silver perch, Unspecked hardyhead, freshwater catfish, and Australian smelt were less common.
- Commonwealth environmental water benefited several native fish species (determined with the use of modelling approaches):
 - Several native fish species benefited from the provision of baseflows and improved fish body condition through the provision of freshes
 - Spawning of golden perch was limited over the 2014–20 period, but when it occurred it was positively associated with consistent baseflows and large freshes and with Commonwealth environmental water. However, spawning responses to Commonwealth environmental water differed across monitoring sites and years.
 - Commonwealth environmental water positively influenced recruitment of Australian smelt in some years, primarily due to the provision of small freshes
 - Commonwealth environmental water positively affected individual body condition in golden perch, Murray cod, and common carp (introduced), due primarily to the provision of small freshes.

RESEARCH: FISH POPULATIONS

Fish population models to inform Commonwealth environmental watering

Fish population processes are highly complex and related not just to river flows but many other factors such as habitats, connectivity, fish density and water quality. Population models aim to clearly demonstrate the benefits of environmental water to fish populations. The Fish populations research project is developing fish population models to assist water management, evaluate outcomes of different watering scenarios and help set monitoring targets. While population models have been used for the past 10 years to predict fish responses to a range of management scenarios, this research explicitly links flow management to whole-of-lifecycle responses for a suite of native fish species.

One of the major challenges of riverine science is to generate transferable flow-ecology relationships to unmonitored sites. A strength of the population models is their ability to be applied beyond monitoring areas for predicting fish population responses to flow events. Models are being developed for Murray cod, golden perch and bony herring.

4.1.3 Species diversity – groundcover plants

- Commonwealth environmental water support for groundcover plants:
 - More than 700 plant taxa have been recorded from floodplain, wetland and river monitoring sites since 2014 and, of these, almost 40% (278) are species that have only occurred at sites that have received environmental water
 - This includes submerged (4), amphibious (46) and damp-loving species (50) that are unlikely to persist without environmental water. This highlights the significant role of environmental water in supporting a substantial number of native plant species across the Basin over the past 6 years.
- Commonwealth environmental water support for plants with Indigenous uses
 - Between 2014 and 2020, 69 plant species with traditional Indigenous uses have been recorded
 - While Commonwealth environmental watering has not deliberately targeted plant species of traditional uses, watering to support groundcover vegetation has supported a range of such species
 - 15 species with traditional Indigenous uses occurred only at sites that received environmental water.

4.1.4 Species diversity – waterbirds

- Commonwealth environmental water support for waterbirds:
 - Since 2014, 3,641 GL of Commonwealth environmental water has been delivered to benefit waterbirds, either alone or in combination with other objectives
 - When considered across all valleys, overall waterbird abundances have remained stable over the past 6 years, though the abundance of large waders appears to be in decline
 - 103 waterbird species from 17 families are likely to have benefited from Commonwealth environmental water delivery across the Basin
 - Since 2014, 41 species of conservation significance have, or have potentially, benefited from Commonwealth environmental water delivery.

RESEARCH: WATERBIRDS

Research on waterbird movements and habitat use across the Basin is informing environmental water planning now and also supporting our thinking about how we may use environmental water to support waterbirds

Research is identifying drivers of waterbird movements and habitat use across the Basin. The project team is quantifying spatial and temporal scales of waterbird movements and habitat selection. The team uses local scale short-term movements such as foraging during nesting events, Basin-scale long-term movements and common routes ('flyways'), GPS satellite tracking technology and novel analytical approaches to investigate relationships between waterbird movements, habitats, environmental watering, flooding and other factors.

Information about waterbird movements helps us to understand fluctuations in the diversity and numbers of birds present or breeding both at particular sites and across the Basin, including why waterbirds may not have responded to environmental watering events. It also helps with planning and adaptively managing Basin-wide environmental watering and coordination among sites.

Identification and mapping of movements and key habitats is a first step towards informing the use of environmental water to ensure waterbird species connectivity, population persistence, and diversity.



Figure 4.1 Yellow-billed spoonbills (*Platalea flavipes*) are strongly dependent on surface water for feeding, breeding, roosting and refuge

Photo credit: Freya Robinson, CSIRO

4.1.5 Species diversity – turtles

- Commonwealth environmental water supported turtles
 - 3 turtle species – the eastern long-neck, Macquarie and broad-shelled turtles – are associated with habitats supported by Commonwealth environmental water, particularly in the Murrumbidgee. The maintenance of persistent freshwater habitat during drought is important for turtles. Broad-shelled turtles (endangered in South Australia) in particular may benefit from in-channel and wetland flows provided by Commonwealth environmental water in the Lower Murray.

4.1.6 Species diversity – frogs

SOUTHERN BELL FROGS

The southern bell frog was once widespread through south-eastern Australia. However, altered flow regimes, exotic species and disease have seriously affected populations within the Basin.

Commonwealth environmental water is used to protect remaining populations of southern bell frogs in the Murrumbidgee and Lower Murray. Since 2014 there have been 56 individual Commonwealth environmental watering actions with objectives specifically targeting southern bell frogs, with 93,763 ML delivered to support key populations.

Between 2014 and 2020, 2,342 individuals were recorded within wetlands inundated with Commonwealth environmental water. Populations at key environmental watering sites in the Murrumbidgee have shown a steady increase over time. Southern bell frogs are very vulnerable during droughts, when the availability of freshwater habitat decreases. Targeted delivery of environmental water to key refuges, often using pumping, is critical to ensure adult frogs survive until the next breeding season.



Figure 4.2 Male southern bell frog (*Litoria raniformis*) (listed as vulnerable under the EPBC Act) at a Commonwealth environmental watering site in the lower Murrumbidgee, January 2020

Photo credit: Damian Michael, Charles Sturt University

4.1.7 Vegetation community diversity

- Commonwealth environmental water support for groundcover vegetation communities:
 - Over the past 6 years, Commonwealth environmental water has been used to support around 15% of permanent wetlands, over 40% of permanent tall emergent marsh, and over 25% of freshwater meadows on the managed floodplain
 - Floodplain-wetland vegetation communities of the Basin have distinct functional and structural assemblages based on the hydrological regime they have experienced over the past 6 years
 - There is greater diversity and cover of submerged, amphibious and damp-loving species at sites which have received regular inundation because of the use of environmental water
 - In the absence of environmental water, many floodplain-wetland sites would have experienced drier water regime. This is likely to have resulted in the near-absence of submerged species and considerably less diversity and cover of amphibious and damp-loving species.

4.2 Ecosystem function outcomes 2014–20

ECOSYSTEM FUNCTION – TO PROTECT AND RESTORE ECOSYSTEM FUNCTION

The evaluation question for ecosystem functions was:

- What did Commonwealth environmental water contribute to protecting and restoring energy, carbon and nutrient dynamics, primary production and respiration?

From 2014–20, 181 Commonwealth environmental water actions totalling 5,577 GL were delivered for outcomes linked to water quality, food webs, stream metabolism, productivity and river function.

- Rates of primary production and respiration across all monitored areas in 2019–20 were similar and comparable to long-term average values and trends.
- Independent of Commonwealth environmental water actions, rates of primary production are most strongly influenced by seasonal changes (e.g. light and temperature) and site-specific drivers such as bioavailable nutrient concentrations and reduced light availability due to turbidity
- Volumetric increase in water in rivers during Commonwealth environmental water actions led to an increase in the total amount of organic carbon produced and consumed per day within riverine ecosystems
- Increased flows can substantially decrease rates of both primary production and respiration, likely attributable to dilution effects of increased water volume and disturbance of microbial communities.

4.3 Water quality outcomes 2014–20

WATER QUALITY – TO MEET WATER QUALITY, SALINITY AND DISSOLVED OXYGEN TARGETS

The key evaluation question for water quality was:

- What did Commonwealth environmental water contribute to maintaining water quality and to meet dissolved oxygen, salinity and salt export targets?

4.3.1 Dissolved oxygen

The Basin Plan target for dissolved oxygen is to maintain a value of at least 50% saturation, which equates to a dissolved oxygen concentration of approximately 4 to 5 mg/L. Commonwealth environmental water decreased the likelihood of low dissolved oxygen by increasing water mixing and oxygen exchange at the surface.

4.3.2 Salinity export

The Basin Plan salt export objective (9.09) aims to ensure adequate removal of salt from the Murray River system into the Southern Ocean, and has been set at 2 million tonnes per year.

Monitoring in the Lower Murray¹⁴ has shown that between 2014–20, in 5 out of the 6 years, Commonwealth environmental water accounted for 64% to 100% of total salt export to the Southern Ocean (Table 4.1). In these years, total salt export ranged from 228,293 to 623,999 tonnes, remaining well below the 2 million tonne Basin Plan objective. In 2016–2017 (a high flow year), 1.5 million tonnes were exported of which only 8% was attributable to Commonwealth environmental water.

¹⁴ Ye Q, Giatas G, Bice C, Brookes J, Furst D, Gibbs M, Nicol J, Oliver R, Shiel R, Zampatti B, Bucater L, Deane D, Hipsey M, Huang P, Lorenz, Z, Zhai S (2021) Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project: Lower Murray 2019–20 Technical Report. A draft report prepared for the Commonwealth Environmental Water Office by the South Australian Research and Development Institute, Aquatic Sciences

Table 4.1 Modelled salt export (tonnes) over the barrages to the Coorong estuary and through the Murray Mouth into the Southern Ocean, 2014–20 (taken from Ye et al. 2021)

Scenario	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
Barrages	-	-	-	-	-	-
All water	446,855	288,516	1,504,541	349,893	228,293	623,999
No Commonwealth environmental water	161,791	36,884	1,383,674	109,171	67,396	0
No environmental water	152,406	31,031	1,317,791	48,923	0	0
Murray Mouth	-	-	-	-	-	-
All water	-157,852	-1,850,028	3,679,277	-527,042	-2,680,574	-335,926
No Commonwealth environmental water	-3,202,552	-6,441,297	3,159,985	-3,459,211	-5,151,627	-2,332,963
No environmental water	-5,048,511	-6,649,380	1,958,989	-6,115,353	-5,438,075	-2,332,963

4.4 Resilience outcomes 2014–20

RESILIENCE – TO ENSURE WATER-DEPENDENT ECOSYSTEMS ARE RESILIENT TO CLIMATE CHANGE AND OTHER RISKS AND THREATS

The evaluation question for resilience was:

- What does the evaluation show in relation to resilience to climate change and other risks and threats?
- Maintaining refugia is a key component of managing for resilience at landscape levels:
 - An objective of the Basin Plan is to protect refugia in order to support the long-term survival and resilience of water-dependent populations of native flora and fauna, including during drought to allow for subsequent re-colonisation beyond the refugia
 - Refuge flows are delivered in channel as freshes and baseflows, or to critical wetland habitats as overbank flows (including targeted delivery of water via pumping and regulator diversions). The maintenance of refugial habitat for the southern bell frog and associated wetland species is a key objective for Commonwealth environmental water in the Murrumbidgee, particularly during dry years. These actions support the survival of frogs, native fish and turtles and provide foraging opportunities for waterbirds during dry periods.
- Providing water to support breeding events in wetter years is critical to supporting species abundance to allow them to persist over dry periods
 - Watering events were used across the basin to support frog, fish and waterbird breeding events to enhance population numbers and increase resilience to prolonged dry periods.
- Providing water is critical to providing plant communities with sufficient resilience to persist over dry periods
 - Watering events were used across the basin to support a wide range of vegetation communities. Commonwealth environmental water supported watering of 104,162 ha of palustrine wetlands. 62,725 ha (58%) of the area inundated was river red gum forest and woodland floodplains
 - Watering was able to target vulnerable species including lignum (during water delivery to Narran lakes in 2015–16 and 2019–20) and river cooba (associated with floodplain watering of the Gwydir Wetlands in 2016–17 and 2017–18).

- Providing water to support breeding events in wetter years is critical for species' resilience to stressors such as invasive species
 - Watering events were used across the basin to support frog, fish and waterbird breeding events to support population numbers and enhance resilience to the effects of invasive species such as redfin perch, European carp and foxes.
- Providing water to support the condition of native vegetation increases native species' resilience to the effects of invasive species
 - Watering events were used across the basin to support the condition of a wide range of vegetation communities enhancing their ability to compete with a range of invasive plant species
- Commonwealth environmental water use to protect species from the effects of major disturbances such as blackwater events
 - Watering events were used to reduce the impacts of hypoxic black water and increase the ability of fish species to recover in the Edward/Kolety–Wakool River systems in 2016–18.

RESEARCH: REFUGIA AND RESILIENCE

Identification, characterisation and management of refuge habitat

Refuges are areas that are critical to maintaining the resilience of ecosystems. The Refugia and Resilience research projects seek to understand how ecological refugia are distributed across the Basin and the potential for management of these critical areas to support diversity. The aim of the Refugia Project is to understand more about aquatic refugia habitats, their characteristics and the species they support. The work is focussing on the short (months) and long (years) time frames, so that we can learn more about how refuge habitats change over time and which species use them.

5 ADAPTIVE MANAGEMENT

5.1 What is adaptive management?

Adaptive management can be summarised as ‘learning by doing’ within a robust framework that acknowledges uncertainty and allows for the incorporation of new knowledge as it becomes available. In doing so, adaptive management defines the problem, identifies the resilience of management interventions, and using an iterative process seeks to reduce uncertainty over time via systematic monitoring, evaluation, and learning¹⁵ (Figure 5.1). Effective application of adaptive management is an objective of both the Basin Plan 2012 and the Flow-MER Program.

The Flow-MER Program is in the position where it is able to learn from 6 years of monitoring, evaluation, and research conducted via the LTIM, EWKR and Flow-MER programs, in addition to other sources of information and knowledge. This has helped to develop and adapt our understanding of both outcomes to Commonwealth environmental water, as well as our approaches in undertaking Basin-scale evaluation. We discuss each of these in the following sections.

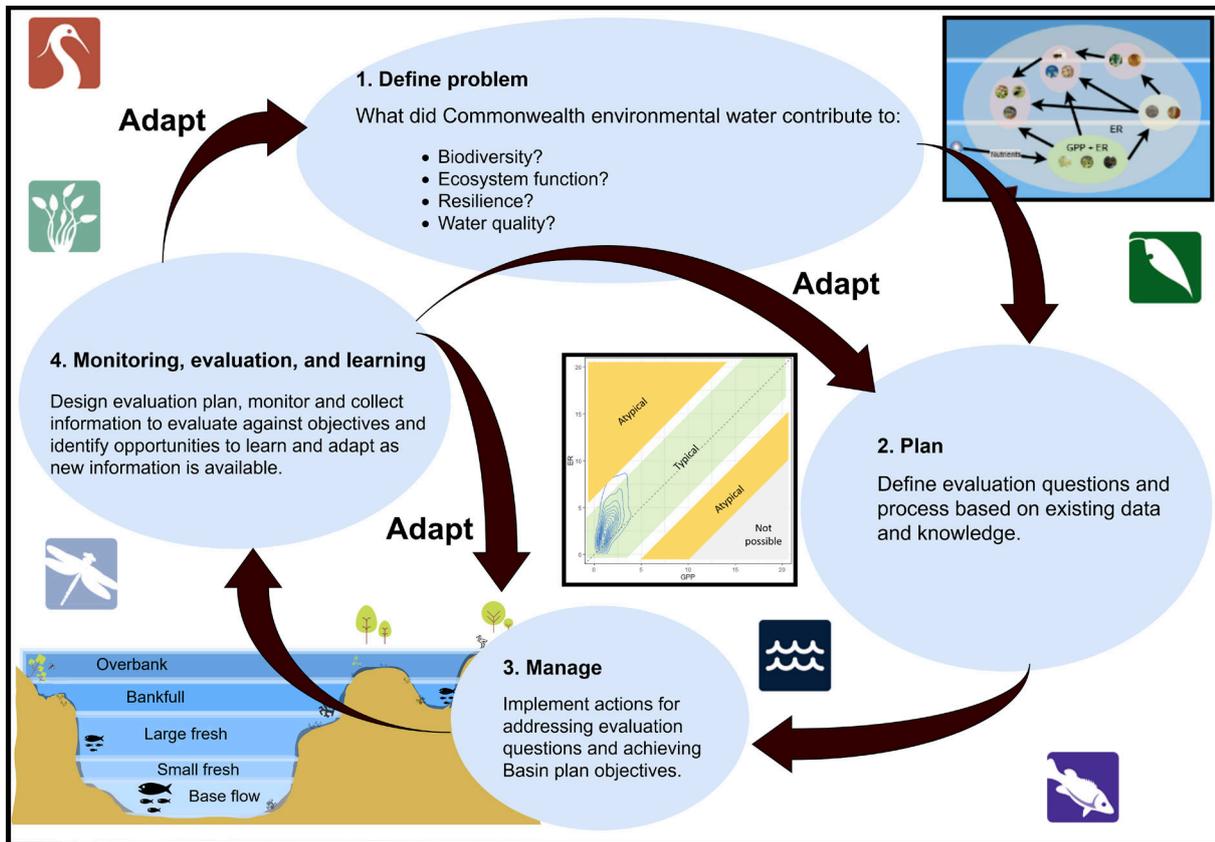


Figure 5.1 The adaptive management cycle modified from MDBA (2017)¹⁶

Planning involves defining the problem, objectives, the link between objectives and proposed actions and selecting actions. Management consists of design and implementation of the actions and evaluation plan. Evaluation comprises the analysis and synthesis of monitoring and research to evaluate success against the objectives and to inform adaptation. Adaptation can happen at any of the steps

¹⁵ Holling C S (1978) *Adaptive environmental management and assessment*, Chichester, U.K.: Wiley; Watts, R. J. et al. Learning from concurrent adaptive management in multiple catchments within a large environmental flows program in Australia. *River Research and Applications* 36, 668-680, doi:https://doi.org/10.1002/rra.3620 (2020)

¹⁶ MDBA (2017) Basin Plan Adaptive Management Framework. MDBA publication 07/18. MDBA, Canberra. ISBN (online): 978-1-925599-75-6.

5.2 Informing delivery of Commonwealth environmental water

At the Basin scale, our evaluation shows that Commonwealth environmental water is supporting ecosystems in Selected Area that are representative of elsewhere in the Basin. Commonwealth environmental water is contributing to the achievement of Basin Plan objectives for biodiversity (including threatened species and communities), ecosystem function, and water quality. Managing and improving existing ecological condition in turn improves ecological resilience to future change and risk, including climate change.

Our assessment is based on current data, knowledge, and tools for evaluating the contribution of Commonwealth environmental water, and acknowledges existing limitations in the attribution of outcomes based on temporal and spatial variability in response.

5.2.1 Biodiversity

With 6 years of continued evaluation of Basin biodiversity, we are improving understanding of:

- the spatial patterning of watering actions in the landscape
- the distribution of water-dependent ecosystems in the Basin
- the distribution of Commonwealth environmental water to the different ecosystem types (e.g. with a greater proportion supporting temporary River Red Gum swamps and marsh ecosystems)
- watering frequencies, at ecosystem, wetland complex, and valley scales.

Specific to the Flow-MER Themes, we have identified:

- The importance of baseflows and small freshes for supporting **native fish**, including during different life stages and particularly during extended drought. Seasonal baseflows appear to be especially critical in the Edward/Kolety–Wakool system, where Commonwealth environmental water contributed to continuous baseflows and thereby maintained connectivity and water quality, both of which are important for supporting fish communities.
- Environmental water is important for maintaining a diversity of hydrological regimes to support distinct functional and structural assemblages of **groundcover plants**.
- There is an opportunity to support **plant species with traditional Indigenous uses** using environmental water, with engagement of Indigenous communities across the Basin to identify plant species that are important and can be supported with environmental water.
- There is the potential for complementary adaptive management actions to be implemented in conjunction with the delivery of Commonwealth environmental water to manage multiple pressures and threats on **waterbird** populations, such as vegetation management, and the management of predation, disease, and toxins.
- Annual inundation of wetlands in the Murrumbidgee, combined with complementary actions (such as the active management of water levels) to manage the impact of exotic fish has coincided with increased recruitment of **southern bell frogs**.
- There are opportunities to support **frog habitats** in other regions, as well as target other species such as the Booroolong frog.

5.2.2 Ecosystem function

Data from 2014 to 2020 provide a strong foundation for the prediction of site-specific metabolic patterns, and as more data is collected, our ability to accurately predict and validate responses within unmonitored regions and to tailor flows to deliver desired responses increases.

Contributions by Commonwealth environmental water to water quality and metabolic outcomes are heavily influenced by the type of flow delivered. It is possible to predict a generalised metabolic response to a type of flow delivery, noting that specific responses are context dependent:.

- Base flow and cease-to-flow. Characterised by low turbidity, high light and potentially warmer water. Primary production is relatively high, but time since last flood and size of last flood will influence carbon and nutrient availability. There is the potential for algal or cyanobacteria blooms.
- Small fresh. Expect a small decrease in primary production and a shift towards ecosystem respiration due to increased turbidity and inundation of in-channel features (such as bars and benches). Eventually there will be a small increase in primary production as nutrients are mobilised.
- Large fresh. Expect a reduction in primary production and a significant increase in ecosystem respiration due to the inundation of benches, incorporation of organic matter and increased turbidity. The magnitude of change is influenced by the amount of organic matter (which is related to the time since last flooding). Primary productivity will eventually increase as nutrients and light increase and the increase in terrestrial carbon is an important energy source for food webs.
- Bankfull. Expect an initial drop in primary production, an increase in ecosystem respiration and – depending on the amount of leaf litter that has accumulated and the timing of the flow – there is the potential for hypoxic black water in the river channel and a shift to terrestrially derived energy for food webs.
- Overbank. Large flow events transport terrestrial material into the river. Expect an immediate reduction in primary production and high rates of ecosystem respiration driving a microbially-based food web while the river channel is connected to the floodplain. There is potential for hypoxic black water events depending on flow volume and load of organic matter entering from the floodplain.

The next step is to improve our understanding of how the food supply for food webs is influenced by Commonwealth environmental water and the relationship between stream metabolism and secondary productivity, to inform Commonwealth environmental water planning.

Given that bankfull and overbank flows are not always possible, smaller flows (e.g. freshes) have the potential to supply new terrestrial carbon from in-channel benches to aquatic food webs. Ecosystem responses will be highly dependent on the amount of litter that has accumulated since the last fresh.

5.2.3 Water quality

Commonwealth environmental water is very important for decreasing the likelihood of low dissolved oxygen, by increasing water mixing and oxygen exchange at the surface, particularly so in the Lower Murray where the river is dominated by slow flowing locks and weirs. In 2019–20, Commonwealth environmental water substantially improved dissolved oxygen levels in the Lower Murray for over 40 days. Commonwealth environmental water can also contribute to maintaining dissolved oxygen levels above desired thresholds during blackwater events, where flows can dilute anoxic water and increase oxygen exchange at the surface. Commonwealth environmental water may also be used to maintain base flows to support aquatic ecosystems during low flow periods.

Commonwealth environmental water is critical for maintaining salinity regimes within a desired range. Commonwealth environmental water has been used to successfully:

- maintain river salinity below 800 EC at Morgan (a river management target of the MDBA and SA Water)
- maintain salt export from the Coorong in low flow years
- contribute to the Basin plan's target of exporting 2 million tonnes of salt from the River Murray System into the Southern Ocean each water accounting period.

5.3 Basin Informing monitoring and evaluation

The evaluation has iteratively improved throughout the last 6 years, due to improvements in acquittal reporting, improvements in the methods and consistency of documenting inundation from Commonwealth environmental water, and 3 major leaps forward in the mapping of water-dependent ecosystems in the Basin by the ANAE. These improve the accuracy of this evaluation and capacity to meaningfully assess the contribution of Commonwealth environmental water to Basin ecosystems and Basin Plan objectives.

Additional advancements include the capacity to:

- assess metabolic function
- model estimated conditions without Commonwealth environmental water to improve our understanding of how Commonwealth environmental water has supported fish response
- assess the potential contribution of Commonwealth environmental flows to influencing hydrological regimes to support vegetation communities

We have also identified 3 areas in which we can continue to build on the existing monitoring and evaluation program: (1) consideration of more detailed inundation analysis for wetland hydrology (2) reviewing expected outcomes and environmental watering objectives; and (3) consideration of monitoring to improve the evaluation.

5.3.1 Detailed hydrology for wetlands

This report considers ecosystems to be potentially supported by Commonwealth environmental water, provided there was evidence they were watered at some point during the year. The annual timestep and aggregated inundation mapping currently constrains our evaluation to an interpretation of annual watering frequencies for target ecosystems that are recipients of Commonwealth environmental water only. A comprehensive evaluation including watering actions delivered by other stakeholders and from natural floods is currently beyond the scope of the Basin-scale project, primarily because most wetlands are not gauged and information on the extent and duration of water is difficult to source or is not collected by other jurisdictions. The risk of misinterpreting insufficient Commonwealth environmental water is high when other sources are not accounted for. We can, however, be more confident if evidence points to Commonwealth environmental watering being too frequent (as additional water sources will only exacerbate the problem of having too much water). Some foundation work is underway in the Flow-MER research program to explore ways of improving the spatial and temporal resolution of the inundation mapping to inform future evaluation (refer text box on Research: Scaling up to the Basin).

Improving knowledge of wetland hydrology is a high priority. Understanding the role of Commonwealth environmental water in maintaining ecosystem diversity could be improved by counterfactual analyses, comparing how ecosystem diversity is supported with and without Commonwealth environmental water. In rivers, we have shown that the counterfactual flow regime (with and without Commonwealth environmental water) can be estimated using models calibrated to river gauges to estimate flows in the absence of environmental water (Guarino and Sengupta 2021). A counterfactual model estimating wetland hydrology with- and without-Commonwealth environmental water at the Basin scale would greatly improve the evaluation of wetland biodiversity (ecosystem diversity, vegetation and fauna). Flow-MER research activities are exploring suitable frameworks for such models to support future evaluation.

Satellite image analysis is being used increasingly to monitor the timing, duration and extent of natural and managed inundation events. The tools and capability exist to map inundation for local areas, with some recent initiatives showing promise for quantifying inundation patterns on larger spatial scales. For example, Geoscience Australia's Wetland Insights Tools can use the 30 years of Landsat image library to analyse inundation in ANAE wetlands. Scaling these tools to the whole Basin (approximately 300,000 ANAE mapping

units) is a challenge that has not yet been attempted, but is an active area of research that should ultimately improve definition of the timing, magnitude and extent of watering actions within the context of the background hydrological regime. This has the potential to:

- improve the ANAE classification of temporary and permanent wetland classes
- improve evaluation of whether Commonwealth environmental water use is appropriate, given the antecedent water history and knowledge of how wetlands respond to inundation (depth, extent, residency times)
- provide fundamental data to establish a counterfactual for wetland inundation in the Basin, to strengthen evaluation of the role of Commonwealth environmental water in maintaining, protecting or restoring ecosystem diversity in the Basin.

RESEARCH: SCALING UP TO THE BASIN

Developing an approach to scaling for evaluating ecosystem diversity

To what degree can we make management decisions at one site based on what we know about another site? This research addresses the degree to which we can generalise our information from one site to inform adaptive management at another. An initial outcome is a data framework for combining information on watering action objectives, timing and duration with inundation extent mapping to improve resolution of spatial and temporal scales of water delivery in the Basin.

This project is developing a multi-scale approach to evaluate diversity at spatial scales better aligned to the scale of watering actions. For example, small scales occur at individual wetlands, and large scales are when the entire river system is affected by large volumes of water being used to flush rivers and fill adjacent wetlands. This work seeks to enable us to evaluate Basin-scale ecosystem diversity at different scales and spatial arrangements of management actions in the Basin. This is intended to help researchers improve the relevance of management advice according to the scale of the ecosystems being focused on.

5.3.2 Expected outcomes and environmental watering objectives

- Defining expected outcomes for ecosystem diversity. Given the historic challenges in assessing and monitoring ecosystem diversity, there are currently no defined expected outcomes for ecosystem diversity. We believe that there is now sufficient learning from the continued evaluation to set realistic and relevant ecosystem objectives. These might be trialled first in the evaluation space and later to contribute to Commonwealth environmental water planning, when predicting outcomes is more certain. The management of ecosystem diversity at the Basin scale is perhaps of greater relevance in the short term to strategic planning and portfolio management to foster consistency with Basin Plan biodiversity objectives. Ongoing monitoring and evaluation will continue to strengthen the evidence linking ecosystem diversity to aspects of the hydrological regimes. Ultimately, this will provide environmental water managers with evidence to more confidently plan for ecosystem diversity outcomes associated with specific watering actions, or a regime of actions planned over a number of years.
- Defining watering objectives for waterbirds. Environmental watering objectives delivered for waterbirds tend to be general in nature. Developing more targeted objectives, that take into account whole-of-life cycle needs of waterbirds and their mobility, could significantly improve waterbird survival and recruitment and improve the likelihood of achieving waterbird population, abundance and diversity targets. This may require further investigation of the data available on waterbird responses to environmental water across all agencies and identifying how these data can best be used and augmented to support evaluation of Basin-wide outcomes.

- Alignment in objectives and expected outcomes for vegetation. There is generally poor alignment between the Basin Plan objectives for vegetation (directed at protecting and restoring water-dependent ecosystems of the Murray–Darling Basin), MDBA’s Basin-Wide Environmental Watering Strategy (focused on condition, extent and specific vegetation communities), and the individual watering actions delivered in each year (which are frequently not specific or well aligned with either the Basin-Wide Environmental Watering Strategy or the Basin Plan). It is recommended that specific objectives for vegetation are better aligned with the overarching frameworks and that more specific objectives are defined. This includes providing clearly defined definitions of ‘good’ condition for non-woody vegetation (desirable or undesirable assemblages/cover of plant species for different community types).

5.3.3 Monitoring and evaluation

- Review the sampling points in future years of monitoring to better support evaluation. Locations that are monitored as part of the Flow-MER program were not located to specifically provide replication across different ecosystem types or to provide data from the key ecosystem types or vegetation communities that reflect current priorities for environmental water. In future monitoring programs, the sampling design for vegetation evaluation should be revisited. This would use the ANAE classification system to stratify the monitoring and focus on relevant ecosystem types.
- **Greater consideration of the watering needs of species of conservation concern.** There are many vertebrate species of conservation concern that have distributions coinciding with Commonwealth environmental water delivery; for example the grey snake, platypus, turtles and regent parrots. To date there has been a small number of Commonwealth environmental water deliveries with objectives related to platypuses, but the success of these actions has not been evaluated. Greater consideration of the water requirements and current distributions in areas targeted with Commonwealth environmental water will support their adaptive management in the Basin. This will require monitoring and evaluation of the response to environmental water delivery. Understanding such responses can also be supported by research. For example, there is a research project on turtle movement being undertaken in the Edward/Kooley–Wakool River systems, which will greatly increase knowledge of turtle response to environmental water delivery and inform future adaptive management.
- Specific monitoring of iconic species or communities. There is no specific monitoring for rare and threatened plant species or communities, or for other iconic plant species (e.g. plant species specifically listed in the Basin Environmental Watering Strategy or culturally significant species). As above, greater consideration of the water requirements and current distributions for important plant species and communities targeted with Commonwealth environmental water will support adaptive management.
- **Greater coordination between monitoring programs.** Monitoring of waterbird, frog, turtle and other vertebrate outcomes is currently spatially and temporally limited, restricting the capacity to evaluate the outcomes of Commonwealth environmental water. Data are mostly available from the Murrumbidgee and Gwydir and only as a continuous time series between 2014–20 in the Murrumbidgee. However, high-quality monitoring programs aimed at evaluating the outcomes of environmental water are also run by state agencies, while the MDBA manages the annual south eastern Australian areal waterbird monitoring program. While these latter data are included within the Atlas of Living Australia (ALA) datasets, a more robust dataset could be derived through greater collaboration and coordination with the complementary state-based programs. This approach is currently being employed in the Murrumbidgee and Gwydir selected areas and could be expanded into other valleys.
- **Further investigation of flow-fish spawning ecology relationships.** Extrapolation of trends beyond Selected Areas for fish responses is currently limited by existing data (i.e. small number of replicate flow years, limited flow variation in flow types among sites and low abundance of many native fish species). This reduces the degree of confidence in reporting on Basin-scale outcomes. There is an opportunity to

elucidate flow-spawning ecology relationships by incorporating more event-based monitoring. Inclusion of new monitoring sites can also assist in determining if trends observed at monitored areas are representative of the broader Basin.

RESEARCH: CONDITION

Influence of ecosystem condition on responses to environmental water

The aim of the Condition research project is to identify measures of ecosystem condition that can be used to adjust expected outcomes and tailor the evaluation to better match the context in which environmental water is delivered. This research is linking species outcomes to the ecosystems that support them and explores how the starting condition of those ecosystems influences outcomes to environmental water.

It is critical to understand when ecosystems can respond to provision of environmental water. This project will seek to develop metrics for assessing the sensitivity to environmental watering through time.

Existing evaluation activities that assess ecosystem responses would benefit from a more sophisticated understanding of why responses may or may not be observed at particular times. For example, it is becoming clear that water temperature is an important factor determining productivity responses to environmental flows.

RESEARCH: ENGAGEMENT WITH INDIGENOUS PEOPLES

Co-designing engagement with Indigenous peoples for better environmental water delivery

Over the last two decades there has been an identified failing in water management to achieve productive and sustainable partnerships with Indigenous people at a national scale. Alienation of Indigenous people from a role in managing Country since colonisation has had a profound effect on opportunities for engagement. This project is recognising those challenges in narrative form, describing examples of successful engagement around environmental water through case studies developed in partnership with traditional owners on-country.

Engaging with Indigenous groups is a challenge in many parts of the Basin. This project seeks to develop approaches which may simplify engagement while protecting cultural values and intellectual property. This activity is framing the engagement of Indigenous perspectives on Australian water management with a particular focus on environmental water. It will meet a need for contextual information and synthesis around Indigenous perspectives on water management to provide a key input to advancing environmental water management.

LINK : To case study on the response of plants with Indigenous uses to the use of environmental water

A case study on **the response of plants with Indigenous uses to the use of environmental water is an area of opportunity for** engagement with Aboriginal communities across the Basin. Engagement could seek to identify plant species **with Indigenous uses** that may be supported with environmental water. This would help establish specific objectives for vegetation outcomes which could be used in adaptive management and evaluation.

RESEARCH: INTEGRATIVE MODELLING

Integrative Basin modelling research

This research project is developing an integrative framework to combine knowledge across Themes and across scales, from Selected Areas to the basin. The project builds on existing understanding and knowledge development in the themes and in the flow-ecology relationships project. It will systematically evaluate the outcomes of Commonwealth environmental watering and hence its value; explore scenarios for environmental water delivery; and understand the reasons for those outcomes. This project uses multiple spatial datasets and information on hydrology and other drivers (temperature, soil moisture and rainfall) to improve the understanding of ecological responses.

Appendix A DETAILED OUTCOMES TABLE

Table A.1 Commonwealth Environmental Outcomes framework against Basin Plan objectives

Basin outcomes	1 year expected outcomes	Long-term expected outcomes	Outcomes 2019–20	Outcomes 2014–20
Biodiversity (Basin Plan S. 8.05)				
Ecosystem diversity	None identified	None identified	191,104 hectares of mapped wetland and floodplain supported	367,909 ha of lakes, wetlands and floodplain supported
			15,591 km of rivers supported	28,426 km of waterways supported
			48 ecosystem types supported	57 ecosystem types supported
			No negative impacts identified	No negative impacts identified
ion	Plant species diversity	Plant species diversity	25% of all recorded taxa in 2019–20 were only recorded at sample points that received environmental water	Of the more than 700 taxa recorded at sample points since 2014, almost 40% (278) are species that have only occurred at sample points that have received environmental water
	Vegetation community diversity	Vegetation community diversity	Supporting the persistence of vegetation communities that include submerged, amphibious and damp-loving species	Supporting the persistence of vegetation communities that include submerged, amphibious and damp-loving species
Species diversity Fish		No loss of native species currently present within the Basin		Cumulatively, all 13 native fish species detected during the monitoring program were still present in 2020
		Improved population structure of key fish species through regular recruitment		For golden perch, improved population structure does not appear evident at any of the Selected Area sites. Golden perch have spatially and temporally episodic recruitment patterns so there were likely recruitment events in other areas of the Basin. There was evidence of Murray cod spawning in all Selected Areas and recruitment occurred in most Selected Areas in most years

Basin outcomes	1 year expected outcomes	Long-term expected outcomes	Outcomes 2019–20	Outcomes 2014–20
		Improved community structure of key native fish species		Differences in fish communities were more evident among Selected Areas than years, noting that some Selected Areas were more similar than others. This suggests that fish communities did not change markedly within Selected Areas during the monitoring program.
Species diversity Waterbirds		Waterbird diversity	65 species reported from annual waterbird counts	103 species from 17 families occurred or were likely to have occurred at sites influenced by Commonwealth environmental water delivery
	Survival and condition Chicks Fledging	Waterbird diversity and population condition	Small numbers of waterbirds reported breeding at Commonwealth environmental water sites in the Murrumbidgee and Millawa	Populations of some species remain stable, however others are reported to be in decline (Porter et al. 2019, Kingsford et al. 2020)
Species diversity Frogs	Young	Adult abundance	Breeding and recruitment by flow responding species including Southern bell frog, Peron’s tree frog, barking and spotted marsh frog’s inland banjo frogs, eastern banjo frogs	Breeding and recruitment reported for all years across multiple catchments
			18 frog species associated with areas of Commonwealth environmental water inundation across 6 catchments	Persistence and in some instances increase of key populations of frogs including southern bell frogs
Species diversity Turtles	Young	Adult abundance	3 turtle species recorded in 2019–20, no hatching turtles were reported	Broad-shelled turtles more frequently associated with areas of Commonwealth environmental water inundation. Hatching turtles of all 3 species reported from Commonwealth environmental water influenced wetlands in the Murrumbidgee
Species diversity Ramsar wetlands	None identified	None identified	Commonwealth environmental water delivered to 8 Ramsar areas inundating 114,856 ha	Commonwealth environmental water delivered to 10 Ramsar areas since 2014
Species diversity Migratory species	None identified	None identified	19 EPBC listed migratory species were associated with Commonwealth environmental water influenced sites	23 EPBC listed migratory species were associated with Commonwealth environmental water influenced sites
Species diversity	None identified	None identified	Breeding by Australasian bittern reported at Central Murray Ramsar sites	41 waterbirds, 1 frog (southern bell frog), 1 woodland bird (regent parrot),

Basin outcomes	1 year expected outcomes	Long-term expected outcomes	Outcomes 2019–20	Outcomes 2014–20	
Threatened species			Successful recruitment and population increase of key southern bell frog populations	1 turtle (broad-shelled turtle) and 1 snake (grey snake) listed under state or commonwealth conservation legislation associated with Commonwealth environmental water influenced sites	
			Regent parrot nesting reported at sites influenced by Commonwealth environmental water		
Ecosystem function (Basin Plan S. 8.06)					
Connectivity	Hydrological connectivity including end of system flows		Commonwealth environmental water accounted for 100% of water released through the Barrages in 2019–20	Commonwealth environmental water has been effective in ensuring that the 2-year minimum flow through the Goolwa Barrage did not fall below the required 600 GL in 5 out of the 6 years	
			191,104 hectares of mapped wetland and floodplain supported		367,909 ha of lakes, wetlands and floodplain supported
			15,591 km of rivers supported		28,426 km of waterways supported
Process	Primary productivity (of aquatic ecosystems)		Commonwealth environmental water has a positive influence on primary production and respiration for 2019–20	Commonwealth environmental water has a positive influence on primary production and respiration for 2014–20	
	Nutrient and carbon cycling		Commonwealth environmental water has a positive influence on protecting and restoring energy, carbon and nutrient dynamics for 2019–20	Commonwealth environmental water has a positive influence on protecting and restoring energy, carbon and nutrient dynamics for 2014–20	
Water quality (Basin Plan S. 9.04)					
Chemical	Salinity		623,999 tonnes of salt exported attributable to Commonwealth Environmental Water alone in 2019–20	Commonwealth Environmental Water accounted for 64–100% of total salt export to the Southern Ocean 2014–20	
	Dissolved oxygen		Commonwealth environmental water assisted in the maintenance of dissolved oxygen concentrations over the summer period 2019–20 in the zones receiving the additional flow		
Resilience (Basin Plan S. 8.07)					
Ecosystem resilience	Individual refuges			Commonwealth environmental water was targeted to support refugial habitats for frogs, fish and turtles in dry years. Over 2014–20, 65 watering events (1,655 GL) were used to support refugia	

Basin outcomes	1 year expected outcomes	Long-term expected outcomes	Outcomes 2019–20	Outcomes 2014–20
	Landscape refuges			Watering events were used across the Basin to support a wide range of vegetation communities, including inundation of 62,725 ha (58%) of river red gum forest and woodland floodplains
	Ecosystem recovery			Watering events were used for flow management to reduce the impacts of hypoxic black water and increase the ability of fish species to recover in the Edwards/Kolety–Wakool system in 2016–18

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