Basin-scale evaluation of 2022–23 Commonwealth environmental water: Synthesis

Commonwealth Environmental Water Holder's Science Program: Flow Monitoring, Evaluation and Research Program (Flow-MER)

October 2024

Australian Government
Commonwealth Environmental Water Holder

FLOW Monitoring Evaluation Research

Acknowledgement of Country

The Flow-MER 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), Baaka (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.

Citation

Flett D, Cuddy SM, Brooks S, Doody T, Dyer F, Egger F, Hladyz S, McGinness H, McInerney P, O'Sullivan J, Rees G, Sengupta A, Tonkin Z, Wassens S, Weber T (2024). Basin-scale evaluation of 2022–23 Commonwealth environmental water: Synthesis. Commonwealth Environmental Water Holder (CEWH), Department of Climate Change, Energy, the Environment and Water, Australia. 92pp

[Citation is in alphabetical order after the first 2 authors]

Acknowledgement of contributors

We take this opportunity to thank all contributors to Flow-MER. Their data collection, analyses and reporting have provided the foundations for this synthesis report. We would like to thank Jane Thomas and Martin Nolan of CSIRO whose input in terms of editing, layout, number checking and map production greatly improved the quality and readability of the report. A final thanks to Peter Davies, the members of the Flow-MER2.0 Independent Advisory Group and Officers of the Commonwealth Environmental Water Holder (CEWH) for their independent reviews.

Document history

Date	Document stage
1-5 June 2024	Drafting period, post availability of evaluation reports
6 June 2024	Draft delivered to CEWH for review
	Response to review period
19 July 2024	Interim report delivered to CEWH (pending agreed revision by 30 September 2024)
15 October 2024	Draft final delivered to CEWH
31 October 2024	Approved final for publication (this document)

Cover illustration

Artist: Nina Rupena. http://www.ninarupena.studio/

OVERVIEW OF FLOW-MER AND THE 2022–23 EVALUATION

The Commonwealth Environmental Water Holder's (CEWH) Science Program invests in monitoring, evaluation and research activities through its Flow Monitoring, Evaluation and Research (Flow-MER) program. The Flow-MER Basin-scale evaluation assesses the contributions of Commonwealth environmental water to meeting the environmental objectives stated in chapters 8 and 9 of the (Murray–Darling) *Basin Plan 2012* and in the *Basin-wide environmental watering strategy*. Six Basin Themes (Figure 1) are evaluated using data from 7 Flow-MER Selected Areas (left-side map, Figure 2) and the 19 valleys (right-side map, Figure 2) where the CEWH holds water entitlements in the Murray–Darling Basin (the Basin). The evaluation builds on work undertaken by its predecessors.[1]

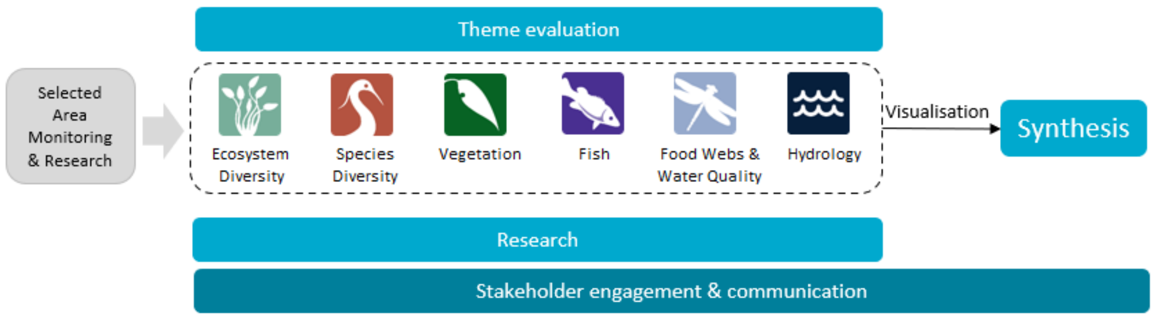

Figure 1 Schematic of the components of the Basin-scale evaluation
The evaluations are informed by Basin-scale research projects, stakeholder engagement and communication, and monitoring data from the 7 Selected Areas.

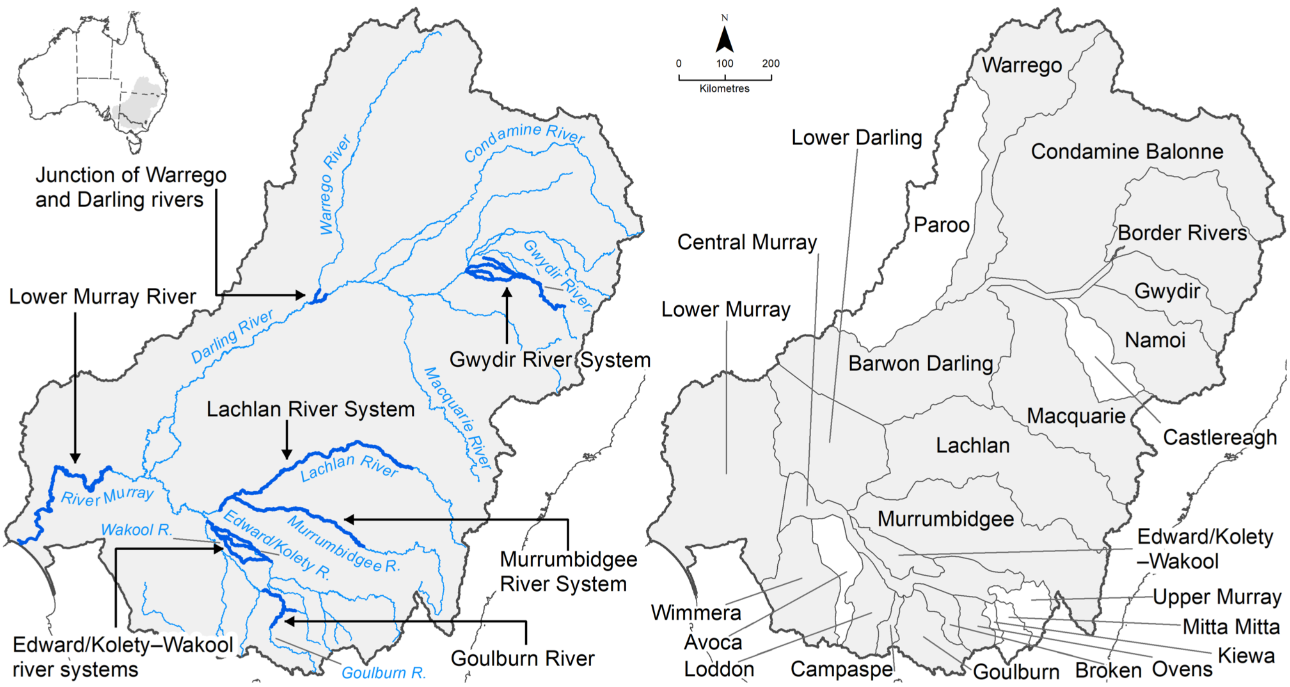

Figure 2 The 7 Selected Areas (left) and 25 valleys (right) established for long-term monitoring of the impacts of environmental watering under the Long Term Intervention Monitoring and Flow-MER (2014–15 to present)
In the valleys map, shaded grey shows the 19 valleys where the Commonwealth holds water entitlements and that are in scope for evaluation; white identifies those valleys that are not in scope.

[1] The Long Term Intervention Monitoring and Environmental Water Knowledge and Research projects (2014–2019).

Evaluating the contribution of Commonwealth environmental water to observed environmental outcomes

To undertake the Basin-scale evaluation, the evaluation team use water delivery and outcomes data provided by the CEWH's Science Program, along with monitoring data provided by the 7 Selected Areas. Other publicly available data may be used where the relevant data are not collected by the Selected Areas.

Evaluation of the contribution of Commonwealth environmental water to observed environmental outcomes for the 6 Basin Themes is dependent on the data available.

> When delivered with other water, ecological outcomes cannot be apportioned with current methods and Commonwealth environmental water is reported as contributing to, or supporting, the environmental outcomes of the watering action.

The multi-year Hydrology (instream), Fish and Vegetation themes have sufficient data to model and compare environmental outcomes both with and without Commonwealth environmental water (counterfactual modelling[2]).

The Ecosystem Diversity, Species Diversity and Vegetation themes identify environmental responses in locations that received Commonwealth environmental water (often in conjunction with other sources of environmental or non-environmental water) and, where feasible, compare with areas that did not receive Commonwealth environmental water.[3]

The Hydrology (inundation) and Food Webs and Water Quality themes use flow and water quality metrics to infer likely outcomes.[3]

The Fish (annual), Vegetation (annual), and Food Webs and Water Quality themes summarise findings across Selected Areas.

Monitoring of ecological outcomes was constrained in 2022–23 due to wet conditions. Outcomes reported for the 2022–23 water year are based on fewer monitoring locations and should be interpreted with caution.

Partnering on watering actions

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). Commonwealth environmental watering actions for the 2022–23 evaluation year and cumulative over the 9 evaluation years (2014–15 to 2022–23) are provided in Table 1.

Table 1 Summary statistics for most recent evaluation year and multi-year evaluation period

Dash (–) statistic not available. CEW = Commonwealth environmental water

	2022–23	2014–23
Volume of CEW actions (GL)	1,385	15,443
Number of CEW actions	102	1,081
% of CEW actions with partners or other flows	36%	–
CEW % of total volume of partnered watering actions	15%	–

Evaluation reporting

Each Basin Theme prepares a technical evaluation report for each water year. Key outcomes and lessons for adaptive management from these evaluation reports are brought into this annual synthesis report together with relevant outcomes from research highlights. To provide consistency over the life of Flow-MER and its predecessors, some content from these annual reports may be reused from previous years. In these cases, all efforts have been made to cite the relevant Long Term Intervention Monitoring, Environmental Water Knowledge and Research or Flow-MER publication. All reports published by the CEWH are available from the Australian Department of Climate Change, Energy, the Environment and Water website.

Flow-MER partnership

> Basin-scale Flow-MER is led by CSIRO in partnership with the University of Canberra. Collaborators on the 2022–23 evaluation include Alluvium, the Arthur Rylah Institute, Charles Sturt University, South Australian Research & Development Institute, NSW Department of Primary Industries, the Australian River Restoration Centre and Brooks Ecology & Technology.

[2] In the counterfactual approach, Commonwealth environmental water is removed from the observed streamflow time series, creating a hypothetical (counterfactual) daily streamflow time series with no Commonwealth environmental water. This approach is used to infer the effects of Commonwealth environmental water because an experimental design with controls and/or before–after comparisons is not possible.

[3] In these evaluations, it is not possible to attribute the Commonwealth's contribution separately to other environmental water.

EXECUTIVE SUMMARY

Strategic management of Commonwealth environmental water by the Commonwealth Environmental Water Holder (CEWH) is central to achieving (Murray–Darling) *Basin Plan 2012* (the Basin Plan) objectives. Water for the environment is strategically used by the CEWH to protect and restore hydrological regimes and connectivity within and between water-dependent ecosystems (Basin Plan S8.06). This involves connecting river reaches during dry times and connecting the river to the floodplain during wetter periods, as well as connecting and maintaining in-channel habitat and providing cues for breeding and movement.

COMMONWEALTH ENVIRONMENTAL WATER DELIVERY IN 2022–23

Annual rainfall in 2022–23 was above or equivalent to the long-term average in Basin valleys. Total runoff in the Basin in 2022–23 was 67,760 GL, much greater than the average of 33,271 GL per year since 2014, when monitoring of Commonwealth environmental water began. Following very wet conditions in 2021–22, high rainfall resulted in high inflows across the Basin. Basin storages started at 91% of total capacity (20,216 of 22,258 GL) in July 2022, increasing to 100% through the water year. High volumes of surface water runoff in 2022–23 generated high flows across Basin river systems, especially in the late winter and spring of 2022, resulting in overbank flooding and extensive floodplain inundation.

Many planned watering actions were not delivered in 2022–23 due to high natural flows; however, wet conditions provided opportunities to extend the duration of inundation of floodplains, wetlands and marshes, providing habitat and resources for recruitment and growing cycles for a range of species.

- In 2022–23, 102 watering actions delivered 1,385 GL of Commonwealth environmental water to rivers, wetlands and floodplains across all 19 Basin valleys where the CEWH holds entitlements.
- Commonwealth environmental water supported 22,205 km of rivers, 202,071 ha of lakes and wetlands, 71,837 ha of floodplains and 23,768 ha of estuary in the Coorong and Murray Mouth.
- Commonwealth environmental water was used to extend the duration of widespread natural flooding in the Condamine Balonne, Lachlan, Gwydir, Macquarie and Murrumbidgee valleys.
- Despite above-average annual rainfall across the Basin, summer was relatively dry in southern valleys and 1,196 GL of Commonwealth environmental water was used to maintain flows in southern river systems.

BASIN-SCALE EVALUATION

The Flow-MER Basin-scale evaluation assesses the contributions of Commonwealth environmental water to meeting environmental objectives stated in chapters 8 and 9 of the Basin Plan and in the *Basin-wide environmental watering strategy* (the Strategy). Six Flow-MER Themes are evaluated using data from Flow-MER monitoring locations in 7 Flow-MER Selected Areas plus data for the 19 Basin valleys where the CEWH holds water entitlements. This synthesis reports on outcomes from the use of Commonwealth environmental water since the beginning of Selected Area monitoring in 2014. The evaluation addresses how Commonwealth environmental water contributed to, supported or influenced environmental outcomes. Detailed findings and supporting evidence are presented in 6 thematic evaluation reports and 7 Selected Area reports (Basin-scale thematic evaluations and Area-scale evaluations are reported separately).

Contribution to Basin Plan objectives since 2014

Commonwealth environmental water has made substantial contributions to achieving the objectives and desired outcomes of the Basin Plan and the Strategy. Outcomes since 2014 are summarised below. For some outcomes, the evaluation can estimate the contribution of Commonwealth environmental water. In most cases, Commonwealth environmental water is shown to have ***supported*** outcomes (that is, in conjunction with other water delivery) or contribution is ***inferred*** from recorded observations at monitoring locations receiving environmental water.

Biodiversity – to protect and restore water-dependent ecosystems

What did Commonwealth environmental water contribute to ecosystem diversity?

Since 2014, 15,443 GL of Commonwealth environmental water has supported 249,079 ha of lakes and wetlands, 187,486 ha of floodplains, 27,715 km of waterways and 23,768 ha of estuarine ecosystems, representing 85% of the diversity of aquatic ecosystems found in the Basin (as measured by Australian National Aquatic Ecosystems [ANAE] types).

Using the ANAE classification system, 66 aquatic ecosystem types have been identified in the Basin, of which 64 ecosystem types (97%) are represented on the area of floodplain that is able to receive Commonwealth environmental water. The frequency of delivery of Commonwealth environmental water over the 9 years broadly aligns with the expected requirements of ecosystem types; that is, more frequent support of permanent rivers, lakes, meadows and permanent tall marsh, and less frequent inundation of temporary channels, swamps and floodplains. Between 2014 and 2023, Commonwealth environmental water supported 56 ecosystem types (85% of the types that occur in the Basin) on at least one occasion.

What did Commonwealth environmental water contribute to species diversity?

Commonwealth environmental water has supported submerged, amphibious and damp-loving plant species, native fish, waterbirds and a range of other fauna, including species of conservation significance.

The delivery of Commonwealth environmental water has played a substantial role in maintaining native plant species across the Basin. 790 plant taxa have been recorded at Flow-MER floodplain, wetland and riverine monitoring locations since 2014, including 520 native groundcover plant species, of which 101 species are listed as rare or threatened. 10% (79) of the recorded plant species have only occurred at locations that experienced a wetter hydrological regime because of environmental water. This includes submerged (2), amphibious (21) and damp-loving (14) species unlikely to persist without environmental water.

Since 2014, 15 native fish species have been recorded from sampling of adult fish communities from riverine monitoring locations and 20 species of frog were reported from wetland monitoring locations. Commonwealth environmental water has had a significant influence on the presence of southern bell frogs (listed as Vulnerable under the Australian *Environment Protection and Biodiversity Conservation Act 1999* [EPBC Act]) and has supported nursery habitats for hatchling Macquarie turtles, long-necked turtles and broad-shelled turtles.

Widespread unregulated floodplain inundation triggered significant waterbird breeding events across the Basin in 2022 and 2023. There was large-scale breeding by aggregate-nesting waterbirds – Australian white ibis, Australian pelicans, royal spoonbill, yellow-billed spoonbill, straw-necked ibis, glossy ibis, little pied cormorant, little black cormorant, Australasian darter, great cormorant, nankeen night-heron, white-necked heron, white-faced heron, eastern great egret and plumed egret. Commonwealth and other environmental water was used in 2022 and 2023 to extend the duration of inundation in support of waterbird breeding.

Commonwealth environmental water has supported habitats of a wide range of waterbird species. Since 2014, 137 waterbird and raptor species, including 59 threatened or migratory species, were recorded from locations that received Commonwealth environmental water. One example is the Australasian bittern (listed as Endangered under the EPBC Act), which requires wetland and floodplain habitats with areas of tall emergent vegetation. Since 2014, 110 known locations of Australasian bittern received Commonwealth environmental water at least once.

What did Commonwealth environmental water contribute to vegetation community diversity?

Environmental water is preventing the loss of characteristic wetland and floodplain plants by maintaining wetter hydrological regimes. In the absence of Commonwealth environmental water, important assemblages of species would be markedly reduced in extent. There would be a reduction in vegetation community richness, with a high risk of permanent transitions to altered vegetation community assemblages and loss of resilience of water-dependent plant communities.

Delivery of Commonwealth environmental water since 2014–15 has resulted in distinct inundation regimes across the floodplains and wetlands of the Basin that display significant differences in functional and structural assemblages of vegetation. There is greater diversity and cover of submerged, amphibious and damp-loving species at locations that have wetter regimes because of environmental watering. In the absence of Commonwealth environmental water, many locations across the Basin would have experienced notably drier water regimes. It is very likely this would have resulted in the near-absence of submerged species and substantially less diversity and cover of amphibious and damp-loving species at these locations.

What did Commonwealth environmental water contribute to sustaining native fish populations?

Commonwealth environmental water has provided a range of benefits to native fish populations and supported critical life-history processes, such as recruitment, body condition and population growth.

Commonwealth environmental water is shown to have contributed to increased fish spawning, recruitment, frequency of occurrence, population growth rates, body condition and improved community composition in some monitoring locations for some species. Fish responses to Commonwealth environmental water delivery were primarily driven by reductions in the number of low-flow days and, to a lesser extent, increased average daily flows and changes in flow variability.

There was no loss of native species – 15 native fish species, including 6 key freshwater species as identified by the Strategy, have been detected over the monitoring program. The number of detected species fluctuated over the monitoring period, although changes were relatively minor and the majority of species were detected regularly. Murray cod spawning and recruitment to young-of-year occurred in most years. The 2016–17 Murray River hypoxic blackwater event and associated major fish death events, or possible fish emigration out of the area, resulted in marked reductions in recruits and adults in several monitoring locations. Murray cod populations have continued to steadily recover from these hypoxic blackwater events in recent years (though recruitment was minimal in most monitoring locations in 2022–23).

Flow-MER research showed that Commonwealth environmental water supported critical life-history processes of golden perch, including spawning, body condition and population growth. Between 2014 and 2023, spawning of golden perch increased with delivery of Commonwealth environmental water. Golden perch need hundreds of kilometres of connected flowing water for their spawning migrations and spawning often coincides with increased flow during spring and summer. Commonwealth environmental water helped maintain their habitat by providing connected flow events across regions and at critical times.

What did Commonwealth environmental water contribute to Ramsar wetlands in the Basin?

11 of the 16 Ramsar wetlands in the Basin can receive Commonwealth environmental water. Since 2014, all 11 received Commonwealth environmental water at least once (in conjunction with other water delivery).

Commonwealth environmental water was delivered to 8 Ramsar sites in 2022–23, supporting approximately 165,000 ha of 51 different ecosystem types within the Ramsar estate. For example, in 2021–22, Commonwealth environmental water supported waterbird breeding in the Gwydir Wetlands, contributing to the first simultaneous breeding across Narran Lake Nature Reserve, the Macquarie Marshes and Gwydir Wetlands Ramsar sites in 24 years. In 2022–23, a wet spring stimulated waterbird breeding across these sites for a second consecutive year and Commonwealth and other environmental water extended the duration of natural flooding to maintain water at nesting and foraging sites.

Ecosystem function – to protect and restore the ecosystem functions of water-dependent ecosystems

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

Environmental flows are used to extend duration of flows, align the timing of flows more closely with the natural regime, or match the natural frequency of flow events.

Over the 9-year period, 27,715 km (52% of all the river length on the managed floodplain) was supported by Commonwealth environmental water, which plays a more significant role during drier periods. For example, Commonwealth environmental water contributed over 97% of total flow in the Darling River at Bourke in 2017–18. Commonwealth environmental water supported a 10% overall increase in flows in the Barwon Darling in 5 out of 9 years of monitoring. The exceptions were the wet periods of 2016–17 and 2020–23, where unregulated water inflows were significantly high. Commonwealth environmental water supported a 30% overall increase in flows in the Murray River in 2015–16, 2017–18 and 2019–20, all of which were significantly dry periods across the Basin.

The Strategy sets flow volume and depth targets for the Coorong, Lower Lakes and Murray Mouth. In drier years, Commonwealth environmental water contributes up to 100% of flows at the barrages. In most years, except in wetter years such as 2021–23, barrage flow requirements are not met, even with Commonwealth environmental water.

What did Commonwealth environmental water contribute to patterns and rates of ecosystem respiration and primary productivity?

Over the 9-year period, riverine ecosystems of the Goulburn, Edward/Kolety–Wakool, Lachlan, Gwydir and Junction of Warrego and Darling river systems were predominantly heterotrophic, that is, consuming more carbon than they were producing.

The Lower Murray River was mostly a net producer of carbon (autotrophic) up to 2021–22, driven by phytoplankton and relatively low turbidity in the slow-flowing channels. However, high flows in 2022 shifted the Lower Murray River into heterotrophy, reflecting a return to a flowing system more closely resembling metabolic patterns at other Areas. The Murrumbidgee River System regularly alternated between heterotrophy and autotrophy over the 9 years, depending on conditions (such as season).

Independent of Commonwealth environmental watering actions, rates of gross 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.

WATER QUALITY – TO MAINTAIN WATER QUALITY AND MEET TARGETS FOR SALT EXPORT, SALINITY AND DISSOLVED OXYGEN

What did Commonwealth environmental water contribute to dissolved oxygen levels and salinity regimes?

In low-flow years, Commonwealth environmental water has become increasingly important for managing dissolved oxygen levels, sustaining salt export from the Basin and for limiting salt import to the Coorong.

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 4–5 mg/L. In drier years, delivery of Commonwealth environmental water has decreased the likelihood of low dissolved oxygen in the Lower Murray by increasing water mixing and oxygen exchange at the surface and elevating flow velocity above 0.18 m/s.

The Basin Plan salt-export objective (2 million tonnes per year) aims to ensure adequate removal of salt from the Murray River system into the Southern Ocean. Commonwealth environmental water has resulted in over 4 million additional tonnes of salt export through the barrages and has reduced salt import by more than 26 million tonnes since 2014. Commonwealth environmental water is important for maintaining salt export from the Basin and limiting net salt import to the Coorong during drier years.

Commonwealth environmental water contributed to maintenance of river salinity (electrical conductivity) below 800 µS/cm at Morgan over the 2014–23 period. Salinity was maintained within the range required for potable water in the Murray River in 2014–23, with water about 10% fresher due to environmental flows.

Key findings

Strategic management of Commonwealth environmental water by the CEWH is central to achieving the Commonwealth's Basin Plan objectives. The Flow-MER Basin-scale Project 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 outcomes from the use of Commonwealth environmental water for the most recent water year (2022–23) 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. Monitoring was constrained in 2022–23 due to wet conditions. Outcomes reported for the 2022–23 water year are based on fewer monitoring locations and should be interpreted with caution.

The most recent water year, 2022–23

- In 2022–23, 102 watering actions delivered 1,385 GL of Commonwealth environmental water to rivers, wetlands and floodplains across all 19 Basin valleys where the CEWH holds entitlements.
- Rainfall in 2022–23 was above the long-term average in most valleys in the Basin. Wetter conditions meant that Commonwealth environmental water was used to extend the duration of widespread natural flooding in the Condamine Balonne, Lachlan, Gwydir, Macquarie and Murrumbidgee valleys.
- Despite wetter conditions across the Basin during most of the year, summer was drier in the south and 1,196 GL of Commonwealth environmental water was used in southern valleys to maintain flows.
- Commonwealth environmental water supported 22,205 km of rivers, 202,071 ha of lakes and wetlands, 71,837 ha of floodplains and 23,768 ha of estuary in the Coorong and Murray Mouth.
- Basin Plan target flow volumes were achieved for the Coorong, Lower Lakes and Murray Mouth in 2022–23 through a combination of natural and other flows and Commonwealth environmental water. Water-level thresholds in the Lower Lakes were maintained (Basin Plan objective 8.06).
- 437 GL of Commonwealth environmental water were delivered to 8 Ramsar sites in 2022–23.
- Of 66 ANAE types found in the Basin, the Commonwealth can deliver environmental water to 64 representative types. In 2022–23, Commonwealth environmental water was delivered to 53 types (or 83% of those able to receive it).
- Due to high natural flows, Commonwealth environmental water made a relatively small contribution to salt export, exporting 151,000 tonnes of salt (5% of total salt export to the ocean) in 2022–23.
- Commonwealth environmental water supported submerged, amphibious and water-dependent plant species: 291 plant species were recorded at wetland and riverine monitoring locations in 2022–23 – 73% were native and 10 species were observed at these locations for the first time.
- 43 groundcover plants known to be used by Aboriginal people were recorded, including 12 only seen at locations that experienced a wetter inundation regime because of environmental water.
- 13 native fish species were detected in 2022–23 at Flow-MER monitoring locations, including an adult river blackfish (*Gadopsis marmoratus*) detected in the Edward/Kolety–Wakool for the first time.
- Spawning of golden perch (*Macquaria ambigua*), a key fish species as denoted by the Strategy, occurred in the Goulburn River. In the Lower Murray River, there was evidence of Murray cod (*Maccullochella peelii*) recruitment and golden or silver perch eggs were detected during unregulated high spring flows.

- Australian smelt (*Retropinna semoni*) had higher abundances (representative of recruitment for this short-lived species) than in previous years in the Edward/Kolety–Wakool and Murrumbidgee river systems, likely because greater hydrological connectivity increased favourable breeding habitats.
- Exotic common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) displayed strong recruitment, likely due to unregulated high flows and overbank flooding providing favourable conditions.
- 84 species of waterbirds, including 35 species of conservation significance, were reported from the Warrego, Darling, Murrumbidgee, Macquarie, Central Murray, Lachlan and Condamine valleys and aggregate-nesting species were recorded breeding across multiple valleys.
- 11 frog species, including the southern bell frog (*Litoria raniformis*), a species of conservation significance, were reported from Flow-MER and NSW monitoring in the Murrumbidgee and Lachlan valleys.

Multiple water years, 2014–23

- Over the 9-year period, 15,443 GL of Commonwealth environmental water were delivered to 56 ecosystem types representing 249,079 ha of lakes and wetlands, 187,486 ha of floodplain, 27,715 km of waterways and 23,768 ha of estuarine ecosystems.
- Between 2014 and 2023, all 11 of the 16 Ramsar sites able to receive Commonwealth environmental water were inundated.
- Commonwealth environmental water has resulted in over 4 million additional tonnes of salt export through the barrages and has reduced salt import by more than 26 million tonnes since 2014.
- Commonwealth environmental water has been used to decrease the likelihood of, and support recovery from, widespread hypoxic events across the Basin.
- Commonwealth environmental water supported 45% of floodplain–wetland Flow-MER monitoring locations, contributing to diversity and cover of submerged, amphibious and damp-loving plant species.
- 790 groundcover plant taxa were recorded at monitored floodplain, wetland and riverine locations since 2014, including 520 native and 216 exotic species; 75 taxa are known to be used by Aboriginal people, including 33 that require flooding to occur.
- 101 groundcover plant species that are listed as threatened were recorded at monitoring locations.
- 15 native fish species and 5 exotic fish species were detected during the 9-year monitoring program by in-channel river sampling of adult fish communities.
- Commonwealth environmental water contributed to increased fish spawning, recruitment, frequency of occurrence, population growth rates, body condition and improved community composition in some monitoring locations and for several species.
- Positive fish responses to the delivery of Commonwealth environmental water were primarily due to reduced number of low-flow days, increased average daily flows and changes in flow variability.
- Since 2014, 117 waterbird and raptor species have been reported – 59 of these are of conservation significance.
- Commonwealth environmental water had a significant influence on the presence of southern bell frogs (listed as Vulnerable under the EPBC Act).

Basin-scale Flow-MER summary metrics 2022–23

Hydrology	
Total surface water runoff in the Basin (GL)	67,760
Total Commonwealth environmental water actions	102
Total Commonwealth environmental water delivered (GL)	1,385
Commonwealth environmental water delivered in northern Basin (GL)	189
Commonwealth environmental water delivered in southern Basin (GL)	1,196
Number of valleys that received Commonwealth environmental water	19
Commonwealth environmental water contribution to barrage releases (GL)	753
Ecosystem Diversity	
Ecosystem types supported (Australian National Aquatic Ecosystems) by Commonwealth environmental water	53
Length of waterways supported by Commonwealth environmental water (km)	22,205
Lakes and wetlands inundated (ha)	202,071
Inundated floodplain (ha)	71,837
Inundated estuarine ecosystems (ha)	23,768
Species Diversity	
Total volume of Commonwealth environmental water delivered targeting species diversity outcomes (GL)	989
Number of Commonwealth environmental water actions	71
Waterbird species supported	84
Waterbird species supported that are of conservation significance	35
Vegetation	
Total Commonwealth environmental water delivered (GL)	904
Number of Commonwealth environmental water actions	68
Number of taxa recorded at monitoring locations (Selected Areas)	291
Number of culturally significant plant taxa recorded	43
Number of rare or threatened species recorded	36
Fish	
Total Commonwealth environmental water delivered (GL)	1,010
Number of Commonwealth environmental water actions	61
Number of native fish species detected from in-channel sampling in Selected Areas	13
Food webs and water quality	
Total Commonwealth environmental water delivered (GL)	1,121
Number of Commonwealth environmental water actions	76
Additional export of salt over barrages due to Commonwealth environmental water (tonnes)	151,000
Reduction of salt import at the Murray Mouth due to Commonwealth environmental water (tonnes)	118,000

Basin-scale Flow-MER summary metrics 2014–23

Hydrology	
Total surface water runoff (GL) (9-year average)	33,271
Total Commonwealth environmental water actions	1,081
Total Commonwealth environmental water delivered (GL)	15,443
Commonwealth environmental water delivered in northern Basin (GL)	1,698
Commonwealth environmental water delivered in southern Basin (GL)	13,744
Number of valleys that received Commonwealth environmental water	19
Commonwealth environmental water barrage releases (GL)	6,038
Ecosystem Diversity	
Ecosystem types supported (Australian National Aquatic Ecosystems)	56
Maximum extent of length of waterways supported (km)	27,715
Lakes and wetlands inundated (ha)	249,079
Inundated floodplain (ha)	187,486
Inundated estuarine ecosystems (ha)	23,768
Species Diversity	
Total Commonwealth environmental water delivered (GL)	8,700
Number of Commonwealth environmental water actions	666
Waterbird species supported	117
Number of waterbird species of conservation significance supported	59
Vegetation	
Total Commonwealth environmental water delivered (GL)	10,590
Number of Commonwealth environmental water actions	746
Number of taxa recorded at monitoring locations (Selected Areas)	790
Number of culturally significant plant taxa recorded	75
Number of rare or threatened species recorded	101
Fish	
Total Commonwealth environmental water delivered (GL)	12,898
Number of Commonwealth environmental water actions	602
Number of native fish species detected from in-channel sampling in Selected Areas	15
Food webs and water quality	
Total Commonwealth environmental water delivered (GL)	12,150
Number of Commonwealth environmental water actions	473
Additional export of salt over barrages due to Commonwealth environmental water (tonnes)	4,153,000
Reduction of salt import at the Murray Mouth due to Commonwealth environmental water (tonnes)	26,078,000

CONTENTS

OVERVIEW OF FLOW-MER AND THE 2022–23 EVALUATION ____ III
Evaluating the contribution of Commonwealth environmental water to observed environmental outcomes iv
Evaluation reporting iv
Flow-MER partnership iv

EXECUTIVE SUMMARY ____ V
Commonwealth environmental water delivery in 2022–23 v
Basin-scale evaluation v
Contribution to Basin Plan objectives since 2014 v

KEY FINDINGS ____ X

BASIN-SCALE FLOW-MER SUMMARY METRICS 2022–23 ____ XI

BASIN-SCALE FLOW-MER SUMMARY METRICS 2014–23 ____ XIII

CONTENTS ____ XIV
Figures xv
Tables.... xvi

ABBREVIATIONS AND TERMS ____ XVII

1 INTRODUCTION ____ 1
1.1 Basin-scale evaluation 1
1.2 Evaluation questions 2
1.3 About this report 2

2 HYDROLOGY AND CONNECTIVITY ____ 4
2.1 Rainfall... 5
2.2 Total runoff in the Basin 6
2.3 Delivery of Commonwealth environmental water 9
2.4 Restoring flows 15
2.5 Lateral connectivity 21
2.6 Basin ecosystems 22
2.7 Ramsar wetlands 23

3 OUTCOMES 2022–23 ____ 28
3.1 Biodiversity outcomes 2022–23 30
3.2 Ecosystem function outcomes 2022–23 37
3.3 Water quality outcomes 2022–23 39

4 OUTCOMES 2014–2023 ____ 41
4.1 Biodiversity outcomes 2014–23 43
4.2 Ecosystem function outcomes 2014–23 53
4.3 Water quality outcomes 2014–23 54
4.4 Resilience outcomes 2014–23 55

5 INFORMING ADAPTIVE MANAGEMENT ____ 56
5.1 What is adaptive management? 57
5.2 Emerging knowledge 58
5.3 Informing delivery of Commonwealth environmental water 61
5.4 Informing monitoring and evaluation 63

Figures

Figure 1 Schematic of the components of the Basin-scale evaluation iii

Figure 2 The 7 Selected Areas (left) and 25 valleys (right) established for long-term monitoring of the impacts of environmental watering under the Long Term Intervention Monitoring and Flow-MER (2014–15 to present)..... iii

Figure 2.1 Maps of annual rainfall conditions across the Basin, 2014–23..... 5

Figure 2.2 Maps of annual surface water runoff in the Basin by river valley, 2014–23 6

Figure 2.3 Annual total runoff in the Basin over the 23-year period 2000–23..... 7

Figure 2.4 Gauge plot showing 2022–23 seasonal flows in Selected Areas, compared to previous seasons 2014–23..... 8

Figure 2.5 An illustrative river cross-section showing the 5 components of the flow regime referenced in this evaluation 9

Figure 2.6 Volume (ML) of water and number of watering actions (in brackets) delivered (left) and the watercourses and area inundated or connected (right) by Commonwealth environmental water, 2022–23..... 11

Figure 2.7 Commonwealth environmental water portfolio showing volume of watering actions (y-axis) by flow component and year, 2014–23 12

Figure 2.8 Commonwealth environmental water portfolio showing the number of watering actions and the proportioning of flow components each year, by flow component and year, 2014–23..... 12

Figure 2.9 Number of Commonwealth environmental watering actions targeted to specific outcomes, 2014–23..... 13

Figure 2.10 Flow regime in water year 2022–23 compared with the long-term observed flow signal in Broken River (Rices Weir). The Commonwealth environmental water contribution is shown in green 16

Figure 2.11 Flow regime in water year 2022–23 compared with the long-term observed flow signal in the Goulburn River (McCoys Bridge). The Commonwealth environmental water contribution is shown in green..... 17

Figure 2.12 Length of waterways connected and wetland inundation for water year 2022–23..... 18

Figure 2.13 Map of annual frequency (from 1 in 9 years to 9 in 9 years) of Commonwealth environmental water in rivers in the Murray–Darling Basin, 2014–23 19

Figure 2.14 Percentage increases in annual flow volumes in (top) the Darling River at Bourke and (bottom) the Murray River at the South Australian border that are directly attributable to Commonwealth environmental water, 2014–23..... 20

Figure 2.15 Area of lakes and wetlands and floodplain (left y-axis) and length of river (right y-axis) receiving Commonwealth environmental water, 2022–23..... 22

Figure 2.16 Ramsar sites in the Murray–Darling Basin..... 25

Figure 2.17 Ecosystem diversity within the Narran Lake Nature Reserve (Narran Lakes) Ramsar Site, showing 2022–23 inundation by 113 GL of Commonwealth environmental water combined with other water. 27

Figure 3.1 Detections of southern bell frogs aligned with inundation by Commonwealth environmental water 36

Figure 3.2 Longer term 2014–22 metabolic fingerprints (contour lines) overlaid with the 2022–23 metabolic fingerprint (dots) for Selected Areas..... 39

Figure 4.1 Contribution of Commonwealth environmental water to number and volume of water actions, 2014–23..... 43

Figure 4.2 Percentage of plant species cover recorded across all Selected Areas in each growth-form group for each water year and across all years, 2014–23 46

Figure 4.3 Average percentage cover of plant functional groups across Selected Areas for each water year and across all years, 2014–23..... 46

Figure 4.4 Releasing a golden perch (*Macquaria ambigua*). Photo: Arthur Rylah Institute...49

Figure 4.5 The Basin, showing the 14 populations included in the golden perch meta-population model 49

Figure 4.6 'Lil', an adult male royal spoonbill, fitted with a satellite tracker backpack (held by Heather McGinness) 51

Figure 4.7 The movements of a nesting adult royal spoonbill in the lower Murrumbidgee catchment 52

Figure 4.8 Modelled additional salt export (thousand tonnes) and reduced salt import due to Commonwealth environmental water (CEW), 2014–23...55

Figure 5.1 The adaptive management cycle modified from the Murray–Darling Basin Authority's Basin Plan adaptive management framework (MDBA 2017)...57

Figure A.1 Commonwealth environmental water portfolio showing volume (left) and number (right) of watering actions, by valley and year, 2014–23 68

TABLES

Table 1 Summary statistics for most recent evaluation year and multi-year evaluation period

Table 2.1 River flows and connectivity expected environmental outcomes as set out in the Strategy...........................15

Table 2.2 Contribution of Commonwealth environmental water to barrage releases (South Australia barrage dashboard accounting data)..21

Table 2.3 Areas of Ramsar sites (hectares) supported by Commonwealth environmental water, 2014–23 25

Table A.1 Commonwealth environmental watering actions by valley and hydrological flow component, 2022–23 66

Table B.1 Commonwealth Environmental Outcomes framework against Basin Plan biodiversity objectives (Basin Plan S8.05) 69

Abbreviations and terms

Term	Description
2014–23	Water years 1 July 2014 to 30 June 2023
2022–23	Water year 1 July 2022 to 30 June 2023
ANAE	Australian National Aquatic Ecosystems, a classification framework which allows groupings of similar ecosystems into a series of classes
the Basin	Short form for the Murray–Darling Basin
Basin Plan	(Murray–Darling) *Basin Plan 2012* made under subparagraph 44 (3)(b)(i) of the *Water Act 2007* Basin Plan 2012 (legislation.gov.au)
CEW	Commonwealth environmental water
CEWH	Commonwealth Environmental Water Holder
CSIRO	Commonwealth Scientific and Industrial Research Organisation
eEcological community	Living organisms described by number of species (diversity), number of individuals (abundance), physical arrangement of species (structure) and 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
Ecosystem diversity	The number of aquatic ecosystem types that are affected by Commonwealth environmental water
Ecosystem functions	Movement of energy and transformation of materials in an ecosystem (e.g. denitrification, respiration)
Ecosystem energetics	The movement of energy in an ecosystem, including photosynthesis, decomposition and respiration
ER	Ecosystem respiration
EPBC Act	Australian *Environment Protection and Biodiversity Conservation Act 1999*
Flow-MER	CEWH's Flow Monitoring, Evaluation and Research program (2019–24)
Food webs	The movement of energy between organisms in an ecosystem, usually as feeding links
the Framework	the *Environmental water outcomes framework*
GPP	Gross primary production
Hydrology	River flow (with and without Commonwealth environmental water)
Managed floodplain	The area of the Basin where watering with Commonwealth environmental water is possible
NSW DCCEEW	New South Wales Department of Climate Change, Energy, the Environment and Water
Palustrine wetlands	Shallow wetlands with a predominance of emergent vegetation (reeds, sedges, shrubs, trees)
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	Areas 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
Remote sensing	The process of collecting data at a distance via satellite or aerial imagery from drones or other aircraft
Resilience	An ecosystem's capacity to tolerate disturbance (resistance) and restore itself (recovery)
Scaling	In an ecological context, scaling represents the ability to predict future ecological response (temporal scaling) at unmonitored locations (extrapolating) or over larger areas than sampled (scaling up)
Species diversity	The number and relative abundance of species in a location. Sometimes referred to as biodiversity
the Strategy	Short form for the *Basin-wide environmental watering strategy* (MDBA 2019)

Term	Description
Stream metabolism	The movement of energy into (via photosynthesis), through (by feeding links) and out of (via respiration) a food web
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)

1 INTRODUCTION

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

River, floodplain and wetland ecosystems are sensitive to changes in flows and watering regimes and the composition and structure of plant and animal communities is strongly influenced by both short-term and long-term flow conditions. Commonwealth environmental water is delivered to rivers and wetlands across the Murray–Darling Basin (the Basin) to supplement flows and support water-dependent ecosystems to achieve a range of specified environmental outcomes.

1.1 Basin-scale evaluation

The Basin-scale evaluation is undertaken across 6 Basin Themes (Figure 1) based on ecological indicators developed for the Long Term Intervention Monitoring project and described in the *Environmental water outcomes framework* (the Framework). While there is line of sight to the *Basin-wide environmental watering strategy* (the Strategy), links between objectives in the Strategy and Flow-MER evaluation questions, while implicit, are not well defined, as the Framework was developed prior to the Strategy. Data obtained from evaluation of environmental water outcomes within the 7 Selected Areas is used in this evaluation and, in many cases, this is also supplemented by other publicly available data (e.g. state agency monitoring).

The Basin-scale evaluation addresses how Commonwealth environmental water contributed to, supported or influenced environmental outcomes. The way in which this is assessed varies between the 6 Basin Themes, depending on the data collected at monitoring locations (in the 7 Selected Areas):

- monitoring of ecological response in locations that received Commonwealth environmental water (potentially in conjunction with other sources of environmental water or non-environmental water)
- modelling to compare outcomes with and without Commonwealth environmental water
- use of flow and water quality metrics to infer unmonitored outcomes (within and outside of the 7 Selected Areas)
- summaries of findings across Selected Areas and across years.

The Basin-scale evaluation reports on the outcomes of delivery of Commonwealth environmental water for 2022–23 against expected outcomes from the Framework using thematic evaluation questions. This synthesis summarises the outcomes of the evaluation according to the Basin Plan objectives for biodiversity, ecological function, water quality and resilience. The evaluation is reported at the whole-of-Basin scale.

The findings of the Basin-scale evaluation are summarised in this synthesis and complement findings from targeted intervention monitoring (for specific watering events) and evaluations undertaken for each of the 7 Selected Areas (and reported separately). Where information is available, the evaluation also reports on achievement of expected outcomes from the Strategy. Evaluation of the environmental outcomes from the delivery of Commonwealth environmental water is presented in 6 separate thematic evaluation reports.[4]

[4] Reports available from the DCCEEW Flow-MER Basin-scale Project publications page.

1.2 Evaluation questions

THE CONTRIBUTION OF COMMONWEALTH ENVIRONMENTAL WATER TO BASIN PLAN OBJECTIVES

Biodiversity – to protect and restore water-dependent ecosystems (Basin Plan 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 vegetation community diversity?

What did Commonwealth environmental water contribute to sustaining native fish populations?

What did Commonwealth environmental water contribute to Ramsar wetlands in the Basin?

Ecosystem function – to protect and restore the ecosystem functions of water-dependent ecosystems (Basin Plan section 8.06)

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

What did Commonwealth environmental water contribute to patterns and rates of ecosystem respiration and primary productivity?

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

Addressed through considering refugia.

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

What did Commonwealth environmental water contribute to dissolved oxygen levels and salinity regimes?

1.3 About this report

Flow-MER provides the CEWH with evidence of how Commonwealth environmental water is helping maintain, protect and restore ecosystems and native species across the Basin. This work supports environmental water managers to demonstrate outcomes, inform adaptive management, and fulfil reporting requirements associated with managing Commonwealth environmental water.

This report summarises environmental outcomes from the delivery of Commonwealth environmental water for the most recent water year (2022–23) and cumulative outcomes for the 9 years since 1 July 2014. Its preparation was led by Dianne Flett and Susan Cuddy, CSIRO, with input from all other members of the Basin-scale Flow-MER evaluation team. It summarises and synthesises information from the most recent Basin-scale evaluation reports in a format that is suitable for briefings and other uses as required by the CEWH. As a synthesis of the evaluation reports, it does not include references. These are provided in the primary reports which are listed below:

- Basin-scale evaluation of 2022–23 Commonwealth environmental water: Hydrology
  - led by Ashmita Sengupta (CSIRO) with Felix Egger and Tony Weber (Alluvium)
- Basin-scale evaluation of 2022–23 Commonwealth environmental water: Ecosystem Diversity
  - led by Shane Brooks (Brooks Ecology)
- Basin-scale evaluation of 2022–23 Commonwealth environmental water: Fish

  - led by Sally Hladyz (Arthur Rylah Institute [ARI], Victorian Department of Energy, Environment and Climate Action [DEECA]), with Zeb Tonkin, Jian Yen, Ben Fanson, Wayne Koster, Jarod Lyon (ARI, DEECA), Chris Bice, George Giatas, Qifeng Ye (South Australian Research and Development Institute), Lee Baumgartner, Nicole McCasker, Ivor Stuart (Charles Sturt University [CSU]), Jason Thiem, Jerom Stocks (NSW Department of Primary Industries), Ben Broadhurst (University of Canberra [UC]), Brenton Zampatti (CSIRO)
- Basin-scale evaluation of 2022–23 Commonwealth environmental water: Vegetation
  - led by Fiona Dyer (University of Canberra) with Will Higgisson, Alica Tschierschke, Margarita Medina (UC), Cherie Campbell (Murray–Darling Basin Authority), Tanya Doody (CSIRO)
- Basin-scale evaluation of 2022–23 Commonwealth environmental water: Species Diversity
  - led by Skye Wassens and Andrew Hall (CSU)
- Basin-scale evaluation of 2022–23 Commonwealth environmental water: Food Webs and Water Quality
  - led by Paul McInerney (CSIRO) with Simon Linke, Gavin Rees (CSIRO), Darren Gilling, Ross Thompson (UC), James Hitchcock (University of Technology Sydney), Darren Ryder
- Basin-scale evaluation of 2022–23 Commonwealth environmental water: Report summary dashboards
  - led by Martin Nolan (CSIRO) with input from Basin Theme leads.

This report, together with the contributing Basin-scale evaluation reports, is available from the DCCEEW Flow-MER Basin-scale Project publications page.

2 HYDROLOGY AND CONNECTIVITY

This chapter describes the hydrological conditions (rainfall, surface water runoff) in the Basin that affect the planning of Commonwealth environmental water delivery – volumes and locations, and how Commonwealth environmental water has contributed to restoring the hydrological regime.

2022–23 AT A GLANCE

- Rainfall in 2022–23 was above the long-term average in most valleys in the Basin. The wetter conditions are markedly different to the low rainfall conditions experienced across most of the Basin for 6 of the 9 years since 2014, when Basin-scale monitoring and evaluation began.
- Total runoff across the Basin was 67,760 GL in 2022–23, much greater than the 9-year annual average of 33,271 GL. Basin storages filled from 91% (20,216 GL) to 100% (22,258 GL) of capacity.
- When wetter conditions are dominant over a water year, less Commonwealth environmental water is needed to maintain ecosystem processes. In 2022–23, the total volume delivered was the lowest since monitoring commenced in 2014, except for very dry years in 2014–15 and 2018–19.
- 1,385 GL of Commonwealth environmental water was provided to rivers, wetlands and floodplains in the 19 valleys where CEWH holds water entitlements, delivered through a total of 102 watering actions. This equates to 6.5% of average Basin storage in 2022–23.
- 1,196 GL (86.4% by volume, of total 2022–23 delivery) of Commonwealth environmental water were delivered in the southern Basin. The northern Basin received 189 GL; 113 GL of this (60% of northern Basin total or 8.2% of Basin total) was delivered in the Condamine Balonne to support the Narran Lakes.
- Even with the wet conditions, this year saw the largest number of base-flow actions, predominantly in the southern Basin valleys. A drier summer following a wet winter and spring necessitated base flows to sustain connectivity. Commonwealth environmental water contributed 12 base-flow interventions in the Edward/Kolety–Wakool and maintained base flows for over 47 days in the Broken–Goulburn system.
- Commonwealth environmental water inundated 202,071 ha of lakes and wetlands, 71,837 ha of floodplains and 23,768 ha of estuary. 22,205 km of waterways were connected due to Commonwealth environmental water releases, increasing connectivity in many Basin valleys.
- 437 GL of Commonwealth environmental water were delivered to 8 Ramsar sites in 2022–23.
- Basin Plan target flow volumes were achieved for the Coorong, Lower Lakes and Murray Mouth in 2022–23. Water level thresholds in the Lower Lakes were maintained (Basin Plan objective 8.06).

2014–23 AT A GLANCE

- The 19 valleys where the Commonwealth holds water entitlements all received Commonwealth environmental water between 2014 and 2023. Over the 9 years, 15,443 GL were delivered in 1,081 watering actions. 27% by volume (4,177 GL) inundated wetlands and floodplains in 14 Basin valleys.
- Between 2014 and 2023, all 11 of the Ramsar wetlands in the Basin that can receive Commonwealth environmental water (11 of 16 in total) were inundated at least once.
- Between 2014 and 2023, Commonwealth environmental water supported 56 ecosystem types (88% of Australian National Aquatic Ecosystems [ANAE] types on the managed floodplain) on at least one occasion, representing 123,336 ha of lakes (including lakes Alexandrina and Albert), 125,743 ha of palustrine wetlands, 187,486 ha of floodplain, 27,715 km of waterways and 23,768 ha of estuarine ecosystems.

2.1 Rainfall

Annual rainfall in 2022–23 was above the long-term average in most valleys; the remaining valleys received rainfall equivalent to the long-term average (Figure 2.1). There was a noticeable distinction between the northern Basin and southern Basin, with rainfall in the southern Basin being well above average.

The wetter conditions are different to the low rainfall conditions experienced in many of the previous years. Many Commonwealth environmental water actions were not delivered due to high natural flows; however, wet conditions also provide opportunities to extend the duration of inundation of floodplains, wetlands and marshes, providing habitat and resources for recruitment and growing cycles for a range of species.

During the 9-year period (2014–23) of Basin-scale monitoring and evaluation, the first 2 years were dry, particularly in the southern Basin, with rainfall the lowest on record (Figure 2.1). In 2016–17, conditions were wetter in the southern Basin and the headwaters of some northern Basin tributaries. Conditions returned to dry across the whole Basin over the period 2017–18 to 2019–20.

In 2020–21, the Basin returned to wetter conditions, with average, above average or very much above average rainfall experienced across the Basin. Those conditions persisted through to 2022–23, although it should be noted that some valleys saw a dry start in the early months of 2023, especially in the southern Basin. The overall wetter conditions resulted in large flow events throughout the Basin.

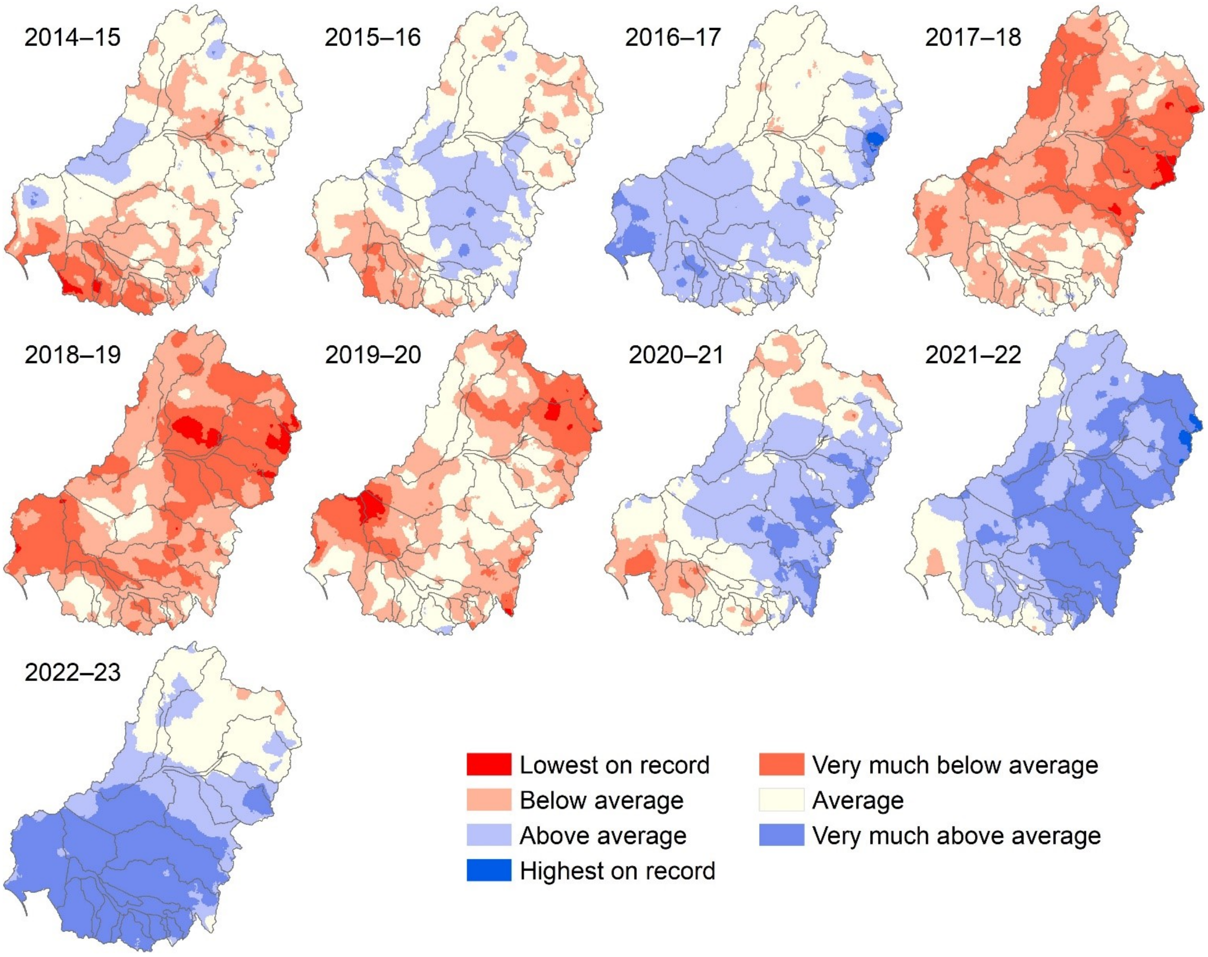

Figure 2.1 Maps of annual rainfall conditions across the Basin, 2014–23
Data source: Bureau of Meteorology.

2.2 Total runoff in the Basin

The last 20 years were a dry period for the Basin, with persistent low inflows during the Millennium Drought and only a brief respite in 2 years (2010–11 and 2011–12) before returning to dry conditions, with some relief also in 2016–17 and returning to wetter conditions in 2020. For the last 3 years, total runoff has been above the average for this century, with most valleys experiencing much wetter conditions (Figure 2.2).

Total runoff[5] in the Basin in 2022–23 was 67,760 GL, much greater than the 23-year average of 30,285 GL since 2000–01 (Figure 2.3, top). Following very wet conditions in 2021–22, with little soil moisture capacity available, high rainfall resulted in high inflows across the Basin. Basin storages started at 91% of total capacity (20,216 of 22,258 GL) in July 2022, increasing to 100% through the water year.

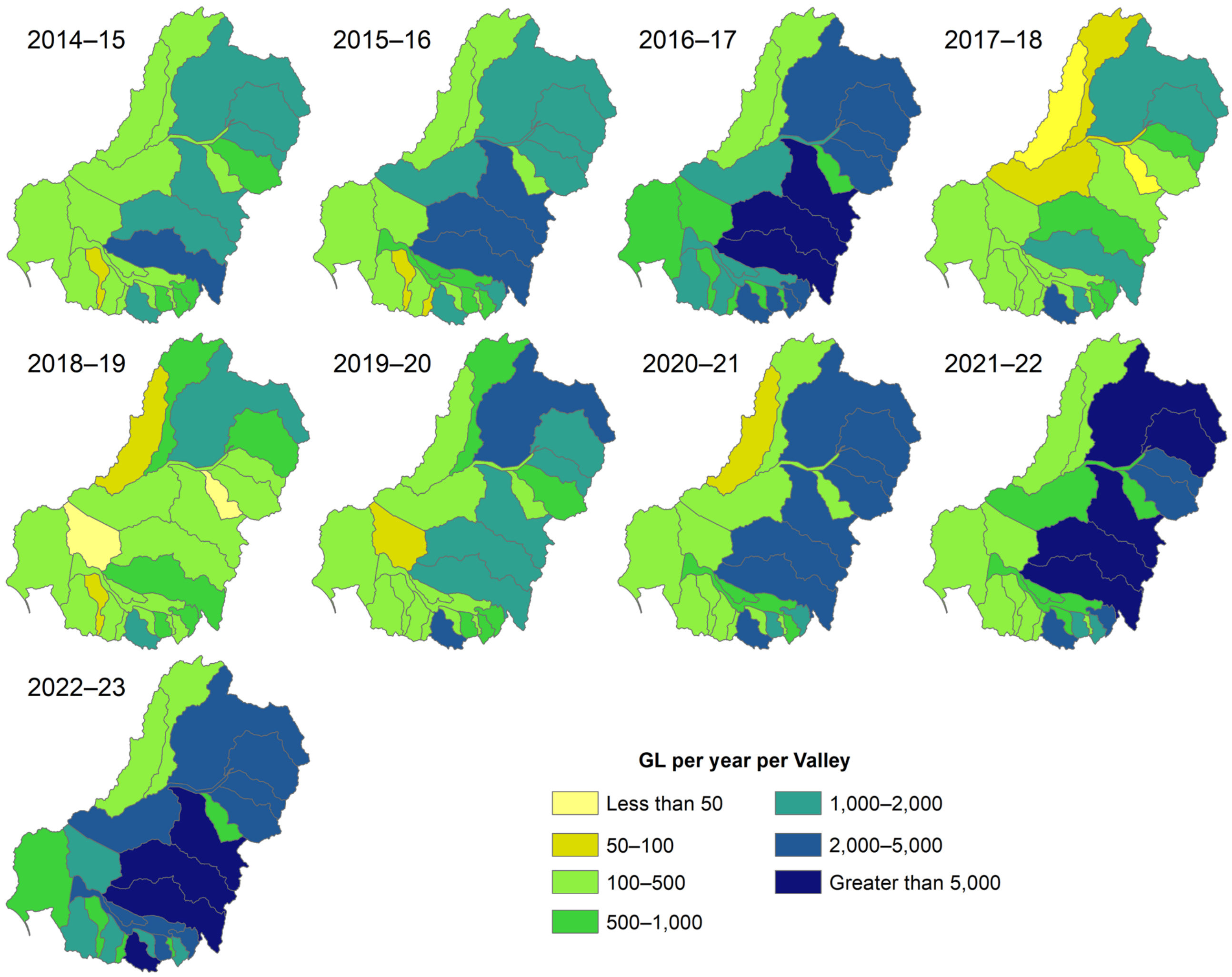

Figure 2.2 Maps of annual surface water runoff in the Basin by river valley, 2014–23

Data is modelled annual surface water volumes in the Basin, generated from rainfall-runoff modelling. The colours indicate total volume of runoff predicted for each year, with lighter colours indicating lower runoff volumes. Data source: CSIRO.

Total runoff in the southern Basin for 2022–23 was 40,808 GL, more than twice the 23-year average of 16,018 GL (Figure 2.3, middle). Total runoff in the northern Basin of 26,952 GL was the fourth highest since 2000–01 (Figure 2.3, bottom) and almost double the 23-year average of 14,267 GL. Only the Lower Murray, Lower Darling, Paroo and Warrego received less runoff than the average for this century (since 2000–01).

[5] Total runoff is calculated as total precipitation less the losses caused by evapotranspiration and includes not only the waters that travel over the land surface and through channels to reach a stream but also interflow (i.e. the water that infiltrates the soil surface and travels by means of gravity toward a stream channel).

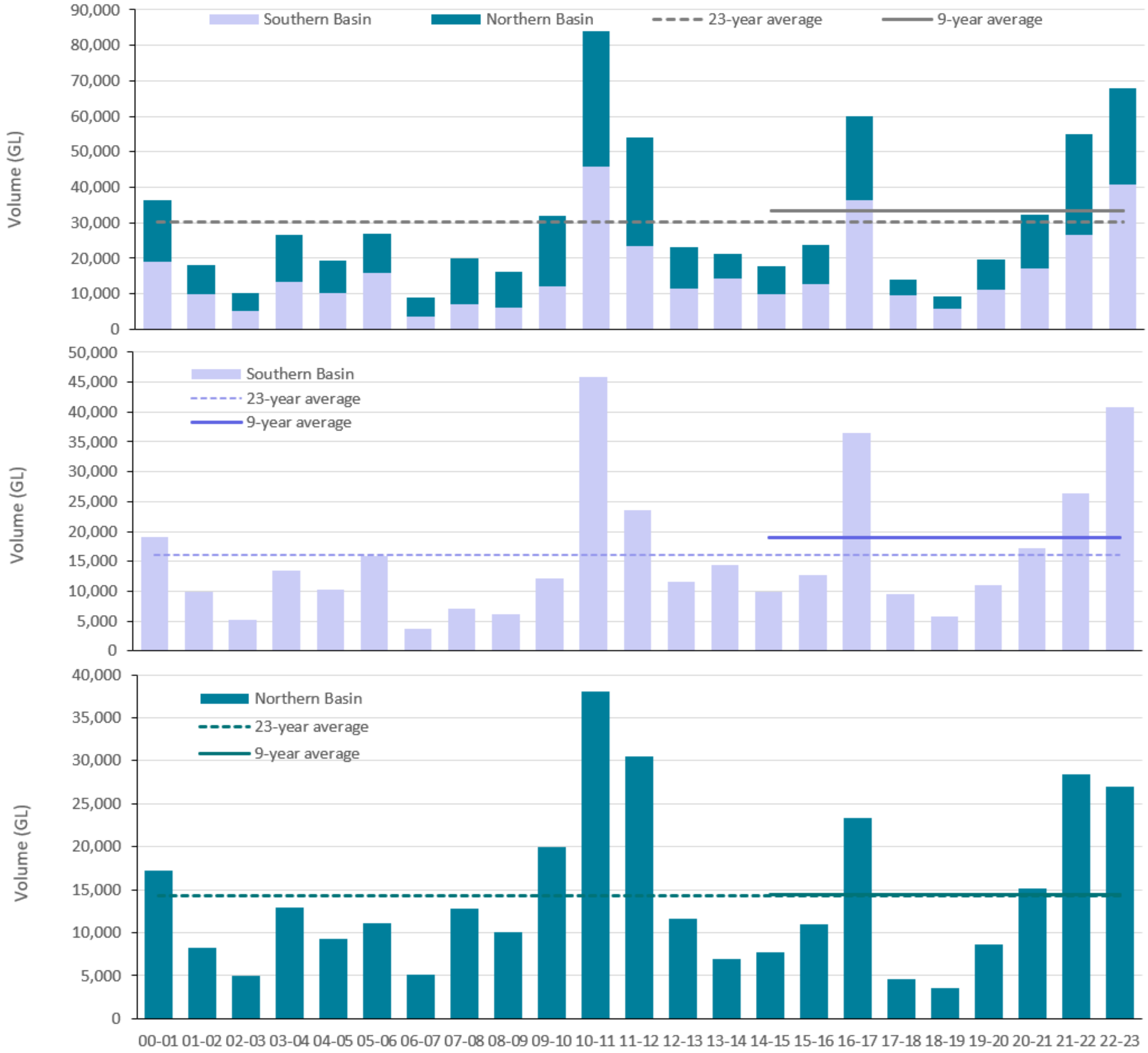

Figure 2.3 Annual total runoff in the Basin over the 23-year period 2000–23

Top chart shows total runoff in the Basin, middle chart shows southern Basin total runoff, bottom chart shows northern Basin total runoff. All charts include 23-year and 9-year averages. Data source: CSIRO.

High volumes of surface water runoff in 2022–23 generated high flows across Basin river systems, especially in the late winter and spring of 2022, resulting in overbank flooding and extensive floodplain inundation. In 2022–23, monitoring areas (Selected Areas, shown in Figure 2) experienced the highest spring flows recorded since 2014 (Figure 2.4). Widespread flooding occurred at many of the monitoring areas.

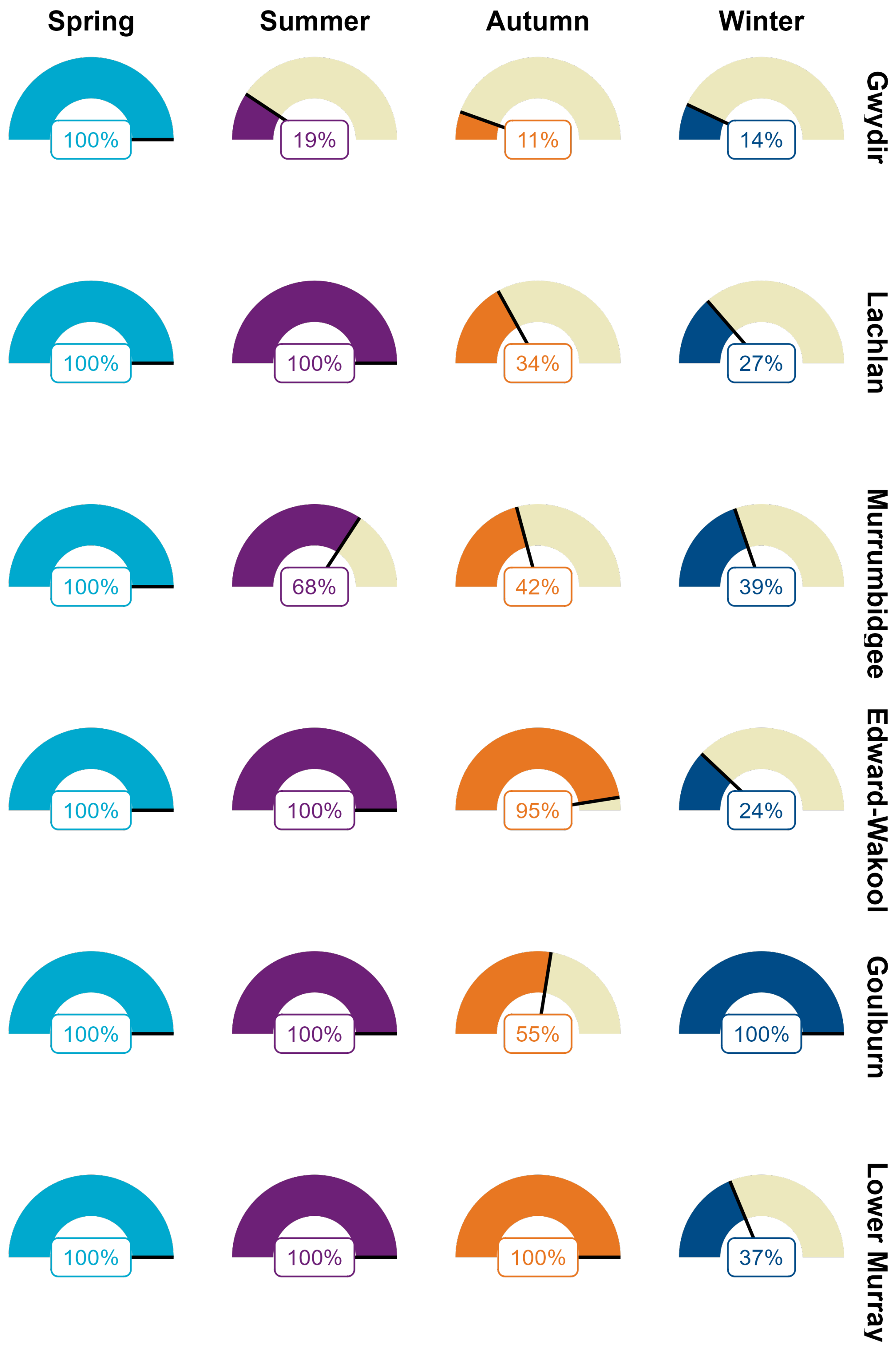

Figure 2.4 Gauge plot showing 2022–23 seasonal flows in Selected Areas, compared to previous seasons 2014–23

Junction of Warrego and Darling rivers Selected Area is not included.

For each Selected Area, the mean flow for each season was calculated. This was then expressed as a percentage of the maximum mean flow recorded for that season between 2014 and 2023. Therefore, 100% indicates that 2022–23 recorded the maximum flow mean since 2014 for that season.

2.3 Delivery of Commonwealth environmental water

Water for the environment is strategically used by the CEWH to protect and restore hydrological regimes and connectivity within and between water-dependent ecosystems (Basin Plan S8.06). This involves connecting river reaches during dry times and connecting the river to the floodplain during wetter periods, as well as connecting and maintaining in-channel habitat and providing cues for breeding and movement. The evaluation considered the impact of Commonwealth environmental water on 4 ecologically important flow components (depicted in Figure 2.5):

- Base flows (low flows) maintain longitudinal connectivity in river systems so that they do not become dry or isolated pools.
- Freshes are small, in-channel events that replenish pools and are important for managing water quality (e.g. algal blooms), allowing fish to move between refugia and supporting the quality, persistence and resilience of in-channel refuge pools. Freshes are commonly used to inundate benches or lower levels of the channel environment, pulsing nutrients and carbon into the system and creating habitat for fish, bugs and plants.
- Lateral connectivity refers to the movement of water between the channel and floodplain, including inundation of floodplain wetlands through overbank flows.
- Upstream–downstream (longitudinal) connectivity.

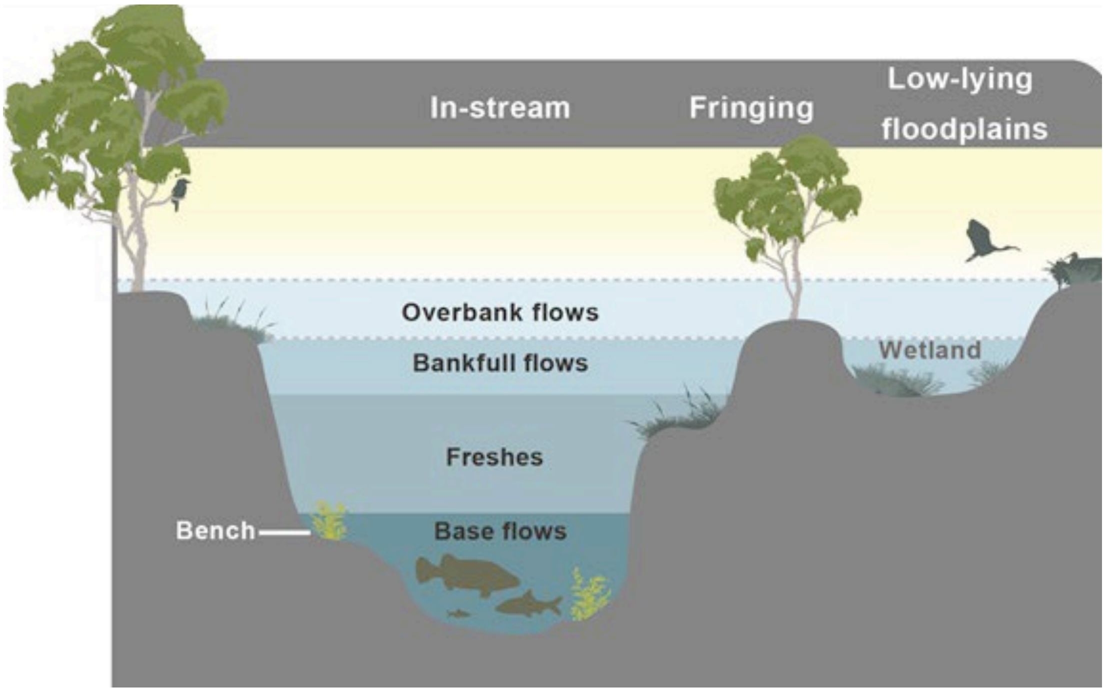

Figure 2.5 An illustrative river cross-section showing the 5 components of the flow regime referenced in this evaluation
Source: Figure 10, the Strategy.

2.3.1 Water year 2022–23

In 2022–23, 1,385 GL of Commonwealth environmental water were delivered through 102 watering actions for rivers, wetlands and floodplains in the 19 valleys where CEWH holds water entitlements (Figure 2.6 and refer to Table A.1). This equates to 2% of the total volume of surface water runoff in the Basin in 2022–23. The total volume of water delivered in 2022–23 was lower compared to recent years, due to the extremely wet conditions. Commonwealth environmental water contributed the smallest volume delivered since monitoring began in 2014, except for 2014–15 (1,193 GL) and 2018–19 (1,163 GL), both much drier years when there was much less Commonwealth environmental water available.

Larger environmental water entitlements are held and delivered in the southern Basin compared to the northern Basin and are accompanied by a wider range of options for active water management. In 2022–23, the southern Basin received 1,196 GL (86.4% by volume and 76% of number of actions) of Commonwealth environmental water, with large deliveries in the Edward/Kolety–Wakool (249 GL), Murrumbidgee (247 GL), Central Murray (146 GL), Lower Murray (162 GL), Goulburn (168 GL) and Lower Darling (148 GL) river systems (refer to Table A.1). More Commonwealth environmental water was delivered in summer (39% of releases); the autumn, spring and winter releases accounted for 17%, 21% and 23%, respectively.

The northern Basin valleys received 189 GL of Commonwealth environmental water delivered as 2 distinct pulses – spring (50% of release) and winter (23% of release). The summer and autumn releases were smaller −11% and 16%, respectively. Like past years, the Condamine Balonne received the largest volume (113 GL, 60%), through 5 watering actions delivered to support overbank and fresh flows. The largest individual pulse started in September, delivering 84 GL to the Narran Lakes. The Barwon Darling, Border Rivers, Gwydir, Macquarie and Warrego valleys all received smaller water deliveries using entitlements held in their valleys. In the Barwon Darling and Warrego, watering actions were primarily to maintain base flows.

In 2022–23, Commonwealth environmental water was delivered to 22,205 km of river length, including channels on the managed floodplain. 61 watering actions (61% by volume) were delivered to river channels, comprising base flows (33 actions), freshes (18 actions) or a combination (10 actions). Commonwealth environmental water supported flows within the river channel (only) in the Barwon Darling, Broken, Campaspe, Goulburn, Loddon, Lower Darling, Namoi, Ovens and Wimmera river systems (refer to Table A.1).

Wetlands in the Gwydir, Macquarie, Central Murray, Edward/Kolety–Wakool, Lachlan and Murrumbidgee benefited from delivery of Commonwealth environmental water, including internationally significant Ramsar sites. 22 watering actions were delivered to support wetlands (15% by volume) and 19 were combined actions supporting instream and overbank flows (24% by volume) (refer to Table A.1).

The timing and duration of high flow events, as well as the conditions after flood events, are important for Basin ecosystems and delivery of Commonwealth environmental water. In 2022–23, Commonwealth environmental water was used to water wetlands, improve water quality by maintaining dissolved oxygen levels above critical thresholds, maintain high flow rates during spring and summer and reduce rapid recessions, and provide variable base flows and winter freshes and autumn freshes.

While Basin valleys were generally very wet in 2022–23, there were periods in the year where flows were lower than usual. In the southern Basin, high natural flows in spring gave way to a drier summer and quickly receding river flows, and Commonwealth environmental water was delivered to support base flows and freshes. The use of Commonwealth environmental water deliveries to maintain water quality and dissolved oxygen levels likely lessened the impact of hypoxic water conditions and associated fish deaths.

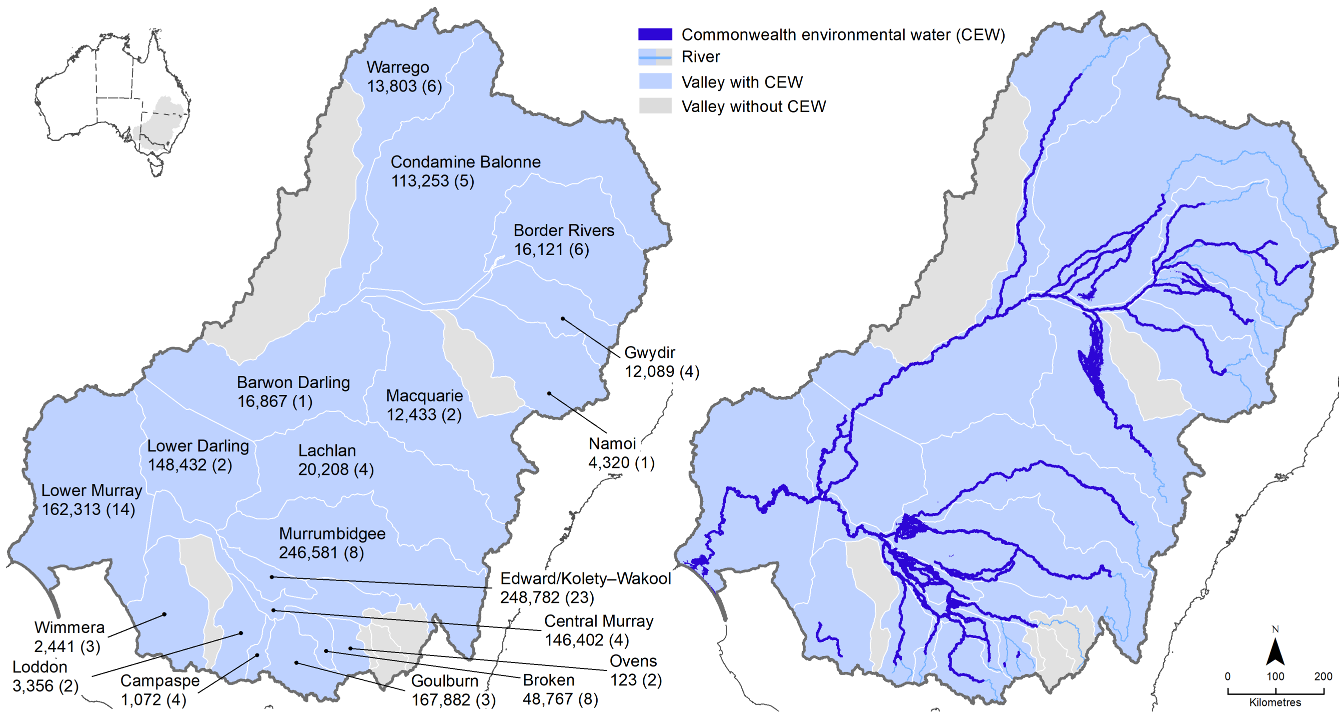

Figure 2.6 Volume (ML) of water and number of watering actions (in brackets) delivered (left) and the watercourses and area inundated or connected (right) by Commonwealth environmental water, 2022–23
Those valleys shaded grey are the 5 valleys where CEWH does not hold water entitlements.

2.3.2 Water years 2014–23

The 19 valleys where the Commonwealth holds water entitlements (Figure 2) all received Commonwealth environmental water at some time between 2014 and 2023. Over the 9 years from 2014–23, 15,443 GL of Commonwealth environmental water were delivered in 1,081 watering actions. 27% by volume (4,177 GL), representing 46% of the total number of actions, was used to inundate wetlands and floodplains in 11 of the 25 Basin valleys. In the other 8 valleys where the Commonwealth holds water entitlements – the Barwon Darling, Broken, Campaspe, Goulburn, Loddon, Namoi, Ovens and Wimmera rivers – flows are managed with little overbank inundation, but in-channel base flows and freshes were delivered in most years (refer to Table A.1). The remaining 5 Basin valleys – the Paroo, Castlereagh, Mitta Mitta, Upper Murray and Avoca valleys – do not have Commonwealth environmental water entitlements.

The 11 southern Basin valleys received most of the water by volume as well as by the number of actions (refer to Table A.1). Among the southern Basin valleys, the Lower Murray received the largest deliveries (5,952 GL, 402 watering actions), supporting end-of-system flows to the Coorong, Lower Lakes and Murray Mouth. The Murrumbidgee, Central Murray and Goulburn river systems also received a large portion of the environmental water portfolio. In the northern Basin valleys, the Condamine Balonne received the highest volume of Commonwealth environmental water (43% through 18 actions). In contrast, the Border rivers received a larger number of smaller deliveries (7% through 50 actions).

Over the 9-year period 2014–23, Commonwealth environmental water was delivered for low and high flows and within and out of the channel (Figure 2.7). 46% of watering actions over the 9 years supported wetlands, except for water years 2016–17 and 2022–23, in which most actions comprised freshes and base flows, respectively (Figure 2.8). Delivery of Commonwealth environmental water over the 9-year period typically targeted Basin Plan environmental outcomes for vegetation, fish and waterbirds (Figure 2.9). Commonwealth environmental water also supported longitudinal river connectivity for instream ecosystem processes and water quality objectives, including mitigation of hypoxic blackwater events and algal blooms.

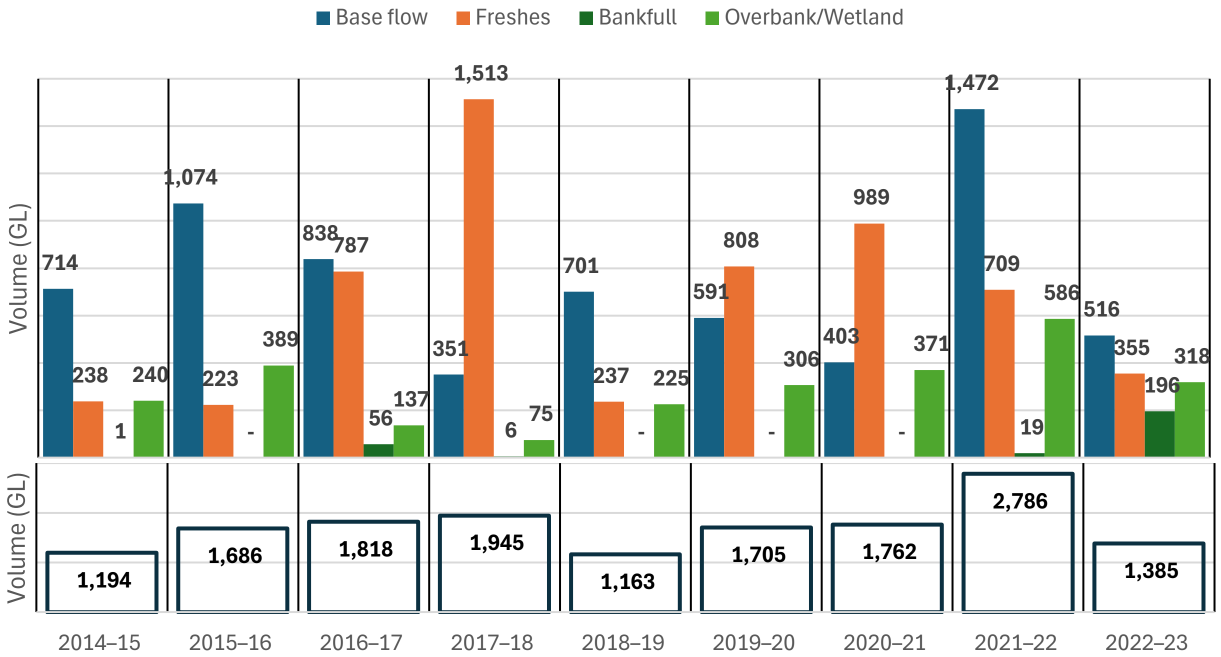

Figure 2.7 Commonwealth environmental water portfolio showing volume of watering actions (y-axis) by flow component and year, 2014–23

Volumes per component are displayed above each bar. Annual volumes are displayed inside boxes at the bottom of the figure.

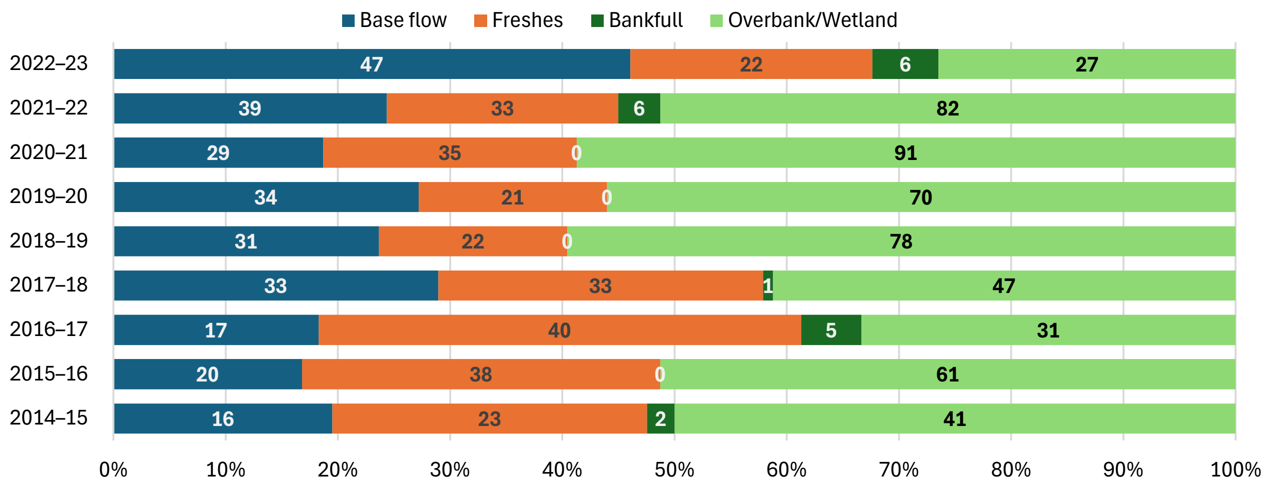

Figure 2.8 Commonwealth environmental water portfolio showing the number of watering actions and the proportioning of flow components each year, by flow component and year, 2014–23

The number of watering actions is displayed inside each component of the stacked bar.

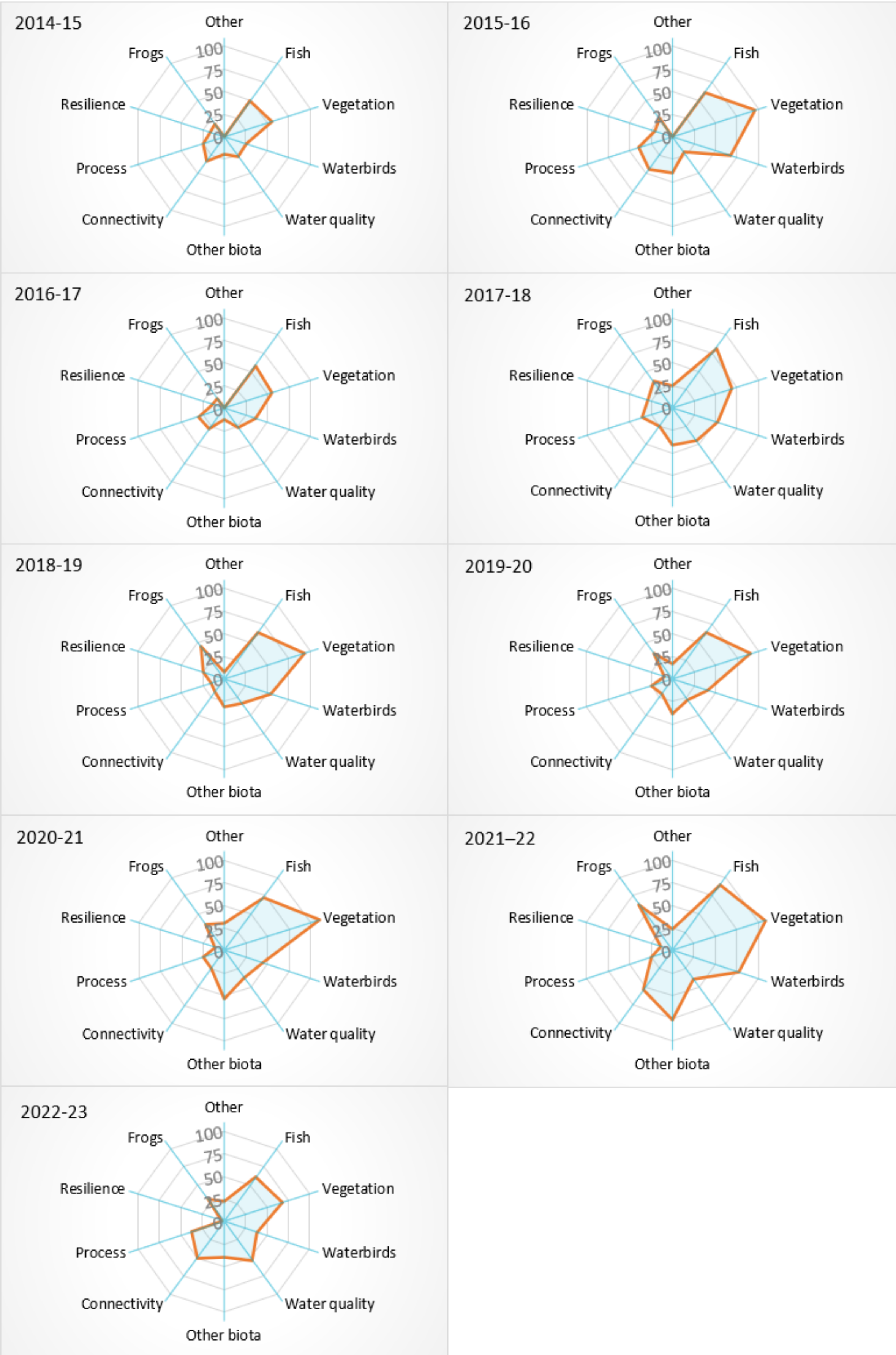

Figure 2.9 Number of Commonwealth environmental watering actions targeted to specific outcomes, 2014–23

Actions include multiple objectives. Note that very few watering actions explicitly target resilience or connectivity.

HIGHLIGHT: COORDINATING WATERING ACTIONS FOR MULTIPLE OUTCOMES

Optimising the timing and delivery of Commonwealth environmental water is critical to maximising environmental outcomes. Coordinating the timing and delivery of watering actions across valleys enables ecological outcomes to be achieved at the Basin scale. For example, in the 2020–21 water year, actions were coordinated to include one large system-scale pulse, commencing in spring and concluding in summer – enabling environmental water to support favourable conditions in the Basin following extended drought.

Spring is a time of increased biological activity in the Basin, with fish spawning, waterbird breeding and nesting, and vegetation growing, seeding and recruiting. Environmental water was used to increase the extent and duration of wetland and floodplain inundation events, increase the magnitude and duration of fresh and overbank pulses and increase base flow levels. Three watering actions were coordinated across the Macquarie, Lower Darling/Baaka and Murrumbidgee river systems in spring 2020 for 3 different flow components (fresh, base flow, wetland) and Basin Themes (Vegetation, Fish, Waterbirds) contributing to improved ecological outcomes across the Basin. For example, in 2020–21, coordinated actions included:

SUPPORTING FISH BREEDING IN THE LOWER DARLING/BAAKA

- 24,852 ML (11,187 ML of Commonwealth environmental water and 13,665 ML from The Living Murray) were delivered as base flow to the Lower Darling/Baaka from 15 September 2020 to 17 January 2021.

Primary action. Support Murray cod breeding, recruitment and health along the Lower Darling / Baaka, from Menindee Lakes to Wentworth, and dispersal of golden perch from Menindee Lakes into the Lower Darling / Baaka, timing flows with Murray cod breeding season, also supporting breeding of golden and silver perch. Boost river levels to 400 ML/day to support recovery of native fish populations after very dry conditions.

Desired outcomes. Water for the environment increased flow rates and enabled connection of the Menindee Lakes and the Murray River, aiding native fish recovery and instream productivity. This was the first opportunity for environmental water to support Murray cod breeding, recruitment and river health since extensive fish death events during 2018 and 2019 in the Lower Darling/Baaka. Increased flow allowed Murray cod to access more areas where they can spawn and forage and larval fish can shelter.

Other benefits include water quality improvements in the Lower Darling/Baaka through the mixing of the water column, helping to decrease the risk of extensive blue-green algal blooms. This would also benefit other freshwater fauna, such as freshwater shrimp, mussels and smaller native fish, in these areas.

SUPPORTING AND TRIGGERING WATERBIRD BREEDING IN THE MURRUMBIDGEE

- 174,494 ML (106,564 ML Commonwealth environmental water, 11,930 ML NSW General security licences and 56,000 ML NSW Environmental Water Allowance) were delivered for wetland flows to Gayini Nimmie-Caira wetlands (and to Yanga National Park – interconnected system) between 27 July 2020 and 27 June 2021.

Primary action. Support refuge habitat for waterbirds. Support large-scale aggregate waterbird breeding.

Desired outcomes. Water for the environment triggered and supported the breeding of over 15,000 straw-necked ibis (*Threskiornis spinicollis*) and 3,000 glossy ibis (*Plegadis falcinellus*) nesting pairs, and smaller numbers of many other species, at Eulimbah Swamp in Gayini Nimmie-Caira. Wetland inundation also benefits other taxa, such as frogs, fish and turtles, by maintaining refuge habitat and providing opportunities for breeding and recruitment.

2.4 Restoring flows

This section presents findings from the Hydrology evaluation for the 2022–23 water year, compared with the prior 8 years of monitoring, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Hydrology' report (available from the DCCEEW Flow-MER Basin-scale Project publications page).

WHAT DID COMMONWEALTH ENVIRONMENTAL WATER CONTRIBUTE TO RESTORATION OF THE HYDROLOGICAL REGIME?

In 2022–23, Commonwealth environmental water:

- improved flow regime in strategic locations through provision of baseflows
- improved lateral and longitudinal connectivity in most valleys by extending extent and duration of natural flooding.

The Basin Plan (Section 8.06 *Protection and restoration of ecosystem functions of water-dependent ecosystems*) requires the protection and restoration of hydrological connectivity within and between water-dependent ecosystems, including:

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

The Strategy sets expected environmental outcomes for river flows and connectivity (Table 2.1). This evaluation considers the impact of delivery of Commonwealth environmental water on restoration of flows, including low flows (base flows), flow increases in the river channel (freshes and bankfull), floodplain inundation (overbank), and longitudinal and lateral (wetland) connectivity.

Table 2.1 River flows and connectivity expected environmental outcomes as set out in the Strategy

Objective	Quantified expected environmental outcome
Maintained base flows	At least 60% of natural levels
Improved overall flow	10% more into the Barwon–Darling, 30% more into the River Murray, 30 –40% more to the Murray Mouth (and it open to the sea 90% of the time) (barrage flows >2,000 GL/year)
Maintained connectivity in areas where it is relatively unaffected	Between rivers and floodplains in the Paroo, Moonie, Nebine, Warrego and Ovens
Improved connectivity with bankfull and/or low floodplain flows	By 30–60% in the Murray, Murrumbidgee, Goulburn and Condamine–Balonne By 10–20% in remaining catchments
Maintain the Lower Lakes above sea level	Maintain the water level in Lake Alexandrina above 0.4 m Australian Height Datum

2.4.1 Base flows

The Strategy sets environmental outcomes for base flows (Table 2.1). In 2022–23, the target of at least 60% of natural base flow levels were met in all valleys due to high natural flows. In addition, targeted delivery of base flows led to flow regime improvement in many valleys and, in some cases, clearly provided progress towards improved flow regimes.

Across the Basin, excessive periods of reduced base flows were mainly avoided due to the widespread wet conditions in 2022–23. Even though rainfall was higher than usual, some valleys, such as the Broken River, required environmental water throughout the year once larger flow peaks were receding.

Of the watering actions delivered in 2022–23, 33 were dedicated to supporting base flows and 16 actions were delivered for base flows as part of multicomponent flow events (49 actions in total). Most base flows were delivered in early 2023 as rivers were drying after record rainfall during spring. Due to wet conditions in 2022–23, base flows (or above) were maintained across the Basin for most of the year (> 300 days) except for the Broken and Warrego river systems – base flows (or above) were maintained in the Broken River system for 172 days and the Warrego River system for 235 days.

Rivers in the northern Basin are naturally intermittent, becoming disconnected waterholes in drier periods. In the northern Basin, small quantities of Commonwealth environmental water were used to maintain base flows in the Barwon Darling (1% duration, equivalent to 3.7 days) and Namoi (1.5% duration, equivalent to 5.3 days) rivers. In the south, river systems are more naturally connected, and Commonwealth environmental water contributed more substantially to maintaining base flows in the Broken and Goulburn rivers (both 13% duration, equivalent to 47 days). The Broken system required Commonwealth environmental water once larger flow peaks were receding. Similarly, the Goulburn system experienced a large spring flow peak, with receding flows in summer and autumn when Commonwealth environmental water was used to maintain base flows.

HIGHLIGHT: Actively managing low flows during wet years

Environmental flows are used to extend duration of flows, align the timing of flows more closely with the natural regime, or match the natural frequency of flow events. In 2022–23, despite wetter conditions, Commonwealth environmental water was used to maintain base flows, extend the duration of higher flow events for environmental objectives (for example, to maintain bird breeding), and reduce the rate of recession of flows after flooding to support downstream water quality objectives.

Case #1: Despite record rainfall, the Broken River system relied on environmental water to maintain base flows once larger flow peaks were receding. Commonwealth environmental water was delivered throughout autumn 2023 in response to a low dissolved oxygen event in late summer. Figure 2.10 shows a comparison of the long-term flow scenario to the observed flow regime in water year 2022–23. During summer and autumn, base flows were maintained by Commonwealth environmental water. Targeted base flow releases led to flow regime improvement and supported water quality objectives.

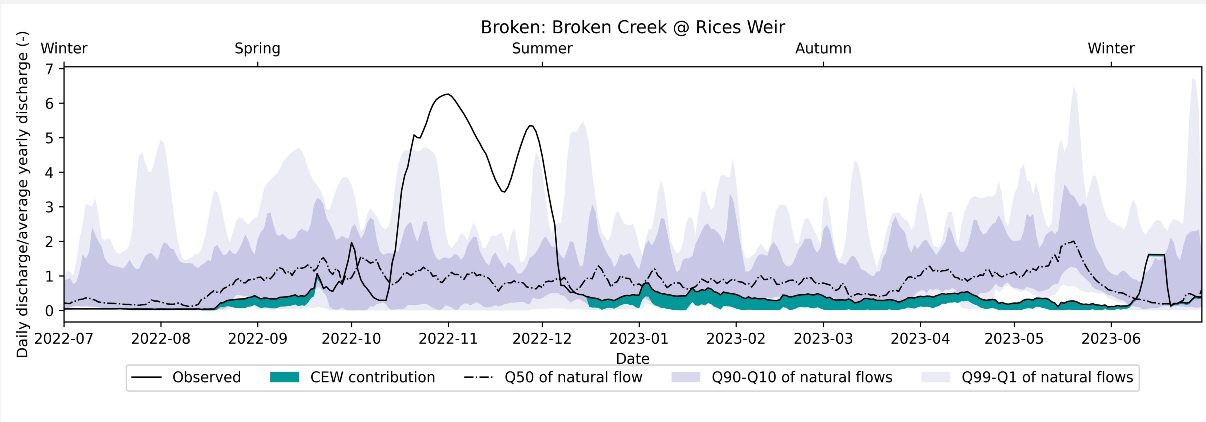

Figure 2.10 Flow regime in water year 2022–23 compared with the long-term observed flow signal in Broken River (Rices Weir). The Commonwealth environmental water contribution is shown in green

The time series presents the daily discharge value in the water year divided by the average discharge in the water year, a dimensionless discharge measure (y-axis). The quantile ranges present the median dimensionless flow signal (Q50), the range of the 90th to the 10th percentile (Q90–Q10) and the 99th to the 1st percentile (Q99–Q1) at Rices Weir (1976–96).

Case #2: Commonwealth environmental water delivered a large fresh in the Goulburn River in July and August 2022 in response to dry conditions (Figure 2.11). This was followed by high natural flows from September onwards, which were substantially larger than what is possible through environmental water deliveries. While flows in the lower Goulburn River are altered compared to the long-term flow regime, Commonwealth environmental water may be used to partially restore flow components.

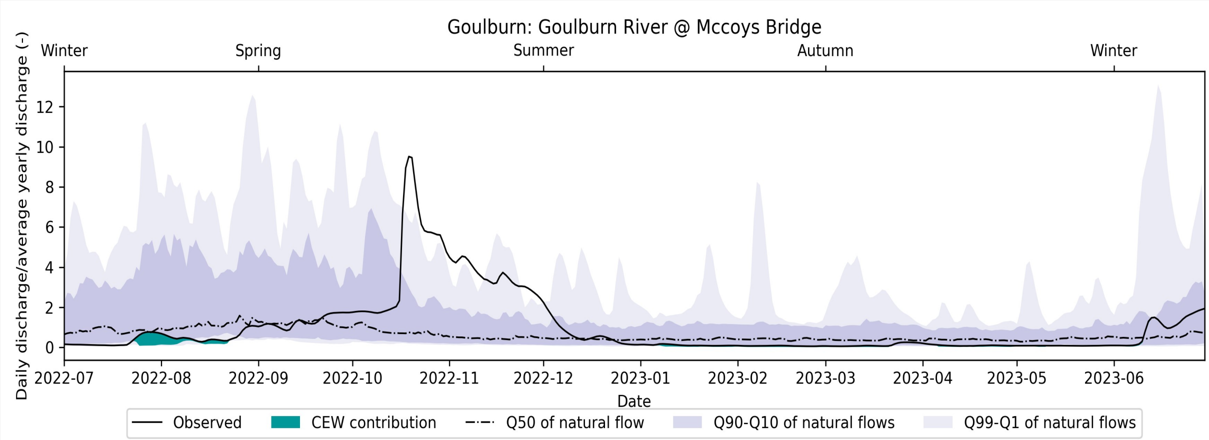

Figure 2.11 Flow regime in water year 2022–23 compared with the long-term observed flow signal in the Goulburn River (McCoys Bridge). The Commonwealth environmental water contribution is shown in green

The time series presents the daily discharge value in the water year divided by the average discharge in the water year, a dimensionless discharge measure (y-axis). The quantile ranges present the median dimensionless flow signal (Q50), the range of the 90th to the 10th percentile (Q90–Q10) and the 99th to the 1st percentile (Q99–Q1) at McCoys Bridge (1976–96).

2.4.2 Freshes

All valleys, except the Condamine Balonne, received Commonwealth environmental water for freshes in 2022–23. Eighteen actions were delivered to enhance freshes. Another 8 actions were delivered with base flows as the primary flow component (26 fresh actions), and there were 21 multicomponent flow events (47 in total).

In 2022–23, naturally occurring freshes were widespread across the Basin due to wetter conditions in spring of 2022 leading to higher-than-normal natural flows. With a return to hot and dry conditions in early 2023, some valleys required Commonwealth environmental water deliveries for autumn freshes to maintain water quality (for example, the Macquarie and Gwydir rivers). Other Commonwealth environmental water deliveries were to increase the duration of overbank flooding.

In the north, flows in the Macquarie River system were ‘fresh’ for more than half of the year (> 200 days). However, the contribution of Commonwealth environmental water was about 2 days. High flows in the Warrego River system lasted 21 days, about 3 days of which were supported by Commonwealth environmental water.

In the southern Basin, freshes extended for up to 300 days in some valleys. Commonwealth environmental water was used to support freshes in all valleys except for the Campaspe and Ovens, varying from small contributions (0.3% duration) in the Lachlan to significant contributions to of ‘low’ freshes in the Lower Darling/Baaka River system (11% duration) and ‘high’ freshes in the Goulburn River system (14% duration).

2.4.3 Connectivity along rivers

Commonwealth environmental water improved the overall connectivity in the Basin in 2022–23 (Figure 2.12), with the highest longitudinal connectivity (comparable to 2021–22) over the 9 years. In 2022–23, Commonwealth environmental water supported longitudinal connectivity through 22,205 km of Basin waterways along 41% of the river length on the managed floodplain.

In the northern Basin, the Barwon Darling, Condamine Balonne, Border Rivers, Macquarie and Warrego experienced improved longitudinal connectivity due to Commonwealth environmental water. The southern Basin, Central Murray, Edward/Kolety–Wakool, Lachlan, Lower Darling/Baaka, Lower Murray and Murrumbidgee had an increase in in-channel connectivity due to Commonwealth environmental water.

Cumulatively over the 9 years, Commonwealth environmental water has led to approximately 158,815 km of longitudinal connectivity of Basin rivers, with a maximum extent of 27,715 km (52% of the river length on the managed floodplain). Wetter years have higher connectivity, with Commonwealth environmental water delivered in conjunction with other flows, leading to a greater outcome. Over 2014–23, the total length of connectivity supported by Commonwealth environmental water was highest in the Murrumbidgee valley, followed by the Barwon Darling.

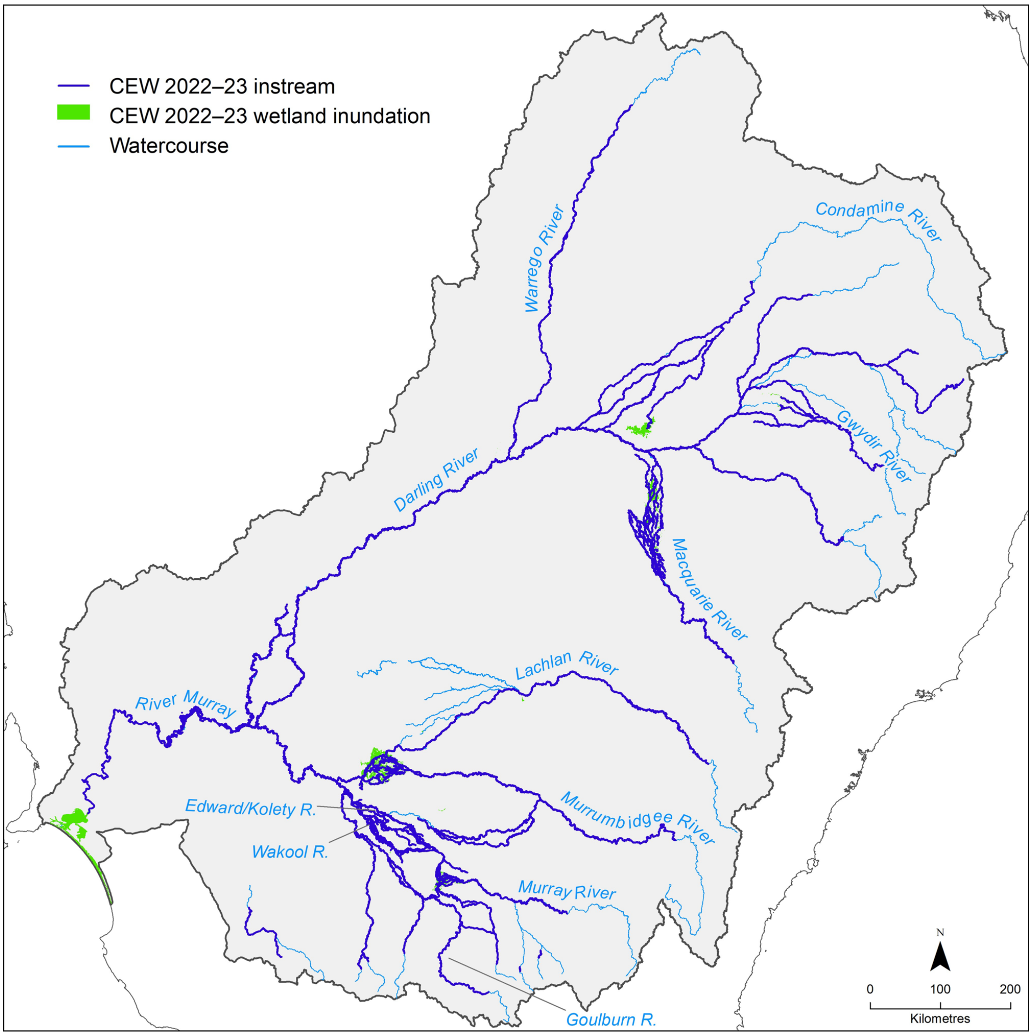

Figure 2.12 Length of waterways connected and wetland inundation, 2022–23

Over the 9-year period, 52% of all the river length on the managed floodplain (representing 27,715 km of river) was supported by Commonwealth environmental water (Figure 2.13). 35% (or 9,609 km) was watered in every year along permanent lowland sections of the Barwon, Macquarie, Gwydir, Lachlan, Murrumbidgee, Edward/Kolety–Wakool, Murray, Ovens, Broken, Goulburn and Loddon rivers. Permanent reaches in the lowland sections of the Bokhara, Culgoa, Lower Darling/Baaka and Campaspe rivers, and the smaller upland, transitional Severn River, received Commonwealth environmental water in 8 of the 9 years. Some temporary rivers also received water in 7–8 of the years: Gunbower Creek, Tuppal Creek, Moonie River and the lower end of the Warrego River (Figure 2.13).

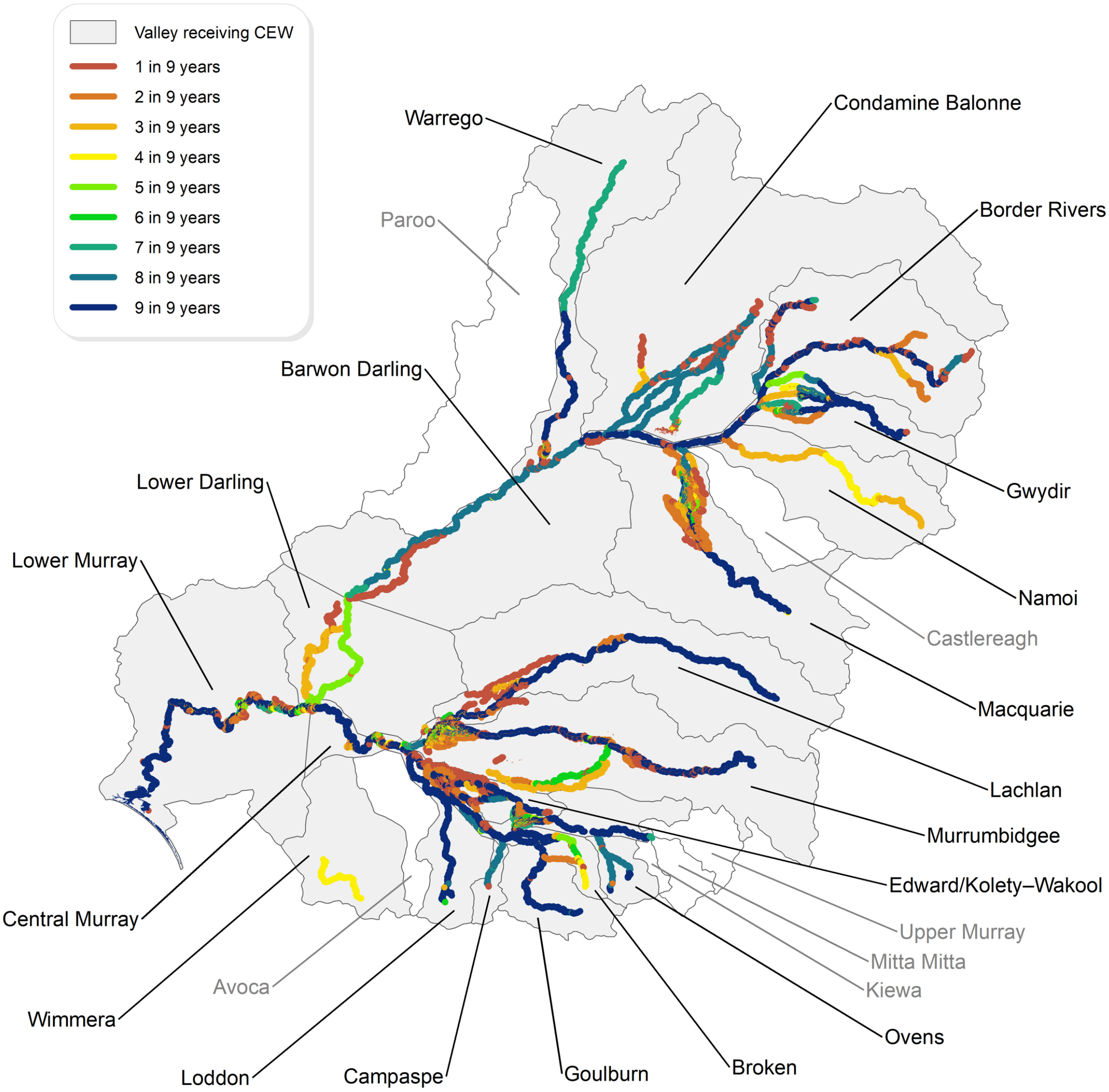

Figure 2.13 Map of annual frequency (from 1 in 9 years to 9 in 9 years) of Commonwealth environmental water in rivers in the Murray–Darling Basin, 2014–23

> The Strategy sets expected outcomes for connectivity as increased flows into the Murray and Darling rivers (Table 2.1). Due to high inflows, longitudinal connectivity targets were met through natural flows in 2022–23 rather than through the delivery of Commonwealth environmental water.

Natural flows were high in 2022–23 and, consequently, the contribution of Commonwealth environmental water to end-of-valley targets (as expressed as a percentage of total annual flow volume) was smaller than previous years (shown in Figure 2.14). Commonwealth environmental water plays a more significant role during drier periods; for example, contributing over 97% of total flow in the Darling River at Bourke in 2017–18. Commonwealth environmental water supported a 10% overall increase in flows in the Barwon Darling in 5 out of 9 years of monitoring. The exceptions were the wet periods of 2016–17 and 2020–23, when unregulated water inflows were significantly high. Commonwealth environmental water supported a 30% overall increase in flows in the Murray River in 2015–16, 2017–18 and 2019–20, all of which were significantly dry periods across the Basin.

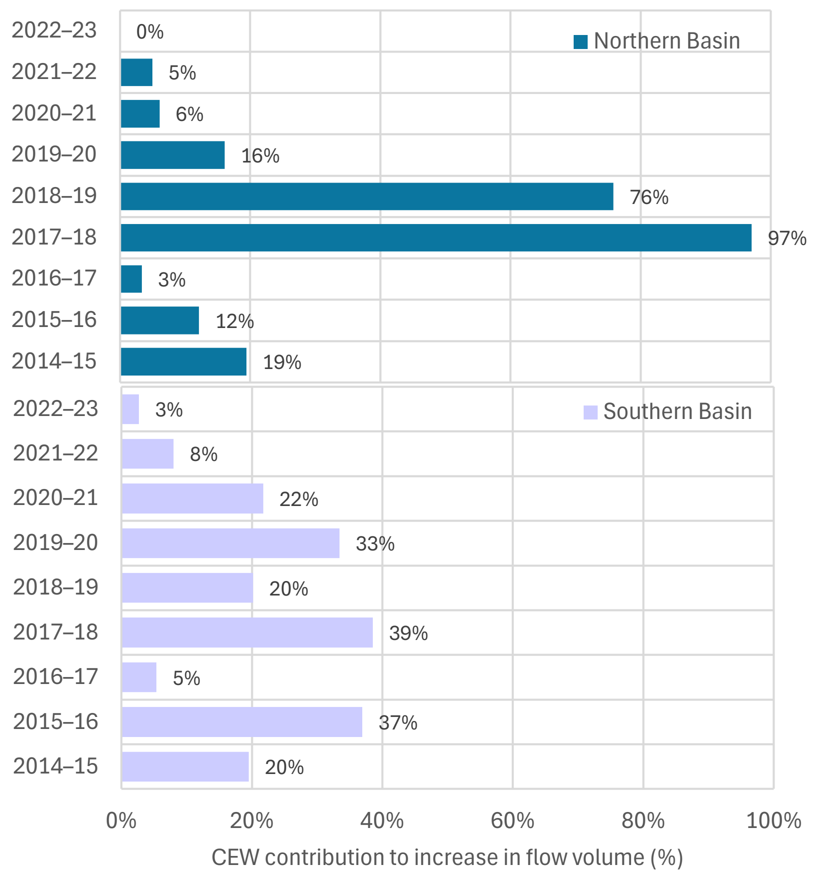

Figure 2.14 Percentage increases in annual flow volumes in (top) the Darling River at Bourke and (bottom) the Murray River at the South Australian border that are directly attributable to Commonwealth environmental water, 2014–23

For the northern Basin valleys, up to water year 2021–22, Louth was used as the point of evaluation. CEW = Commonwealth environmental water.

2.4.4 End-of-Basin flows

The Strategy sets flow volume and depth targets for the Coorong, Lower Lakes and Murray Mouth (Table 2.1). In 2022–23, due to high natural flows, barrage releases were above the 2,000 GL/year target without Commonwealth environmental water. Similarly, water levels in Lake Alexandrina did not fall below the 0.4 m Australian Height Datum target primarily due to high natural flows.

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. For example, the Coorong, Lower Lakes and Murray Mouth depends on freshwater flows that deliver longitudinal hydrological connectivity from upstream.

In 2022–23, Commonwealth environmental water contributed 753 GL to barrage releases (Table 2.2). In drier years, Commonwealth environmental water contributes up to 100% of flows at the barrages. In most years, barrage flow requirements are not met even with Commonwealth environmental water.

Table 2.2 Contribution of Commonwealth environmental water to barrage releases (South Australia barrage dashboard accounting data)

	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2021–23
CEW contribution (GL)	454	561	802	757	377	685	808	841	753
CEW contribution (% of barrage releases)	46	100	12	89	100	100	65	14	3
Barrage release (GL)	987	561	6,484	854	377	685	1,247	6,161	21,597

CEW = Commonwealth environmental water.

2.5 Lateral connectivity

The Strategy sets environmental outcomes for lateral connectivity, as an increase in the frequency of freshes, bankfull and overbank flow events (Table 2.1). In 2022–23, naturally wet conditions meant these outcomes were met without Commonwealth environmental water. Commonwealth environmental water was used to extend the duration of flow events.

Wetter conditions in 2022–23 resulted in high flows across the Basin, providing opportunities for extending the area and duration of inundation of floodplains and wetlands (Figure 2.15). In 2022–23, Commonwealth environmental water was delivered to floodplains and wetlands in 19 of the 25 valleys of the Basin:

- 202,071 ha of lakes and wetlands (14% of the area of lakes and wetlands on the managed floodplain)
- 22,205 km of permanent and temporary lowland rivers (41% of river length on the managed floodplain)
- 71,837 ha of floodplain, of 11 different floodplain vegetation communities, representing 5% of the managed floodplain in the Basin
- 23,768 ha of estuary habitat in the Coorong, Lower Lakes and Murray Mouth and 100% of the estuary on the managed floodplain, contributing to maintaining the ecological character of the Coorong and the Lakes Alexandrina and Albert Wetland Ramsar Site.

Specifically, in 2022–23, Commonwealth environmental water inundated:

- 5,953 ha of lakes and wetlands and 12,536 ha of floodplain in the Condamine Balonne, supporting 1,576 km of waterways
- 25,561 ha of lakes and wetlands and 19,905 ha of floodplain in the Macquarie, supporting 2,318 km of waterways
- 28,585 ha of lakes and wetlands and 3,509 ha of floodplain in the Central Murray, supporting 2,126 km of waterways
- 14,178 ha of lakes and wetlands and 32,325 ha of floodplain in the Murrumbidgee, supporting 3,002 km of waterways.

From 2014–23, Commonwealth environmental water supported:

- 123,336 ha of lakes (41% of lake area on the managed floodplain) for the Basin, including lakes Alexandrina and Albert

- 125,743 ha of palustrine wetland (25% of the wetland area on the managed floodplain)
- 187,486 ha of floodplain (12% of floodplain ecosystem area on the managed floodplain)[6]
- 27,715 km of waterway (52% of the river length on the managed floodplain)
- 23,768 ha of estuarine ecosystem (100% of the estuary on the managed floodplain).

Some floodplains in the Gwydir, Murrumbidgee, Lachlan, Central Murray, Lower Murray and Macquarie valleys were inundated nearly every year (7 or more of the 9 years). The Macquarie Valley received Commonwealth environmental water in 8 of the 9 years, targeting the restoration and protection of wetlands within the Macquarie Marshes. The Murrumbidgee received Commonwealth environmental water in 9 of the 9 years and the largest 1-in-9-year inundation magnitude, with 57,497 ha watered.

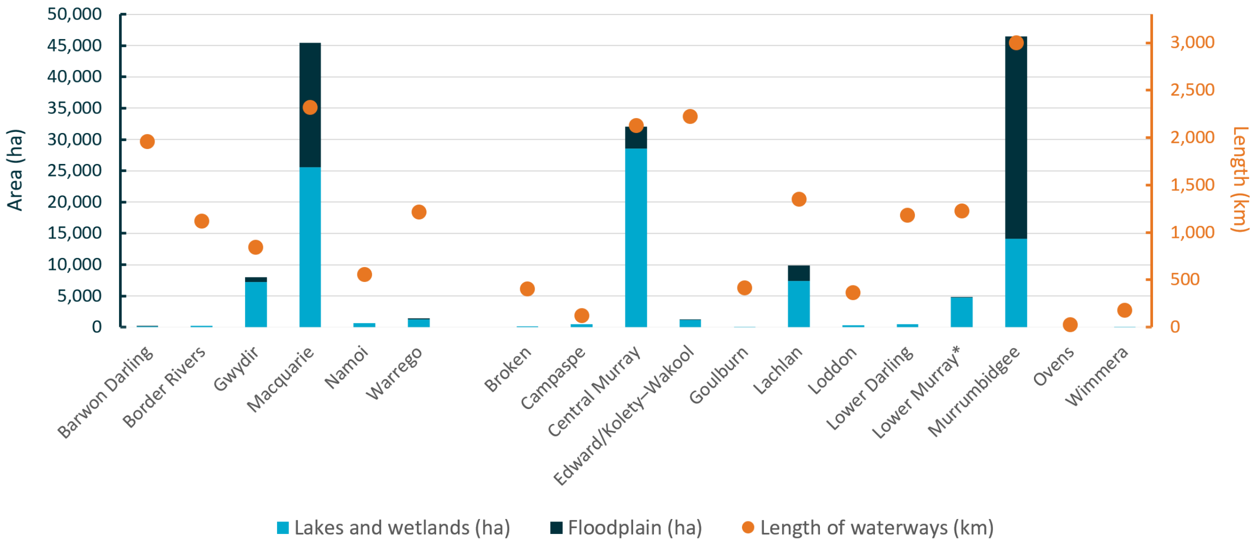

Figure 2.15 Area of lakes and wetlands and floodplain (left y-axis) and length of river (right y-axis) receiving Commonwealth environmental water, 2022–23

Lower Murray does not include Lower Lakes.

2.6 Basin ecosystems

This section presents findings from the Ecosystem Diversity evaluation for the 2022–23 water year, compared with the prior 8 years of monitoring, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Ecosystem Diversity' report (available from the DCCEEW Flow-MER Basin-scale Project publications page).

What did Commonwealth environmental water contribute to ecosystem diversity?

Commonwealth environmental water contributed to Basin Plan objective at paragraph 8.05(2)(a) *to protect and restore a subset of all water-dependent ecosystems of the Murray–Darling Basin*:

- Of the Basin ecosystem types, 97% occur on the managed floodplain. In 2022–23, 53 ANAE ecosystem types – representing 83% of the ecosystem diversity on the managed floodplain – received Commonwealth environmental water.
- The 9-year watering history (2014–23) included a similar diversity of ecosystem types through the years but a wide difference in the total areal extent.

[6] These 12 floodplain types comprise 11 floodplain types upstream of the Coorong, Lower Lakes and Murray Mouth and one additional type (paperbark-dominated floodplain) adjacent to the Coorong.

Using the ANAE classification system, 66 aquatic ecosystem types have been identified and mapped in the Basin.[7] 64 ecosystem types (97%) are represented on the managed floodplain – the area where watering with Commonwealth environmental water is possible – and the relative abundance (by area) of ecosystem types is similar when comparing the managed floodplain to the whole Basin.

In 2022–23, Commonwealth environmental water supported 53 ANAE ecosystem types (80% of types in the Basin and 83% of types on the managed floodplain). Over the 9-year period 2014–23, Commonwealth environmental water supported 56 ecosystem types (85% of the ANAE ecosystem types in the Basin and 88% of the ANAE types currently mapped on the managed floodplain), representing:[8]

- 125,743 ha of 21 types of palustrine wetland
- 187,486 ha of 12 types of floodplain
- 27,715 km of 7 types of waterway
- 23,768 ha of 9 types of estuarine ecosystems.

The frequency of delivery of Commonwealth environmental water across the Basin over the 9 years broadly aligned with the expected requirements of ecosystem types – more frequent support of permanent rivers, lakes, meadows and permanent tall marsh, and less frequent inundation of temporary channels, swamps and floodplains. Watering is responsive to climatic conditions and is sufficiently flexible to deliver water in accordance with Strategy priorities. Ecosystem types that in areas where they are able to receive environmental water are broadly representative of ecosystem types elsewhere in the Basin.

Temporary sedge/grass/forb marsh is the most extensive ecosystem type on the managed floodplain (131,050 ha), and 12% (15,642 ha) was watered at least once over the 9-year period 2014–23, with many of these areas watered multiple times. The Gwydir Wetlands and Macquarie Marshes received regular delivery of Commonwealth environmental water to inundate permanent and temporary tall emergent marsh, freshwater meadow, permanent wetland, permanent forb marsh and permanent sedge/grass/forb marsh.

Temporary river red gum swamp has the largest area supported by Commonwealth environmental water (37,781 ha). Most of this area has received Commonwealth environmental water in 7 of the 9 years since 2014–15, corresponding to water deliveries to Barmah–Millewa Forest. Temporary river red gum swamp is commonly supported by environmental water, due to its proximity and connectedness to lowland river channels. Fringing river red gums and swamps connected to waterways receive water during channel freshes or weir pool raising actions, in addition to actions that specifically target overbank flooding.

2.7 Ramsar wetlands

What did Commonwealth environmental water contribute to Ramsar wetlands in the Basin?

Basin Plan objective at paragraph 8.05(2)(a) is *to protect and restore a subset of all water-dependent ecosystems of the Murray–Darling Basin, including by ensuring that declared Ramsar wetlands that depend on Basin water resources maintain their ecological character*. In support of this objective, Commonwealth environmental water was delivered to 8 Ramsar sites in 2022–23, supporting approximately 165,000 ha of 51 ecosystem types within the Ramsar estate (including Lakes Alexandrina and Albert and the Coorong).

[7] This report uses the Bureau of Meteorology's Geofabric v3 river line mapping to categorise river ecosystems. The ANAE includes 4 additional river types to cater for gaps in the polygon mapping for rivers that are not used in the 2022–23 evaluation but have contributed to totals in previous years.

[8] Total figures for the Basin, including the Coorong, Lower Lakes and Murray Mouth, except where stated otherwise.

Eleven of the 16 Ramsar wetlands[9] in the Basin (Figure 2.16) are actively supported by Commonwealth environmental water. The remaining 5 Ramsar sites cannot receive environmental water due to their location in the river system.

In 2022–23, 437 GL of Commonwealth environmental water (1,050 GL across all water holders) were delivered to 8 Ramsar sites in the Basin. In many instances, water delivered to floodplains is returned to the river and subsequently inundates Ramsar sites downstream. For example, water in the Barmah Forest flows back into the Murray and may inundate Gunbower Forest, Hattah–Kulkyne Lakes and Riverland Ramsar sites further downstream. Since 2014, Commonwealth environmental water has supported 11 Ramsar areas (often in combination with other environmental water [Table 2.3]).

In 2022–23, following widespread natural flooding at the Gwydir Wetlands: Gingham and Lower Gwydir (Big Leather) Watercourses, Macquarie Marshes, Narran Lake Nature Reserve and Barmah Forest Ramsar sites, Commonwealth environmental water was delivered to these Ramsar wetlands, supporting vulnerable vegetation communities and waterbird breeding.

Highlights of the contribution of Commonwealth environmental water in 2022–23 include:

- maintenance of waterbird breeding aggregations that formed after widespread natural flooding at the Gwydir Wetlands: Gingham and Lower Gwydir (Big Leather) Watercourses, Macquarie Marshes, Narran Lake Nature Reserve and Barmah Forest Ramsar sites
- watering of vegetation listed as critical; for example:
  - 99 ha (100%) of freshwater meadows in the Barmah Forest Ramsar Site, with observations of growth and flowering of Moira grass (*Pseudoraphis spinescens*)
  - nationally vulnerable river swamp wallaby-grass (*Amphibromus fluitans*) supported at Pollack Swamp in the NSW Central Murray Forests Ramsar Site
  - extensive inundation (2,676 ha, 98%) of the tall marsh of the Macquarie Marshes Ramsar Site
  - extensive inundation (1,544 ha, 39%) of lignum (*Muehlenbeckia florulenta*) in the Narran Lake Nature Reserve Ramsar Site
- maintenance of end-of-system flows in the Coorong, Lower Lakes and Murray Mouth.

[9] Convention on Wetlands of International Importance (the Ramsar Convention 1971).

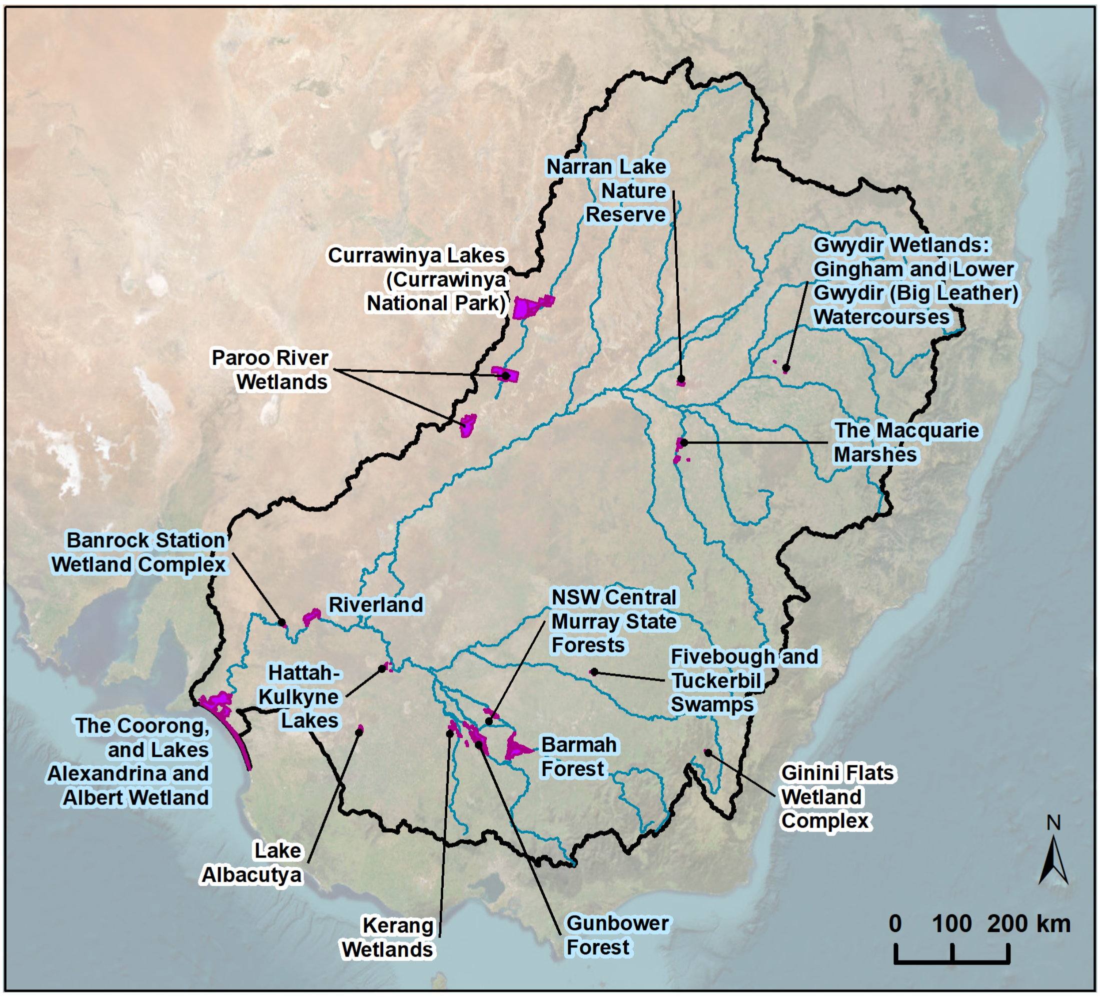

Figure 2.16 Ramsar sites in the Murray–Darling Basin

Those receiving Commonwealth environmental water between 2014–23 are highlighted in blue.

Table 2.3 Areas of Ramsar sites (hectares) supported by Commonwealth environmental water, 2014–23

Most water delivery to Ramsar sites was in conjunction with other water, and the areal contribution of Commonwealth environmental water cannot be apportioned.

Ramsar area	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
Gwydir Wetlands[a]	648	565	649	618	736	0	588	519	701
Narran Lake Nature Reserve	0	0	838	0	0	4,380	1,697	2,376	2,322
Macquarie Marshes	5,471	6,118	8,364	8,632	6,848	0	7,143	11,396	10,232
Banrock Station Wetland Complex	11	495	0	301	91	59	37	243	0
Barmah Forest[b]	0	24,647	0	24,969	24,747	24,116	24,614	25,923	25,526
Gunbower Forest[c]	0	-	-	-	-	-	-	-	419
The Coorong, and Lakes Alexandrina and Albert Wetland	116,843	116,843	116,843	116,848	116,848	117,022	117,022	116,848	116,871
Fivebough and Tuckerbil Swamps	0	0	0	272	599	272	599	0	0
Hattah-Kulkyne Lakes	965	954	0	842	0	125	0	0	0
NSW Central Murray Forests[b]	0	6,091	0	5,875	7,165	3,794	5,410	16,520	6,252
Riverland	**504**	**3,574**	**321**	**4,277**	**3,298**	**2,775**	**3,904**	**1,452**	**55**

[a] Gingham and Lower Gwydir (Big Leather) Watercourses

[b] For this table, NSW Central Murray Forests includes Koondrook and Werai Forests – Millewa forest is included with Barmah Forest

[c] No inundation mapped; however, Commonwealth environmental water supporting 52 km of Gunbower Creek base flows within the Gunbower Forest Ramsar Site.

HIGHLIGHT: WATERING RAMSAR WETLAND SITES FOR A SECOND CONSECUTIVE YEAR

In 2021–22, environmental water supported waterbird breeding in the Gwydir Wetlands, contributing to the first simultaneous breeding across **Narran Lake Nature Reserve, the Macquarie Marshes** and **Gwydir Wetlands** Ramsar sites in 24 years. In 2022–23, a wet spring stimulated waterbird breeding across these sites for a second consecutive year, and environmental water was used to extend the duration of natural flooding to maintain water at nesting and foraging sites.

GWYDIR WETLANDS: GINGHAM AND LOWER GWYDIR WATERCOURSES

The Gwydir Wetlands Ramsar site consists of 4 small wetlands in the Gwydir River wetland system. It contains extensive stands of water couch in freshwater meadows that are important for waterbirds. In 2022–23, Commonwealth environmental water was used to supplement New South Wales (NSW) Environmental Contingency Allowance water and maintain water at nesting and foraging sites over summer, until breeding completed. Environmental water inundates 701 ha (83% of the Ramsar site), supporting around 4,000 ibis nesting at Goddard's Lease, and freshwater meadows (672 ha), temporary tall emergent marsh (17 ha) and unvegetated clay pans (7 ha) at Old Dromana and Gingham Watercourse in the Ramsar Site.

THE MACQUARIE MARSHES

In 2021–22, environmental water was used to support waterbird breeding and provide foraging habitat for juvenile birds. The Macquarie Marshes Ramsar Site is within the larger Macquarie Marshes ecosystem that comprises Macquarie Marshes Nature Reserve and the privately owned Wilgara Wetland and U-Block. The site includes significant tall marsh and river red gum forest communities and an abundance and diversity of waterbirds and aggregate-nesting waterbird species.

Providing water to the Macquarie Marshes to support waterbird habitat was a Basin priority for 2022–23. In total, more than 30 GL were delivered, including 10 GL of Commonwealth environmental water, from February to March 2023. This maintained water levels in breeding aggregations to support completion of waterbird breeding and provide foraging habitat for juvenile birds.

NARRAN LAKE NATURE RESERVE

In 2021–22, environmental water supported the largest waterbird breeding event on Narran Lakes in a decade. The Narran Lake Nature Reserve is the northern part of a large terminal lake system at the end of the Narran River. The site contains extensive channelised wetlands supporting lignum, river cooba (*Acacia salicina*) and black box (*Eucalyptus largiflorens*) vegetation used for breeding by waterbirds.

Providing water to Narran Lakes was a Basin priority for 2022–23, to support lignum communities and waterbird breeding and recruitment for a second consecutive year. During July and August 2022, 113 GL of Commonwealth environmental water were delivered to the Lower Balonne floodplain.

Combined with natural flooding, 10,233 ha of the Ramsar site was inundated (56%), supporting 80–98% of the river red gum and tall marsh habitats, critical to the ecological character of the Ramsar site, and 12,294 ha of lignum was ultimately inundated across the Narran Lakes. Marshes and floodplain trees (coolabah [*Eucalyptus coolabah*], river cooba and river red gum [*Eucalyptus camaldulensis*]) were inundated, and permanent wetlands (Long Arm, Back Lake and Clear Lake) were filled (Figure 2.17). These areas support rookeries and feeding and roosting habitat for nesting straw-necked ibis, spoonbills, egrets and cormorants. Over 7,000 straw-necked ibis nests and around 500 royal spoonbill nests were recorded.

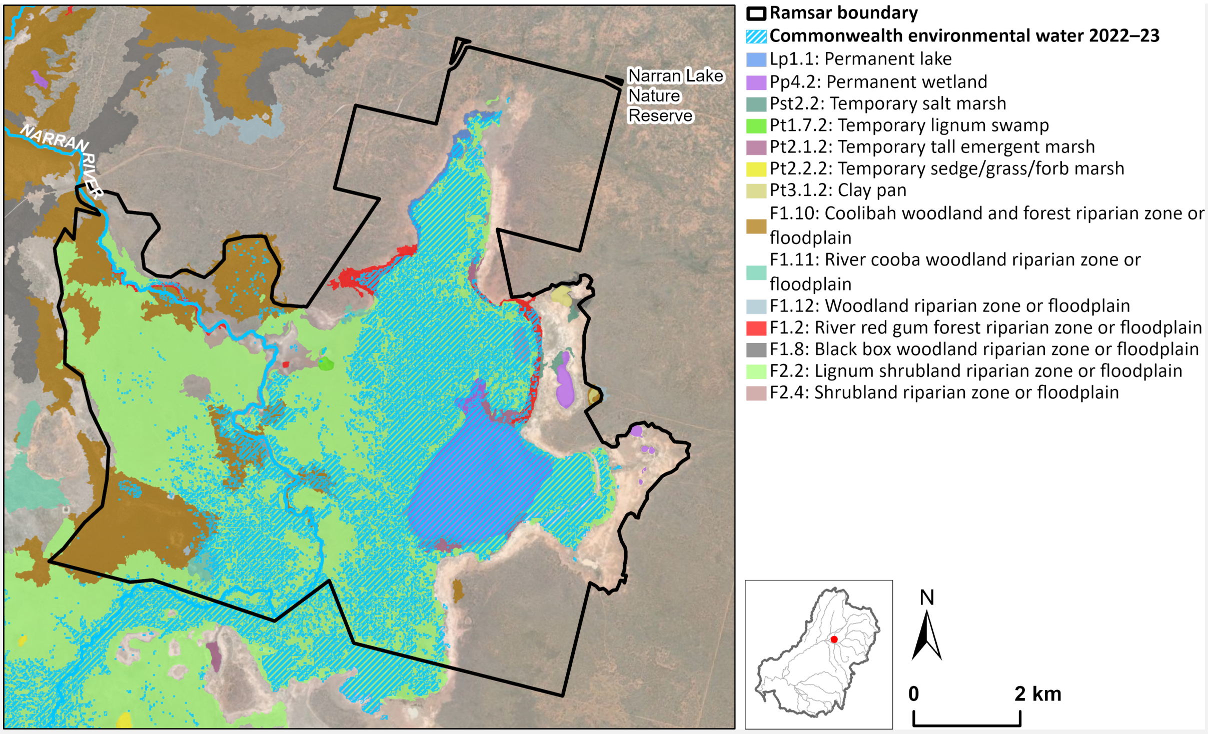

Figure 2.17 Ecosystem diversity within the Narran Lake Nature Reserve (Narran Lakes) Ramsar Site, showing 2022–23 inundation by 113 GL of Commonwealth environmental water combined with other water

3 OUTCOMES 2022–23

AT A GLANCE

VEGETATION

- Environmental water was important for maintaining the presence of submerged, amphibious and water-dependent plant species in the Basin in 2022–23.
- 68 water actions – totalling 904 GL – targeted vegetation outcomes. This is around half the volume delivered for vegetation in the previous year, due to the very wet conditions in 2022–23.
- 291 plant species were recorded in 2022–23, 73% of which were native. 10 previously unrecorded taxa were observed at wetland and riverine monitoring locations in the Basin.
- The extended wet conditions appear to favour native species, with the highest proportion of taxa and the greatest cover of native species observed between 2014 and 2023 being recorded over the past 2 years (2021–22 and 2022–23).
- 43 taxa used by Aboriginal people were recorded, including 12 recorded only at locations that experienced a wetter inundation regime because of environmental water.
- There was a greater proportion and cover of submerged and amphibious plants observed at sites that had wetter inundation regimes maintained using environmental water.

NATIVE FISH

- 61 water actions – totalling 1,010 GL – targeted native fish outcomes to enhance connectivity, provide cues for movement, improve habitat and, to a lesser extent, for targeted species outcomes.
- In this wet year, Commonwealth environmental water was used to water wetlands, improve water quality to maintain dissolved oxygen levels, maintain high flow rates during spring and summer, reduce rapid recession of river flows, and provide variable base flows and freshes. There were few direct associations to fish outcomes, as conditions throughout most of the Basin were dominated by high natural flows.
- 13 native fish species were detected in 2022–23 at monitoring locations, compared with 15 native fish species detected over the monitoring period (2014–23). An adult river blackfish (*Gadopsis marmoratus*) was detected in the Edward/Kolety–Wakool river systems for the first time (Flow-MER monitoring location).
- Golden perch (*Macquaria ambigua*) spawning occurred in the Goulburn River, and golden and/or silver perch eggs were detected in the Lower Murray River. Spawning was largely associated with unregulated high spring flows. Recruitment of golden perch was evident in the Lower Murray River, with little evidence of recruitment in other areas.
- There was evidence of Murray cod (*Maccullochella peelii*) recruitment in the Lower Murray River. In other areas, high flows and velocities during key spawning periods may have displaced eggs and larvae, or Murray cod prey, and impacted negatively on recruitment.
- Australian smelt (*Retropinna semoni*) had higher abundances (representative of recruitment for this short-lived species) than in previous years in the Edward/Kolety–Wakool and Murrumbidgee river

systems, likely because greater hydrological connectivity increased favourable breeding habitats (within-channel and connecting wetlands) and food resources for this species.

- Murray–Darling rainbowfish (*Melanotaenia fluviatilis*) had lower abundance (representative of recruitment) than in previous years at most Selected Areas, likely due to high flows negatively impacting on the populations, as this species prefers low-to-moderate stable flows for optimal spawning and recruitment.
- Some exotic species (common carp [*Cyprinus carpio*], goldfish [*Carassius auratus*]) displayed strong recruitment in 2022–23, which may be due to the unregulated high flows and overbank flooding providing favourable conditions.

WATERBIRDS

- 39 water actions – totalling 699 GL – targeted waterbird outcomes.
- Combined Flow-MER and complementary NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) data were available for the Gwydir River System, Junction of Warrego and Darling rivers, Murrumbidgee River System, Macquarie Marshes, Central Murray, Lachlan and Condamine (Narran Lakes). In total, 103,329 individuals representing 84 species were reported.
- 18 conservation-significant species were identified from the combined Flow-MER and NSW DCCEEW monitoring in 2022–23, including 3 species listed under the Australian *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) – Australasian bittern (*Botaurus poiciloptilus*), sharp-tailed sandpiper (*Calidris acuminata*) and Latham's snipe (*Gallinago hardwickii*). Other species of significance included the threatened black-necked stork (*Ephippiorhynchus asiaticus*), blue-billed duck (*Oxyura australis*), freckled duck (*Stictonetta naevosa*) and marsh sandpiper (*Tringa stagnatilis*).
- Aggregate-nesting species were recorded breeding across multiple valleys. Species included the Australian white ibis (*Threskiornis molucca*), royal spoonbill (*Platalea regia*), yellow-billed spoonbill (*Platalea flavipes*), straw-necked ibis (*Threskiornis spinicollis*), glossy ibis (*Plegadis falcinellus*), little pied cormorant (*Microcarbo melanoleucos*), little black cormorant (*Phalacrocorax sulcirostris*), Australasian darter (*Anhinga novaehollandiae*), great cormorant (*Phalacrocorax carbo*), nankeen night-heron (*Nycticorax caledonicus*), white-necked heron (*Ardea pacifica)*, eastern great egret (*Ardea alba modesta*) and plumed egret (*Ardea plumifera*).

OTHER ENVIRONMENTAL OUTCOMES

- Commonwealth environmental water contributed to the Basin Plan salt-export objective of 2 million tonnes per year by exporting 151,000 tonnes of salt (approximately 5% of the total salt export to the ocean in 2022–23).
- Commonwealth environmental water was delivered to support the life cycles of nationally and state-listed threatened species, including the broad-shelled turtle (*Chelodina expansa*), Murray hardyhead (*Craterocephalus fluviatilis*), platypus (*Ornithorhynchus anatinus*) and southern bell frog (*Litoria raniformis*).
- 11 frog species were detected from combined Flow-MER and complementary NSW DCCEEW monitoring. Southern bell frog adults and tadpoles were identified in locations receiving Commonwealth environmental water in the lower Murrumbidgee, and adults were detected in the lower Lachlan.

3.1 Biodiversity outcomes 2022–23

Environmental watering can play a crucial role in maintaining species and community diversity across the Basin. Many water-dependent species and ecosystems found in the Basin 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. This section describes the importance of Commonwealth environmental water for maintaining Basin ecosystems and the biodiversity that depends on them. Monitoring of ecological outcomes in 2022–23 was constrained due to wet conditions restricting access to monitoring locations or high waters reducing efficiency of standard methodology (e.g. electrofishing). Outcomes from this recent year should be treated with some caution until further assessments are made in future years.

During 2022–23, 1,385 GL of Commonwealth environmental water targeted multiple outcomes, including 989 GL for outcomes relating broadly to biodiversity (waterbirds and other fauna), 904 GL for vegetation outcomes and 1,010 GL for fish outcomes (noting that individual watering actions may include outcomes for any or all of biodiversity, fish and vegetation).

3.1.1 Vegetation

This section presents findings from the Vegetation evaluation for the 2022–23 water year, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Vegetation' report available from the Australian Department of Climate Change, Energy, the Environment and Water website).

WHAT DID COMMONWEALTH ENVIRONMENTAL WATER CONTRIBUTE TO PLANT SPECIES DIVERSITY?

WHAT DID COMMONWEALTH ENVIRONMENTAL WATER CONTRIBUTE TO VEGETATION COMMUNITY DIVERSITY?

Changes in flow regimes are likely to significantly impact vegetation diversity across multiple scales, from local presence and abundance of plant species to landscape-scale vegetation community composition and structure. This evaluation reports on the contribution of Commonwealth environmental water to the diversity and condition of non-woody vegetation, including aquatic macrophytes, herbs, sedges and rushes.

Evaluation of vegetation community diversity considers the composition and structure of vegetation assemblages occurring in riverine and floodplain–wetland habitats, including water plant functional groups (submerged, amphibious, damp, woody flood-dependent, terrestrial), species growth forms (forbs, grasses, ferns), native and exotic species, rare and threatened species, and species that are known to be used by Aboriginal people. After 3 consecutive wet years, differences were still observed in the 2022–23 vegetation assemblages associated with sites that have a wetter inundation regime supported by environmental water, compared with those that have a drier inundation regime. There was a greater proportion and cover of submerged and amphibious plants observed at sites that had wetter inundation regimes maintained using environmental water. It is likely that the absence of environmental water there would have resulted in a near-absence of submerged species and considerably less diversity and cover of amphibious and damp-loving species at many sites in the Basin.

Vegetation diversity outcomes for 2022–23 include:

- **Commonwealth environmental water support for vegetation communities.** 904 GL of Commonwealth environmental water were delivered for vegetation outcomes through 68 watering actions during 2022–23. As a result of wet conditions, this was less than half of the volume delivered for vegetation outcomes in 2021–22. These actions helped sustain vegetation communities that include submerged, amphibious or damp-loving species and contributed to maintaining a diversity of riverine and floodplain–wetland ecosystem types in the Basin.

- **Strategy annual watering priorities for vegetation, 2022–23.** Vegetated ecosystems were supported in agreement with the Strategy's Basin-wide annual watering priorities for 2022–23.
  - Non-woody vegetation priorities to provide opportunities for growth were met. Commonwealth environmental water was delivered to 31,137 ha of meadow and marsh upstream of the Lower Lakes, 8,876 ha of marsh around the Lower Lakes and 5 ha of sedge/forb/grassland riparian zone or floodplain, and 22,205 km of river channel was inundated, supporting non-woody riverbank vegetation.
  - A rolling priority to maintain the extent, improve the condition, and promote recruitment of forests and woodlands was met, with Commonwealth environmental water delivered to 69,888 ha of woody wetlands (swamps) and inundated 71,303 ha of woody floodplain vegetation.
  - A rolling priority to maintain the extent and improve the condition of lignum shrublands, and an annual priority to support the continued recovery of lignum shrublands at Narran Lakes and other key sites in the northern Basin, were met, with 13,021 ha of lignum floodplain inundated. Another 298 ha of temporary lignum swamp received Commonwealth environmental water.
  - An annual priority to support recovery of core wetland vegetation and emerging vegetation, by supplementing natural flows at key sites in the Macquarie Marshes, was met by watering a total of 25,561 ha of wetlands and 19,905 ha of floodplain in the Macquarie Valley, including 10,232 ha (56%) of the Macquarie Marshes Ramsar Site.
  - A rolling priority to expand the extent and improve the condition of Moira grass in Barmah–Millewa Forest was met by Commonwealth environmental water and natural flooding, which promoted Moira grass growth and flowering.
  - Annual priorities to increase inundation higher on the floodplain, to support parched and stressed forests and woodlands at key sites in the Lower Murray valley and provide flows to improve the health of black box communities higher on the floodplain, were met by extensive natural flooding. Commonwealth environmental water made a small contribution (less than 5% of the area of black box on the managed floodplain), with 93 ha of temporary black box swamp and 8 ha of black box woodland riparian zone or floodplain watered in the Central Murray Valley.
- **Commonwealth environmental water support for groundcover plants**
  - Environmental water has contributed to maintaining the cover (amount) of water plants. There was a greater proportion and cover of submerged and amphibious plants observed at sites that had wetter inundation regimes maintained using environmental water.
  - Following extended wet conditions, 291 plant taxa were observed in 2022–23 across floodplain, wetland and riverine monitoring locations. Most were native plants (73% of taxa). 13 new plant species were observed, including 10 new species recorded in locations monitored since 2014.
  - The extended wet conditions appear to favour native species, with the highest proportion of taxa and the greatest cover of native species recorded in the past 2 years (2021–22 and 2022–23).
  - By supporting wetter inundation regimes in 2021–22 and 2022–23, environmental water has supported submerged, amphibious and damp-loving species, such as ferns and fern allies, sedges and rushes. This contributes to structural diversity of vegetation and provides habitat diversity.
  - Without environmental water, there would likely have been a near-absence of submerged species and less diversity and cover of amphibious and damp-loving species at 45% of monitoring locations.
- **Commonwealth environmental water support for plants with traditional Aboriginal uses**
  - 43 taxa used by Aboriginal people were recorded in 2022–23, including 12 recorded only at locations that experienced a wetter inundation regime because of environmental water.

- These plants are used for food (14 taxa), fibre and shelter (3 taxa), medicine (3 taxa), fishing and hunting (1 taxon) or have multiple uses (remaining taxa).
- 17 plants used by Aboriginal people require support by flooding, including 5 amphibious, 2 submerged and 10 damp-loving taxa.

- **Commonwealth environmental water support for threatened species**
  - 36 listed species were recorded at monitored locations in 2022–23.

3.1.2 Native fish

This section presents findings from the Fish evaluation for the 2022–23 water year, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Fish' report available from the Australian Department of Climate Change, Energy, the Environment and Water website).

WHAT DID COMMONWEALTH ENVIRONMENTAL WATER CONTRIBUTE TO SUSTAINING NATIVE FISH?

Many of the critical life-history processes for fish (pre-spawning condition and maturation, spawning cues and movements, larval and juvenile dispersal, growth and survival) are linked either directly or indirectly to the flow regime. In the Basin, the delivery of environmental water is a key approach to supporting critical life-history processes and sustaining and restoring native fish populations. This evaluation reports on the contribution of Commonwealth environmental water to sustaining native fish.

In 2022–23, the Murray–Darling Basin experienced unregulated high flows and overbank flooding, with extensive floodplain inundation in some areas. In this wet year, Commonwealth environmental water inundated wetlands, improved water quality by maintaining dissolved oxygen levels above critical thresholds, maintained high flow rates during spring and summer, reduced the rapid recession of flows, and provided variable base flows and freshes. Unregulated high flows and overbank flooding in some areas provided favourable conditions for exotic species, with very strong recruitment of common carp and goldfish.

Outcomes for native fish in 2022–23 included:

- **Commonwealth environmental water providing flows and habitat for native fish**
  - 1,010 GL of Commonwealth environmental water were delivered for fish expected outcomes, through 61 watering actions, primarily to enhance connectivity or provide cues to support fish movement, improve habitat, and for various targeted species outcomes.
  - Australian smelt had higher relative abundances and recruitment compared with previous years in the Edward/Kolety–Wakool and Murrumbidgee river systems. Although some small-bodied native species are less dependent on flows for spawning and recruitment than large-bodied species, higher flows likely facilitated hydrological connectivity and increased available habitat and food resources for this small-bodied native fish species.
  - Abundance and recruitment of the Murray–Darling rainbowfish was lower than previous years. High natural flows may have impacted populations of this species, as it prefers low-to-moderate stable flows during their extended spawning and recruitment period (late spring to early autumn).
  - Analysis indicated positive associations for Commonwealth environmental water and small-bodied fish recruitment for Australian smelt and Murray–Darling rainbowfish in the Goulburn River.
- **Murray cod populations**
  - There was evidence of recruitment of Murray cod in the Lower Murray River.
  - Elsewhere, low abundances of young-of-year were observed, possibly due to high natural flows (and associated high velocities) during the main spawning and larval development period displacing eggs

or larvae, or Murray cod prey, or potentially hypoxic conditions leading to fish emigration or mortality.
  - Analysis indicated a positive association for Commonwealth environmental water supporting Murray cod recruitment in the Goulburn River, due to a reduction in the number of low-flow days.
- Golden perch populations
  - Golden perch spawned in the Goulburn River, and the eggs from golden and/or silver perch were detected in the Lower Murray River. Analysis indicated no positive associations for Commonwealth environmental water supporting spawning, which suggests spawning was largely associated with unregulated high spring flows.
  - Recruitment of golden perch occurred in the Lower Murray River. However, there was limited evidence of recruitment in the other monitoring locations. It is possible high flows may have reduced the detectability of larvae, eggs and new recruits, or limited spawning/recruitment may be due to competition or predation from the strong recruitment of common carp (assuming food limitation).
  - Future monitoring of juvenile fish and year-class assessments will provide important information on golden perch recruitment during the 2022–23 flood period.
  - Golden perch recruitment was low in most monitoring locations except in the Lower Murray River.
- Strategy annual watering priorities for fish in 2022–23
  - No loss of native species was evident in monitoring locations, with 13 native fish species detected in 2022–23 at monitored sites. In 2022–23, for the first time, there was detection of an adult river blackfish (*Gadopsis marmoratus*) in the Edward/Kolety–Wakool river systems.
  - Evidence of Murray cod recruitment was minimal in most monitoring locations except in the Lower Murray, possibly due to high flows and flooding displacing eggs or larvae, or Murray cod prey, from recruitment areas during the spawning period, or past hypoxic conditions causing fish emigration or fish deaths. Poor recruitment of Murray cod has been observed elsewhere in the southern Basin.[10]

3.1.3 Waterbirds

This section presents findings from the Species Diversity evaluation for the 2022–23 water year, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Species Diversity' report available from the Australian Department of Climate Change, Energy, the Environment and Water website).

WHAT DID COMMONWEALTH ENVIRONMENTAL WATER CONTRIBUTE TO SPECIES DIVERSITY?

- What was the contribution of Commonwealth environmental water to the diversity and abundance of waterbirds?
- What was the contribution of Commonwealth environmental water to threatened species and ecological communities?
- What was the contribution of Commonwealth environmental water to migratory species listed under international agreements – Bonn Convention, China–Australia Migratory Bird Agreement (CAMBA), Japan–Australia Migratory Bird Agreement (JAMBA) or Republic of Korea–Australia Migratory Bird Agreement (ROKAMBA)?

There are over 100 waterbird species known to occur in the Basin. This includes 16 species listed under the

[10] Stoios R, Tonkin Z, Yen J, Kitchingman A and Lyon J (2023) *Floodwater short-term impacts and potential recovery paths of freshwater fish populations*, unpublished report for the Victoria Department of Energy, Environment and Climate Action – Water and Catchments Division, Arthur Rylah Institute for Environmental Research, Department of Energy, Environment and Climate Action.

EPBC Act and 25 species listed under international migratory waterbird treaties (Bonn Convention, CAMBA, JAMBA or ROKAMBA).[11] There is growing evidence of the importance of environmental water to maintain waterbird populations in Australia.[11] Evaluation of outcomes for waterbirds (as well as frogs**,** turtles and other water-dependent aquatic reptiles, mammals and birds; Section 3.1.4) considers outcomes for listed threatened species as defined under the EPBC Act and relevant state legislation.

In 2022–23, there was widespread natural inundation across much of the managed floodplain, with Commonwealth environmental water used to sustain waterbird breeding events. A total of 299 GL of Commonwealth environmental water were delivered, with objectives related to waterbird breeding across 6 valleys: Murrumbidgee (76 GL), Central Murray (94 GL), Gwydir (3 GL), Macquarie (10 GL), Wimmera (2 GL) and Condamine Balonne (Narran Lakes) (113 GL). The largest volumes were delivered to the Narran Lakes to support lignum rookery habitat. Multiple actions were undertaken between July and September 2022.

Top-up flows designed to sustain rookeries occurred in the Murrumbidgee, Macquarie Marshes, Gwydir and Central Murray. In the Murrumbidgee, flows were delivered between December 2022 and March 2023 to sustain large rookeries in Bala (Gayini). In the Central Murray, Commonwealth environmental water was delivered between December 2022 and January 2023 to support waterbird breeding in Boals Deadwoods (Barmah Forest) and Gulpa wetlands complex (Millewa Forest). Summer flows to sustain rookeries also commenced in February to March 2023 in the Macquarie Marches and January to March in Gwydir. In the Wimmera, flows commenced in March 2023 and continued through to June 2023, targeting the Wimmera River and Mt William Creek with objectives to 'maintain current species diversity; improve breeding success and numbers' of waterbirds.

> Widespread unregulated floodplain inundation triggered significant waterbird breeding events across the Basin. There was large-scale breeding by aggregate-nesting waterbirds – Australian white ibis, Australian pelicans, royal spoonbill, yellow-billed spoonbill, straw-necked ibis, glossy ibis, little pied cormorant, little black cormorant, Australasian darter, great cormorant, nankeen night-heron, white-necked heron, white-faced heron, eastern great egret and plumed egret. Commonwealth and other environmental water was used to extend the duration of inundation in support of waterbird breeding.

Combined Flow-MER and complementary NSW DCCEEW data on waterbird observations were available for the Gwydir River System, Junction of Warrego and Darling rivers, Murrumbidgee River System, Macquarie Marshes, Central Murray, Lachlan and Condamine (Narran Lakes).

Outcomes for waterbirds in 2022–23 include:

- Widespread unregulated floodplain inundation triggered waterbird breeding in the Murrumbidgee, Lachlan, Gwydir, Central Murray, Condamine Balonne and Macquarie valleys.
- **Commonwealth environmental water support for waterbirds**
  - 699 GL of Commonwealth environmental water were delivered to support waterbirds through 39 watering actions.
  - Commonwealth environmental water was delivered between December 2022 and March 2023 to sustain waterbird rookeries in the Murrumbidgee, Macquarie Marshes, Gwydir and Central Murray.
  - Aggregate-nesting species were recorded breeding across multiple valleys. Species included the Australian white ibis, Australian pelicans, royal spoonbill, yellow-billed spoonbill, straw-necked ibis, glossy ibis, little pied cormorant, little black cormorant, Australasian darter, great cormorant, nankeen night-heron, white-necked heron, white-faced heron, eastern great egret and plumed egret.

[11] *Waterbirds of the Murray–Darling Basin, 2017 Basin Plan Evaluation*, Murray–Darling Basin Authority. Canberra ACT.

- 84 waterbird species were reported from 8 functional groups and 2 water-associated groups (reed-inhabiting passerines and raptors) from monitoring locations in the Gwydir, Warrego, Darling, Macquarie, Murrumbidgee, Central Murray, Lachlan and Condamine Balonne (Narran Lakes) rivers.

- **Commonwealth environmental water support for threatened and/or listed waterbirds**
  - 35 conservation-significant species were identified from the combined Flow-MER and NSW DCCEEW monitoring in 2022–23, including 3 species listed under the EPBC Act – Australasian bittern (*Botaurus poiciloptilus*), sharp-tailed sandpiper (*Calidris acuminata*) and Latham's snipe (*Gallinago hardwickii*).
  - Other species of significance included the threatened black-necked stork (*Ephippiorhynchus asiaticus*), blue-billed duck (*Oxyura australis*), freckled duck (*Stictonetta naevosa*) and marsh sandpiper (*Tringa stagnatilis*).

3.1.4 Other fauna – turtles, snakes and frogs

This section presents findings from the Species Diversity evaluation for the 2022–23 water year, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Species Diversity' report available from the Australian Department of Climate Change, Energy, the Environment and Water website).

What did Commonwealth environmental water contribute to species diversity?

- What was the contribution of Commonwealth environmental water to the diversity and abundance of frogs, turtles and other water-dependent vertebrates?
- What was the contribution of Commonwealth environmental water to threatened species and ecological communities?

- **Commonwealth environmental water support for frogs and other biota**
  - 31 watering actions delivered 144 GL of Commonwealth environmental water with objectives related to frogs, and 39 watering actions delivered 319 GL with objectives related to 'other biota'.
  - In 2022–23, 11 species of frog were detected at monitored locations, with the most widespread being the spotted marsh frog (*Limnodynastes tasmaniensis*), barking marsh frog (*Limnodynastes fletcheri*) and Peron's tree frog (*Litoria peronii*).
  - A single record of Sudell's froglet (*Neobatrachus sudellae*) was detected in the Yanco–Billabong creek system during Murrumbidgee monitoring.
- **Commonwealth environmental water support for threatened species**
  - 10 watering actions delivered 297 GL with at least one watering objective related to listed species.
  - Southern bell frog (*Litoria raniformis*) (listed as Vulnerable under the EPBC Act) adults and tadpoles were identified in the lower Murrumbidgee, and adults were detected in the lower Lachlan.
  - Commonwealth environmental water supported habitat for nationally and state-listed threatened species, including the grey snake (*Hemiaspis damelii*), regent parrot (*Polytelis anthopeplus*), platypus, large-footed myotis (*Myotis macropus,* also known as the southern myotis) and southern bell frog.

Highlight: Supporting the recovery of the threatened southern bell frog

Commonwealth environmental water significantly benefitted southern bell frogs (*Litoria raniformis*), a species listed as vulnerable under the EPBC Act. The southern bell frog is a large, wetland-dependent frog found in floodplain wetlands in the Murrumbidgee River System, Lachlan River System, Central Murray and Lower Murray. This sensitive species needs its critical refuge habitats maintained by water during dry periods. Flow-MER research has shown that even a 2-year dry spell can make a wetland uninhabitable for this frog. Targeted watering objectives for this species include supporting its habitat, breeding and recruitment. The delivery of Commonwealth environmental water since 2014 has increased the number of sites occupied by the frog (Figure 3.1). Many of these are sites the frog had previously disappeared from – meaning that the southern bell frog is moving back into areas where it once lived and being supported in areas where it continues to live, thanks to the delivery of environmental water by the Commonwealth and other environmental water managers.

In the Murrumbidgee, southern bell frogs have been monitored since 2000. Over the past 5 years, the frogs have moved back into wetlands through the North Redbank and Western Lakes areas where they hadn't been seen for more than 10 years. And southern bell frogs successfully produced their next generation in the Murrumbidgee, Central Murray and Lower Murray valleys after inundation supported by Commonwealth environmental water.

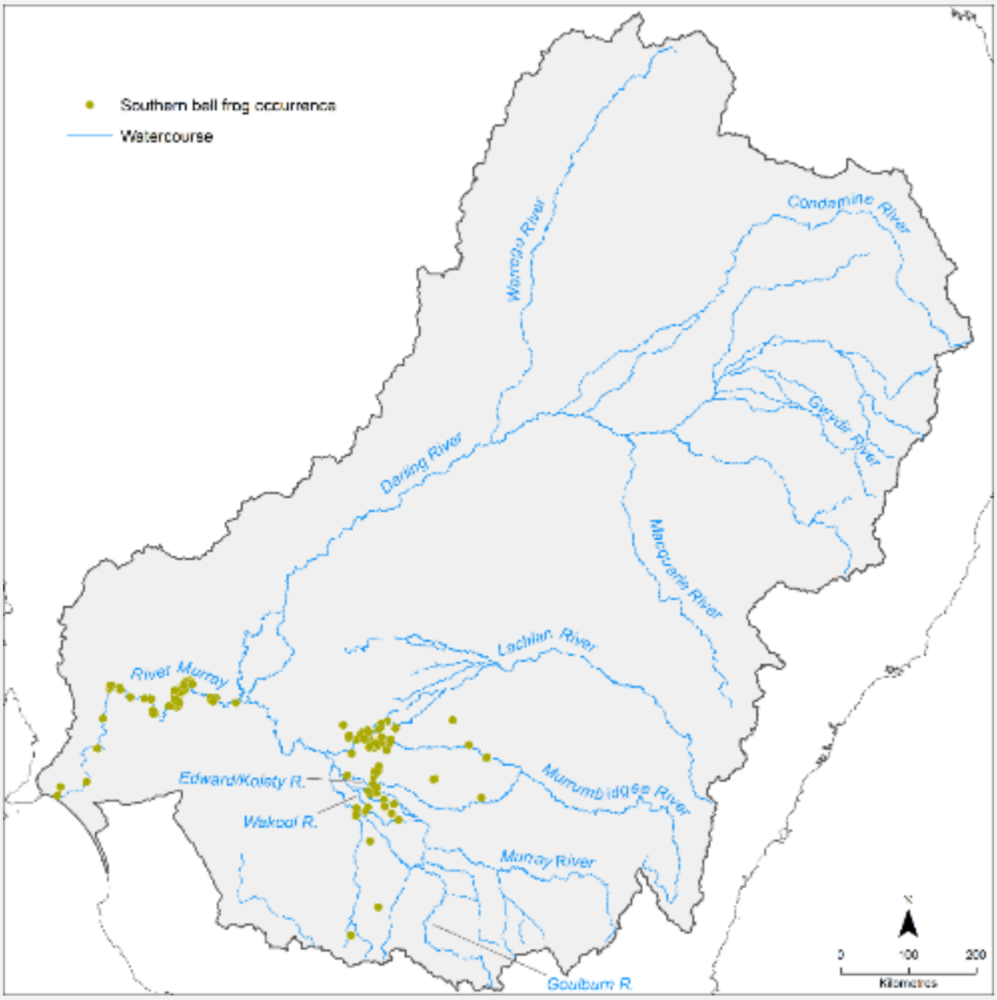

Figure 3.1 Detections of southern bell frogs aligned with inundation by Commonwealth environmental water
Data source: Atlas of Living Australia, including NSW Department of Climate Change, Energy, the Environment and Water, Long Term Intervention Monitoring, Flow-MER.

3.2 Ecosystem function outcomes 2022–23

This section presents findings from the Foodwebs and Water Quality evaluation for the 2022–23 water year, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Foodwebs and Water Quality' report available from the Australian Department of Climate Change, Energy, the Environment and Water website).

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

Native fish, vegetation and waterbirds rely on a range of ecosystem functions to support healthy populations. Food webs illustrate how much energy (carbon) is moving between organisms or groups and show the role of individual animal species or connections in sustaining life across an ecosystem. Without energy, organisms have no capacity for growth and reproduction. Understanding the relationship between the provision of energy for food webs and flow is critical for environmental water management.

Aquatic food webs are underpinned by 2 fundamental biological processes: (1) gross primary production (GPP) and (2) ecosystem respiration (ER). Collectively termed 'stream metabolism' in rivers, GPP describes the rate of new organic matter generation via photosynthesis, and ER describes the rate at which organic matter is recycled. Net ecosystem production – the difference between GPP and ER – determines whether carbon accumulates (autotrophic) or is depleted (heterotrophic) within an ecosystem.

Commonwealth environmental water can support higher ER rates and heterotrophic production if flows lead to increases in terrestrial carbon subsidies to the river channel (e.g. litter). The amount of litter incorporated into the river channel is governed primarily by flow type (e.g. bankfull and overbank flows may mobilise large quantities of litter, while freshes may be limited to small quantities of litter from in-channel features) and antecedent patterns (e.g. climate, time since last flow, magnitude of last flow).

Increasing flow reduces the volumetric rate of primary production but increases cross-sectional channel GPP, particularly in reaches where the channel broadens, by increasing the cross-sectional area of the photic zone. Although rates of GPP and ER are not direct estimates of secondary production by higher trophic levels, ecological theory and existing empirical evidence suggest that this increased ecosystem metabolism will be correlated with higher consumer productivity.

Understanding ecosystem function

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 accumulated leaf litter and the timing of the flow – hypoxic blackwater 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 blackwater events, depending on flow volume and load of organic matter entering from the floodplain.

A metabolic fingerprinting approach was used to visualise and diagnose change in stream metabolism (Figure 3.2). This approach shows whether metabolic responses to flow conditions are within the typical metabolic regime of a location or if they represent atypical conditions at that location. Atypical metabolic conditions may indicate a desirable state (such as high GPP and ER) or an undesirable state (such as algal blooms and hypoxic blackwater). Fingerprints above the diagonal dotted line in Figure 3.2 represent locations that are heterotrophic (consuming more carbon than they are producing), while those below the line are autotrophic (deriving energy and nutrients from within the river channel). Microbial processing rates are highly sensitive to temperature, so the highest rates of GPP and ER are recorded in summer.

In 2022–23, 76 Commonwealth environmental water actions – totalling 1,121 GL – targeted ecological outcomes for water quality, food webs, stream metabolism, productivity and river function. 53 watering actions targeted water quality and 37 targeted ecosystem processes or food webs.

- **Food webs, stream metabolism, gross primary productivity and ecosystem respiration**
  - All 7 monitoring areas were net consumers of carbon (ratio of GPP to ER < 1). This highlights the importance of terrestrial organic carbon in the Basin as a major energy source in these systems made available through channel and floodplain connectivity.
  - Season was the primary driver of rates of stream metabolism, with the highest daily rates of GPP and ER consistently recorded in summer.
  - There were significant relationships between stream metabolism and flow. Higher flows generally decreased in-channel volumetric rates of GPP and ER, likely due to disturbance and dilution effects. However, responses were variable among sites, emphasising a high level of context dependency, likely related to channel morphology and other site-specific characteristics.
- **The 2014–22 metabolic fingerprints for monitored Areas** are overlaid with the 2022–23 metabolic data (Figure 3.2). Shaded areas above the line indicate heterotrophic systems that are consuming more carbon than they are producing. This information provides context for understanding stream metabolism for the 2022–23 year and does not demonstrate impacts of environmental water delivery.
  - The Goulburn, Edward/Kolety–Wakool, Lachlan, Gwydir and Junction of Warrego and Darling rivers reside above the 1:1 line, indicating that, most of the time, these ecosystems were heterotrophic and consuming more carbon than they were producing.
  - The Murrumbidgee and the Lower Murray River Junction of Warrego and Darling rivers, River Systems are dispersed around the 1:1 line, alternating between heterotrophy and autotrophy, depending on conditions (such as season).
  - The 2022–23 Lower Murray River fingerprint (displayed as dots overlaid in Figure 3.2) resides predominantly above the 1:1 line and is highly dispersed on the ER axis, reflecting variable overall metabolic throughput dominated by heterotrophy. This pattern is unusual in the Lower Murray River and is likely reflecting more lotic (flowing) conditions than previous sampling periods, acting to disperse phytoplankton and reduce GPP and the potential delivery of more labile carbon.

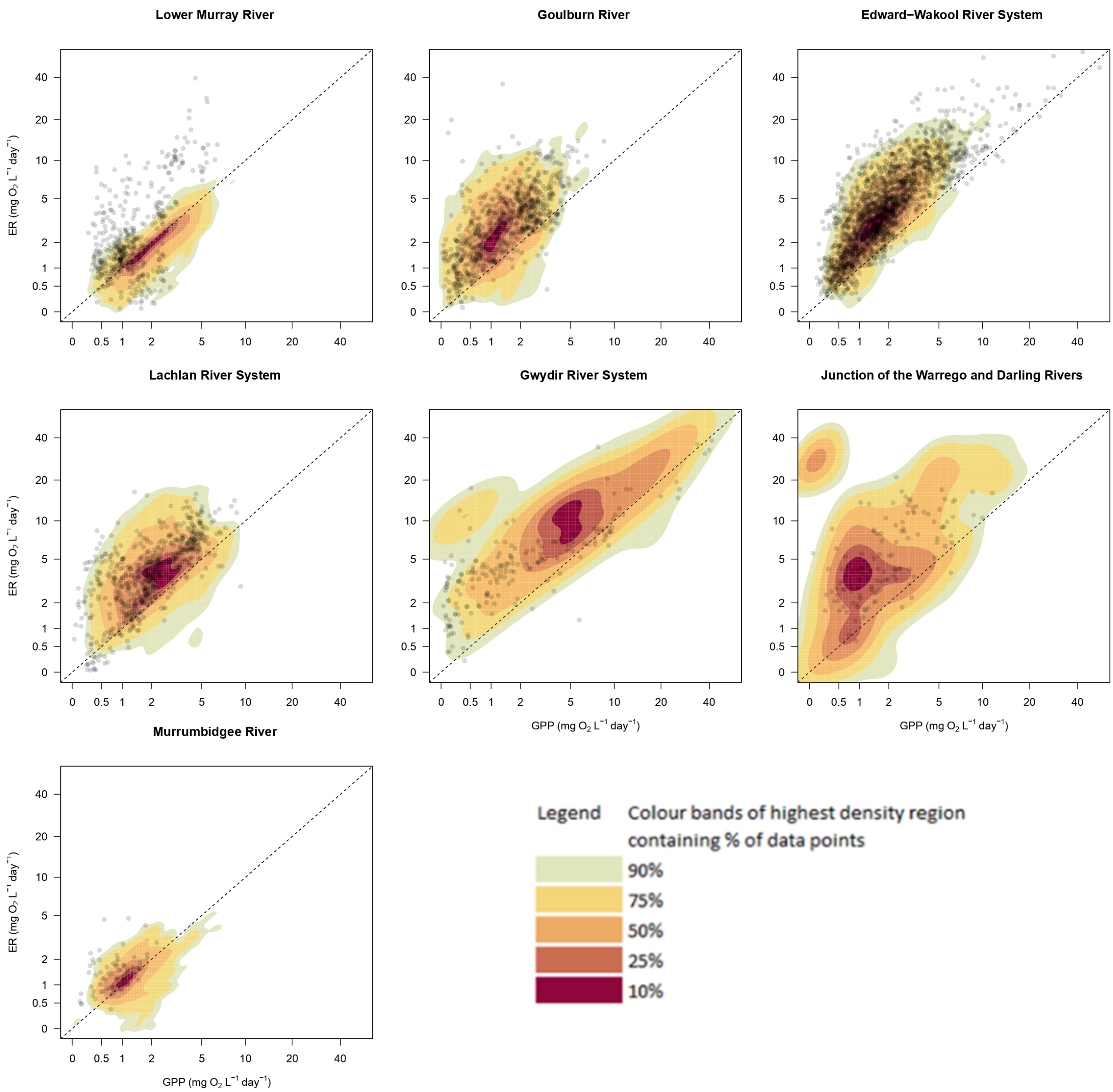

Figure 3.2 Longer term 2014–22 metabolic fingerprints (contour lines) overlaid with the 2022–23 metabolic fingerprint (dots) for Selected Areas
Note log scale on x-axis and y-axis.

3.3 Water quality outcomes 2022–23

This section presents findings from the Foodwebs and Water Quality evaluation for the 2022–23 water year, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Foodwebs and Water Quality' report available from the Australian Department of Climate Change, Energy, the Environment and Water website).

WHAT WAS THE CONTRIBUTION OF COMMONWEALTH ENVIRONMENTAL WATER TO MAINTAINING WATER QUALITY AND MEETING TARGETS FOR DISSOLVED OXYGEN, SALINITY AND SALT EXPORT?

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. Water quality objectives and associated watering actions aim to prevent or reduce the impact of poor water quality (low dissolved oxygen, high salinity, algal blooms) on ecosystems, plants and animals. Maintenance of water quality is critical to the completion of life cycles for native fish, vegetation and waterbirds.

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 4–5 mg/L.

- In past years, delivery of Commonwealth environmental water has decreased the likelihood of low dissolved oxygen in the Lower Murray by increasing water mixing and oxygen exchange at the surface and elevating flow velocity above 0.18 m/s. Once flow velocity is greater than 0.4 m/s, there is no additional benefit for gas exchange. During 2022–23, naturally high flows maintained flow velocity above 0.4 m/s in the Lower Murray River, and so the addition of Commonwealth environmental water did not influence gas exchange and saturation levels.
- Environmental watering actions in the Edward/Kolety–Wakool river systems and Murrumbidgee River System helped to maintain dissolved oxygen concentrations and prevent the development of hypoxic blackwater events.

3.3.2 Salt export and salinity

The Basin Plan salt-export objective (section 9.09) aims to ensure adequate removal of salt from the Murray River system into the Southern Ocean.

- **151,000 tonnes of salt was exported due to Commonwealth environmental water.**
  - Commonwealth environmental water was responsible for the export of approximately 5% of the salt exported from the Basin through the barrages in 2022–23, equating to 8% of the Basin target.
  - Commonwealth environmental water was responsible for the reduction of salt import into the Coorong estuary in 2022–23 by approximately 118,000 tonnes.
- **Commonwealth environmental water contributed to low river salinity in South Australia** by diluting salt in the Lower Murray River channel. Commonwealth environmental water is important for maintaining salt export from the Basin and limiting net salt import to the Coorong.

4 Outcomes 2014–2023

At a glance

Vegetation

- 10,590 GL of Commonwealth environmental water were delivered in 746 independent watering actions for vegetation outcomes since 2014.
- Over the 9 years since 2014, Commonwealth environmental water supported permanent lowland rivers, freshwater meadows and permanent tall marsh, with these habitats being watered more frequently than most treed swamps, and palustrine wetlands being watered more frequently than floodplains. Without environmental water and in the absence of overbank flooding, these ecosystems would transition to vegetation communities typical of drier conditions.
- Commonwealth environmental water has contributed to distinct hydrological regimes across the Basin, which are likely to have contributed to the observed diversity in functional and structural assemblages of vegetation.
- Without Commonwealth environmental water, 45% of floodplain–wetland monitoring locations would have experienced drier water regimes, resulting in less diversity and less cover of submerged, amphibious and damp-loving plant species. By maintaining these species assemblages, Commonwealth environmental water is preventing a permanent transition in vegetation community assemblages and a loss of resilience of water-dependent plant communities.
- 790 taxa were recorded at monitored floodplain, wetland and riverine locations since 2014, including 520 native and 216 exotic species.
- Almost 10% of the plant taxa observed at monitoring locations are known to be used by Aboriginal people for uses including food, fibre, shelter, medicine, messages and boundaries, dreaming/storytelling or ceremonial, and basket weaving.
- 33 of the plants used by Aboriginal people require flooding to occur, including 8 amphibious taxa, 3 submerged taxa, 13 damp-loving taxa and 9 woody flood-dependent taxa.
- 101 groundcover plant species that are listed as threatened were recorded at monitoring locations.

Native fish

- 12,898 GL of Commonwealth environmental water were delivered in 602 independent watering actions for outcomes targeting native fish since 2014.
- 15 native species and 5 exotic species were detected during the 9-year monitoring program by in-channel river sampling of adult fish communities in monitored areas. The number of native species detected did not vary greatly among years.
- Counterfactual modelling showed that Commonwealth environmental water contributed to increased fish spawning, recruitment, frequency of occurrence, population growth rates, body condition and improved community composition in some monitoring locations and for several species.
- Positive fish responses to Commonwealth environmental water delivery were primarily driven by reductions in the number of low-flow days and, to a lesser extent, increased average daily flows and changes in flow variability.

- Positive fish responses to Commonwealth environmental water delivery were most pronounced in the Goulburn River and Lower Murray River and, to a lesser extent, in the Edward/Kolety–Wakool river systems, Murrumbidgee River System and Lachlan River System. In the Gwydir River System, there were very few positive fish responses to Commonwealth environmental water delivery.

Waterbirds

- 7,291 GL of Commonwealth environmental water were delivered for outcomes for waterbirds since 2014.
- Commonwealth environmental water has supported habitats of a wide range of waterbird species, including straw-necked ibis, white ibis, glossy ibis, royal spoonbills, yellow spoonbills, cormorants, darters, grebes and several species of duck.
- Since 2014, 117 waterbird species were recorded on the managed floodplain (for a subset of Basin valleys).
- 1,877 GL of Commonwealth environmental water were delivered to benefit listed threatened or migratory species, either alone or in combination with watering objectives.
- Since 2014, 59 listed threatened or migratory waterbird species were identified from the managed floodplain. Of these, 57 were reported from habitats receiving Commonwealth environmental water.

Other outcomes

- Since 2014, Commonwealth environmental water has been responsible for the export of more than 4,153 million tonnes of salt through the barrages and has reduced import of salt through the Murray Mouth by almost 26,078 million tonnes.
- Commonwealth environmental water has helped to decrease the likelihood of widespread hypoxic events across the Basin. In wet years, environmental water was used to pre-flush systems and maintain dissolved oxygen concentrations. In dry years, environmental water was used to increase flow volumes and increase water mixing.
- Since 2014, 1,897 GL of Commonwealth environmental water were delivered to support frogs (and other objectives).
- Commonwealth environmental water has supported broad-shelled turtles (threatened in South Australia) and created nursery habitats that supported hatchling Macquarie turtles, long-necked turtles and broad-shelled turtles.
- Commonwealth environmental water is known to have supported habitats and populations of threatened species, including 7 plant species, 59 bird species, one frog (southern bell frog), one turtle (broad-shelled turtle), one snake (grey snake) and the Murray hardyhead (fish).
- Commonwealth environmental water had a significant influence on the presence of southern bell frogs (listed as Vulnerable under the EPBC Act).

4.1 Biodiversity outcomes 2014–23

This evaluation reports on outcomes from Commonwealth environmental water for 2014–23 and assesses the contribution of Commonwealth environmental water to Basin Plan objectives.

From 2014 to 2023, a total of 15,443 GL of Commonwealth environmental water were delivered in the Basin through 1,081 watering actions (Figure 4.1). Many watering actions target more than one outcome. Of those watering actions with objectives relating to biodiversity, 602 actions totalling 12,898 GL targeted fish, 746 actions totalling 10,590 GL targeted vegetation, and 666 watering actions totalling 8,700 GL targeted waterbirds, frogs, turtles, platypus and rakali.

	Fish	Vegetation	Species diversity*	Water quality#
	Number of watering actions			
2014–15	49	55	42	40
2015–16	61	96	83	53
2016–17	58	56	45	47
2017–18	82	69	70	65
2018–19	64	94	73	37
2019–20	64	90	71	44
2020–21	73	110	92	52
2021–22	90	108	119	59
2022–23	61	68	71	76
	Volume of watering actions			
2014–15	1,082	704	334	1,089
2015–16	1,551	1,567	1,296	1,269
2016–17	1,659	1,360	987	1,596
2017–18	1,835	1,780	1,704	1,605
2018–19	1,080	490	424	729
2019–20	1,081	738	319	1,172
2020–21	1,416	833	691	1,331
2021–22	2,186	2,214	1,956	2,237
2022–23	1,010	904	989	1,121

Figure 4.1 Contribution of Commonwealth environmental water to number and volume of water actions, 2014–23

Volumes are rounded to the nearest GL. Some actions contribute to multiple flow components. Primary flow component is tabled.
* Combines actions for waterbirds, frogs and other biota; # combining water quality and ecosystem processes.

4.1.1 Vegetation

This section presents findings from the Vegetation evaluation for the 9 years from 2014–23, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Vegetation' report available from the Australian Department of Climate Change, Energy, the Environment and Water website).

Environmental water is preventing the loss of characteristic wetland and floodplain plants by maintaining wetter hydrological regimes across the managed portion of the Murray–Darling Basin. In the absence of Commonwealth environmental water, important assemblages of species would have been markedly reduced in extent during dry periods. There would be a reduction in vegetation community richness, with a high risk of permanent transitions to altered vegetation community assemblages and loss of resilience of water-dependent plant communities.

Between 2014 and 2023, there were 746 watering actions – totalling 10,590 GL of Commonwealth environmental water – that targeted expected outcomes for vegetation. Environmental water has resulted in 5 distinct inundation regimes for 73 monitored floodplain and wetland locations across the Basin. The wetter of these inundation regimes are almost entirely the result of the delivery of environmental water. These vegetation communities have distinct functional and structural assemblages of plants, attributed in part to the inundation regime they have experienced. Similar patterns are observed elsewhere in the Basin experiencing similar hydrological change. This demonstrates how environmental water, over the past 9 years, is maintaining functionally important assemblages of species and diverse vegetation communities.

Basin Plan objective at paragraph 8.04(a): to protect and restore water-dependent ecosystems of the Murray–Darling Basin.

- Environmental watering has contributed to a greater diversity and cover of submerged, amphibious and damp-loving species. Without Commonwealth environmental water, many locations across the Basin would have experienced drier water regimes. It is very likely this would have resulted in the near-absence of submerged species and substantially less diversity and cover of amphibious and damp-loving species at these locations.
- The evidence indicates that environmental water has contributed to a greater number of plant species and increased vegetation community diversity. Over the past 9 years, watering frequencies broadly align with expected needs of vegetation groups. Permanent lowland rivers, freshwater meadows and permanent tall marsh were watered more frequently than most treed swamps, and palustrine wetlands were watered more frequently than floodplains. Without environmental water and in the absence of other overbank flooding, these ecosystem types would be expected to transition to ecosystem types more typical of drier hydrological regimes.
- By maintaining distinct inundation regimes and corresponding vegetation communities, environmental water has contributed to the longer-term resilience of water-dependent plant communities across the Basin. By maintaining submerged, amphibious and damp-loving species, environmental water is preventing a permanent transition to altered vegetation community assemblages and a loss of resilience of water-dependent plant communities.

Specific outcomes since 2014 include:

- **Commonwealth environmental water is supporting groundcover plants**
  - Environmental water is preventing the loss of characteristic wetland and floodplain plants by maintaining wetter hydrological regimes, helping to maintain biodiversity across the Basin.
  - 790 taxa were recorded at monitored floodplain, wetland and riverine locations since 2014. This includes 520 native and 216 exotic species.
  - Without Commonwealth environmental water, 45% of monitoring locations would have experienced a drier inundation regime. This is likely to have resulted in less diversity and cover of submerged, amphibious and damp-loving species.
  - This highlights the significant role of environmental water in supporting a substantial number of native plant species across the Basin over the past 9 years.
- **Commonwealth environmental water support for plants with traditional Aboriginal uses**
  - While Commonwealth environmental water has not deliberately targeted plant species of traditional uses, watering to support groundcover vegetation has supported a range of such species.
  - Almost 10% of the plant taxa observed at monitoring locations are known to be used by Aboriginal people for uses including food, fibre, shelter, medicine, messages and boundaries, dreaming/storytelling or ceremonial, and basket weaving.

  - Since 2014, a total of 75 plant species with traditional Aboriginal uses including as food (32), fibre and shelter (5), medicine (7), hunting or fishing (1), messages and boundaries, dreaming/storytelling or ceremonial, and basket weaving were recorded from monitoring locations.
  - 33 of the plants used by Aboriginal people require flooding to occur, including 8 amphibious taxa, 3 submerged taxa, 13 damp-loving taxa and 9 woody flood-dependent taxa. For example, the 3 submerged taxa (2 species of cumbungi [*Typha domingensis* and *Typha orientalis*] and the common reed [*Phragmites australis*]) are culturally important species to Aboriginal people and are used as food, fibre and shelter and in dreaming/storytelling or ceremonial use. Cumbungi requires near-permanent water while the common reed requires flooding every few years.
- **Commonwealth environmental water support for rare and threatened plant species**
  - 7 groundcover plant species that are listed as threatened, either nationally (under the EPBC Act) or within the state where they were detected, were recorded at monitoring locations. 4 of these are considered flow-dependent.

HIGHLIGHT: WATER-DEPENDENT PLANT COMMUNITIES

Vegetation species and community responses to environmental water are described using structural and functional attributes, such as:

- functional groups – submerged, amphibious, damp-loving, woody flood-dependent, terrestrial
- species growth forms – forbs, grasses, ferns
- native and exotic species and rare and threatened species
- species that are known to be used by Aboriginal people.

790 plant taxa were recorded at monitoring locations since 2014. 71% of species and 86% of total cover were native plants. After 9 years of variable wet–dry conditions, species are still being observed that have not previously been recorded at the monitoring locations. This highlights the temporal complexity of large and variable river–floodplain systems and the importance of long-term monitoring.

The greatest proportional cover of native plants was recorded over the last 2 years (92% to 96%), accompanied by the greatest proportion of native species (74% to 73%). It is likely that above-average rainfall conditions combined with environmental watering have contributed to these increases.

The dominant growth form was forbs (62% of species). This was followed by grasses (15%), sub-shrubs (8%), and sedges and rushes (6%). Forbs had the greatest average cover in most years (8% to 15%), followed by sedges and rushes (7% to 16%) and grasses (4% to 14%). The wetter conditions in the last 2 years saw an increase in cover of ferns and fern allies and sedges and rushes (Figure 4.2) that was greatest at sites which had wetter inundation regimes maintained by Commonwealth environmental water since 2014 (see Figure 3.13 of the Vegetation report). Azolla and *Marsilea* species have driven the increased cover of ferns and fern allies, and *Typha*, *Eleocharis* and *Cyperus* species have driven an increased cover of sedges and rushes, favouring wetter conditions.

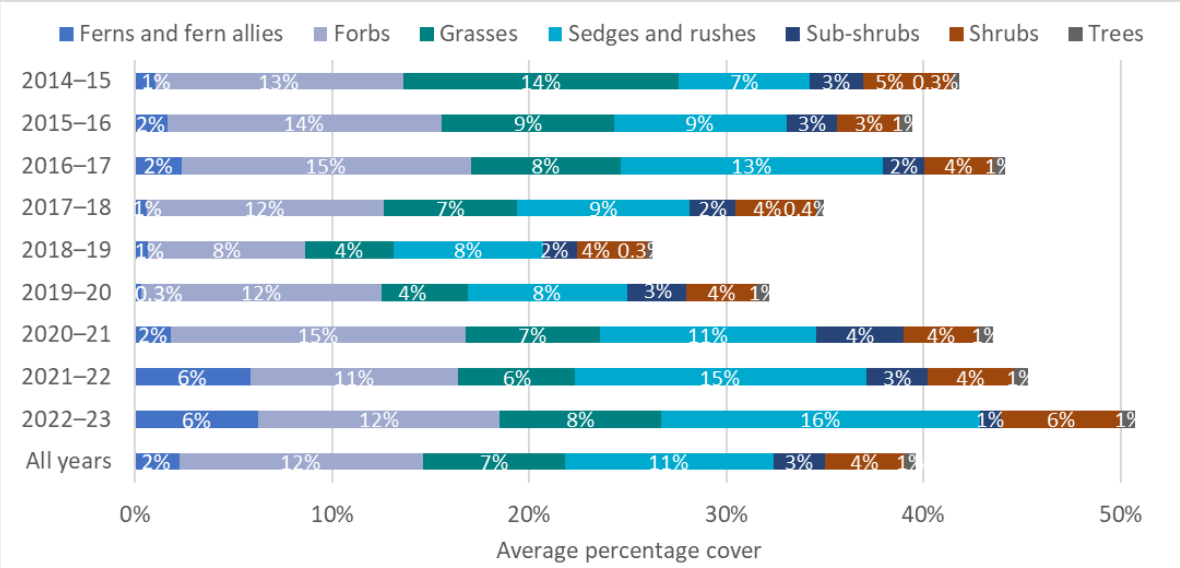

Figure 4.2 Percentage of plant species cover recorded across all Selected Areas in each growth-form group for each water year and across all years, 2014–23

Amphibious taxa had the greatest average cover (Figure 4.3) in all years except for 2019–20, when terrestrial taxa dominated following widespread dry conditions. Damp-loving taxa were the next-most dominant (6 of the 9 years). Submerged taxa increased in the last 2 years during wet conditions.

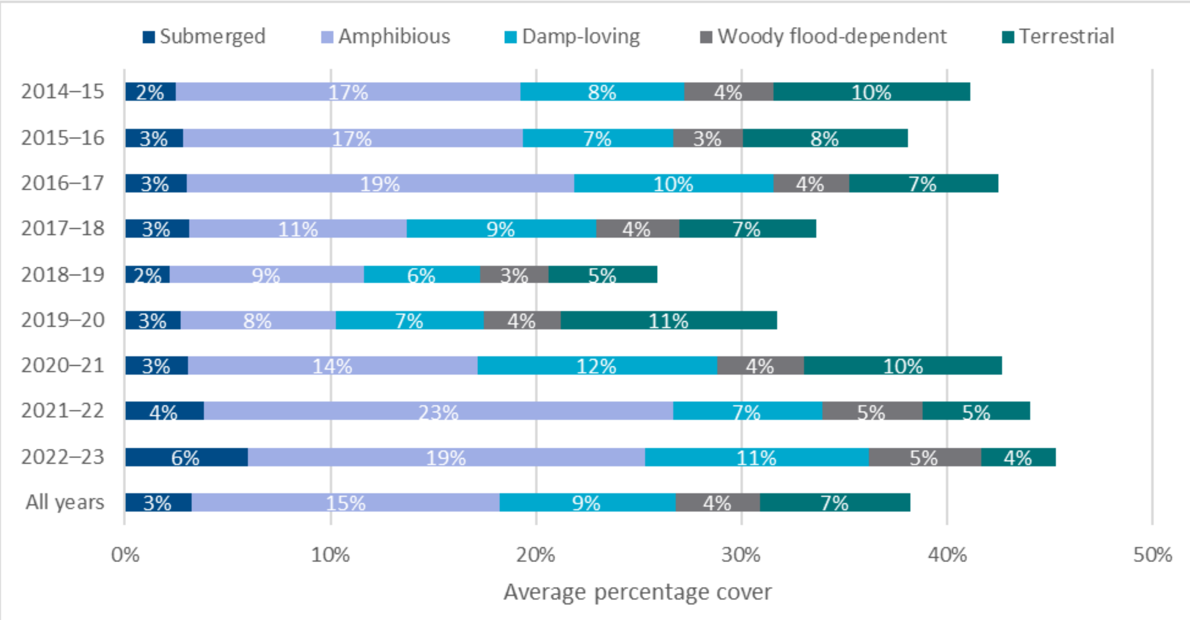

Figure 4.3 Average percentage cover of plant functional groups across Selected Areas for each water year and across all years, 2014–23

4.1.2 Native fish

This section presents findings from the Fish evaluation for the 9 years from 2014–23, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Fish' report available from the Australian Department of Climate Change, Energy, the Environment and Water website).

Between 2014 and 2023, there were 602 watering actions – totalling 12,898 GL of Commonwealth environmental water – that targeted expected outcomes for fish. Commonwealth environmental water has provided a range of benefits to native fish populations and supported critical life-history processes, such as recruitment, body condition and population growth.

Observations since 2014

- 12,898 GL of Commonwealth environmental water were delivered in 602 independent watering actions for outcomes for native fish since 2014.
- 15 native species and 5 exotic species were detected during the 9 years of in-channel river sampling of adult fish communities in monitoring areas. This includes 6 key freshwater species as identified by the Strategy. The number of native species detected did not vary greatly among years. Golden perch, Murray cod and carp gudgeon (*Hypseleotris* spp.) were detected in all years in all monitored areas, while silver perch (*Bidyanus bidyanus*), flathead gudgeon (*Philypnodon grandiceps*) and Australian smelt (*Retropinna semoni*) had patchier spatial and temporal distributions.
- Commonwealth environmental water decreased the number of low-flow days and increased average daily flows to varying degrees in monitored areas. These patterns were most evident in the Goulburn River and Lower Murray River and, to a lesser extent, in the Edward/Kolety–Wakool river systems, Murrumbidgee River System and Lachlan River System. Restoring specific flow components (such as winter flows to aid recruitment, summer flows to enhance water quality, and spring flows to enhance lotic habitats, breeding success and recruitment) is known to have significant benefits in these river systems, particularly for Murray cod.

> Basin Plan objective at paragraph 8.04(a): to protect and restore water-dependent ecosystems of the Murray–Darling Basin; and improvements in recruitment and populations of native fish (Schedule 7; Schedule 12, item 7). The Strategy lists 5 expected outcomes for fish to be achieved by 2024, of which 2 are addressed in this evaluation.

1. No loss of native species currently present within the Basin

- Most native fish species were detected consistently over the monitoring period (2014–23). Cumulatively, 15 native fish species, including 6 key freshwater species as identified by the Strategy, were detected during the monitoring program.

2. Improved population structure of key fish species through regular recruitment

- Murray cod spawning and recruitment to young-of-year occurred in most years. The 2016–17 Murray River hypoxic blackwater event and associated major fish death events, or possible fish emigration out of the area, resulted in marked reductions in recruits and adults in several monitoring locations. Murray cod populations have continued to steadily recover from these hypoxic blackwater events in recent years, although recruitment was poor in 2022–23 at most monitoring locations except the Lower Murray River. Localised fish deaths were reported in some monitoring locations, but there was no evidence of further large-scale fish deaths. However, there were large-scale fish death events recorded at other unmonitored locations in the basin.[12]
- From 2014–23, golden perch spawning was detected in the Goulburn River, Lachlan River System, Lower Murray River and Murrumbidgee River System, although only low numbers of recruits were detected in most monitoring locations. However, low levels of recruitment are often not detected until cohorts reach larger sizes and are more readily sampled. More recently, there was successful recruitment in the Lower Murray in the past 2 years, with limited evidence at other monitoring locations. Population size structure in most monitoring locations in most years indicates the population is dominated by adult fish, with few juveniles observed. This most likely reflects the spatially and

[12] Office of the NSW Chief Scientist & Engineer (2023) *Independent review into the 2023 fish deaths in the Darling–Baaka River at Menindee*.

temporally episodic nature of major recruitment events for the species (and the flows that drive them) and the spatial scale over which populations operate.

Outcomes for native fish since 2014

Analysis demonstrated that Commonwealth environmental water contributed to increased fish spawning, recruitment, population growth, frequency of occurrence and body condition, and improved community composition in some monitored areas for several native species. These fish responses were driven by reductions in the number of low-flow days and, to a lesser extent, increased average daily flows and changes in flow variability (both increases and decreases in flow variability, depending on location).

Specific findings:

- Spawning of golden perch (i.e. presence of larval fish and eggs) increased because of Commonwealth environmental water delivery in some years in all areas monitored for this indicator.
- Recruitment of Australian smelt and Murray–Darling rainbowfish increased because of Commonwealth environmental water (fewer low-flow days, and changes in flow variability) in some years in several areas, as did recruitment of Murray cod in the Goulburn and Lower Murray rivers.
- There was strong evidence that Commonwealth environmental water delivery (fewer low-flow days, and changes in flow variability) contributed to detection of Australian smelt at more sites in most years within monitored areas. Detection of Murray–Darling rainbowfish and bony herring with Commonwealth environmental water delivery were more pronounced within Goulburn River and Lower Murray River sites, while responses were more variable in other monitored areas. These pronounced effects in the Goulburn and Lower Murray rivers resulted from Commonwealth environmental water markedly reducing the number of low-flow days.
- The growth rate for the adult Murray cod population increased with the delivery of Commonwealth environmental water (fewer low-flow days and changes in flow variability) in most monitored areas. The population growth rate for golden perch increased with delivery of Commonwealth environmental water in some years in the Goulburn River (fewer low-flow days) and for bony herring in the Edward/Kolety–Wakool, Lower Murray and Murrumbidgee rivers (fewer low-flow days).
- Individual body condition for Murray cod increased due to Commonwealth environmental water (fewer low-flow days and increased average daily flows) in some years in monitored areas. Strong responses for Murray cod were found in the Gwydir, Lower Murray and Murrumbidgee river systems. Bony herring body condition increased with delivery of Commonwealth environmental water (changes in flow variability) in some years in the Edward/Kolety–Wakool, Lachlan and Murrumbidgee river systems.
- The predicted contribution of Commonwealth environmental water to Murray cod and Murray–Darling rainbowfish recruitment at unmonitored locations was found to be greatest in the southern Basin, although there is higher uncertainty in the predicted effects of Commonwealth environmental water in the northern basin, which is limited to a single monitoring location (Gwydir river system). Currently, predictions at unmonitored locations are with low confidence without local data in these unmonitored locations to test with model predictions.

HIGHLIGHT: Enhancing spawning, recruitment and movement of golden perch

Environmental water delivered benefits for golden perch across the Murray–Darling Basin.

Golden perch (*Macquaria ambigua*; Figure 4.4) are found throughout the Murray–Darling Basin. They are a popular angling fish and are culturally important to First Nations people. Flow-MER research and evaluation showed that Commonwealth environmental water supported critical life-history processes of golden perch, including spawning, body condition and population growth.

Data from tagged golden perch shows that the greater the flow, the more likely golden perch are to move throughout a river system. Understanding relationships between flows and fish movements, at varying spatial scales, informs the delivery of Commonwealth environmental water to best benefit fish populations.

Between 2014 and 2023, spawning of golden perch increased with delivery of Commonwealth environmental water. Golden perch need hundreds of kilometres of connected flowing water for spawning migrations, and spawning often coincides with increased flow during spring and summer. Environmental water helped maintain their habitat by providing connected flow events across regions and at critical times.

Modelling showed that numbers of golden perch across the Basin went up when Commonwealth environmental water was delivered, strengthening populations against future environmental change. The Basin-wide model was developed by integrating knowledge of life-history processes (such as spawning and movement) with information on the connectivity and spatial scale of golden perch populations (Figure 4.5).

The model also showed that bigger river discharges, such as those boosted by Commonwealth environmental water (and seen in the very wet 2022–23 water year), enhance fish spawning, recruitment and movement – ultimately supporting the populations and recovery of golden perch and other native fish.

Figure 4.4 Releasing a golden perch (*Macquaria ambigua*). Photo: Arthur Rylah Institute

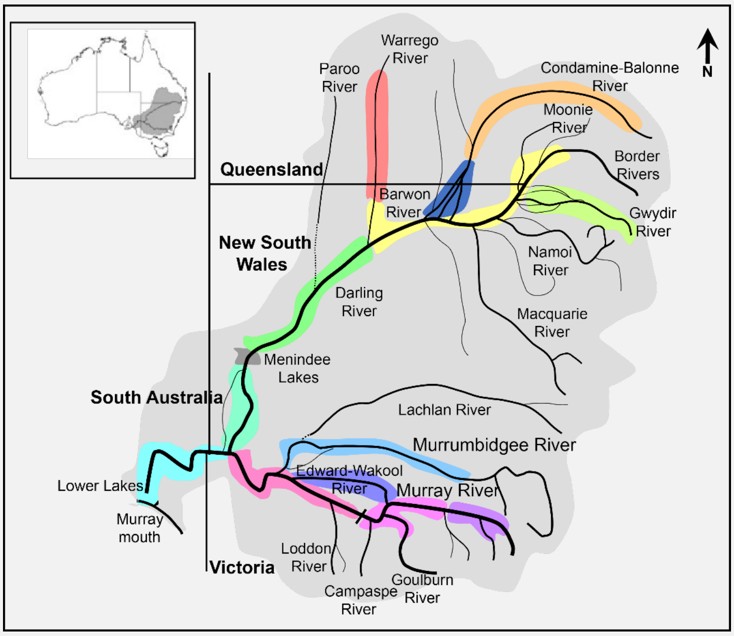

Figure 4.5 The Basin, showing the 14 populations included in the golden perch meta-population model

4.1.3 Waterbirds

This section presents findings from the Species Diversity evaluation for the 9 years from 2014–23, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Species Diversity' report (available from the DCCEEW Flow-MER Basin-scale Project publications page).

Waterbirds are a key priority for environmental watering in floodplain and wetland habitats. Critical waterbird habitats and multiple populations of listed waterbird species are associated with locations periodically inundated by environmental water. There is also potential for other complementary adaptive management actions to support the effectiveness of environmental water and, ultimately, waterbird recruitment. Environmental water, vegetation management and management of pressures and threats, such as predation, disease and toxins, all interact with habitat availability and quality to affect waterbird movements, condition, growth, survival and mortality, as well as breeding initiation and frequency.

Observations since 2014

- 7,291 GL of Commonwealth environmental water were delivered for outcomes for waterbirds.
- Commonwealth environmental water has supported habitats of a wide range of waterbird species, including straw-necked ibis, white ibis, glossy Ibis, royal spoonbills, yellow spoonbills, cormorants, darters, grebes and several species of duck.
- 137 waterbird and raptor species were recorded on the managed floodplain from 2014–23. Data is highly variable between valleys, with the most records derived from the Murrumbidgee (18%), Lower Murray (16%), Central Murray (16%), and the Coorong, Lower Lakes and Murray Mouth (15%)
- Since 2014, 84 waterbird species were observed at monitoring locations, including 44 waterbird species of conservation significance (threatened and listed migratory species).
- 1,877 GL of Commonwealth environmental water were delivered to benefit listed threatened or migratory species, either alone or in combination with watering objectives.
- Since 2014, 59 listed threatened or migratory waterbird and raptor species were reported. Of these, 57 were reported from habitats that received Commonwealth environmental water.

HIGHLIGHT: SUPPORTING THREATENED SPECIES (WATERBIRDS)

Australasian bittern (*Botaurus poiciloptilus*)

The Australasian bittern is a rare species with scattered distribution through eastern Australia. The Basin contains core habitat for this species. It is federally listed as Endangered under the EPBC Act and is also listed in Victoria, South Australia and New South Wales. It is a large, nocturnal wading bird that requires wetland and floodplain habitats with areas of tall emergent vegetation. Since delivery began in 2014, 110 known locations of Australasian bittern received Commonwealth environmental water at least once.

Glossy ibis (*Plegadis falcinellus*)

The glossy ibis is a wading waterbird. It is a listed migratory species under the Bonn Convention and is listed in South Australia. It is highly nomadic and has a wide distribution across eastern and northern Australia. Since delivery began in 2014, 183 known locations of glossy ibis received Commonwealth environmental water at least once.

Australasian shoveler (*Spatula rhynchotis*)

The Australasian shoveler is a species of dabbling duck and is listed in Victoria and South Australia. This species is highly mobile with a wide distribution that extends throughout eastern Australia and south-western Australia. Since delivery began in 2014, 233 known locations of Australasian shoveler received Commonwealth environmental water at least once.

HIGHLIGHT: Providing for waterbirds throughout their life

Commonwealth environmental water is supporting waterbirds throughout their life cycle. The delivery of environmental water for waterbirds has previously focused on nesting and fledging. But supporting chicks until they become breeding adults – which can take several years – improves success and helps meet the specific watering objectives of increasing the numbers and diversity of waterbirds.

Flow-MER research has satellite-tracked 5 species of waterbirds across the Murray–Darling Basin – straw-necked ibis (*Threskiornis spinicollis*), Australian white ibis (*Threskiornis molucca*), royal spoonbill (*Platalea regia*), great egret (*Ardea alba*) and plumed egret (*Ardea plumifera*). This has generated new knowledge about waterbird movements, including movement strategies, timing, routes and habitat use. It has also tracked when these birds nest, their stages of nesting, and how far and where they move while foraging and caring for their chicks. Beyond nesting movements, the research has also identified sites for foraging, roosting, stopover and refugia that are important for non-breeding birds.

The GPS tracking provides (Figure 4.6) near-real time data on when and where waterbirds are moving. This helps explain the monitored responses of waterbird numbers and breeding to both environmental water and natural flooding. It can inform immediate management as well as longer-term planning.

Understanding the needs of nesting waterbirds and their offspring, including when those needs change throughout their lives, is critical to informing the delivery and management of environmental water – meaning better outcomes for waterbirds across the Basin.

The movements of a nesting adult royal spoonbill nesting in Yanga National Park and foraging in Gayini are shown in Figure 4.7. Lines show the paths taken during nesting events, and line lightness/darkness indicates nesting stages, including nest establishment, incubation, immobile chicks and mobile chicks.

Figure 4.6 'Lil', an adult male royal spoonbill, fitted with a satellite tracker backpack (held by Heather McGinness)

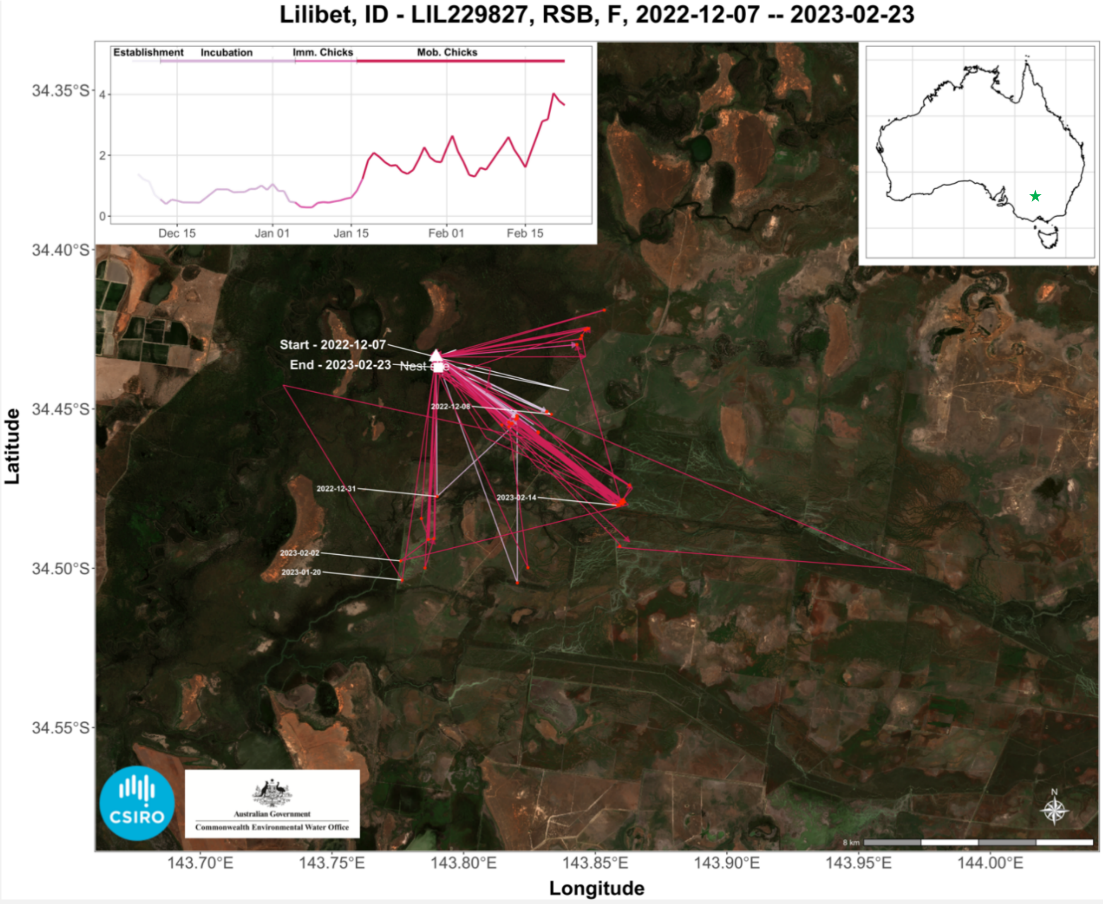

Figure 4.7 The movements of a nesting adult royal spoonbill in the lower Murrumbidgee catchment

The inset shows the map of Australia and the green star shows the bounding box captured by this image. The top-left inset shows the moving average distance (km) through the nesting stages.

4.1.4 Other fauna – turtles, snakes and frogs

This section presents findings from the Species Diversity evaluation for the 9 years from 2014–23, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Species Diversity' report (available from the DCCEEW Flow-MER Basin-scale Project publications page).

Observations since 2014

- Since 2014, 1,897 GL of Commonwealth environmental water were delivered that had at least one objective related to outcomes for frogs. Watering objectives typically focus on either general habitat maintenance (habitat), while more targeted objectives focus on frog breeding (breeding), maintaining critical refuge habitat for frogs (refuge), and providing opportunities for breeding and recruitment of the southern bell frog.
- Since 2014, 20 species of frog were reported from wetlands inundated with Commonwealth environmental water in the Murrumbidgee River System, Junction of Warrego and Darling rivers, Macquarie Marshes and Gwydir River System.
- Frog species richness has been very stable within the Murrumbidgee across water years.
- Since 2014, 3993 GL of Commonwealth environmental water were delivered to support other biota including mammals (platypus and rakali), woodland birds (regent parrot), frogs and reptiles (turtles and snakes).

- Commonwealth environmental water has supported broad-shelled turtles (threatened in South Australia) and created nursery habitats that supported hatchling Macquarie turtles, long-necked turtles and broad-shelled turtles.
- Commonwealth environmental water has supported habitats and populations of threatened species, including one frog (southern bell frog), one turtle (broad-shelled turtle) and one snake (grey snake).
- Commonwealth environmental water had a significant influence on the presence of southern bell frogs (listed as Vulnerable under the EPBC Act).

HIGHLIGHT: SUPPORTING THREATENED SPECIES (SOUTHERN BELL FROG)

Southern bell frog (*Litoria raniformis*)

The southern bell frog is a large wetland-dependent frog species, restricted to floodplain wetlands in the southern Basin. It is federally listed as Vulnerable under the EPBC Act and is also listed in Victoria, South Australia and New South Wales. Since Commonwealth environmental water delivery began in 2014, 161 known locations of southern bell frogs received Commonwealth environmental water at least once.

4.2 Ecosystem function outcomes 2014–23

This section presents findings from the Foodwebs and Water Quality evaluation for the 9 years from 2014–23, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Foodwebs and Water Quality' report (available from the DCCEEW Flow-MER Basin-scale Project publications page).

From 2014–22, 473 Commonwealth environmental watering actions – totalling 12,150 GL – were delivered for outcomes linked to water quality, food webs, stream metabolism, productivity and river function.

Channel and floodplain morphology (both at the site and immediately upstream) should be a strong driver of context-dependent metabolic responses to flow. For example, in shallow river channels with low banks, a small increase in flow volume may lead to relatively large increases in inundated surface area. Such increases to wetted area are likely to increase metabolic throughput by creating proportionally larger surface-area-to-volume ratios, leading to a larger photic zone and potential increases in rates of GPP (noting lag times for autotrophic communities to colonise). In such circumstances, there is also a greater likelihood of incorporating more terrestrial organic carbon from litter, also driving up rates of ER. In contrast, even moderate increases in flow volume that occur in river reaches that are deeply incised are likely to lead to only small increases in wetted surface area. Here, metabolic throughput would likely decrease, since any increases in surface area are likely to be exceeded by dilution and disturbance influences.

- Rates of GPP and ER across all Selected Areas in the 2022–23 water year were broadly similar and comparable with the previous 8-year record. Over the 9 years, riverine ecosystems of the Goulburn, Edward/Kolety–Wakool, Lachlan, Gwydir and Junction of Warrego and Darling river systems were predominantly heterotrophic and consuming more carbon than they were producing.
- The Murrumbidgee River System regularly alternated between heterotrophy and autotrophy over the 9 years, depending on conditions (such as season).
- The Lower Murray River was mostly a net producer of carbon (autotrophic) up to 2021–22, driven by phytoplankton and relatively low turbidity in the slow-flowing channels. However, high flows in 2022 shifted the Lower Murray River into heterotrophy, reflecting a return to a flowing system more closely resembling metabolic patterns at other Areas.

- Independent of Commonwealth environmental water actions, rates of GPP 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.

4.3 Water quality outcomes 2014–23

This section presents findings from the Foodwebs and Water Quality evaluation for the 9 years from 2014–23, presented in full in the 'Basin-scale evaluation of 2022–23 Commonwealth environmental water: Foodwebs and Water Quality' report (available from the DCCEEW Flow-MER Basin-scale Project publications page).

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 4–5 mg/L. When the addition of Commonwealth environmental water increases mean water velocities above ~0.18 m/s in the Lower Murray River, it can help increase dissolved oxygen concentrations. Under these circumstances, Commonwealth environmental water decreases the likelihood of low dissolved oxygen by increasing water mixing and oxygen exchange at the surface. Commonwealth environmental water is most important for decreasing the likelihood of low dissolved oxygen during years with low base flows.

In 2014–23, Commonwealth environmental water decreased the likelihood of low dissolved oxygen in the Lower Murray River by contributing to maintaining flow velocities above the 0.18 m/s threshold. In 2022–23, natural flows were above 0.4 m/s, and oxygen exchange was naturally higher. Environmental water did not contribute to gas exchange under these conditions.

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

In low-flow years, Commonwealth environmental water has become increasingly important for sustaining salt export from the Basin and for limiting salt import to the Coorong. Since 2014–15, Commonwealth environmental water has been responsible for an additional 4 million tonnes of salt exported through the barrages (Figure 4.8). While Commonwealth environmental water has played a key role in salt export from the Basin, salt export remains below the Basin Plan target, with the greatest export of 1.07 million tonnes occurring in 2020–21. Commonwealth environmental water contributed to maintenance of river salinity (electrical conductivity) below 800 µS/cm at Morgan over the 2014–23 period. Salinity was maintained within the range required for potable water in the Murray River in 2014–23, with water about 10% fresher due to environmental flows.

Basin plan objectives for water quality

- **Section 9.08.** There is strong evidence that Commonwealth environmental water played an important role in maintaining water quality during 2014–23. For example, Commonwealth and other environmental water was used in 2016 to ameliorate anoxic conditions and improve water quality.
- **Section 9.09**. Since 2014, Commonwealth environmental water has exported over 4 million tonnes of salt through the barrages (~22% of the Basin Plan target) and reduced salt import by 26 million tonnes.
- **Paragraph 9.14(5)(a).** Where Commonwealth environmental water has increased mean water velocities above ~0.18 m/s in the Lower Murray River, it has contributed to improving dissolved oxygen concentrations.
- **Paragraph 9.14(5)(c)**. During 2014–23, Commonwealth environmental water contributed to maintaining river salinity below the 800 µS/cm target at Morgan and maintaining salinity within the range for potable water in the Murray River, averaging around 10% fresher due to environmental flows.

	Barrages	Murray Mouth
Scenario	Additional export of salt due to CEW (thousand tonnes)	Reduction of salt import at the Murray Mouth (thousand tonnes)
2014–15	285	3,045
2015–16	252	4,591
2016–17	121	519
2017–18	685	3,774
2018–19	783	5,115
2019–20	677	3,995
2020–21	602	4,351
2021–22	597	570
2022–23	151	118
Total	4,153	26,078

Figure 4.8 Modelled additional salt export (thousand tonnes) and reduced salt import due to Commonwealth environmental water (CEW), 2014–23

Measures are salt export through the barrages to the Coorong estuary and reduction in import of salt through the Murray Mouth into the Coorong from the Southern Ocean attributable to Commonwealth environmental water. Source: Ye et al. 2024, 2022-23 Lower Murray MER Summary Report, to be available at https://www.dcceew.gov.au/cewh/resources-media/publications.

4.4 Resilience outcomes 2014–23

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 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 connecting or maintenance flows are delivered in-channel as freshes and base flows 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 River System, 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 in enhancing population size and increasing likelihood of persistence 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.

  - There were regular actions in the Gwydir Wetlands and Macquarie Marshes that inundated permanent and temporary tall emergent marsh, freshwater meadow, permanent wetlands, permanent forb marsh and permanent grass marshes.
  - Watering targeted vulnerable species including lignum (during water delivery to Narran Lakes) and river cooba (associated with floodplain watering of the Gwydir Wetlands).
- 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, common carp and foxes.
- Providing water to support the condition of native vegetation increases native species' resilience to long dry periods.
  - Watering events were used across the Basin to support the condition of vegetation communities that require regular inundation, thus enhancing their ability to cope with unfavourable conditions.
- Protecting species from the effects of major disturbances such as hypoxic blackwater events.
  - Watering events were used to reduce the impacts of hypoxic blackwater and increase the ability of fish species to recover in the Edward/Kolety–Wakool river systems in 2016–18.

HIGHLIGHT: ENHANCING RESILIENCE DURING A WET YEAR

Commonwealth environmental water is critical during dry years to reduce low-flow days and inundate critical areas and it is often the only water on the floodplain. However, during wet years, the outcomes of Commonwealth environmental water are less obvious. 2022–23 was one of the wettest years on record, with extensive flooding and inundation across the Basin. As a result, Commonwealth environmental water was used strategically to extend both the duration and extent of inundation and support favourable outcomes by providing more water in specific areas. Commonwealth environmental water was used to fill gaps in the hydrograph to extend the duration of flows to maintain high flow rates in-channel during spring and summer and fill wetlands by connecting distributary creeks. Consequently, targeted watering actions resulted in multiple positive and enhanced outcomes across the Basin. For example:

- A combination of natural flooding and Commonwealth environmental water resulted in the third consecutive year where the Ramsar areas in the Narran Lakes, Macquarie Marshes and Gwydir Wetlands systems supported simultaneous breeding of waterbirds.
- Commonwealth environmental water supported improvements in abundance and health of vegetation, increasing seed bank reserves and opportunities for recruitment and improving conditions in degraded wetlands after years of extended drought. More than 290 plant taxa were recorded in 2022–23 across all floodplain, wetland and riverine monitoring locations, with a notable increase in the presence of aquatic species such as floating aquatic ferns and emergent aquatic species, likely to be the result of the combination of natural flooding and the use of Commonwealth environmental water.
- Commonwealth environmental water extended flows providing opportunities for spawning and movement of migratory species. There was evidence of successful recruitment of golden perch and Murray cod in the Lower Murray and Australian smelt, a small-bodied native fish species had higher relative abundances (representative of recruitment for this short-lived species) than in previous years.
- Commonwealth environmental water was responsible for exporting 151,000 additional tonnes of salt (4.9%) through the barrages. Dilution flows also helped to prevent the development of hypoxic blackwater events.

5 INFORMING 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 learning (Figure 5.1). Effective application of adaptive management is an objective of both the Basin Plan and Flow-MER.

Flow-MER is learning from 9 years of monitoring, evaluation and research, and from other sources of information and knowledge. This has helped to develop and adapt understanding of outcomes from Commonwealth environmental water and approaches to undertaking Basin-scale evaluation. These are discussed in the following sections.

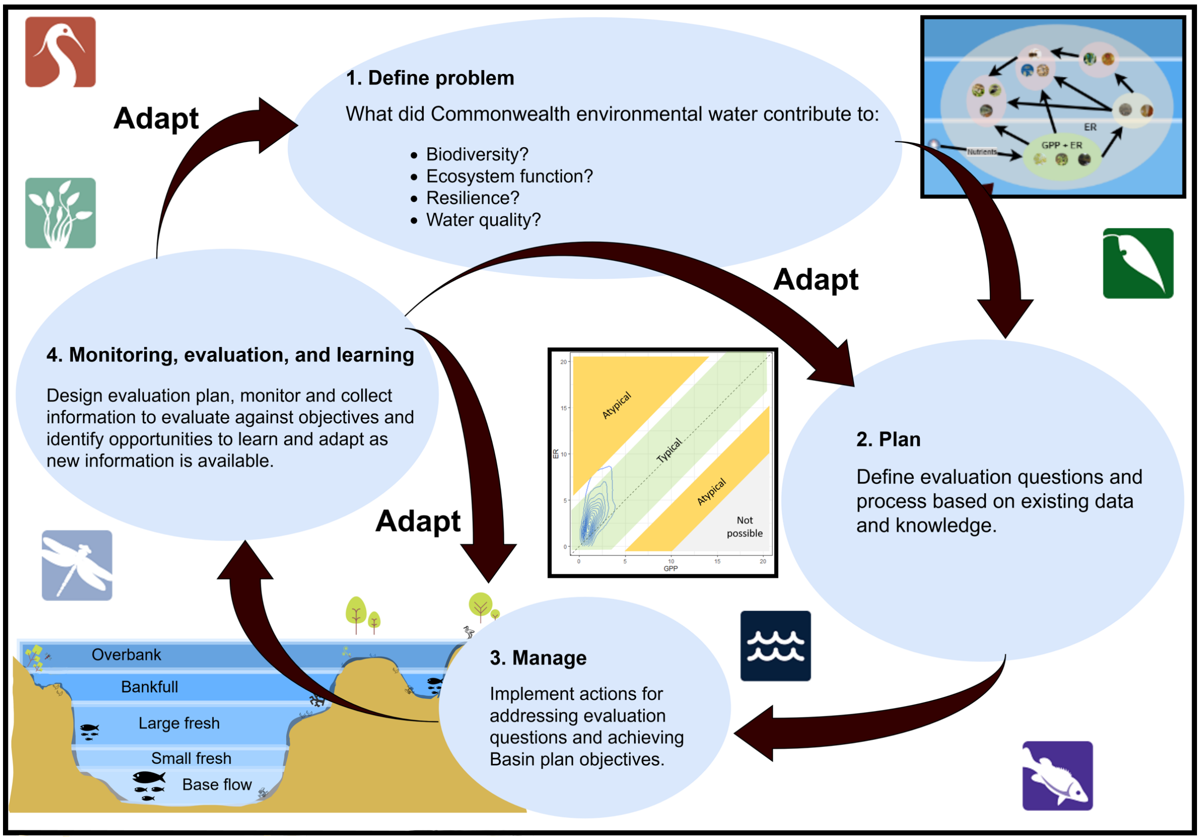

Figure 5.1 The adaptive management cycle modified from the Murray–Darling Basin Authority's Basin Plan adaptive management framework (MDBA 2017)

Planning involves defining the problem, objectives and 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.

5.2 Emerging knowledge

5.2.1 Basin Ecosystems

Developing an approach to scaling for evaluating ecosystem diversity

This project developed approaches for scaling evaluation of watering outcomes from individual habitat patches to the whole Basin. This work has provided tools for evaluating ecosystem diversity at spatial scales aligned to the scale of watering actions.

This project continues in 2024 to finalise the report: *Scaling up: a framework for using local information for regional evaluation.*

Identification and characterisation of refuge habitat

Wetlands and lakes are refuges for plants and animals during droughts and other hard times. Maintaining refugia in the Murray–Darling Basin is a key objective of Commonwealth environmental watering – and knowing where they are and how to prioritise them will best inform watering actions. This project used systematic conservation planning to map wetlands and lakes in the Basin, identify those of high ecological value and that can receive Commonwealth environmental water, and prioritise those most likely to be refugia for important species and ecosystems.

Learn more in the research report *Identifying and characterising refugia habitat for target organisms across the Murray–Darling Basin* (PDF 8.1 MB).

5.2.2 Vegetation

Changes in flow regimes are likely to significantly impact vegetation diversity across multiple scales, from the presence and abundance of local plant species to vegetation composition and structure at landscape scales. The Basin-scale vegetation evaluation assesses the contribution of Commonwealth environmental water to achieving vegetation species and community diversity outcomes across wetland, floodplain and riverine habitats. Flow-MER research is improving understanding of how best to use Commonwealth environmental water to achieve outcomes for vegetation, including iconic tree species such as river red gum and black box.

Remote sensing responses of woody vegetation to environmental water

Trees provide many ecosystem and amenity values and they are also sensitive to changes in climate and water flows. Monitoring how trees in riverine ecosystems across the Murray–Darling Basin respond to water stress is challenging. This research developed a Basin-scale remote-sensing product that combines deep knowledge of water use for 2 key riverine tree species – river red gum and black box – with current and historical satellite images. This robust and fine-scale data can determine trends in tree water use and responses to changed water availability – improving knowledge of water needs for riverine trees in the Basin.

Learn more in the research report *Generation of tree-specific spatial evapotranspiration data to monitor the response of woody vegetation to water availability*.

Influence of ecosystem condition on responses to environmental water

Understanding ecosystem condition can help explain environmental outcomes observed in response to environmental watering of different ecosystem types. Research applied measures of ecosystem condition to tailor expected outcomes and evaluation to better match the context under which water is being delivered. Research is linking species outcomes to the ecosystems that support them and determining how the condition of those ecosystems influences outcomes from water for the environment. The outcomes of this work apply to ecosystem type mapping, environmental water prioritisation frameworks, and setting of expected outcomes for watering actions.

This project continues to early 2025, exploring new vegetation condition metrics, using knowledge from vegetation and condition research projects, and broadening the scope to include trees and shrubs.

Developing an environmental water energetics response model

Food webs sustain all life. From microscopic plants to the mighty Murray cod, organisms in aquatic food webs rely on river flows so they can grow, reproduce, move, eat – and be eaten. River flows affect the cascade of energy from lower levels of a food web, such as leaf litter, to higher organisms, such as birds. This research developed an energetics response model to evaluate the contribution of Commonwealth environmental water to food webs under different flow scenarios. This new knowledge showed that Commonwealth environmental water has led to increased biomass across the river ecosystem, including for critical species such as Murray cod and golden perch.

Learn more in the research report *Basin-scale food webs research informing Commonwealth environmental watering* (PDF 5.8 MB).

5.2.3 Native fish

Flow-MER evaluation shows that Commonwealth environmental water provides a range of benefits to native fish populations and supports 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 locations. Flow-MER research is providing new information and tools for better targeting of water delivery to support native fish populations and to better evaluate and, in some cases, predict responses of native fish to environmental water.

Fish population models to inform Commonwealth environmental watering

Rivers aren’t healthy without fish. Native fish populations in the Murray–Darling Basin have suffered major declines, and they are a key target for delivery of Commonwealth environmental water. Understanding fish responses to flows throughout their life cycle is critical for targeting delivery of Commonwealth environmental water. This research developed population models for golden perch, Murray cod and bony herring, with the fishes’ life histories – from spawning to adulthood – guiding model development. The models can test various watering scenarios, evaluate likely outcomes, and help set monitoring targets. They showed that, for most of the Basin, delivery of Commonwealth water for the environment increased fish recruitment.

New knowledge

Population models demonstrated Basin-scale benefits of Commonwealth environmental water for golden perch, with increases in both maximum and minimum abundances, even under variable hydrological conditions. However, for Murray cod, the benefits of Commonwealth environmental water were less clear, with changes in hydrology due to climate change predicted to have greater impacts on population outcomes than Commonwealth environmental water. Further research is needed to adapt future water deliveries to address altered flow regimes under climate change.

Learn more in the research report *Fish population models to inform Commonwealth water for the environment* (PDF 9.2 MB).

Additional research tested the sensitivity of the models for golden perch and Murray cod. This process tests whether variation in any model inputs (such as flow) have disproportionate impacts on model outputs (such as larval survival). The research found that there were some differences in population outcomes between scenarios with and without Commonwealth environmental water, but the models are robust to this uncertainty and they are appropriate tools to assess the contributions of Commonwealth environmental water to improving native fish populations in the Basin.

Learn more in the research report *Fish population models: sensitivity to key life history characteristics in the Murray cod and golden perch population models* (PDF 4.5 MB).

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

Fish need to be able to move around rivers – up and down channels as well as sideways onto floodplains – to feed and reproduce. Regulation of river flows can hamper fish movement and reduce their populations. This research analysed fish movement over time using satellite trackers and information from otoliths (fish ear bones) and matched this up with corresponding river flows in areas where the fish were moving. Golden perch and Murray cod moved more and farther with increasing river discharge, giving them more opportunities to spawn and feed. This new knowledge will improve delivery of Commonwealth environmental water for habitat connectivity, fish passage, and maintaining refugia for migrating fish.

New knowledge

Complementary electronic and natural tag data revealed that, across their broad geographic range, golden perch and Murray cod undertook regional (> 5 km) and inter-regional (> 100 km) movements that were significantly influenced by the magnitude of river discharge. Telemetry data indicated that for every 1-unit increase in standardised discharge, the odds of golden perch moving increased by 4.86-fold, compared to a 1.44-fold increase for Murray cod.

Learn more in the research report *Regional and inter-regional fish movement responses to river discharge to inform Commonwealth water for the environment* (PDF 7.7 MB).

5.2.4 Waterbirds

Waterbird movements and site use across the Basin

Waterbirds need water and wetlands to forage, nest and rest. Knowing how, when and where waterbirds move is essential for supporting them with environmental water. This project satellite-tracked movements of ibis, spoonbills and egrets from 2016 to 2023. Knowledge gained from this research helps to adaptively manage Commonwealth environmental water to support waterbirds over their entire life cycle.

Waterbird breeding, foraging, stopover and refuge sites are managed through decisions affecting water, habitat and other factors, such as predation. To inform this decision-making, Flow-MER research used avian satellite transmitters to track the movements of waterbirds at local, Area and Basin scales. The data show the spatial and temporal scales and drivers of waterbird movements and site use, including breeding, foraging, stopover, refugia and Ramsar sites. Statistical models have been developed for aggregate-nesting straw-necked ibis, royal spoonbill and Australian white ibis. Tracking of plumed egret and great egret, which are highly dependent on environmental watering, has commenced. The knowledge obtained from this project is directly relevant to the planning and management of Commonwealth environmental water.

New knowledge

Flow-MER research has identified spatially explicit common routes for waterbird movement and connectivity, including a major 'flyway' crossing the Murray–Darling Basin, providing important context for the selection and prioritisation of watering sites. Research quantified waterbird movements, informing delivery of environmental water and prioritisation (e.g. for nesting, foraging and nomadic/migration distances, home ranges, breeding movements). We now have modelling and mapping of movement patterns and habitats used by different species and age groups, during both nesting and non-nesting periods, including quantification of critical information on breeding timing, duration, stages and site selection. Spatial and temporal foraging patterns and foraging habitat selection during and after nesting provide further information to inform water delivery. This research has also quantified and mapped post-breeding dispersal timing, routes, distances and habitat use for both juveniles and adults, with implications for environmental watering of foraging habitats to support these life stages.

Learn more in the research report *Satellite-tracking waterbird movements in the Murray–Darling Basin* (PDF 31.3 MB).

5.3 Informing delivery of Commonwealth environmental water

At the Basin scale, 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 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. In 2022–23, delineation of the managed floodplain was expanded using 9 years of evidence from the Long Term Intervention Monitoring project (2014–19) and Flow-MER inundation mapping. This has added 359,091 ha to the known area of aquatic ecosystems that can be managed with environmental water in the Basin.

5.3.1 Biodiversity

At the Basin scale, the 9-year evaluation of watering frequencies suggests the CEWH's current water allocation and delivery is qualitatively fit for purpose. 9 years of continued evaluation of Basin biodiversity has improved 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 the scales of ecosystems, wetland complexes and valleys.

Recommendations for vegetation

- Continue to deliver environmental water to maintain inundation regimes at floodplain–wetland locations that are central to supporting vegetation species and community diversity at the Basin scale.
- Consider opportunities to use environmental water to further support plant species known to be used by Aboriginal people and engage Aboriginal communities across the Basin to identify culturally important plant species that can be supported with environmental water.
- Establish key hydrological metrics to support the evaluation of vegetation outcomes in areas where riverine vegetation is the focus of environmental water management.

Recommendations for fish

- In wet and flood years, there is an opportunity to use Commonwealth environmental water delivery to build on these natural events to support fish population recovery (e.g. dilution flows to reduce hypoxic blackwater events and fish deaths or flows to help disperse migratory species) or maximise benefits from the post-flood period (e.g. filling gaps in the hydrograph to optimise spawning and recruitment in the season following floods). The use of Commonwealth environmental water to optimise fish outcomes during wet conditions is unlikely to be a one-size-fits-all watering scenario across the basin. It will be specific to the fish species and targeted to responses, with consideration of climate, hydrological regime, geolocation, and prevailing threats.
- Commonwealth environmental water should continue to be managed to mitigate the number of low-flow days and increase average daily flows to support fish populations. This will become increasingly important during the transition out of the wet La Niña climate patterns. Commonwealth environmental water contributions provided a range of benefits to native fish populations and supported critical life-history processes, such as recruitment, body condition and population growth. In the absence of Commonwealth environmental water, there would likely be further declines in fish populations or loss of species in some Selected Areas.
- Modelling successfully predicted Murray cod and Murray–Darling rainbowfish recruitment at unmonitored sites, and the effects of Commonwealth environmental water on these 2 species were assessed. Population models tested various flow scenarios and identified those with the most benefit for Murray cod and golden perch populations. This provides strong evidence that the findings from monitored locations (selected areas) are transferable to inform planning for watering actions at sites across the Basin.
- Native fish face multiple compounding threats, many of which are not related to flow. Integrating Flow-MER into the broader Basin recovery framework – such as objectives from threatened species recovery plans, complementary measures (e.g. fish passage and exotic species control) and action plans, the *Native fish recovery strategy*, the Basin Plan and the Strategy – will bring together currently disparate efforts to support fish recovery.

Recommendations for waterbirds and other fauna

- Explicit identification is needed within each valley of the occurrence and water needs of listed threatened and migratory species that occur within the managed floodplain. A more detailed assessment of the distribution of key species and current water management practices in each valley is critical to identify ‘blind spots’ where the water requirements of these species are not being met.
- Increased surveillance is needed of conservation-significant species that are known to occur in habitats frequently targeted with Commonwealth environmental water delivery, including platypus, large-footed myotis (also referred to as southern myotis) and grey snake.

- While many waterbirds are highly mobile, improvements in waterbird health and survival, particularly in the first year of life, can be made by ensuring foraging habitats are maintained year-round within key valleys. In addition, there is a need for better coordination between valleys to set and meet targets for waterbird habitats at the Basin scale, particularly in dry years when refuge habitats are critical.

5.3.2 Ecosystem function

Data from 2014 to 2023 provide a foundation for the prediction of site-specific metabolic patterns over time as data is collected, and responses to delivery of Commonwealth environmental water are validated. The next step is to to understand how the food supply for food webs is influenced by Commonwealth environmental water and the relationship between stream metabolism and secondary productivity.

Improving understanding of site-specific drivers of metabolic responses to flow will improve capacity to predict responses in unmonitored areas. There is scope to focus future Basin-scale reporting for food webs and water quality on improving understanding of how the food supply for food webs is influenced by Commonwealth environmental water (e.g. the recovery of metabolic activity following flow disturbance, and the influence of disturbance on food webs).

5.3.3 Water quality

Environmental water is very important for decreasing the likelihood of low dissolved oxygen by increasing water mixing and oxygen exchange at the surface, particularly in the Lower Murray where the river is dominated by slow-flowing locks and weirs. Commonwealth environmental water can contribute to maintaining dissolved oxygen levels above desired thresholds during hypoxic blackwater events, when flows can dilute anoxic water and increase oxygen exchange at the surface. Commonwealth environmental water can also 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 (electrical conductivity) below 800 µS/cm at Morgan (a river management target of the Murray–Darling Basin Authority 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 Murray River System into the Southern Ocean each water accounting period.

5.4 Informing monitoring and evaluation

The evaluation has iteratively improved throughout the last 9 years, due to improvements in acquittal reporting, improvements in the methods and consistency of documenting inundation from Commonwealth environmental water, and major leaps forward in the mapping of water-dependent ecosystems in the Basin by the ANAE. These improve the accuracy of the evaluations and the capacity to meaningfully assess the contribution of Commonwealth environmental water to Basin ecosystems and Basin Plan objectives.

We have identified 3 areas to improve the existing monitoring and evaluation program:

(1) consideration of more detailed inundation analysis for wetland hydrology

(2) review of expected outcomes and environmental watering objectives

(3) consideration of monitoring to improve the evaluation.

5.4.1 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 the evaluation to an interpretation of annual watering frequencies for target ecosystems that 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.

Improving knowledge of wetland hydrology is a high priority, including improving the accuracy of sub-annual inundation and counterfactual inundation data to support better understanding and evaluation of the influence of individual and collective watering actions on ecosystem responses. Understanding the role of Commonwealth environmental water in maintaining ecosystem diversity could be improved by counterfactual analyses that compare how ecosystem diversity is supported with and without Commonwealth environmental water. In rivers, the Hydrology evaluation shows 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. 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).

5.4.2 Expected outcomes and environmental watering objectives

Flow-MER evaluation is constrained by evaluation questions developed prior to the development of the Strategy (which are therefore only loosely aligned) and by watering objectives and expected outcomes from the delivery of environmental water that are not clearly defined. Expected outcomes require better definition and quantification if they are to be effectively evaluated (and used for planning). Development of watering objectives for ecosystem types and expected ecosystem-scale outcomes would support a performance-driven evaluation to assess the impact of Commonwealth environmental water beyond the current simplistic view that documents the pattern of water delivery with assumed benefits. For example:

- Better align specific objectives for watering actions with both Basin Plan objectives and the desired outcomes in the Strategy.
- Setting of specific valley-wide objectives for species with conservation significance should be considered, to coordinate water delivery for all stages of a species' life cycle.
- Define expected outcomes for ecosystem diversity. There is now sufficient learning from the evaluation to set realistic and relevant ecosystem objectives. These would support evaluation and contribute to planning for the delivery of Commonwealth environmental water.
- Define watering objectives for waterbirds. Environmental watering objectives for waterbirds tend to be general in nature. Developing more targeted objectives that consider the whole-of-life-cycle needs of waterbirds and their mobility could significantly improve waterbird survival and recruitment and improve the likelihood of achieving targets for waterbird population, abundance and diversity. This may require investigation of waterbird responses to environmental water across all data sources and identifying how these data can best be used to support evaluation of Basin-wide outcomes.
- Align objectives and expected outcomes for vegetation and fish. There is generally poor alignment between Basin Plan objectives for vegetation (directed at protecting and restoring water-dependent ecosystems of the Murray–Darling Basin), the 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 Strategy or the Basin Plan). The situation is similar

for fish. It is recommended that watering objectives are more clearly defined and aligned under the Strategy and that more specific objectives are defined for water delivery.

5.4.3 Monitoring and evaluation

Each year, Flow-MER evaluation highlights opportunities within the current program to improve how monitoring and evaluation is undertaken and, in so doing, more effectively report on the environmental outcomes from the delivery of Commonwealth environmental water. This year, the following opportunities for improvement are noted.

- **Review monitoring sampling points to better support evaluation.** Improve the design of Flow-MER monitoring, especially around sampling site locations and representativeness, and by adding more measures and indicators to make it fit for purpose for the evaluation against Basin Plan objectives and Strategy outcomes. Flow-MER monitoring locations are not located to provide replication across different ecosystem types or to provide data from key ecosystem types that reflect current priorities for environmental water. For example, future monitoring design should use the ANAE classification system to stratify monitoring locations for vegetation communities.
- **Consideration of the watering requirements for species of conservation concern.** There are many species of conservation concern that have distributions coinciding with Commonwealth environmental water delivery. To date, there has been a small number of deliveries of Commonwealth environmental water with objectives related to, for example, platypuses, but the success of these actions has not been evaluated. Consideration of the water requirements and current distributions for species of conservation significance in areas targeted with Commonwealth environmental water will support their adaptive management in the Basin and inform evaluation.
- **Specific monitoring of iconic species or communities.** There is no specific monitoring for threatened plant species or communities or for other iconic plant species (e.g. plant species specifically listed in the 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.
- **Coordination between monitoring programs.** Monitoring of outcomes for waterbirds, frogs, turtles and other vertebrates is currently spatially and temporally limited, restricting the capacity to evaluate the outcomes of Commonwealth environmental water. Collaboration and coordination with complementary government programs would provide a more robust dataset for evaluation. Support is required for sharing data between local, state and federal agencies so that information on monitoring activities and ecosystem responses to environmental water is widely available.
- **Extrapolation of trends beyond Area-scale**. Extrapolation for fish outcomes from the delivery of Commonwealth environmental water is limited by data (i.e. limited spatial coverage of waterways across the basin, low abundance of many native fish species). This reduces the degree of confidence in reporting on Basin-scale outcomes. Collaboration and coordination with complementary state-based monitoring programs would provide a more robust dataset for evaluation.

Appendix A COMMONWEALTH ENVIRONMENTAL WATERING ACTIONS

Table A.1 Commonwealth environmental watering actions by valley and hydrological flow component, 2022–23

The flow component terms (base flow, fresh, bankfull, overbank, wetland) are those used by the Commonwealth Environmental Water Holder when describing the watering actions. Cell values are number of actions and values in parentheses are volumes in megalitres (ML). Dash (–) indicates that the watering action did not include that flow component.

Valley	Base flow	Base flow, fresh	Base flow, fresh, bankfull	Fresh	Fresh, base flow	Fresh, overbank, bankfull	Bankfull, fresh, overbank	Overbank	Overbank, fresh	Wetland	Total actions (volume, ML)
Northern Basin											
Barwon Darling	–	1 (16,867)	–	–	–	–	–	–	–	–	1 (16,867)
Border Rivers	–	–	1 (5,487)	2 (1,136)	1 (86)	2 (9,412)	–	–	–	–	6 (16,121)
Condamine Balonne	–	–	–	–	–	–	–	–	5 (113,253)	–	5 (113,253)
Gwydir	–	1 (4,508)	–	1 (2,045)	–	–	–	–	–	2 (5,536)	4 (12,089)
Macquarie	–	–	–	1 (2,189)	–	–	–	–	–	1 (10,244)	2 (12,433)
Namoi	–	–	–	1 (4,320)	–	–	–	–	–	–	1 (4,320)
Warrego	–	–	5 (13,581)	–	–	–	–	1 (222)	–	–	6 (13,803)
Southern Basin											
Broken	7 (48,001)	–	–	1 (766)	–	–	–	–	–	–	8 (48,767)
Campaspe	3 (1,003)	–	–	1 (69)	–	–	–	–	–	–	4 (1,072)
Central Murray	2 (1,123)	–	–	1 (51,310)	–	–	–	–	–	1 (93,969)	4 (146,402)
Edward/Kolety–Wakool	12 (35,860)	3 (14,348)	–	–	–	–	6 (195,550)	–	–	2 (3,024)	23 (248,782)
Goulburn	2 (63,315)	–	–	1 (104,567)	–	–	–	–	–	–	3 (167,882)
Lachlan	–	–	–	3 (19,525)	–	–	–	–	–	1 (683)	4 (20,208)
Loddon	1 (97)	–	–	1 (3,259)	–	–	–	–	–	–	2 (3,356)
Lower Darling/Baaka	2 (148,432)	–	–	–	–	–	–	–	–	–	2 (148,432)

Valley	Base flow	Base flow, fresh	Base flow, fresh, bankfull	Fresh	Fresh, base flow	Fresh, overbank, bankfull	Bankfull, fresh, overbank	Overbank	Overbank, fresh	Wetland	Total actions (volume, ML)
Lower Murray	1 (49,649)	3 (112,201)	–	–	–	–	–	–	–	10 (463)	14 (162,313)
Murrumbidgee	–	–	–	4 (155,670)	–	–	–	–	–	4 (90,911)	8 (246,581)
Ovens	1 (50)	–	–	1 (73)	–	–	–	–	–	–	2 (123)
Wimmera	2 (1,753)	–	–	–	1 (689)	–	–	–	–	–	3 (2,441)
Total	33 (349,282)	**8 (147,924)**	**6 (19,068)**	18 (344,930)	**2 (775)**	**2 (9,412)**	**6 (195,550)**	**1 (222)**	**5 (113,253)**	21 (204,829)	102 (1,385,244)

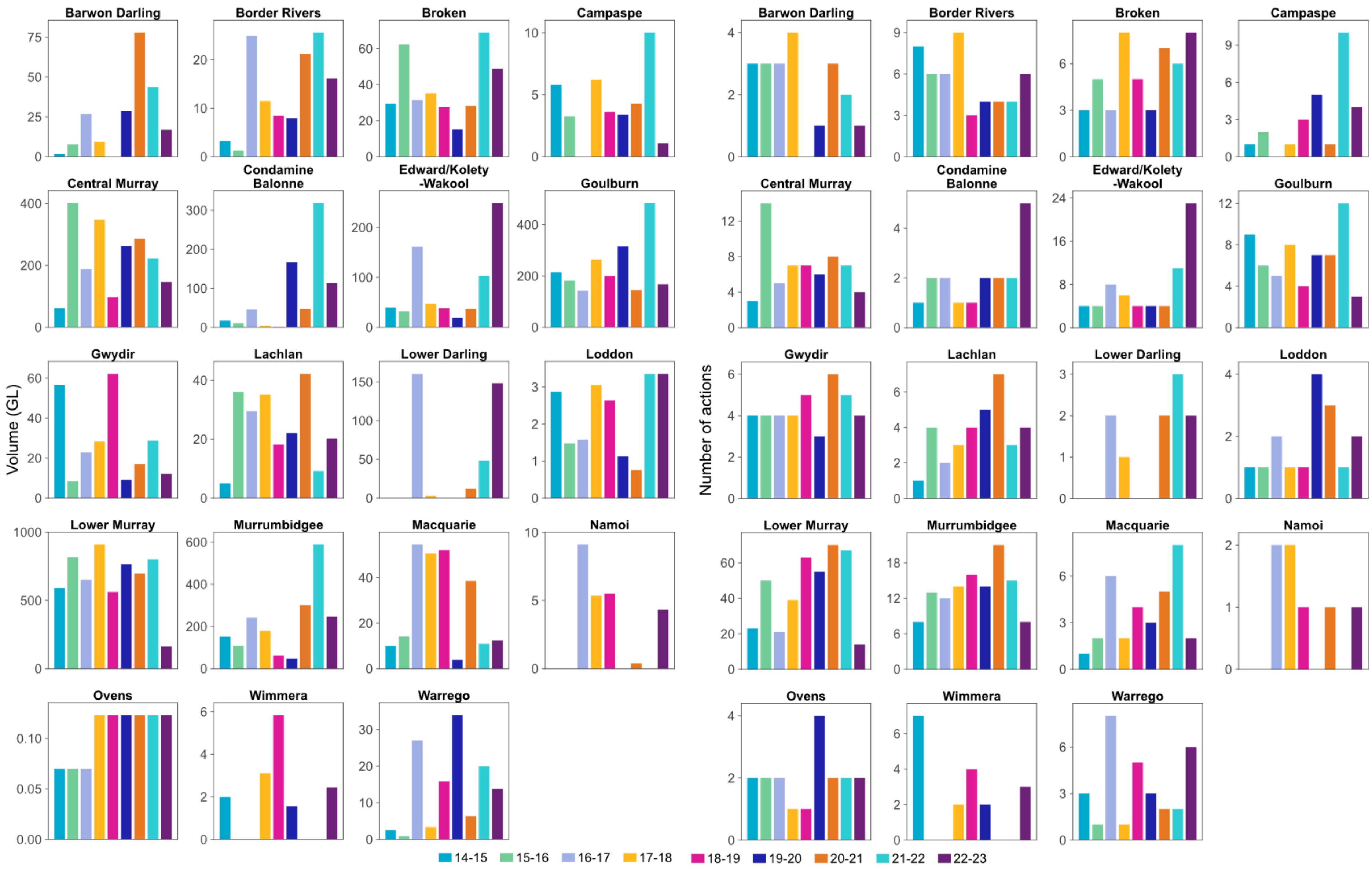

Figure A.1 Commonwealth environmental water portfolio showing volume (left) and number (right) of watering actions, by valley and year, 2014–23

Appendix B DETAILED OUTCOMES TABLE

Table B.1 Commonwealth Environmental Outcomes framework against Basin Plan biodiversity objectives (Basin Plan S8.05)

Basin outcomes	One-year expected outcomes	Long-term expected outcomes	Outcomes 2022–23	Outcomes 2014–23
Biodiversity (Basin Plan S. 8.05)				
Ecosystem diversity	None identified	None identified	202,071 ha of mapped lakes and wetland supported	249,079 ha of lakes and wetlands supported
			22,205 km of rivers supported	27,715 km of waterways supported
			71,837 ha of floodplain inundated	187,894 ha of floodplain supported
			23,768 ha of estuary supported with fresh water	23,768 ha of estuary supported
			53 Basin ANAE ecosystem types supported	59 Basin ANAE ecosystem types supported
Ecosystem diversity: Ramsar wetlands	None identified	None identified	Commonwealth environmental water delivered to 8 Ramsar sites, supporting a subset of critical components, processes and services	Commonwealth environmental water was delivered to support environmental outcomes in 11 Ramsar sites in the Basin, noting that Commonwealth environmental water is often delivered in partnership with water held by the Murray–Darling Basin Authority (e.g. The Living Murray Program), as well as water from the states
Species diversity: vegetation	Plant species diversity	Plant species diversity	Even after 3 wet years, there was a greater proportion and cover of submerged and amphibious plants observed at sites that had wetter inundation regimes maintained using environmental water	It is very likely that the absence of environmental water would have resulted in the near-absence of submerged species and considerably less diversity and cover of amphibious and damp-loving species at 45% of monitored sample points
	Vegetation community diversity	Vegetation community diversity	291 plant taxa, representing 57 families, were recorded across 80 monitored sites	By maintaining submerged, amphibious and damp-loving species, environmental water is preventing a permanent transition to altered vegetation community assemblages and a loss of resilience of water-dependent plant communities

Basin outcomes	One-year expected outcomes	Long-term expected outcomes	Outcomes 2022–23	Outcomes 2014–23
Species diversity: fish		No loss of native species currently present within the Basin	The Basin-scale evaluation was not designed to detect loss of native species within the Basin. 13 native fish species were detected by the monitoring program. For the first time, there was detection of an adult river blackfish in the monitoring program, in the Edward/Kolety–Wakool river systems	There is no evident loss of species at the Selected Areas. However, the contribution of Commonwealth environmental water to this Strategy outcome is unknown. Cumulatively, 15 native fish species were detected during the monitoring program
		Improved population structure of key fish species through regular recruitment	Recruitment of golden perch was evident in the Lower Murray River, but there was little evidence of recruitment in other Selected Areas. There was evidence of recruitment of Murray cod in the Lower Murray River, while recruitment was limited (zero or low abundances of young-of-year detected) in other Selected Areas	Across the Basin, there is evidence of recruitment of golden perch. However, the contribution of Commonwealth environmental water to this Strategy outcome is unknown. There is evidence of recruitment of Murray cod in most years at the Selected Areas. Counterfactual modelling indicated Commonwealth environmental water contributed to increased Murray cod recruitment in some years in the Goulburn River and Lower Murray River (an association with moderate-to-strong confidence). At the other Selected Areas, Murray cod recruitment responses to Commonwealth environmental water were more variable
		Improved community structure of key native fish species	Setting community metrics for assessing Commonwealth environmental water is challenging since the Strategy outcome does not provide any guidance as to what is considered an improvement	Counterfactual modelling showed that, in the Goulburn River, there was low-to-medium confidence of positive effects, and in the Lower Murray River and Murrumbidgee River System, there was low confidence of positive effects on the community metric (the proportion of catch that was native) in association with Commonwealth environmental water in multiple years. There were more variable responses in the other Selected Areas
Species diversity: waterbirds		Waterbird diversity	84 waterbird species were reported from annual waterbird counts	137 waterbird species were observed and likely to have benefited from delivery of Commonwealth environmental water across the Basin
	Survival and condition	Waterbird diversity and population condition	Continuous high-water allocations and widespread unregulated floodplain inundation triggered significant waterbird breeding events in the Murrumbidgee, Lachlan, Gwydir, Central Murray, Condamine Balonne and Macquarie valleys. Species include the Australian white ibis, royal spoonbill, yellow-billed spoonbill, straw-necked ibis, glossy ibis, little pied cormorant, little black cormorant, Australasian darter, great cormorant, nankeen night-heron, white-necked heron, eastern great egret and plumed egret	Aggregate nesting waterbird breeding events were identified in the Murrumbidgee, Lachlan, Gwydir, Central Murray, Condamine Balonne and Macquarie valleys

Basin outcomes	One-year expected outcomes	Long-term expected outcomes	Outcomes 2022–23	Outcomes 2014–23
Species diversity: frogs	Young	Adult abundance	11 species were detected. The most widespread species were spotted marsh frog, barking marsh frog and Peron's tree frogs. Southern bell frogs were detected in 2 regions the Murrumbidgee and the lower Lachlan. There is a single record of Sudell's frog, which was detected in the Yanco-Billabong as part of the Murrumbidgee surveys	Frog species richness is very stable within the Murrumbidgee across water years. Available abundance data is not sufficiently robust to support an evaluation
Species diversity: turtles	Young	Adult abundance	Abundance not reported	Abundance not reported
Species diversity: threatened and migratory species	None identified	None identified	35 listed waterbird species were detected and had a distribution that coincided with habitats inundated by Commonwealth environmental water. Frequently detected species included Caspian tern, southern bell frog, glossy ibis, Murray hardyhead, white-bellied sea-eagle and Australasian bittern	59 listed threatened or migratory waterbird and raptor species were identified from the managed floodplain. Of these, 57 were reported from habitats that received Commonwealth environmental water on at least one occasion
Ecosystem function (Basin Plan S. 8.06)				
Connectivity	Hydrological connectivity including end of system flows			Commonwealth environmental water had an important role to play in meeting long-term objectives to protect and restore connectivity within and between water-dependent ecosystems, particularly in the Lower Murray River
			297,676 ha of lakes, wetlands, floodplain and estuary supported	460,741 ha of lakes, wetlands, floodplain and estuary supported
			22,205 km of waterways supported	27,715 km of waterways supported
Process	Primary productivity (of aquatic ecosystems)		Commonwealth environmental water had a positive influence on primary production and respiration	Evidence from all Selected Areas that Commonwealth environmental water had a positive influence on primary production and respiration
	Nutrient and carbon cycling		Commonwealth environmental water had a positive influence on protecting and restoring energy, carbon and nutrient dynamics	Commonwealth environmental water had a positive influence on protecting and restoring energy, carbon and nutrient dynamics
Water quality (Basin Plan S. 9.08; 9.09; 9.14)				

Basin outcomes	One-year expected outcomes	Long-term expected outcomes	Outcomes 2022–23	Outcomes 2014–23
Chemical	Salinity		151,252 tonnes of salt exported through barrages were estimated as being attributable to Commonwealth environmental water Commonwealth environmental water contributed to maintenance of salinity (electrical conductivity) below 800 µS/cm at Morgan.	Commonwealth environmental water accounted for 80%–100% of annual environmental flow releases through the barrages (the only mechanism for salt export from the Basin) during the dry years (between 2014–15 and 2020–21 except for 2016–17). Since 2014–15, Commonwealth environmental water has been responsible for over 4.2 million tonnes of additional salt exported through the barrages and has reduced salt import by more than 26 million tonnes.
	Dissolved oxygen		There were clear benefits of environmental flow provision in March 2023 in terms of increasing oxygen concentrations and reducing the potential for blackwater events.	Commonwealth environmental water can help reduce the likelihood of low dissolved oxygen concentrations in the Lower Murray River, if the contribution increases water velocities above a level of ~0.18 m/s. Below this level, surface oxygen exchange is poor. Reducing the likelihood of low dissolved oxygen concentrations can be achieved by increasing water mixing when flows are otherwise low.
Resilience (Basin Plan S. 8.07)				
Ecosystem resilience	Individual refuges			180 watering events (2,868 GL) were used to support refugia
	Landscape refuges			Watering events were used across the Basin to support a wide range of vegetation communities. Commonwealth environmental water supported watering of 125,743 ha of palustrine wetlands and 187,894 ha of floodplains
	Ecosystem recovery			Watering events were used for flow management to support the recovery of in-stream aquatic vegetation and large-bodied native fish in the Edwards/Kolety–Wakool system following the 2016 hypoxic blackwater event.

https://flow-mer.org.au

Australian Government
Commonwealth Environmental Water Holder

Partners

CSIRO

University of Canberra

Collaborators

Arthur Rylah Institute for environmental research

alluvium

BROOKS.eco Ecology & Technology

Charles Sturt University

Government of South Australia Department of Primary Industries and Regions

SARDI South Australian Research and Development Institute

University of New England

NSW Government Department of Primary Industries

Deakin University

ARRC Australian River Restoration Centre