2017–18 Basin-scale evaluation of Commonwealth environmental water – Synthesis Report

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La Trobe University offices are located on the land of the Latje Latje and Wiradjuri peoples. We undertake work throughout the Murray–Darling Basin and acknowledge the traditional owners of this land and water. We pay respect to Elders past, present and future.

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1 Background

1.1 The Commonwealth *Water Act 2007*

The *Water Act 2007* (Cwlth) (The Act) provides the legal basis for the determination of sustainable water extraction limits within the Basin. The Act establishes the Murray–Darling Basin Authority (MDBA) to develop the *Murray–Darling Basin Plan 2012* (Basin Plan), which defines these limits, and the Commonwealth Environmental Water Holder (CEWH) to manage the environmental flows that result and gives greater powers to the Bureau of Meteorology to obtain and disseminate water information across the country.

To support the implementation of these arrangements and rebalance the system between the environment and consumptive use, the Australian Government is investing in recovering water through investment in irrigation efficiency and the buyback of entitlements from irrigators.

The CEWH is a statutory position responsible for managing the water that the Australian Government acquires for the purpose of protecting or restoring environmental assets so as to give effect to international agreements (BP S104). In undertaking this role, there are three options available to the CEWH at any given time in managing the portfolio:

- use the environmental water which accrues to the entitlement, with the release of water from storage or the manipulation of other in-stream or floodplain infrastructure (with the timing, flow rate and volume released designed to have maximum environmental benefit)
- carryover the water in storage for use in a future year (under the same rules that apply to irrigators)
- trade (buy or sell water) with irrigators in order to improve environmental outcomes at a future time or in a different valley (e.g. sell water when it is not needed and buy when it is).

The MDBA is an independent, expertise-based agency responsible for leading the planning and management of Basin water resources. It has key roles in:

- developing and overseeing the implementation of all aspects of the *Basin Plan 2012*
- coordinating state and federal agencies in the management of the water resources
- evaluating and auditing the implementation of the Basin Plan.

1.2 Roles and responsibilities under the Basin Plan

The Basin Plan, a legislative instrument, sets out the roles and responsibilities for reporting on environmental outcomes of the MDBA, state governments and the CEWH:

- the MDBA is responsible for reporting on achievements against the environmental objectives of the Basin Plan at the Basin scale (i.e. whole of drainage basin),
- state governments are responsible for reporting on achievements against the environmental objectives of the Basin Plan at an asset scale (i.e. rivers, wetlands, floodplains),
- the CEWH is responsible for reporting on the contribution of Commonwealth environmental water to the environmental objectives of the Basin Plan (at multiple scales).

These reporting obligations set up the architecture for the monitoring and evaluation that is required to enable a determination by the MDBA of overall Basin Plan outcomes, as indicated in Figure 1.

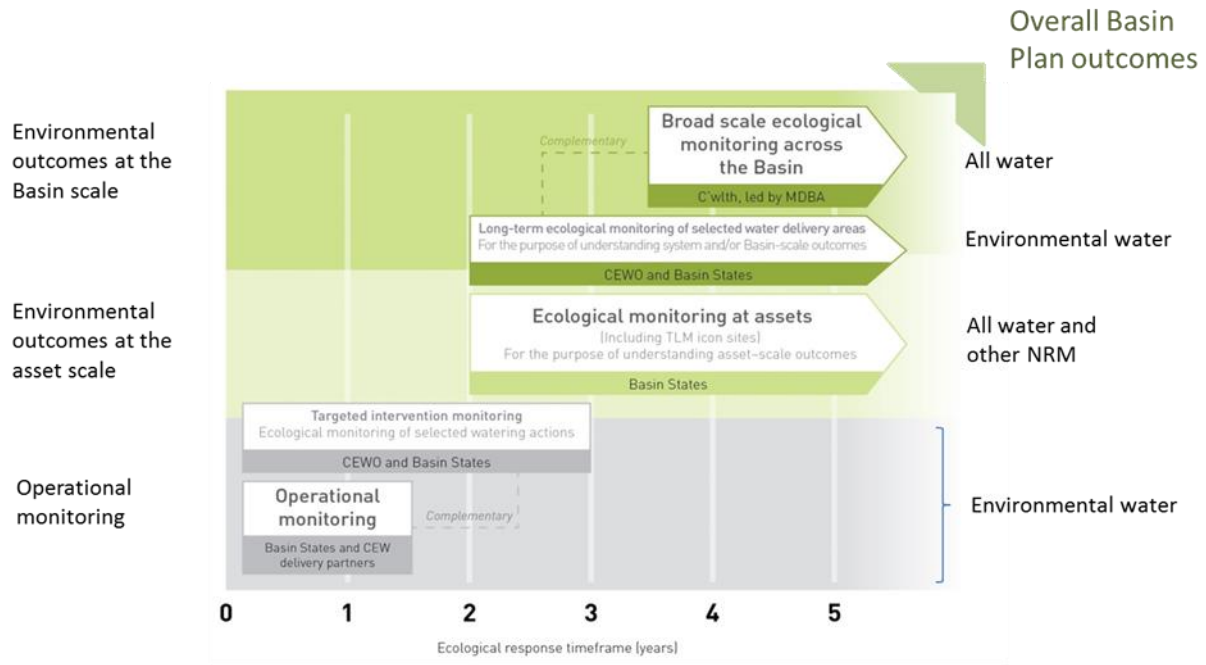

Figure 1. Monitoring and evaluation reporting obligations (adapted from Commonwealth Environmental Water Office 2013).

1.3 Monitoring aquatic ecosystem responses to environmental flows

Within this framework, the CEWH needs to ensure that its monitoring and evaluation activities will enable it to meet is reporting obligations and demonstrate both value for money from the Australian Government's investment and support adaptive environmental flow management over time.

The common elements of all reporting requirements are the Basin Plan environmental objectives, or more specifically, the environmental objectives contained within the Environmental Watering Plan (Chapter 8 of the Basin Plan). These objectives are Basin scale and long term. For example (s 8.05(3)):

> *An objective is to protect and restore biodiversity that is dependent on Basin water resources by ensuring that:*
>
> *(a) water-dependent ecosystems that support the life cycles of a listed threatened species or listed threatened ecological community, or species treated as threatened or endangered (however described) in State law, are protected and, if necessary, restored so that they continue to support those life cycles; and*
>
> *(b) representative populations and communities of native biota are protected and, if necessary, restored.*

However, environmental flows are delivered at an asset scale in the short term. To bridge this gap, the Commonwealth Environmental Water Office's (CEWO's) Long Term Intervention Monitoring (LTIM) Project is based around an Outcomes Framework[1] (CEWO 2013b) which describes the outcomes expected from environmental flows at 1- and 5-year time scales that will contribute to the longer term objectives of the Environmental Watering Plan.

These outcomes help guide the monitoring that needs to take place to support an evaluation of the impact of environmental flows and are based on cause-and-effect diagrams that describe the

[1] http://www.environment.gov.au/water/cewo/publications/environmental-water-outcomes-framework

relationships between different parameters in response to environmental flows, reflecting current scientific knowledge.

This Outcomes Framework also ensures that the monitoring undertaken by the CEWO is aligned with the broader scale monitoring undertaken by the MDBA for vegetation, fish, waterbirds and hydrological connectivity and for which there are quantified environmental targets described in a Basin-wide Watering Strategy (MDBA 2014) – one of the key planning documents that guides all environmental water use within the Basin.

The Basin-wide Environmental Watering Strategy provides the next level of detail on the environmental objectives and targets, with 'quantified expected outcomes' identified for four components: river flows and connectivity; native vegetation; waterbirds; and native fish. Examples of the expected outcomes include:

- a 20–25% increase in waterbirds by 2024
- a 10–15% increase in mature Murray cod and golden perch at key sites
- maintenance of the current area and condition (and in some regions, improved condition) of river red gum, black box, coolabah and lignum communities
- improved overall flow, such as 10% more flow in the Barwon–Darling river system, 30% more flow in the Murray River and 30–40% more flow to the Murray Mouth.

These outcomes are the MDBA's best assessment of how the Basin's environment will respond over the next decade as a result of implementing the Basin Plan and associated water reforms. It is the responsibility of the MBDA to evaluate the contribution of Basin Plan reforms to achieving these targets using its own monitoring information and that obtained from Basin states and the CEWO.

2 Introduction

2.1 What is the Long Term Intervention Monitoring Project?

The LTIM Project is assessing the ecological effects of Commonwealth environmental water and its contribution to Basin Plan[2] environmental objectives. The LTIM Project aligns with the CEWO Monitoring, Evaluation, Reporting and Improvement (MERI) Framework (CEWO 2013a) and will provide information that will help improve the management of environmental water, through adaptive management. Monitoring is being conducted at seven areas (called Selected Areas) across the Basin (Figure 2) from 2014–15 to 2018–19 and the evaluation is undertaken across the entire Basin and includes all watering actions.

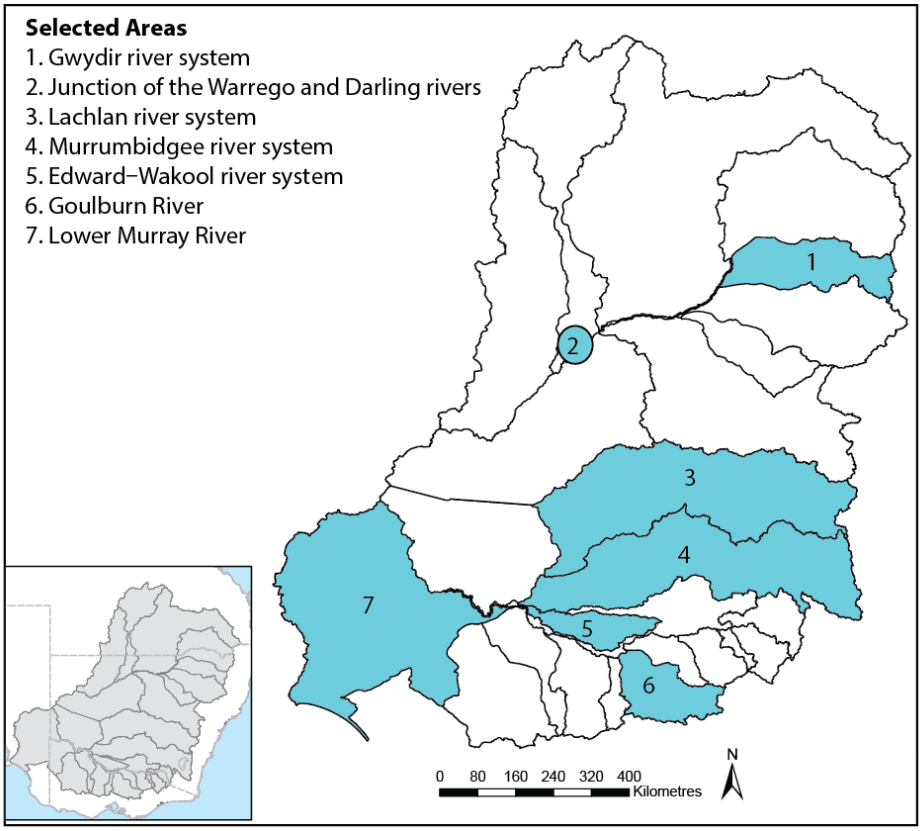

Figure 2. General location of the seven Selected Areas where the LTIM Project is measuring the effects of Commonwealth environmental water.

The five high-level objectives of the LTIM Project are to:

1. evaluate the contribution of Commonwealth environmental watering to the objectives of the MDBA's Environmental Watering Plan
2. evaluate the ecological outcomes of Commonwealth environmental watering at each of the seven Selected Areas
3. infer ecological outcomes of Commonwealth environmental watering in areas of the Basin not monitored
4. support the adaptive management of Commonwealth environmental water
5. monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

[2] The Basin Plan has been prepared by the Murray–Darling Basin Authority for subparagraph 44 (2)(c)(ii) of the *Water Act 2007* (Cwlth): http://www.mdba.gov.au/basin-plan

The LTIM Project is evaluating the effect of Commonwealth environmental water at several spatial scales. Evaluation at the site and regional (Selected Area) scales is being completed by monitoring teams at each of the Selected Areas and is documented in individual reports that are published on the CEWO website annually.[3] Evaluation is also being conducted at the Basin scale, which seeks to integrate information from monitoring at Selected Areas and other information sources to determine outcomes from the portfolio of Commonwealth environmental water across the Basin. This report documents the Basin-scale evaluation for the first four years of the LTIM Project (2014–18), with a focus on the outcomes from Year 4 (2017–18) and cumulative outcomes from 2014–18.

2.2 How are we evaluating outcomes at the Basin scale?

The development of the Basin-scale evaluation is described in the LTIM Project Logic and Rationale document (Gawne *et al.* 2013)[4] and the Basin Evaluation Plan (Gawne *et al.* 2014).[5] These documents provide an overview of the LTIM Project and the selection process for six ecological indicators or 'matters' for Basin evaluation:

- **ecosystem diversity** – the aquatic ecosystem types (e.g. wetlands, rivers, streams) that benefited from Commonwealth environmental water
- **hydrology** – river flow and wetland water regimes modelled with and without Commonwealth environmental water
- **stream metabolism and water quality** – rates of instream primary productivity and decomposition, salinity and pH
- **vegetation diversity** – plant species' responses with respect to extent, diversity and condition
- **fish** – short- and long-term responses of fish with respect to movement, condition, abundance and diversity
- **biodiversity** – effects on diversity of all biota from monitoring and observations.

This Basin-scale evaluation report draws together the results of each Basin Matter to provide an integrated assessment of the outcomes of Commonwealth environmental water. Evaluation is provided in the context of the 2017–18 watering year, but includes a cumulative assessment across the first three yours of the LTIM Project 2014–18 and is provided in three parts:

1. **integrated Basin-scale evaluation** – a summary of the achievements of Commonwealth environmental water under three broad themes of the Basin Plan (biodiversity, ecological function and resilience)
2. **contributions to Basin Plan environmental objectives** – a tabulation of progress toward these long-term goals in the first four years
3. **adaptive management** – a summary of key 'lessons learned' for improved environmental water outcomes.

[3] https://www.environment.gov.au/water/cewo/monitoring/ltim-project

[4] http://www.environment.gov.au/water/cewo/publications/long-term-intervention-monitoring-project-logic-and-rationale-document

[5] http://www.environment.gov.au/water/cewo/publications/cewo-ltim-basin-evaluation-plan

2.3 Context: the 2017–18 watering year

2.3.1 Climate and water availability

Rainfall conditions were below average across much of the Basin in 2017–18, with the northern Basin particularly dry (Figure 1). A small proportion of the Southern Basin including the Goulburn and Upper Murray experienced average rainfall conditions. Dry conditions have been common, however, in the Basin for the four-years from mid-2014 to mid-2018, the period of LTIM Basin-scale reporting to date.

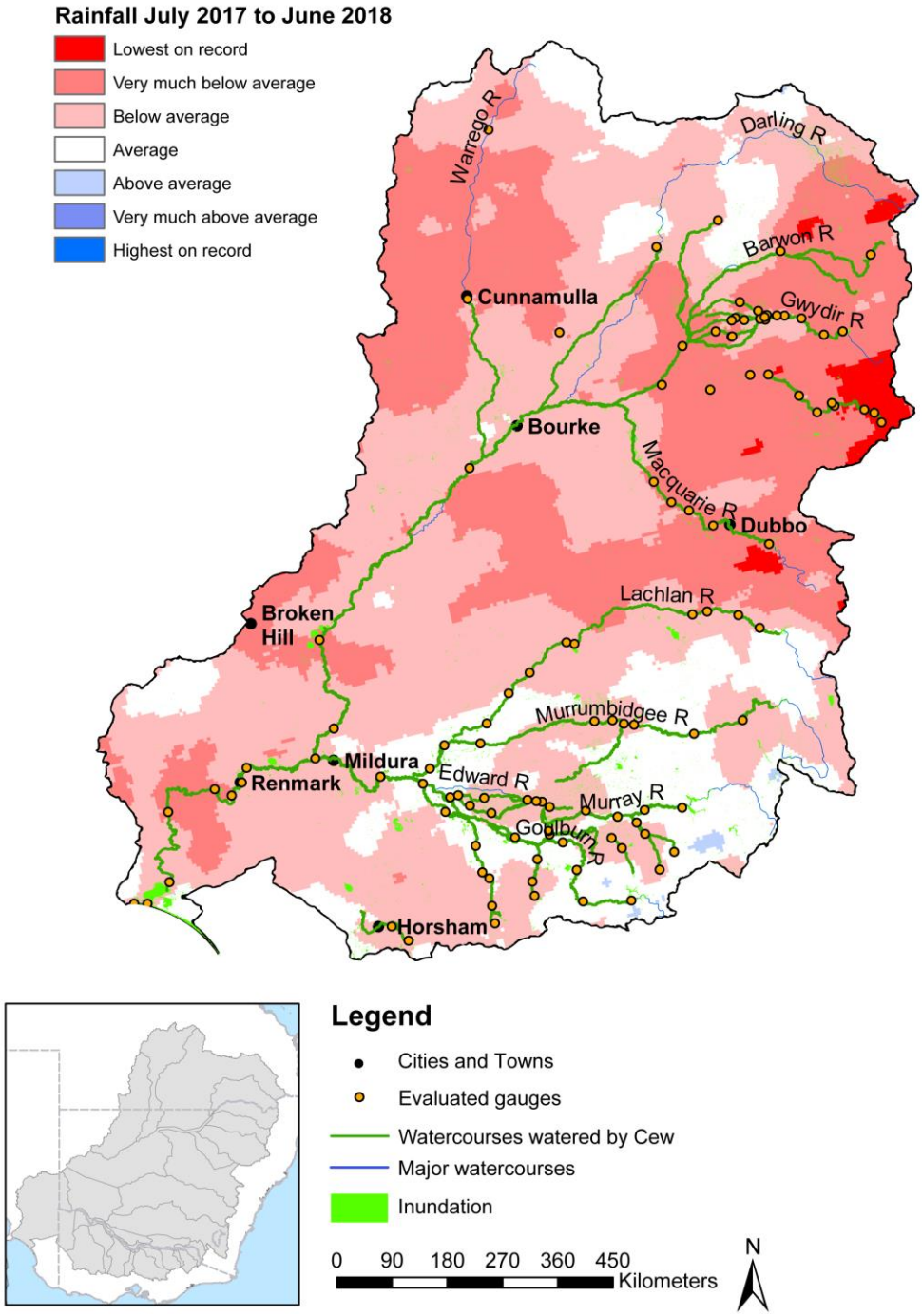

Figure 3. Rainfall, areas inundated and streams watered by Commonwealth environmental water during the 2017–18 watering year.

2.3.2 Commonwealth environmental water delivery in 2017–18

Commonwealth environmental water contributed to 115 watering actions across 19 catchments in the 2017–18 watering year (Appendix A). A net total of 1267 gigalitres of Commonwealth environmental water was delivered. Through the use of return flows, Commonwealth environmental water was used and reused, effectively contributing 1945 gigalitres of water. Reflecting the dry conditions, the majority of water (70%) was delivered as base flow or freshes in rivers and streams to protect and maintain in-channel habitats and water quality (Table 1). Many of these watering actions were undertaken collaboratively with state jurisdiction partners.

Table 1. Summary of Commonwealth environmental watering actions 2017–18 (see Appendix B).

Valley	Flow type (no. of actions)						
	Base	Fresh	Bankfull	Overbank	Wetland	Fresh & baseflow	Fresh & Wetland
Barwon–Darling		4					
Border Rivers	1	7				1	
Broken	5	1				1	1
Campaspe		1					
Central Murray	1	1			3		
Condamine–Balonne	1						
Edward–Wakool	4	2					
Goulburn	3	4	1				
Gwydir	1	2			1		
Lachlan	2	1					
Loddon		1					
Lower Darling		1					
Lower Murray	8	2		6	25		
Macquarie					1		1
Murrumbidgee	1				12		1
Namoi	1	1					
Ovens	1						
Warrego		2					
Wimmera	1	1					

The objectives of watering actions are described in terms of 'expected outcomes', which describe the desired ecological effects of environmental watering for any given watering action. These are developed through a process that accounts for both conditions across the Basin in the months leading up to environmental water delivery and localised site-based conditions at target aquatic ecosystems. The majority of watering actions have multiple expected outcomes, with water delivered to benefit a range of species, ecological functions and processes. In 2017–18, the most prevalent expected outcomes of Commonwealth environmental water were to support fish and vegetation (Table 2).

2.3.1 The first four years in context: 2014–18

In the northern basin, the 4-year average inflows (since mid 2014) have been the lowest for any four year period since 2001 (Figure 4). This continues a 6 year period of very low inflows across the northern basin. In contrast, the southern basin inflows have been close to average for the period

since 2001. The lowest inflow period in the southern basin since 2001, was at the end of the millennium drought (mid-2006 to mid-09). Southern basin inflows have remained higher than these extreme lows since the drought broke.

Table 2. Summary of 'expected outcomes' for Commonwealth environmental watering actions 2017–18 (see Appendix A).

Valley	Fish	Vegetation	Birds	Frogs	Other biota	Connectivity	Processes	Resilience	Water quality
Barwon–Darling	4							4	4
Border Rivers	9				3	2	2	2	7
Broken	6	3	1		1				5
Campaspe	1	1			1				
Central-Murray	5	3	3	1		2	2		1
Condamine–Balonne						1		1	
Edward–Wakool	6	6		6	6	6	6	6	6
Goulburn	7	7			6				4
Gwydir	4	1	1		1	4	3	1	2
Lachlan	2						2		
Loddon	1								
Lower Darling	1					1	1		1
Lower Murray	18	32	30	14	9	4	16	4	4
Macquarie	1	1	1		1	1	1		
Murrumbidgee	11	12	11	9	12	1	1	11	8
Namoi	1						1		
Ovens	1					1			
Warrego	2						1	1	
Wimmera	2	2	2		2	1			2
Total (% of all watering actions)	**72**	**60**	**43**	**26**	**37**	**23**	**30**	**27**	**39**

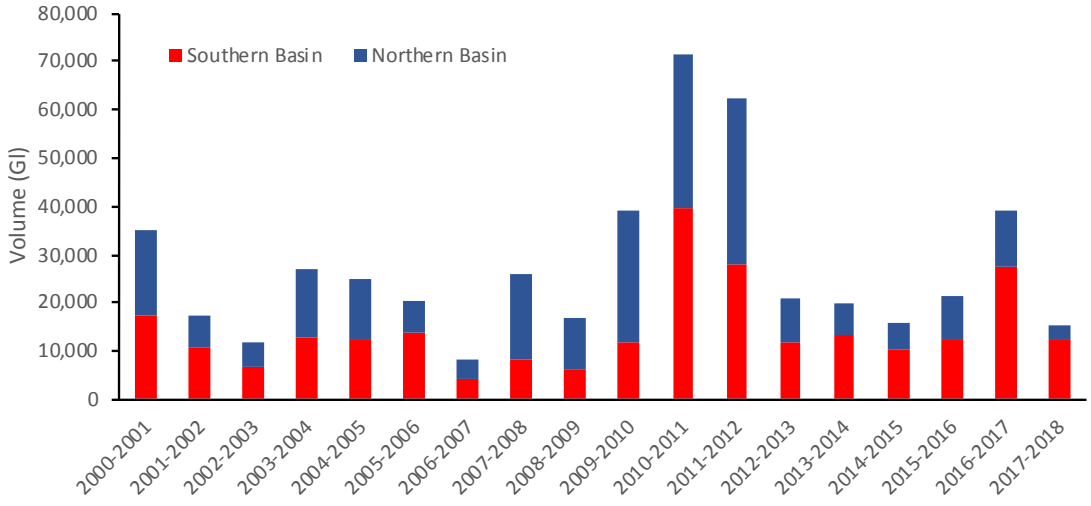

Figure 4: Annual surface water inflows in the Murray-Darling Basin 2000–2018 (Source: BoM National Water Account, 2019).

3 Basin-scale evaluation

There are six Basin Matters (ecological indicators monitored using standard methods across Selected Areas and evaluated at the Basin scale) and the full details on the methods and the results of evaluations for each of these can be found in Appendices:

B: Hydrology
C: Stream Metabolism and Water Quality
D: Ecosystem Diversity
E: Vegetation Diversity
F: Fish
G: Biodiversity.

Provided here is an integrated assessment of the outcomes of Commonwealth environmental water in 2017–18 and cumulatively over the first four years of LTIM (2014–18), across the three broad themes of the Basin Plan as defined by the CEWO Outcomes Framework (CEWO 2013b): biodiversity, ecosystem function and resilience. This section draws together the main findings of each of the Basin Matter evaluations in the context of prevailing climate in the Basin during the period of water delivery.

3.1 Biodiversity

Basin-scale biodiversity outcomes

- Over the first four years of LTIM, Commonwealth environmental water inundated half of all wetland types in the Basin and influenced more than five percent of the mapped extent of 14 wetland types.
- A significant proportion of plant taxa recorded across all monitored Selected Areas in 2017–18 were only recorded from sample points that were inundated by Commonwealth environmental water delivered during 2017–18.
- Over the past four years 101 waterbird species have been recorded at sites that received Commonwealth environmental water, with more than one percent of the population supported for over 20 species.
- Water has been delivered to 10 of the 16 Ramsar sites in the Basin, with good evidence to suggest that Commonwealth environmental water contributed to maintaining the ecological character of those sites.

In terms of biodiversity, Basin-scale evaluation seeks to address the questions:

- 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?

Four Basin Matters assess the effects of Commonwealth environmental water on aspects of biodiversity: Ecosystem Diversity (Appendix D), Vegetation Diversity (Appendix E) and Fish (Appendix F). Biodiversity (Appendix G) integrates the biodiversity outcomes of these Basin Matters together with information from other sources to provide an aggregated list of species and communities that potentially benefited from Commonwealth environmental water each year.

3.1.1 Basin Matter evaluations related to biodiversity 2017–18

In the 2017–18 watering year, Commonwealth environmental water was delivered to 19 of 22 catchments across the Basin. Commonwealth environmental water, in conjunction with natural flows and other sources of environmental water, contributed to improved flow outcomes along approximately 19 000 kilometres of river channel and influenced almost 300 000 hectares of mapped wetland and floodplain ecosystems (Figure 5 and Table 3).

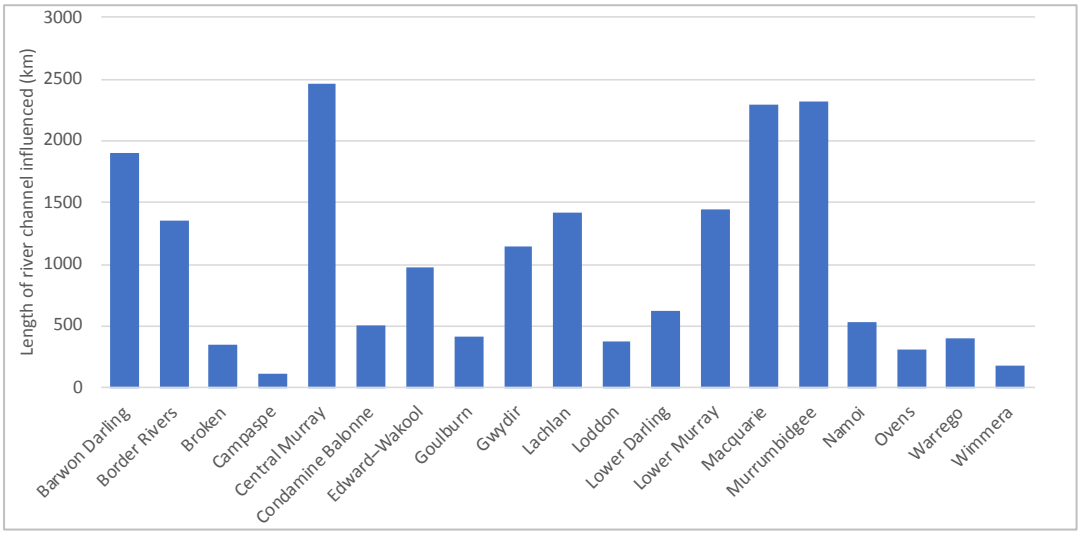

Figure 5. Length of river where flow regimes were enhanced by the delivery of Commonwealth environmental water in the 2017–18 watering year.

Table 3. Area of floodplain and wetland inundation in the 2017–18 watering year.

Catchment name	Lakes and wetland area influenced[6] (ha)	Floodplain area inundated (ha)
Broken	181	–
Central Murray	35 783	7716
Edward–Wakool	104	23
Gwydir	5303	2074
Lachlan	5822	3437
Lower Darling	335	37
Lower Murray*	31 223*	2135
Lower Murray (Coorong Lakes Alexandrina and Albert and Murray Mouth)	Fresh: 100 614 Estuary: 23 123	9
Macquarie	38 509	6130
Murrumbidgee	18 416	15 390
Total	**259 413**	**36 951**

* Excludes the Coorong, Lakes Alexandrina and Albert and the Murray Mouth.

Inundation mapping showed that large areas and significant proportions of the mapped extent of several vegetation communities were influenced by Commonwealth environmental water in 2017–18, including over five percent of the mapped extent of six wetland types:

- Permanent wetland
- Permanent lake
- Permanent saline wetland
- Permanent tall emergent marsh
- Temporary swamp
- Temporary river red gum swamp.

[6] Area influenced by Commonwealth environmental water = the sum of the all wetland areas that received water even if the inundation mapping showed that only a portion of the wetland was inundated. The area *influenced* by Commonwealth environmental water acknowledges that aquatic ecosystems are complex interconnected systems and delivering water to part of a wetland contributes benefits to the entire wetland system.

A significant proportion of plant species recorded across all monitored Selected Areas in 2017–18 were only recorded from locations that were inundated by Commonwealth environmental water. These included 30 plant species (representing proximately nine percent of all plant species recorded across the Basin in 2017–18) from locations inundated by Commonwealth environmental water in the Murrumbidgee river system as well as 30 species from the Goulburn and seven from the Edward-Wakool river system. Many of these unique species likely benefitting from Commonwealth environmental water were aquatic or amphibious forbs, grasses and sedges/rushes.

Commonwealth environmental water contributed to the maintenance of vegetation cover and species richness in inundated wetlands of the Murrumbidgee river system, sustaining distinctive vegetation communities in comparison to non-inundated wetlands which exhibited sharp declines in vegetation cover and species richness during this period. Furthermore, inundated wetland vegetation communities in the Murrumbidgee river system increased the diversity of vegetation communities present across the entire Basin during 2017–18.

In 2017–18, over 70% of watering actions targeted fish outcomes, with over half targeting fish habitat and / or movement, and one third targeting spawning and / or recruitment noting that most watering actions have multiple expected outcomes (Figure 6). Across the Selected Areas wetland inundation was important in maintaining good habitat for fish (e.g. Lachlan, Lower Murray). Where wetland inundation occurred, there were increases in the mean length of larval fish as well as successful spawning outcomes for the most abundant species e.g. Australian smelt (*Retropinna semoni*). For example, in the Edward Wakool more Australian smelt larvae were found where environmental watering occurred. Commonwealth Environmental water also allowed significant movement in key species such as Murray cod, golden perch, silver perch and freshwater catfish.

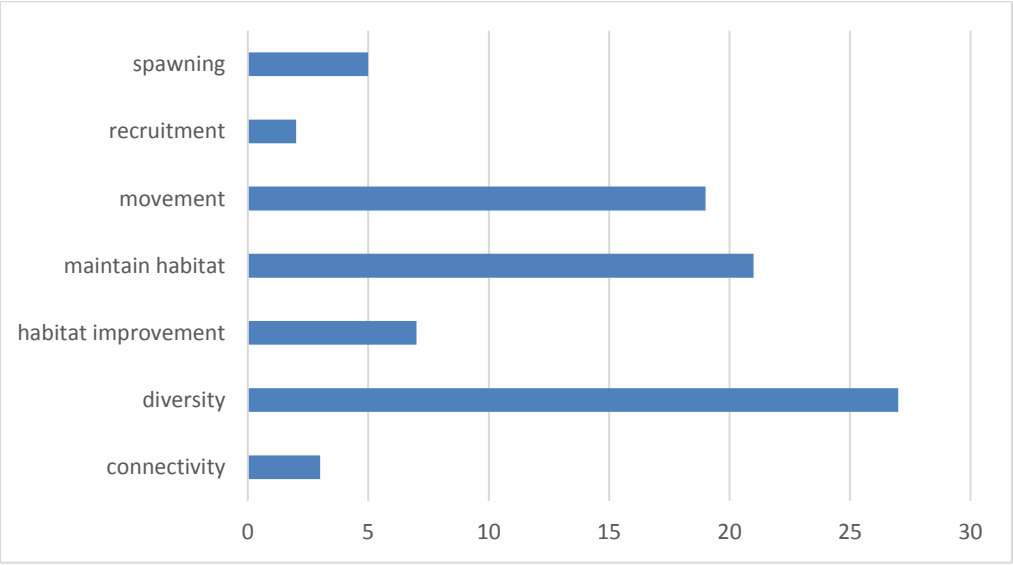

Figure 6. Commonwealth environmental watering actions in 2017–18 with expected outcomes for fish.

3.1.2 Basin-scale biodiversity outcomes 2014–18

Commonwealth environmental watering actions over the first four years of the LTIM Project contributed to the inundation of a wide range of ecosystem types within the Basin that included approximately 60 % of wetland, lake and floodplain ecosystem types. Lists of ecosystems, species and communities that potentially benefited from Commonwealth environmental water in the first three years of LTIM (2014–18) are provided in Appendix G and are comprised of:

- 71 species of native plants
- 16 species of native fish
- 48 species of bush bird
- 101 species of wetland dependent bird[7]
- 20 species of frog
- 3 species of turtle.

Maintaining the ecological character of Ramsar sites

There are 16 Ramsar sites in the Basin and over the period 2014–18, Commonwealth environmental water has been delivered to 10 of these sites (Table 4). Riverland Ramsar sites are not included as there were no watering actions with expected outcomes between 2014–18.

Table 4. Ramsar sites that have been the target of Commonwealth environmental watering actions 2014–18.

Ramsar site	Commonwealth environmental water			
	2014–15	2015–16	2016–17	2017–18
Banrock Station		X		X
Barmah Forest		X		X
Central Murray Forests		X		X
Coorong, Lakes Alexandrina and Albert	X	X	X	X
Fivebough and Tuckerbil Swamps				X
Gunbower Forest		X	X	X
Gwydir Wetlands	X	X	X	X
Hattah-Kulkyne Lakes	X	X		X
Macquarie Marshes	X	X	X	X
Narran Lakes			X	

From 2014–18, Commonwealth environmental water contributed to multi-year strategic inundation of Ramsar Sites designed specifically to maintain ecological character. There are some clear examples of managing water regimes over multiple years highlighting the contribution of Commonwealth environmental water. For example, at Gunbower Creek water was delivered each year between 2015–18 as part of a three year Environmental Water Agreement with the Commonwealth Environmental Water Office (CEWO). The purpose was to provide a flow regime aimed at improving fish habitat and lifecycle cues. Prior to the implementation of environmental water in Gunbower Creek, the system dried to a series of residual pools in the off-irrigation system. This was recognised as having a negative effect on fish recruitment and survival with no Murray cod (*Maccullochella peelii*) in size classes that represent fish less than three years of age (Sharpe *et al.* 2014). Following the implementation of Commonwealth environmental watering, there is evidence of recruitment of five native species: Australian smelt, carp gudgeon (*Hypseleotris* spp.), Murray cod, Murray-Darling rainbow fish (*Melanotaenia fluviatilis*) and unspecked hardy-head (*Craterocephalus*

[7] Note that this is the first report that has included data collected from the Coorong and Lower Lakes, which has added additional (typically coastal) species to this list.

stercusmuscarum) (Bloink & Robinson 2016). There has been a marked improvement in the population age-structure of Murray cod in the system, showing evidence of increased recruitment and survival. There have also been the first reporting of freshwater catfish being present in over 15 years (CPS Enviro 2018).

Threatened species

Forty-nine significant species were recorded at sites that received environmental water in 2014–18. This includes 18 international migratory waterbird species, 18 nationally listed threatened species and 17 species listed under state legislation. It is anticipated that as LTIM progresses and more data become available, this list will not only grow, but our understanding of how Commonwealth environmental water is benefitting these species across the Basin will also increase.

There is very good evidence that Commonwealth environmental water is contributing to maintaining populations of Australasian bittern with over 10 % of the estimated population of the species recorded at the Barmah-Millewa Forest sites. The species prefers shallow wetlands with emergent vegetation (Menkhorst 2012), which has been the target of environmental water at this Ramsar site twice in the period 2014–18.

In addition, several national listed species are regularly supported at the Coorong and Lower Lakes sites including the Australian fairy tern (*Sternula nereis nereis*) and four international migratory waders that are also listed as vulnerable or critically endangered under Environment Protection and Biodiversity Conservation (EPBC) Act.

There are a relatively large number of records for southern bell frog from several locations around the Basin that received Commonwealth environmental water including the Murrumbidgee wetlands, Banrock Station and wetlands along the Lower Murray (CEWO unpublished). This species of frog is considered “flow dependent” and has been shown to move in response to artificial watering, rather than rainfall (Wassens *et al.* 2010) indicating that it can benefit from environmental watering at key habitats.

Waterbird diversity and abundance

There is evidence from a variety of sources including Selected Area monitoring under LTIM, as well as other monitoring programs, that Commonwealth environmental water is contributing to waterbird diversity and abundance at a Basin scale. A total of 888 000 individual wetland dependent birds have been recorded at sites that received Commonwealth environmental water over the past four years (see Appendix G). There is a growing body of evidence that the strategic use of Commonwealth environmental water is helping to sustain waterbirds during critical life-stages by providing different habitats for foraging and breeding as well as through the provision of drought refuges (see Text Box 1).

Providing a diversity of habitat for a diversity of waterbirds

From 2014–2018, 101 waterbird species have been recorded at sites that received Commonwealth environmental water. In addition to providing habitat for foraging, there is a growing body of evidence of environmental water supporting a broad range of functions for waterbirds including critical life stages of breeding, migration, moulting and drought refuge. The high diversity of waterbirds and the range of functions supported is a product of providing a diversity of habitats across the Basin.

Large open water bodies in spring and early summer for moulting waterfowl
Waterfowl undergo an annual moult of their primary flight feathers, during which individuals are flightless for a period of two to five weeks, which makes them more vulnerable to predators. The Australian shelduck is the only species of waterfowl in Australia known to form large moulting congregations. The species will migrate to permanent wetlands with expanses of open water which provide a refuge during this vulnerable stage (Firth 1982). Commonwealth environmental water was used to maintain permanent open water habitat at Banrock Station supporting 160 moulting Australian shelduck in 2017–18.

Suitable habitat and high productivity to support waterbird breeding
Although breeding of waterbirds has occurred in all four years of the LTIM project, the most notable example was during the 2016–17 watering year. Large scale breeding occurred at a number of locations, with 1000s of nests of colonial breeding birds in the Lachlan, Murrumbidgee and Macquarie catchments supported by Commonwealth environmental water. Most of these waterbirds required vegetated habitat (generally shrubs and trees) to be inundated for the duration of breeding from nest building to fledging of young. Reproductive success was improved through the use of water by maintaining water depths under nesting colonies (Brandis 2017), and by providing adequate foraging habitats in adjacent wetland areas.

Supporting international migratory species
A number of locations across the Basin that received Commonwealth environmental water supported migratory shorebirds from the East Asian-Australasian Flyway. The majority of these birds migrate from breeding grounds in North-east Asia and Alaska to non-breeding grounds in Australia and New Zealand, covering the journey of 10,000 kilometres twice in a single year. The lifecycle of most international migratory shorebirds involves (Bamford et al. 2008):

- breeding in May to August (northern hemisphere);
- southward migration to the southern hemisphere (August to November);
- feeding and foraging in the southern hemisphere (August to April); and
- northward migration to breeding grounds (March to May).

These species typically require shallow wetland or mudflat habitat of high productivity in order to build up sufficient reserves to complete the return journey to the northern hemisphere. While the Coorong has supported the largest number and highest diversity of these species (of sites that received Commonwealth environmental water) they have also been recorded at several inland sites.

Maintaining drought refuges in dry times
With the exception of 2016–17 in the southern Basin, the period 2014–18 was characterised by dry climatic conditions. Commonwealth environmental water has contributed significantly to maintaining wet habitat for waterbirds and other biota across much of the Basin. This includes providing large artificial floods in Hattah-Kulkyne Lakes and Macquarie Marches during 2017–18 as well as keeping areas of the Gwydir wetlands inundated each year. Waterbirds benefit both directly by the immediate provision of foraging habitat and indirectly through maintaining important habitats for critical life stages over longer periods.

White ibis chicks at Barmah (Keith Ward).

Text box 1. Commonwealth environmental water contributions to supporting waterbirds.

Fish diversity and abundance

Fish sampling in 2017–18 generally shows the continuing legacy effects of the 2016–17 blackwater and flooding event, which reduced numbers of mature Murray cod and golden perch in a number of rivers, including the Edward-Wakool River System, Murrumbidgee River, Lachlan River and Gwydir River. Given the low adult numbers in some river systems, it may take several years before populations of some species show an appreciable recovery. In contrast to some large bodied fish (e.g. Murray cod and golden perch), abundances of small bodied fish species (e.g. Australian smelt and carp gudgeons) have increased after the 2016–17.

Many fish that survived the 2016–2017 flood events increased in body condition (weight at length) suggesting higher growth rates following those higher flows, and this improved condition was maintained in 2017–2018. This was evident for Murray cod, golden perch and common carp in multiple areas that were monitored. Commonwealth environmental water has likely contributed to these outcomes by increasing productivity (see section 3.2.2).

There is widespread evidence of native fish successfully spawning in response to flow pulses created by the delivery of Commonwealth environmental water, although this varies in intensity between species, between Selected Areas and between times of the year. Golden perch spawning is highly variable from year to year, but is associated with flow pulses, providing other conditions are also met (temperature, fish condition). A number of flow actions have targeted golden perch spawning, and these actions appear successful. In contrast, Murray cod spawning has occurred in most years and most rivers, which is unsurprising given that flow is not important in the spawning of this species. For this reason, Commonwealth environmental watering actions have been targeted toward other species.

Commonwealth environmental water has also been effectively used as a cue to trigger fish movement. Movement is critical to allow fish to recolonise habitats following disturbances such as the 2016–17 blackwater event. Flow pulses act as both a cue to move, and also can increase minimum depths in shallow cross sections, and overtop low level barriers, thereby acting as both a behavioural and physical driver of connectivity.

While spawning events for native fish have been successfully achieved across multiple rivers in the Basin, recruitment of large bodied native to the juvenile size-classes was low in 2017–18. This likely reflects the low numbers of breeding adult of species such as Murray cod and golden perch. Strategies for using Commonwealth environmental water to increase fish recruitment remains an active area of research.

While spawning events for native fish have been successfully achieved across multiple rivers in the Basin, recruitment of golden perch and Murray cod to the juvenile age-classes (1 year and above) was low in 2017–18 for Murray cod, and has been low throughout the period 2014–18 for golden perch. This may reflect the low numbers of breeding adults of species such as Murray cod and Golden perch, particularly as a result of the 2016–17 fish kills associated with hypoxic blackwater in some rivers. Strategies for using Commonwealth environmental water to increase fish recruitment remains an active area of research.

3.2 Ecosystem function

Basin-scale ecosystem function outcomes

- Commonwealth environmental water has contributed to restoring the flow regime through provision of base flows across the Basin and the contributions to improved frequency and duration of freshes in the southern Basin.
- Without the delivery of these baseflows many aquatic refuge habitats would have been lost.
- Commonwealth environmental water has contributed to maintaining connectivity through the Murray Mouth, particularly in low flow years.
- There is evidence to suggest that the delivery of in-channel flows using environmental water can result in increased productivity in the southern Basin.

3.2.1 Basin Matter evaluations related to ecosystem function

Ecosystem function can be defined in many ways, but in the context of Basin evaluation relates to the processes that occur within ecosystems and between species and communities (Jax 2005). Common functions in aquatic ecosystems include water movement along rivers and between rivers and wetlands (hydrological connectivity), nutrient cycling, primary production, decomposition, predation, competition and movement (migration and dispersal of plants and animals between rivers, estuaries and wetlands).

In this fourth LTIM year, two Basin Matters specifically considered the effects of Commonwealth environmental water on ecosystem function; Hydrology (Appendix B) and Stream Metabolism and Water Quality (Appendix C). In terms of ecosystem function, Basin-scale evaluation seeks to address the following questions:

- Hydrology
    - What did Commonwealth environmental water contribute to restoration of the hydrological regime?
    - What did Commonwealth environmental water contribute to hydrological connectivity?
- Stream metabolism
    - What did Commonwealth environmental water contribute to patterns and rates of decomposition?
    - What did Commonwealth environmental water contribute to patterns and rates of primary productivity?

3.2.2 Basin-scale ecosystem function outcomes 2014–18

Restoration of the hydrological regime

From 2014–18, the vast majority of Commonwealth environmental watering actions have targeted base flows and freshes in seeking to restore the hydrological regimes of the Basin's waterways. The Hydrological Basin Matter has evaluated the effect of Commonwealth environmental water in improving the hydrological regime by comparing the observed water regimes with what would have occurred in the absence of water resource development and extraction across two base flow thresholds and three fresh thresholds (Figure 7). The full evaluation is provided in Appendix B, with a short summary of highlights presented here.

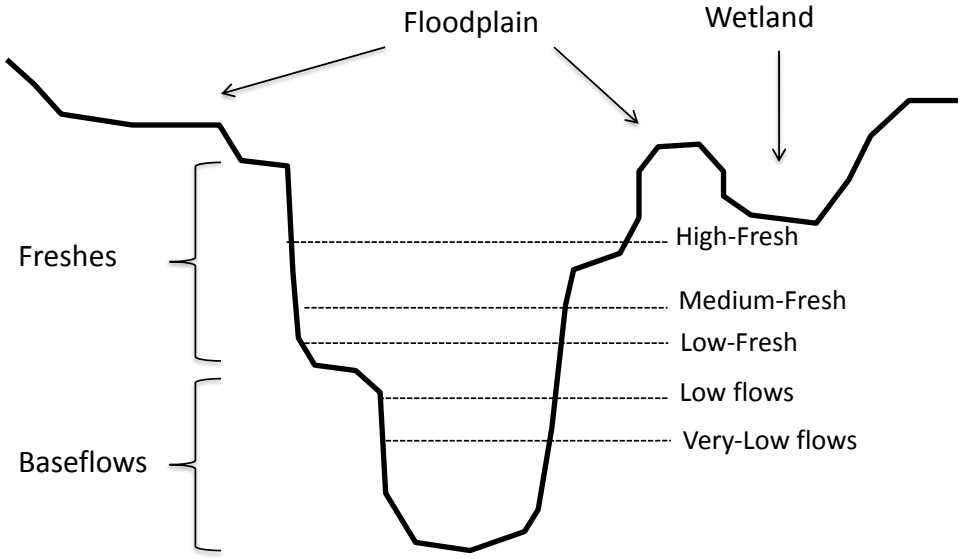

Figure 7. Conceptual diagram indicating water levels corresponding to the flow freshes and base flows used in the hydrological evaluation (for more detail see Appendix B).

Commonwealth environmental water has contributed to maintaining baseflows throughout the period 2014–18. Despite this, periods below of very low flows persisted across the northern Basin, including the Barwon Darling, and Commonwealth environmental water has had a negligible effect on base flow regimes in the northern unregulated rivers. The situation in the southern Basin is different, where Commonwealth environmental water has contributed to mitigating periods of very low flows (Figure 8) and low flows in the southern Basin (see Appendix B).

In 2017–18, low and medium freshes were infrequent in the Queensland valleys and largely absent in the Barwon-Darling (Figure 13 and 14). This is like previous years although a high frequency of freshes did occur across these valleys in the 2016–17 year. There was minimal contribution of environmental flows to freshes in these valleys. Except for the Broken River, low freshes are delivered with an acceptable frequency across the southern Basin with large contributions from Commonwealth environmental water in the lower Murray and Goulburn valleys. Moderate and high freshes are lacking in many valleys of the southern Basin including the lower Murray, Edward-Wakool, Loddon, Goulburn, and Broken valleys. (Figure 9).

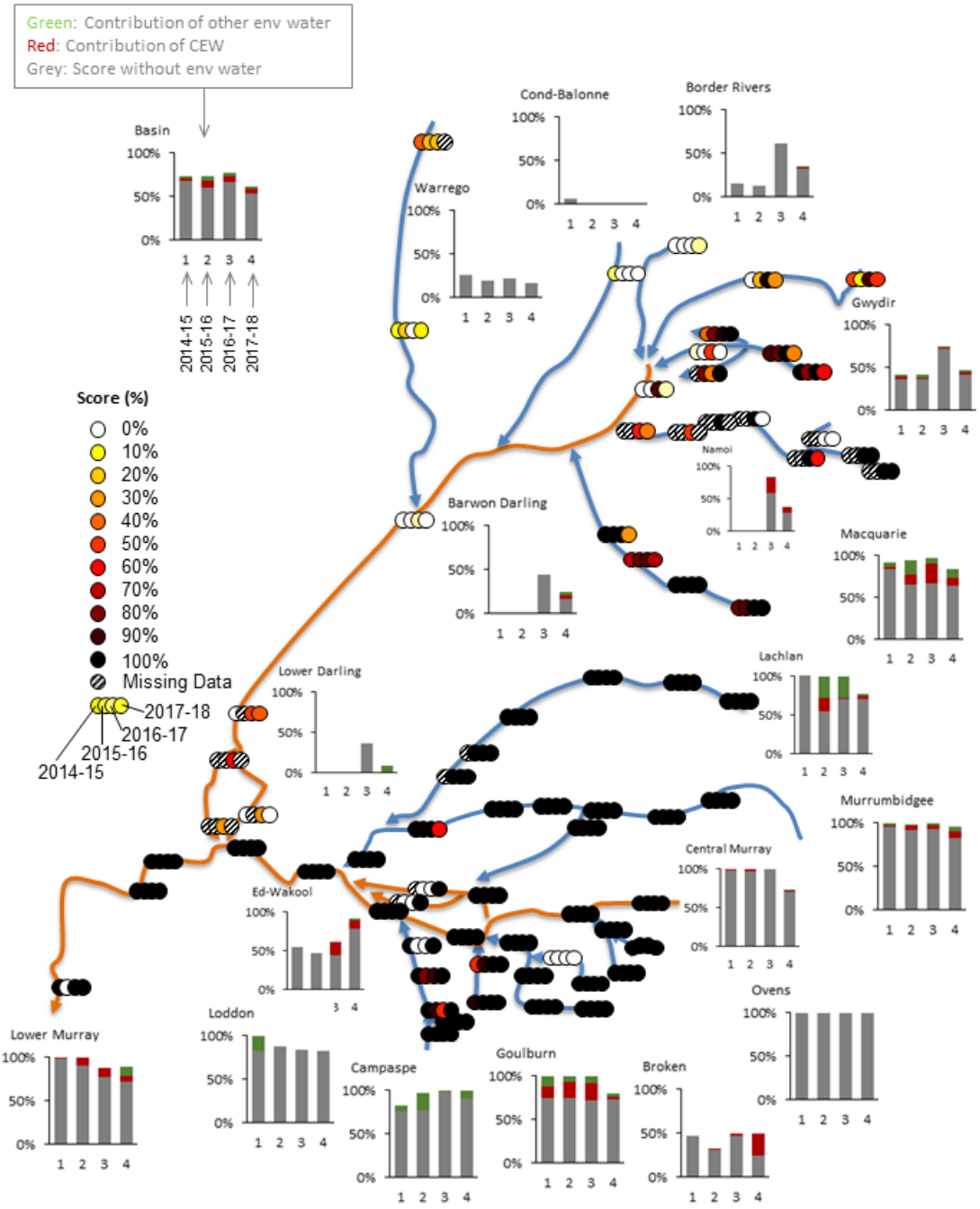

Figure 8. Average contribution of Commonwealth environmental water and other environmental water entitlements to low base flow durations across each valley in the period 2014–18. Scores range from 0% (extremely dry) to 100% (normal conditions). See Appendix B for more detailed explanation on scoring and further details.

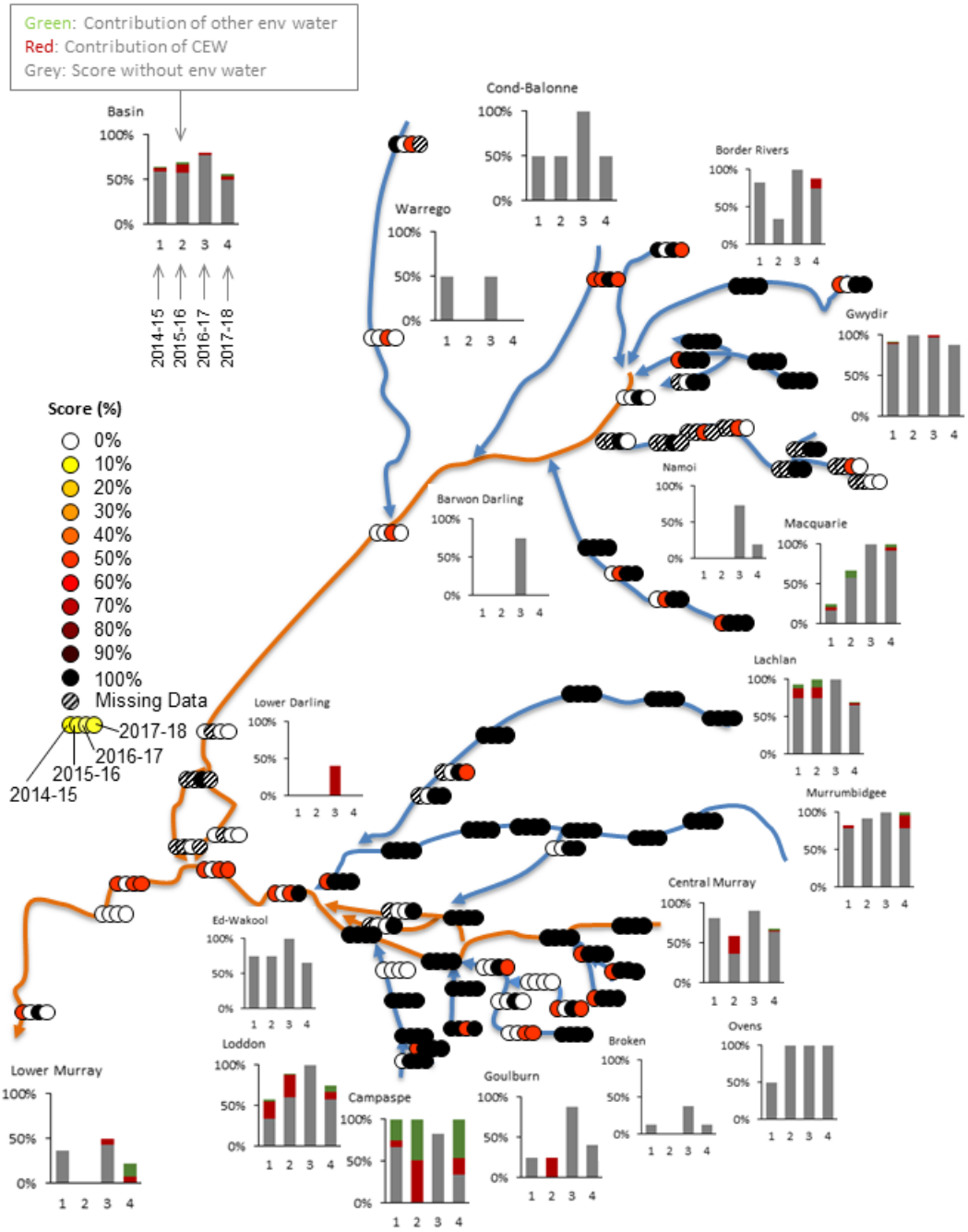

Figure 9. Average contribution of Commonwealth environmental water and other environmental water entitlements to medium fresh durations across each valley in the four years of LTIM monitoring. Scores range from 0% (extremely dry) to 100% (normal conditions). See Appendix B for more detailed explanation on scoring and further details.

Hydrological connectivity

Commonwealth environmental water also contributed to connectivity through its effect on the Murray Mouth opening in the period 2014–18. Connectivity between the Southern Ocean and the Murray River is important for a number of reasons, including for fish species that migrate between inland and ocean environments as well as for maintaining water quality in the Coorong and Lower Lakes, by allowing nutrients and salts to flush out to sea. During periods of low flow, sands are deposited and there is increased risk of the mouth of the Murray closing (Colby *et al.* 2010).

The contribution of Commonwealth environmental water to barrage flows has varied over the period 2014–18. In 2015–16, Commonwealth environmental water was the sole contributor to barrage flows and in the absence of Commonwealth environmental water it is likely that the Murray Mouth would have remained largely closed from December 2015. In contrast, 2016–17 was a wetter year, and there were larger volumes of water over the barrages and Commonwealth environmental water contributed just 12% of flows (Table 5).

The Basin-wide environmental watering strategy (Murray-Darling Basin Authority 2014) contains a target of "*barrage flows are greater than 2000 Gl/year on a three-year rolling average basis for 95% of the time, with a two year minimum of 600 GL at any time*." Data suggest that this target has been met, with the three-year average to 2017–18 of 2715 GL. Commonwealth environmental water has contributed to keeping flows above the threshold in all LTIM years and to the three-year average being met in 2017–18.

Table 5. Contribution of Commonwealth environmental water to Barrage releases in gigalitres (GL)**.**

Indicator	2014–15	2015–16	2016–17	2017–18
Commonwealth environmental water (GL)	453	736	811	755
Total barrage release (GL)	986	736	6558	851
Percentage of total flow contributed by Commonwealth environmental water (%)	46	100	12	89

Stream metabolism

Stream metabolism comprises two ecological processes: primary production (use of light, nutrients and carbon dioxide to produce organic material through photosynthesis) and decomposition (recycling of organic matter). Stream metabolism is measured through changes in dissolved oxygen, as the process of primary production produces oxygen and decomposition uses it. Healthy aquatic ecosystems require both processes, with primary production providing the basis of food for organisms higher up the food chain, and decomposition providing essential nutrients to maintain plant growth.

There are four ways that water regimes can influence rates of primary production and decomposition in aquatic systems:

1. By increasing suitable habitat for primary producers and decomposers, which is strongly influenced by flow.
2. Entrainment, movement and exchange of nutrients and organic carbon from external sources to the river system. This includes streamside zones, floodplain wetlands, backwaters, and low-lying benches and bars within the channel, all of which are inundated and connected by different flow volumes.
3. Mixing and resuspension of material within the river or stream. For example, organic material that accumulates in pools and other slow flowing habitats (e.g. backwaters, weir pools). Increasing flows may mobilise these organic material stores, increase rates of stream metabolism, and reduces excessive build-up of organic material.
4. Disruption and scouring of biofilms – biofilms comprise algae, fungi and bacteria on sediments and plants in the river and can contribute significantly to stream metabolism. Over time they can senesce and become less active due to sedimentation. Very high flows can scour these older biofilms and sediments, allowing younger more productive biofilms to re-establish (Ryder *et al.* 2006).

The majority of Commonwealth environmental water is delivered as in-channel flows, most commonly baseflows and freshes (see Table 1). The evaluation of stream metabolism data collected over the first four years of LTIM, however, has indicated that these in-channel flows can have a positive effect on ecosystem productivity. There is a clear increase in carbon production in the southern Basin Selected Areas, with an increase in flows from very low base flows to moderate freshes (Figure 10).

Analysis of data from the Goulburn River, indicates that in spring and autumn, increasing flows from very low flows to low flows (just one category of flow type) can effectively double rates of production. This increase in productivity depends on spring flow pulses - if flows are increased in winter, cold temperatures limit the rates of biological activity. This provides us with important information for adaptive management of environmental water to maximise productivity.

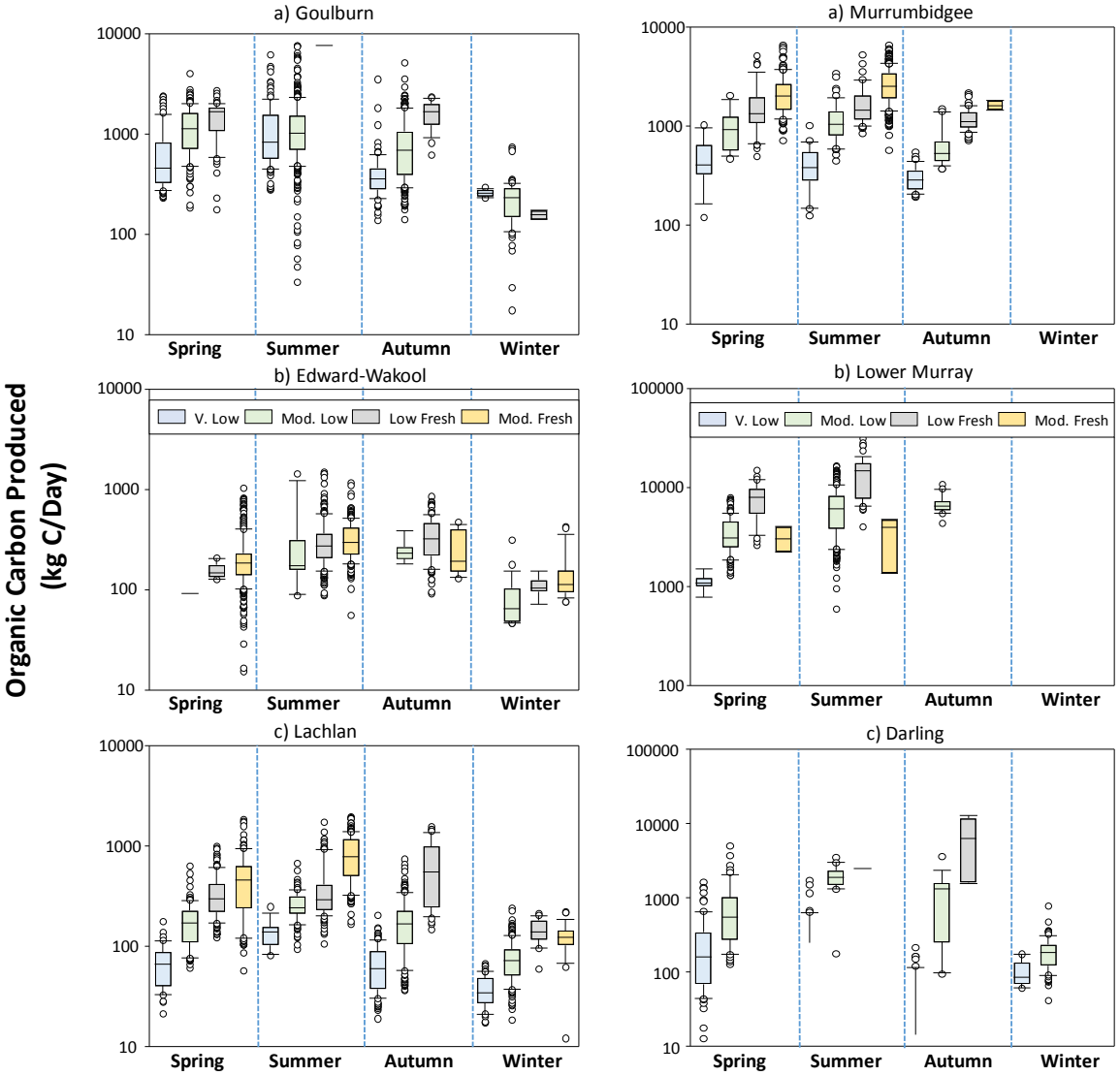

Figure 10. Relationship between flow category (as per Figure 7) and organic carbon production and consumption 2014–17 in the Selected Areas. See Appendix C for more detail.

3.3 Resilience

Basin-scale resilience outcomes

- Resilient ecosystems are able to withstand and recover from disturbances such as drought.
- Enhancing resilience is a key goal for water managers, particularly in terms of increasing the capacity of the Basin ecosystems to recover from extreme drought.
- Commonwealth environmental water contributes to resilience by protecting refuge habitat by providing baseflows, maintaining ecosystem diversity, and increasing hydrological connectivity (either through baseflows or flow pulses), which facilitates ecological connectivity.
- In 2017–18 Commonwealth environmental water was used to create large artificial floodplain inundations at both Hattah Lakes and Macquarie Marshes. While there were immediate benefits to biota following inundation, it is expected that the floods would have improved condition, making these systems more resilient to future dry periods.
- Commonwealth environmental is contributing to improved resilience of waterbirds by supporting substantial (> 1%) of the total population of at least 20 species.

Resilience can be defined as a system's capacity to respond to disturbance (resist, recover and adapt) so as to still retain essentially the same function, structure and therefore identity (Colloff & Baldwin 2010; Gawne *et al.* 2013). In Australian aquatic ecosystems that are adapted to periods of both wet and dry conditions, resilience can be related to the ability to recover function, species and communities in the wet phase, following a dry period (Brock *et al.* 2003). The science of understanding resilience is in its infancy and indicators of resilience are still being explored. At the Basin scale, resilience can be considered as a factor of (McCluney *et al.* 2014):

- Diversity of habitats and ecosystems – the different habitats and ecosystems support species and biota under different conditions and a mosaic of habitats increases resilience at a landscape scale. For example, temporary wetland and floodplain systems may provide greater food resources during wet periods, but under dry conditions biota may need to move to permanent water, which acts as refuges.
- Connectivity of those habitats and ecosystems – is required so that species and propagules (seeds, plants material, invertebrate eggs) can move between systems to both escape adverse conditions and aid in recovery following disturbance.
- Condition of biota – plants and animals that are healthy are better able to withstand adverse environmental conditions.

Considering these factors, environmental water can influence the resilience of aquatic ecosystems and the species that depend on them in a number of ways, including:

- maintaining the diversity of ecosystems across the Basin
- ensuring that refuges are of sufficient quality and quantity to support biota during adverse conditions
- maintaining connectivity along rivers and between rivers and wetland habitats
- improving or maintaining the condition of individuals, populations and communities of plants and animals.

3.3.1 Large-scale artificial inundation at high value sites

In 2017–18, Commonwealth environmental water contributed to large scale floodplain inundation at two Ramsar sites. At Hattah-Kulkyne Lakes 111 933 ML of environmental water (32 145 ML of which was Commonwealth environmental water) was delivered to inundate 11 lakes within the Ramsar site and a moderate amount of surrounding floodplain comprising of river red gum and black box woodland. At the Macquarie Marshes, 23 000 hectares of wetland was inundated by environmental water, including over 7000 hectares of the Ramsar site. In both of these instances, large areas of floodplain and wetland that would otherwise have remained dry was inundated for several months. The magnitude of these events is highlighted by comparing inundation in 2016–17 with 2017–18 at

the Macquarie Marshes (see map below). While the extent of Commonwealth environmental water was similar in both years, in 2016–17 environmental water was used to augment a large natural flood, while in 2017–18 environmental water represented the only significant surface water in an otherwise dry landscape.

The short-term effects of the wide scale artificial inundation in 2017–18 included high diversity and moderate abundance of waterbirds, with over 50 species of waterbirds recorded and the nationally endangered Australian painted snipe observed at both locations. There were also positive responses from frogs, turtles and other wetland dependent fauna as well as an improvement in vegetation condition. The effects on ecological character, however, are likely to be longer lasting, with expected increases in resilience of wetland ecosystems as a result of multi-year inundation.

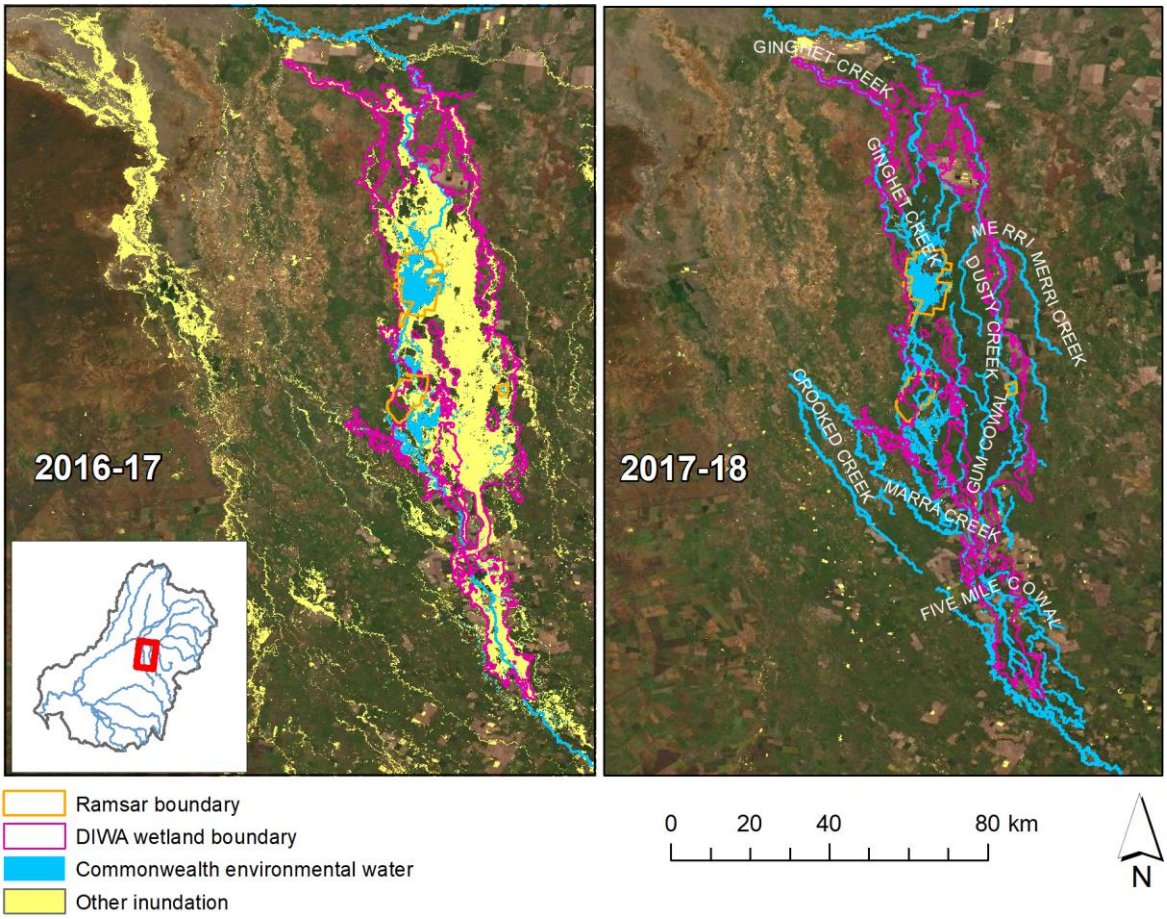

Figure 11. Contribution of Commonwealth environmental water to inundation at the Macquarie Marshes in 2016–17 and 2017–18.

3.3.2 Contributing to resilience through maintaining ecosystems and populations

From 2014–18, Commonwealth environmental water has contributed to the inundation of large areas of wetland habitat throughout the Basin (Figure 12). For some aquatic ecosystem types (temporary river red gum swamp, permanent tall emergent marshes), this equates to more than half the total area in the Basin being influenced by Commonwealth environmental water. The broad pattern of ecosystem types supported by Commonwealth environmental water reflects the similarity in the distribution of watering actions among years with 50% of wetland, lake and floodplain ecosystem types in the Basin receiving Commonwealth environmental water in all four years and conversely 40% of ecosystem types have not received any Commonwealth environmental water during the same period. Ecosystem types not supported by Commonwealth environmental water occupy only 2.4% of the wetland area in the Basin (51 000 ha) and are mostly located in unregulated valleys or in tributaries above water storages.

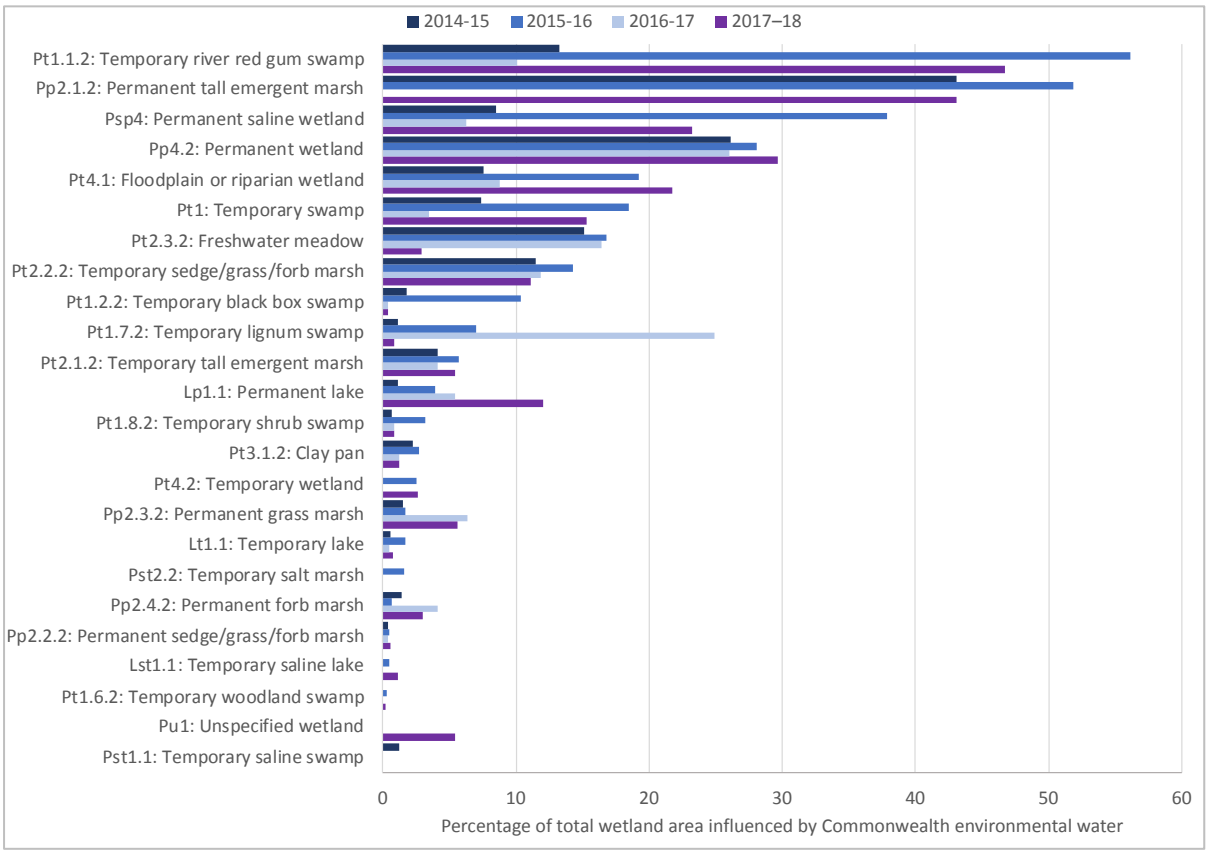

Figure 12. The proportion of the mapped extent of wetland types influenced by Commonwealth environmental water 2014–18 (See Appendix C for more detail).

Although not all of the ecosystems inundated by Commonwealth environmental water have been monitored, the MDBA Aerial Waterbird Surveys cover the major wetlands in the Basin each year. A total of 888 000 individual waterbirds were recorded at sites that received Commonwealth environmental water over the past four years (data from MDBA) (Figure 13). Of note is that the Coorong and Lower Lakes generally represents the largest number of waterbirds of the sites that receive Commonwealth environmental water. In 2014–15; 2015–16 and 2017–18, the Coorong supported between 80 and 90% of the total waterbird abundance at sites included in aerial surveys that received Commonwealth environmental water. In 2016–17, however, when there was wide-scale inundation of inland landscapes (augmented by environmental water) the Coorong and Lower Lakes Site represented just 14% of the total abundance. This highlights the continental scale distributions of many waterbirds and their ability to respond to climatic conditions, moving opportunistically to areas of highest productivity (Kingsford *et al.* 2010; Wen *et al.* 2016).

Wetlands International (2012) provides population estimates for waterbirds across the globe and in Australia. Supporting greater than one percent of the population of any species of waterbird is considered to be significant with respect to maintaining that species and is one of the criteria for listing a wetland of international importance under the Ramsar Convention. Cumulative totals (within a single year but across sites) indicate that Commonwealth environmental water is likely to have supported greater than one percent of the population of 21 waterbird species (Table 6). By supporting significant proportions of the population of a species, Commonwealth environmental water is contributing to improved resilience at a population scale.

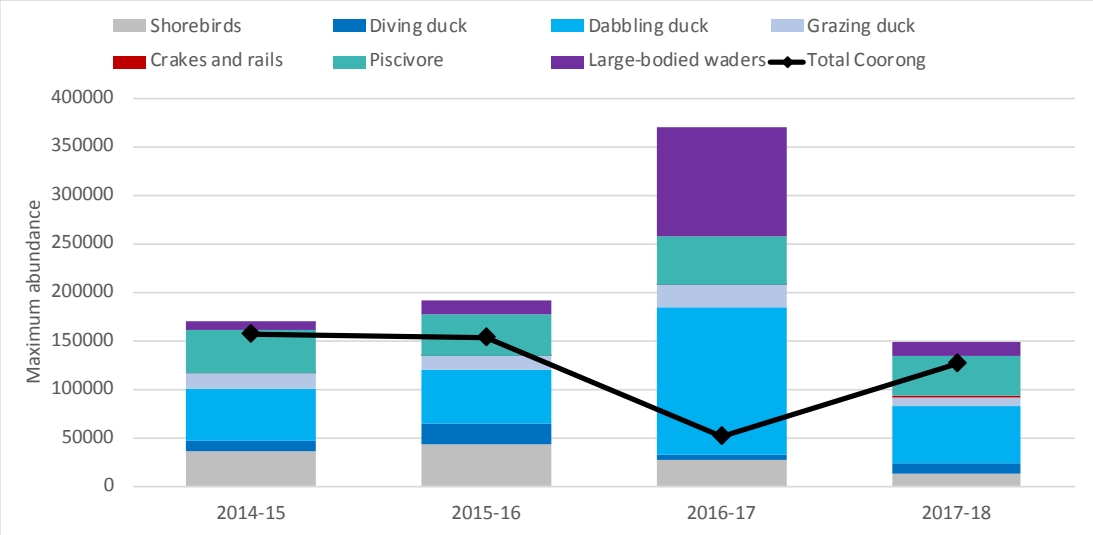

Figure 13. Total abundance of waterbirds from sites that received Commonwealth environmental water (source MDBA Aerial Waterbird Survey; data provided by MDBA). Note that shorebirds cannot be distinguished to species in aerial surveys and so Australian shorebirds and migratory shorebirds are combined into a single group.

Table 6. Waterbird species for which > 1% of the population have been recorded in a single year at sites that received Commonwealth environmental water ((data provided by MDBA, with data from several ground surveys added). CLL = Coorong and Lower Lakes, Inland = all other sites.

Species	1% of the population*	Total abundance from multiple sites							
		2014–15		2015–16		2016–17		2017–18	
		Inland	CLL	Inland	CLL	Inland	CLL	Inland	CLL
Australasian bittern	5			48				50+	
Australian fairy tern	15		165		108				
Australian pelican	1400		10 735	4051	9232	13 191	5492		7953
Australian shelduck	10 000		13 926		12 953				
Australian wood duck	10 000					17 658			
Banded lapwing	1000					1984			
Black-winged stilt	1750					5043			
Black swan	10 000				10 129				
Eastern great egret	1000					2295			
Great cormorant	1000		17 383		14 593		8925		13 706
Great crested grebe	250				556				
Grey teal	20 000		41 954		40 431	138 795			46 890
Little black cormorant	10 000								11 002
Pied cormorant	1000		9044		5568		3294		4392
Red-necked avocet	1100		3980		3830				1795
Red-necked stint	3200				16 430				
Sharp-tailed sandpiper	1600		4066				9242		
Straw-necked ibis	10 000					74 725			
White-faced heron	10 000					2338			
White-necked heron	1000			302		792		1035	
Yellow-billed spoonbill	250	436		2480				1753	

* Population estimates from Wetlands International (2012).

4 Adaptive management

Key adaptive management messages

- Floodplain ecosystems are naturally complex, and dynamic, consisting of habitats that experience a diversity of inundation periods over time. This dynamic mosaic of wetting and drying promotes high levels of biodiversity by providing diverse habitats and conditions in different areas that are suited to distinct groups of plants and animals.
- LTIM monitoring has shown that inundation regimes with different frequencies of wet and dry and different water depths, both within a wetland and at a landscape scale, promotes diversity in vegetation communities and waterbirds.
- The monitoring is also helping researchers to better understand the water requirements of different species, and how the inundation history at individual sites influences what happens when water is delivered within a given year.
- Environmental water delivery has been effective in promoting fish spawning and movement, however rates of recruitment in most monitoring areas has been low over the period 2014–18. This remains an active area of research to understand how environmental watering can help increase recruitment outcomes.

In this first four years of the LTIM Project there are a small number of lessons learned related to environmental watering. These have been summarised below drawing together recommendations from both the Basin Matter Reports (Appendices B to G) and the 2017–18 Selected Area Reports.

4.1 A dynamic mosaic of wetting and drying promotes biodiversity

At both the wetland and landscape scales, variability in water regimes is important for maintaining (and restoring) biodiversity. In the first four years of LTIM, this has been evidenced by the responses observed in both vegetation and waterbirds.

Greater species diversity and heterogeneity of vegetation communities at landscape and Basin scales is highly likely to be promoted by delivery of Commonwealth environmental water that generates a diversity of hydrologic regimes within and between wetlands over both short (i.e. annual) and longer time frames. In contrast, regular and predictable watering of some wetland areas at the expense of occasionally delivering water to some less regularly inundated parts of the wetland landscape has the potential to result in reduction in plant species diversity at both local and landscape scales as well as declines in the heterogeneity of vegetation communities. It is important to recognize, however, that in some regions (e.g. the Murrumbidgee), some areas of semi-permanent inundation will also contribute to spatial and temporal heterogeneity of wetland vegetation by promoting vegetation communities dominated by a few (or single) highly productive aquatic or amphibious plant species. Trade-offs may be required, however, between maintaining high levels of aquatic plant growth amongst a few dominant species in semi-permanent wetlands and promoting vegetation diversity across the broader landscape.

To promote diversity of vegetation communities across the Basin, prioritisation of watering actions should aim to generate a dynamic mosaic of wetting and drying regimes at multiple scales an allow for semi-permanent inundation of some wetlands and moderate to infrequent inundation of others.

With respect to waterbirds, monitoring across Selected Areas and other locations in the Basin where large numbers of waterbirds occurred in response to environmental water (e.g. Macquarie Marshes), noted that a mosaic of habitats not only increases diversity, but facilitates recruitment from large scale breeding events. Different species and functional groups of waterbirds have different habitat requirements with respect to breeding. For example, some colonial nesting species require inundated tree and shrub habitats for nesting, other species utilise inundated reeds and rushes and others prefer island habitats for breeding. By ensuring a mosaic of habitats within wetlands and at a landscape scale, environmental water supports a greater number of breeding

species. In addition, the foraging requirements of waterbirds are often different to those for breeding. For example, large bodied waders that nest colonially in inundated trees and shrubs, may feed in shallow inundated wetlands other colonial nesting species require deeper, open water areas in which to fish. Consideration of providing (or augmenting areas inundated naturally to provide) habitats for foraging as well as nesting will lead to improved recruitment of fledglings.

4.2 A hierarchy of needs for environmental water influences both water delivery and evaluation

The Selected Areas of the LTIM Project cover a broad diversity of landscapes, climatic features and aquatic ecosystems. This ranges from intermittent and episodic wetland systems that experience and tolerate various periods of drying through to near permanent rivers and lakes. There are a large number of variables that influence the water regime requirements of an aquatic ecosystem at any given point in time including (Arthington *et al.* 2006; Poff & Zimmerman 2010; Arthington & Balcombe 2011; Bino *et al.* 2014):

- ecosystem type
- optimums and tolerances of the aquatic biota that are dependent on that system
- individual, population and community condition
- recent inundation history
- presence and severity of other (non-flow) related stressors (e.g. pest plants and animals, intensity of surrounding land use).

Taking into account these factors, aquatic ecosystems could be considered in a hierarchy of need for environmental water, analogous to Maslow's hierarchy of five basic human needs[8] (Figure 14). In terms of environmental water, the ultimate goal may be a fully restored, near natural flow regime, but an aquatic ecosystem cannot move from the bottom of the hierarchy (i.e. a state of prolonged dry where most aquatic ecosystem functions have been compromised) to a restored flow regime with a single environmental water delivery or natural flow event.

The expected outcomes and planning of environmental water delivery should be guided by the position of the target aquatic ecosystem in question. For example, the Western Floodplain within the Junction of the Warrego and Darling Rivers Selected Area in 2017–18 was characterised by dry conditions and this was reflected in vegetation communities being in the poorest condition since the LTIM project began (Southwell *et al.* 2018). This makes inundation of this system a priority (when water is available) and a positive ecological response is likely to be achieved with water delivered at any time and in any manner. Conversely, several Selected Areas (e.g. Goulburn River) have river systems that are also used as water delivery channels for irrigation and other consumptive use. In portions of these systems prolonged periods of dry are not observed, and as such, the bottom levels of the hierarchy can be considered to be met. The needs for these systems are further up the hierarchy and reflect a more nuanced delivery of environmental water that restores a particular aspect of the flow regime. Expected outcomes and planning of environmental water in these systems take this into account.

Just as environmental water planning and delivery needs to (and indeed does) take into account this hierarchy of needs, so does evaluation of the success (or otherwise) of the watering action. Restoring water to a dry system could be considered successful if a positive ecological response is observed. At the other end of the scale, however, more specific outcomes (e.g. spawning, recruitment, fledging) may be required to indicate the effectiveness of environmental watering.

[8] Maslow (1981) proposed that personal growth could only be achieved as each of the needs in a hierarchy are met. For example, one cannot be motivated to achieve social goals if the basic needs of food and shelter are unmet.

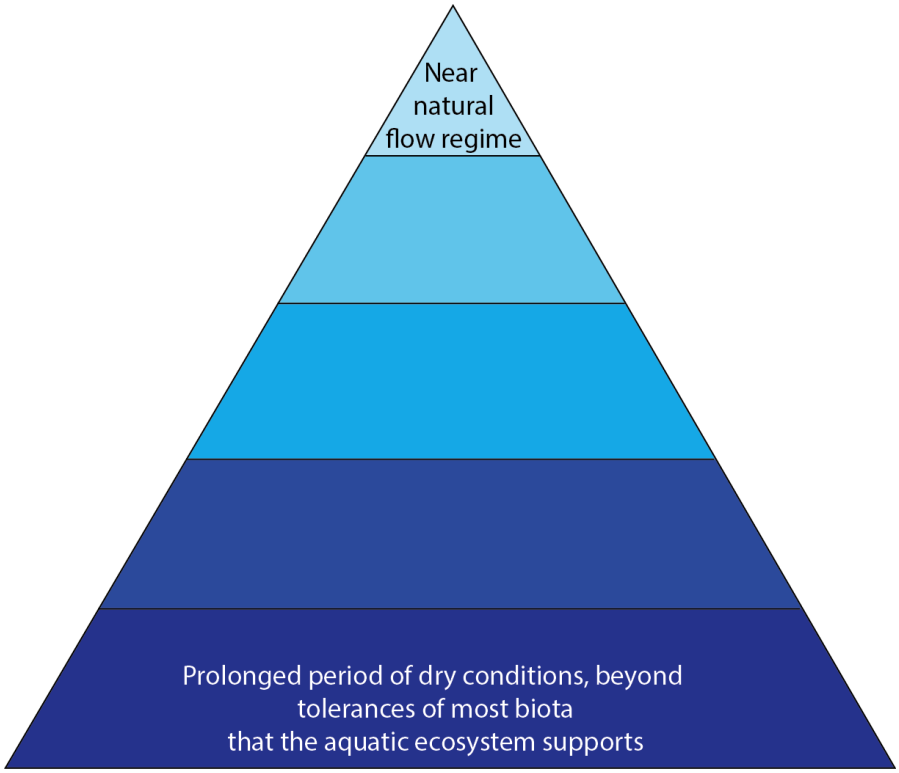

Figure 14. Hypothetical hierarchy of environmental watering needs based on current and antecedent conditions (after Maslow 1941).

4.3 Delivery of water in-channel can, to a certain extent, influence stream metabolism

Floodplain reconnection is a major driver of productivity in lowland rivers, however, there is now evidence that delivering smaller in-channel pulses can stimulate productivity. In many instances, the management of Commonwealth environmental water will be limited to freshes and base flows due to either the volumes of water available or delivery constraints within the system. In these instances, there are several considerations for maximising in-stream productivity to benefit aquatic biota:

1. In considering the trade-offs between magnitude of delivered flow (i.e. how high the water will rise up the bank of the channel) and duration (the length of time that a flow can be sustained), there are two alternative scenarios that could achieve productivity outcomes:
   - If shortening the duration of the flow would significantly increase the extent of lateral connection, then it may be worth increasing magnitude and reducing duration.
   - If, however, there is limited scope to achieve significant lateral connectivity, then a longer smaller flow is likely to have a greater influence on metabolism as it will enable colonisation and accumulation of primary producers and decomposers.
2. If stream metabolism is a priority outcome either in its own right or in order to achieve outcomes for fish or waterbirds, then opportunities to connect the river to potential sources of nutrients and organic matter should be explored. These may include upstream opportunities or through the use of infrastructure to inundate and then return water to the main channel. Recognising that increased productivity is only beneficial to a point, after which hypoxic conditions can develop. The key will be to better understand how to provide much needed carbon and nutrients to benefit aquatic biota, but not so much as to result in localised hypoxia.

4.4 Delivery of water is meeting spawning objectives, but recruitment of native fish needs a boost.

While spawning events for native fish have been successfully achieved across multiple rivers in the Basin, recruitment of large bodied native fish to the juvenile age-classes (1 year and above) was low in 2017–18, and has been low throughout the period 2014–18. This likely reflects the low numbers of breeding adult of species such as Murray cod and golden perch, particularly as a result of the 2016–17 fish kills associated with hypoxic blackwater in some rivers.

There are a number of strategies from an adaptive management perspective that may help increase native fish recruitment. For example, ensuring that sufficient food and habitat resources are available, may be influenced by flow. However, other factors, such as high quality habitat associated with fallen timber, macrophytes, and other forms of habitat structure, may also be a limiting factor. Determining how environmental water and other complementary measures can be used to enhance fish recruitment remains an active area of research being invested in by the Commonwealth.

5 Contribution to Basin Plan objectives

The relevant objectives of the Basin Plan were used as the basis for developing a framework that could be used to assess the contribution of Commonwealth environmental water to achieving those objectives (CEWO 2013b). The Outcomes Framework is a nested hierarchy that links the overarching Basin Plan objectives of biodiversity, ecosystem function, resilience and water quality to indicators and outcomes that could be expected from environmental water at two time steps:

- within a 1-year time frame (1-year expected outcomes)
- within a 1–5-year time frame (5-year expected outcomes).

The Outcomes Framework is the distillation of the combined ecological knowledge of flow–ecology relationships and was underpinned by the development of conceptual models (cause–effect diagrams) and literature reviews (CEWO 2013b; Gawne *et al.* 2013).

Despite the limitation of the data available in 2014–18, the Outcomes Framework provides a template for synthesising the effects of environmental water and progress towards meeting Basin Plan objectives. There is evidence across the Basin that Commonwealth environmental water is contributing to each of the broad Basin Plan objectives in a number of ways (Table 7).

It should be noted that while this framework is presented hierarchically, there is a degree of overlap and synergy between outcomes. For example, resilience outcomes influence other areas of the framework through ensuring survival of biota via the provision of refuges, for example; and are in turn influenced by other factors such as ecosystem diversity and connectivity between those ecosystems. This summary should be considered a snapshot of the contributions of Commonwealth environmental water to Basin Plan objectives, but be read in the context of the evaluations described in summary in the previous sections of this report and in detail in Appendices B to G.

Table 7. Contribution of Commonwealth Environmental Water Office (CEWO) watering in 2014–18 to Basin Plan objectives.

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2017–18	Measured and predicted 1–4- year outcomes 2014–18
Biodiversity (Basin Plan S. 8.05)	Ecosystem diversity		None identified	None identified	Over 296 000 hectares of mapped wetland and floodplain inundated 71% of the different aquatic ecosystem types represented in areas influenced by Commonwealth environmental water	75% of the different aquatic ecosystem types inundated with Commonwealth environmental water.
	Species diversity	Vegetation	Vegetation diversity	Reproduction Condition	A significant proportion of native species, including numerous aquatic forbs, grasses and sedges/rushes, only present in areas inundated by Commonwealth environmental water.	Presence of some native species likely to be dependent on inundation by Commonwealth environmental water. Decrease in exotic taxa.
			Growth and survival	Germination Dispersal	Greater vegetation cover in wetlands inundated by Commonwealth environmental water in the Murrumbidgee river system. Significant increases in species richness in wetlands inundated by Commonwealth environmental water during draw down phase.	Enhanced diversity of vegetation communities at Basin scale in response to delivery of Commonwealth environmental water.
		Macro-invertebrates	Macro-invertebrate diversity			
		Fish	Fish diversity	Condition	Improved condition of many native fish species.	Variable condition over time, but individuals that survived the 2016–17 floods improved in condition and this was maintained through 2017–18.
				Larval abundance Reproduction	Golden perch and Murray cod were both observed spawning in some parts of the Basin.	Spawning of golden perch in most years.
			Larval and juvenile recruitment			Maintenance of at least three species of native fish (Murray cod, golden perch, carp gudgeons) across all Selected Areas in all

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2017–18	Measured and predicted 1–4- year outcomes 2014–18
						years. Successful recruitment of small bodied native fish in most years.
		Waterbirds	Waterbird diversity		70 species of waterbird recorded across all functional feeding groups	101 waterbird species recorded at sites that have received Commonwealth environmental water.
			Waterbird diversity and population condition (abundance and population structure)	Survival and condition	Supporting greater than 1% of the relevant populations of nine species of waterbird.	Greater than 1 % of the population of 21 species.
				Chicks	Breeding recorded for several species in low to moderate numbers.	Smaller scale breeding at localised sites that receive environmental water in drier years. Commonwealth environmental water augmenting large floods in wet periods to improve reproductive success.
				Fledglings		
		Other vertebrate diversity		Young	Breeding of many frog species including some temporary wetland specialists. Some evidence of turtle breeding.	Breeding of frogs at several locations across the four years. No evidence of turtle breeding.
			Adult abundance		Large numbers of several species recorded including the southern bell frog.	Continued foraging habitat provided.
Ecosystem Function (Basin Plan S. 8.06)	Connectivity			Hydrological connectivity including end of system flows	Evidence of lateral and longitudinal connectivity in a number of river systems. Maintained an open Murray Mouth.	Evidence of lateral, longitudinal connectivity in a number of river systems Maintained an open Murray Mouth.
				Biotic dispersal and movement		
				Sediment transport		
	Process			Primary productivity (of aquatic ecosystems)	Evidence that in-channel freshes can result in increases in stream metabolism.	Evidence that in-channel freshes can result in increases in stream metabolism.
				Decomposition		
				Nutrient and carbon cycling		

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2017–18	Measured and predicted 1–4- year outcomes 2014–18
Resilience (Basin Plan S. 8.07)	Ecosystem resilience		Population condition (individual refuges)	Individual survival and condition (individual refuges)	Large-scale inundation in several areas (e.g. Hattah Lakes and Macquarie Marshes) by Commonwealth environmental water have maintained / improved condition of ecosystems and biota in what would have otherwise been a dry landscape. Inundation of 40 – 50% of aquatic ecosystems that could receive water in a dry year.	A large proportion of aquatic ecosystem types in the Basin have been maintained through the use of environmental water.
			Population condition (landscape refuges)			
				Individual condition (ecosystem resistance)		
			Population condition (ecosystem recovery)			Over the first four LTIM years over 1% of the population of 21 water bird species have been supported by Commonwealth environmental water.
Water quality (Basin Plan S. 9.04)	Chemical			Salinity		
				Dissolved oxygen		Commonwealth environmental water has helped to maintain dissolved oxygen levels in several river systems.
				pH		
				Dissolved organic carbon		
	Biological			Algal blooms		

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Appendix A – 2017–18 Commonwealth environmental watering actions

Table A1. Watering actions that included Commonwealth environmental water in 2017–18. Note that many of these actions were implemented in conjunction with other environmental water (The Living Murray, state environmental water) but only the Commonwealth environmental water component is shown here. Expected outcomes have been translated into the categories of the Outcomes Framework for simplicity (Con. = connectivity; Proc. = processes (primary production/decomposition); Res. = resilience; WQ = water quality).

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Barwon-Darling: Barwon-Darling River and fringing wetlands (Mungindi to Menindee)	00111-49	6295	01/07/17 - 15/08/17	Fresh	S	-	-	-	-	-	-	P	S
Barwon-Darling: Barwon-Darling River and fringing wetlands (Mungindi to Menindee)	00111-49	1717	26/10/17 - 31/10/17	Fresh	S	-	-	-	-	-	-	P	S
Barwon-Darling: Barwon-Darling River and fringing wetlands (Mungindi to Menindee)	00111-49	735	02/12/17 - 04/12/17	Fresh	S	-	-	-	-	-	-	P	S
Barwon-Darling: Barwon-Darling River and fringing wetlands (Mungindi to Menindee)	00111-49	696	28/02/18 - 02/03/18	Fresh	S	-	-	-	-	-	-	P	S
Border Rivers: Severn River	00111-41	35	Late Nov 2017	Fresh	P	-	-	-	-	-	-	-	S
Border Rivers: Severn River	00111-41	267	28/12/17 - 06/01/18	Fresh	P	-	-	-	-	-	-	-	S
Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	00111-42	293	3/7/18	Fresh	P	-	-	-	-	-	-	-	S
Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	00111-42	349	14/10/17 - 15/10/17	Fresh	P	-	-	-	-	-	-	-	S
Border Rivers: Lower Moonie River and Fringing Wetlands	00111-44	1106	21/10/17 - 30/12/17	Fresh	P	-	-	-	P	S	-	-	S
Border Rivers: Lower Moonie River and Fringing Wetlands	00111-44	1217	03/02/18 - 26/03/18	Fresh	P	-	-	-	P	S	-	-	S

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	10046-03	3252	26/09/17 - 26/10/17	Baseflow	P	-	-	-	S	-	-	-	-
Border Rivers: Dumaresq-Macintyre River and Fringing Wetlands	10046-04	684	21/08/17 - 08/10/17	Fresh, Baseflow	P	-	-	-	-	-	S	-	S
Border Rivers: Border Rivers including floodplain	10074-01	4286	13/04/18 - 21/04/18	Fresh	P	-	-	-	-	-	-	S	-
Lower Broken Creek and fringing wetlands	10041-03	1552	01/07/17 - 17/08/17	Baseflow	P	-	-	-	-	-	-	-	-
Lower Broken Creek and fringing wetlands	10041-03	1121	18/08/17 - 31/08/17	Fresh	-	P	-	-	-	-	-	-	-
Lower Broken Creek and fringing wetlands	10041-03	4674	01/09/17 - 02/10/17	Baseflow	P	-	-	-	-	-	-	-	P
Lower Broken Creek and fringing wetlands	10041-03	6873	03/10/17 - 15/11/17	Baseflow, Fresh	P	P	-	-	-	-	-	-	P
Lower Broken Creek and fringing wetlands	10041-03	3966	16/11/17 - 07/12/17	Baseflow	P	-	-	-	-	-	-	-	P
Lower Broken Creek and fringing wetlands	10041-03	15103	08/12/17 - 15/05/18	Baseflow	-	-	-	-	-	-	-	-	P
Lower Broken Creek and fringing wetlands	10041-03	1444	16/05/18 - 30/06/18	Baseflow	P	-	-	-	-	-	-	-	-
Upper Broken Creek and Moodie Swamp	10042-03	498	18/04/18 - 07/06/18	Fresh, Wetland	P	P	P	-	P	-	-	-	P
Lower Murray: Coorong, Lower Lakes and Murray Mouth	10065-04	326320	01/07/17 - 30/09/17	Fresh	P	S	-	-	S	-	S	-	S
Lower Murray: Coorong, Lower Lakes and Murray Mouth	10065-04	354807	01/10/17 - 31/01/18	Fresh	P	S	-	-	S	-	S	-	S
Lower Murray: Coorong, Lower Lakes and Murray Mouth	10065-04	203279	01/02/18 - 31/05/18	Baseflow	P	S	P	-	S	-	S	-	S

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray: Coorong, Lower Lakes and Murray Mouth	10065-04	9331	01/06/18 - 30/06/18	Baseflow	P	S	-	-	S	-	S	-	S
Campaspe River Catchment	10003-05	6218	13/11/17-28/11/17	Fresh	P	P	-	-	P	-	-	-	-
Central Murray: Barmah-Millewa Forest	10065-02	3344	01/07/17 - 23/03/18	wetland	P	-	-	-	-	-	P	-	-
Central Murray: Gunbower Creek	10030-03	20656	01/07/17 - 30/06/18	Baseflow	P	-	-	-	-	P	-	-	P
Central Murray: Hattah Lakes	10065-03	32145	03/07/17 - 31/10/17	Wetland	P	P	P	-	-	P	-	-	-
Central Murray: River Murray	10065-01	289606	01/07/17 - 31/12/17	Fresh, Overbank	P	P	P	-	-	-	P	-	-
Central Murray: Barham Lake	10065-08	102	23/01/18 - 23/03/18	Wetland	P	S	S	S	-	-	-	-	-
Condamine-Balonne: Lower Balonne floodplain system	00111-46	3985	March 2018	Baseflow	-	-	-	-	-	S	-	S	-
Edward Wakool: Yallakool Wakool System	10070-01	16452	01/09/17 - 01/05/18	Fresh	S	S	-	S	S	S	S	S	S
Edward Wakool: Tuppal Creek	10070-01	1641	21/08/17 - 10/11/17	Baseflow	S	S	-	S	S	S	S	S	S
Edward Wakool: Colligen-Neimur	10070-03	13832	01/09/17 - 01/05/18	Fresh	S	S	-	S	S	S	S	S	S
Edward Wakool: Tuppal Creek	10070-04	933	29/03/18 - 05/05/18	Baseflow	S	S	-	S	S	S	S	S	S
Edward Wakool: Yallakool Wakool System	10054-11	7915	01/07/17 - 30/08/17	Baseflow	S	S	-	S	S	S	S	S	S
Edward Wakool: Colligen-Neimur	10054-12	6370	01/07/17 - 30/08/17	Baseflow	S	S	-	S	S	S	S	S	S
Goulburn: Lower Goulburn River	10064	112232	01/07/17 - 24/07/17	Fresh	P	P	-	-	P	-	-	-	-
Goulburn: Lower Goulburn River	10064	74205	16/09/17 - 11/10/17	Fresh	-	P	-	-	-	-	-	-	-
Goulburn: Lower Goulburn River	10064	3487	08/10/17 - 19/11/17	Baseflow	P	P	-	-	P	-	-	-	P
Goulburn: Lower Goulburn River	10064	11543	16/11/17 - 30/11/17	Fresh	P	-	-	-	-	-	-	-	-
Goulburn: Lower Goulburn River	10064	852	27/11/17 - 05/12/17	Baseflow	P	P	-	-	P	-	-	-	P
Goulburn: Lower Goulburn River	10064	6112	02/12/17 - 22/12/17	Bankfull	P	P	-	-	P	-	-	-	P
Goulburn: Lower Goulburn River	10064	5560	19/12/17 - 09/01/18	Baseflow	P	P	-	-	P	-	-	-	P

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Goulburn: Lower Goulburn River	10064	49989	22/06/18 - 30/06/18	Fresh	P	P	-	-	P	-	-	-	-
Gwydir: Gwydir Wetlands	10069-01	4000	19/12/17 - 17/01/18	Wetland	P	P	P	-	P	P	P	P	-
Gwydir: Mehi River	10069-04	7000	26/08/17 - 04/09/17	Fresh	P	-	-	-	-	P	P	-	P
Gwydir: Mehi River	10069-04	5000	30/10/17 - 20/11/17	Baseflow	P	-	-	-	-	P	P	-	P
Gwydir: Gwydir River system	10074-02	12290	20/04/18 - 23/05/18	Fresh	P	-	-	-	-	P	-	-	-
Lachlan: Lachlan River	10053	32572	27/09/17 - 19/11/17	Baseflow	P	-	-	-	-	-	P	-	-
Lachlan: Lachlan River	10053	951	27/09/17 - 16/10/17	Baseflow	P	-	-	-	-	-	P	-	-
Lachlan: Main channel below Lake Brewster, terminating in Great Cumbung Swamp	10053	1665	17/05/18 - 02/06/18	Fresh	-	-	-	-	-	-	-	-	-
Lower Darling: Lower Darling River	10072-01	2738	21/11/17 - 28/11/17	Fresh	P	-	-	-	-	S	S	-	S
Loddon River Catchment	10001-05	3054	01/10/17 - 30/10/17	Fresh	P	-	-	-	-	-	-	-	-
Lower Murray: Wingillie Station	10065-07	1459	28/09/17 - 20/04/18	Wetland	-	P	P	P	-	-	-	-	-
Lower Murray: Lucerne Day	10065-07	82	28/09/17 - 28/09/17	Wetland	-	P	P	P	-	-	-	-	-
Lower Murray: Lock 7	10065-01	409	08/09/17 - 10/12/17	Overbank	P	P	S	-	-	-	P	-	-
Lower Murray: Lock 7	10065-01	409	22/02/18 - 31/05/18	Baseflow	P	P	-	-	-	-	S	-	-
Lower Murray: Lock 8	10065-01	409	10/09/17 - 06/12/17	Overbank	P	P	S	-	-	-	P	-	-
Lower Murray: Lock 8	10065-01	409	22/02/18 - 31/05/18	Baseflow	P	P	-	-	-	-	S	-	-
Lower Murray: Lock 9	10065-01	409	30/08/17 - 09/10/17	Overbank	P	P	S	-	-	-	P	-	-
Lower Murray: Lock 9	10065-01	409	22/02/18 - 30/05/18	Baseflow	P	P	-	-	-	-	S	-	-
Lower Murray: Lock 15	10065-01	409	05/09/17 - 26/11/17	Overbank	P	P	S	-	-	-	P	-	-
Lower Murray: Lock 15	10065-01	409	23/03/18 - 31/05/18	Baseflow	P	-	-	-	-	-	S	-	-
Lower Murray: Lock 2	10065-06	335	Mid Jul - Early Aug 17	Baseflow	P	-	-	-	-	-	S	-	-
Lower Murray: Lock 2	10065-06	335	Aug – Oct 17	Overbank	P	P	S	-	-	-	P	-	-
Lower Murray: Lock 5	10065-06	1266	Mid Jul - Early Aug 17	Baseflow	P	-	-	-	-	-	S	-	-
Lower Murray: Lock 5	10065-06	1266	Aug - Mid Nov 17	Overbank	P	P	S	-	-	-	P	S	-

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray: Banrock Station - Heron's Bend	10045-02	24	11/12/17 - 27/12/17	Wetland	-	P	P	-	P	-	-	-	-
Lower Murray: Banrock Station - Banrock Bend	10045-02	24	11/12/17 - 27/12/17	Wetland	-	P	P	-	P	-	-	-	-
Lower Murray: Banrock Station - Wigley Reach Depression	10045-02	396	11/12/17 - 10/02/18	Wetland	-	P	P	-	P	-	-	-	-
Lower Murray: Banrock Station - Eastern Lagoon	10045-02	1429	11/12/17 - 23/05/18	Wetland	-	P	P	-	P	-	-	-	-
Lower Murray: Banrock Station - Herons & Banrock's Bend flats	10045-02	132	16/05/18 - 13/06/18	Wetland	-	P	P	-	P	-	-	-	-
Lower Murray: Renmark Wetlands Site 5	10058-01	48	26/3/18 - 27/5/18	Wetland	-	P	P	P	-	P	-	P	-
Lower Murray: Renmark Wetlands Site 8	10058-01	158	09/04/18 - 31/05/18	Wetland	-	P	P	P	-	P	-	P	-
Lower Murray: Renmark Wetlands Site 9	10058-01	58	26/03/18 - 31/05/18	Wetland	-	-	P	P	-	-	-	P	-
Lower Murray: Renmark Wetlands Site 14	10058-01	53	01/08/17 - 28/05/18	Wetland	-	P	P	P	-	P	-	P	-
Lower Murray: Renmark Wetlands Site 15	10058-01	22	01/07/17 - 10/10/17	Wetland	-	P	P	P	-	P	-	-	-
Lower Murray: Berri Evaporation Basin	10065-06	1262	11/08/17 - 30/06/18	Wetland	P	-	-	-	-	-	-	-	-
Lower Murray: Bookmark Creek	10065-06	448	11/08/17 - 30/06/18	Wetland	-	P	P	-	-	-	-	-	-
Lower Murray: Disher Creek	10065-06	50	31/01/18 - 14/02/18	Wetland	P	-	-	-	-	-	-	-	-
Lower Murray: Rilli Reach	10065-09	9	Sept 2017 - June 2018	Wetland	-	P	P	P	-	-	-	-	-
Lower Murray: Calperum Station	10065-09	3894	Oct 2017 - Apr 2018	Wetland	-	P	P	P	-	-	-	-	-
Lower Murray: Riversleigh Lagoon	10065-09	650	Oct 2017 - Feb 2018	Wetland	-	P	P	P	-	-	-	-	-
Lower Murray: Woolenook Bend	10065-09	33	30/10/17 - 13/04/18	Wetland	-	-	P	-	-	-	-	-	-

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray: Gurra Gurra Lyrup Lagoon	10065-09	297	12/12/17 - 15/02/18	Wetland	-	-	P	-	-	-	-	-	-
Lower Murray: Lake Alexandrina Milang Snipe Sanctuary	10065-09	4	02/03/18 - 21/03/18	Wetland	-	-	P	-	-	-	-	-	-
Lower Murray: Clarke's Floodplain	10065-09	13	22/03/18 - 01/06/18	Wetland	-	P	P	P	-	-	-	-	-
Lower Murray: Pike River	10065-09	19	01/04/18 - 27/04/18	Wetland	-	P	P	P	-	-	-	-	-
Lower Murray: Ramco River Terrace	10065-09	5	01/04/18 - 01/06/18	Wetland	-	P	P	P	-	-	-	-	-
Lower Murray: Greenways Landing	10065-09	20	01/04/18 - 30/04/18	Wetland	-	P	P	P	-	-	-	-	-
Murrumbidgee: Nimmie-Caira	10034-13	1738	15/12/17 - 18/12/17	Baseflow	P	S	P	P	P	-	-	S	S
Murrumbidgee: Mid-Murrumbidgee wetlands	10062-01	159283	24/07/17 - 01/09/17	Fresh, Wetland	P	P	P	-	P	P	P	S	-
Murrumbidgee: Yarradda Lagon	10062-02	326	04/07/17 - 24/07/17	Wetland	S	S	S	-	S	-	-	-	-
Murrumbidgee: Gooragool Lagoon	10062-03	1426	18/07/17 - 11/08/17	Wetland	S	S	S	-	S	-	-	-	-
Murrumbidgee: North Redbank	10068-02	5528	09/10/17 - 19/10/17	Wetland	P	S	P	P	P	-	-	S	S
Murrumbidgee: Toogimbie IPA Wetlands	10068-03	1000	07/11/17 - 01/06/18	Wetland	-	-	-	P	-	-	-	P	-
Murrumbidgee: Coonancoocabil Lagoon	10068-04	900	11/12/17 - 02/01/18	Wetland	P	S	P	P	P	-	-	S	S
Murrumbidgee: Oak Creek	10068-05	620	28/12/17 - 02/01/18	Wetland	P	S	P	P	P	-	-	S	S
Murrumbidgee: Yarradda Lagoon	10068-06	178	20/11/17 - 25/11/17	Wetland	-	P	-	-	-	-	-	S	S
Murrumbidgee: Waldaira Lagoon	10068-07	1500	09/02/18 - 07/05/18	Wetland	-	-	-	-	P	-	-	P	-
Murrumbidgee: Sandy Creek	10068-08	400	17/02/18 - 23/04/18	Wetland	P	S	P	P	P	-	-	S	S
Murrumbidgee: Tuckerbill Swamp	10068-09	600	09/04/18 - 16/04/18	Wetland	P	P	P	P	P	-	-	S	-
Murrumbidgee: Nimmie-Caira	10068-10	5000	15/04/18 - 28/05/18	Wetland	P	S	P	P	P	-	-	S	S

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Murrumbidgee: Gooragool Lagoon	10068-11	750	01/06/18 - 30/06/18	Wetland	P	S	P	P	P	-	-	S	S
Macquarie River: Mid-Macquarie River and Macquarie Marshes	10067-01	2239	19/07/17 - 14/08/17	Baseflow	-	-	-	-	-	-	-	-	-
Macquarie River: Mid-Macquarie River and Macquarie Marshes	10067-01	48421	15/08/17 - 12/11/17	Fresh, Wetland	P	P	P	-	P	S	S	-	-
Namoi: Lower Namoi River	10066-01	4100	12/03/18 - 15/05/18	Baseflow	P	S	-	-	-	S	S	-	S
Namoi: Peel River	10063-02	1257	05/06/18 - 18/06/18	Fresh	P	-	-	-	-	-	P	-	-
Ovens River System	10004-04	123	26/03/18 - 29/03/18	Baseflow	P	-	-	-	-	P	-	-	-
Warrego: Upper Warrego River and fringing wetlands	00111-48	3347	01/07/17 - 30/06/18	Fresh	S	-	-	-	-	-	-	S	-
Warrego: Lower Warrego River and fringing wetlands	152-10	0	01/04/2018	Fresh	P	-	-	-	-	S	-	-	-
Wimmera River	10007-01	2734	12/02/18 - 30/06/18	Baseflow	P	P	P	-	P	P	-	-	P
Mt William Creek	10007-01	374	09/04/18 - 18/04/18	Fresh	P	P	P	-	P	-	-	-	P

Appendix B – 2017–18 Basin-scale evaluation of Commonwealth environmental water – Hydrology report

Appendix C – 2017–18 Basin-scale evaluation of Commonwealth environmental water – Stream Metabolism & Water Quality report

Appendix D – 2017–18 Basin-scale evaluation of Commonwealth environmental water – Ecosystem Diversity report

Appendix E – 2017–18 Basin-scale evaluation of Commonwealth environmental water – Vegetation Diversity report

Appendix F – 2017–18 Basin-scale evaluation of Commonwealth environmental water – Fish report

Appendix G – 2017–18 Basin-scale evaluation of Commonwealth environmental water – Biodiversity report