2016–17 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) 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 a 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. In undertaking this role, there are three options available to the CEWH at any given time:

- 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.

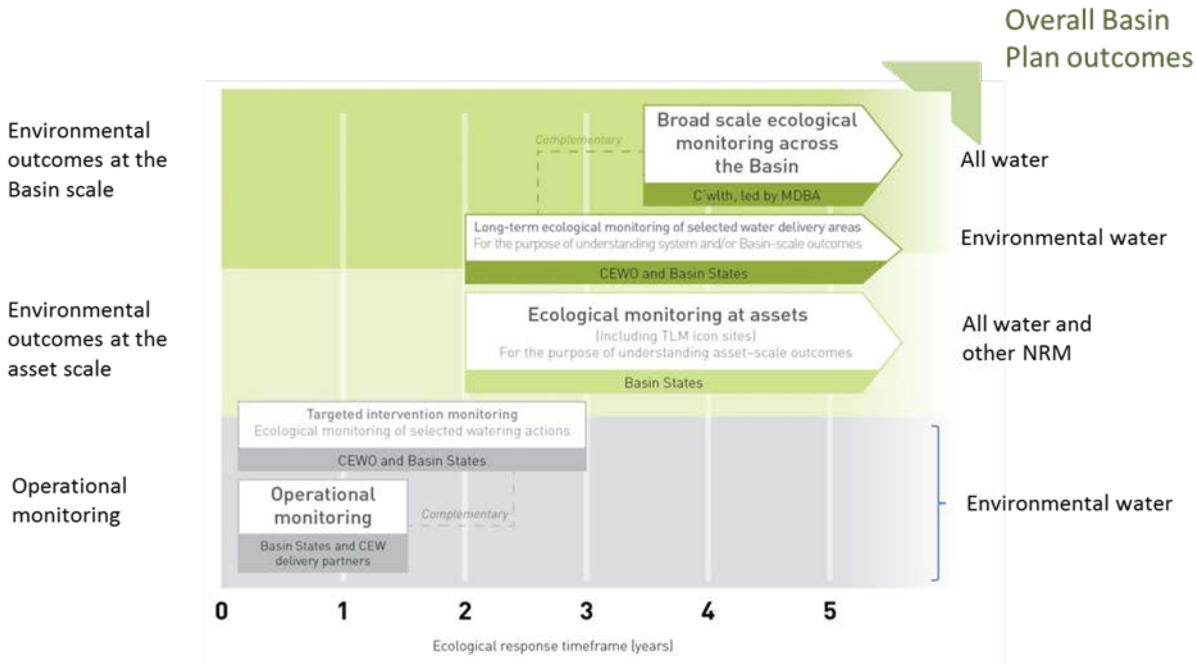

Figure 1. Monitoring and evaluation reporting obligations (Source: Commonwealth Environmental Water Office).

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 its 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.

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

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 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 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.

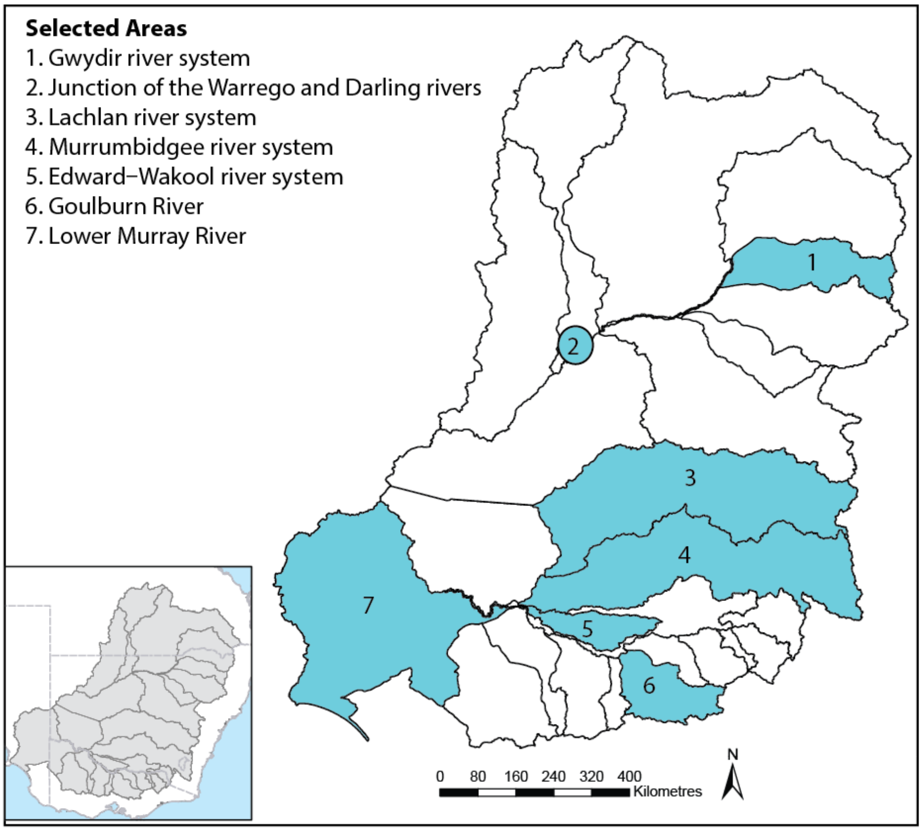

Figure 2. General location of the seven Selected Areas where the LTIM Project is measuring the effects of Commonwealth environmental water.

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 three years of the LTIM Project (2014–17), with a focus on the outcomes from Year 3 (2016–17) and cumulative outcomes from 2014–17.

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 2016–17 watering year, but includes a cumulative assessment across the first three years of the LTIM Project (2014–2017) 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 three years
3. **adaptive management** – a summary of key 'lessons learned' for improved environmental water outcomes.

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[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 2016–17 watering year

2.3.1 Climate and water availability

Rainfall conditions were average to above average across the Basin in 2016–17 (Figure 1). The southern Basin and the eastern NSW portion of the northern Basin experienced above average rainfall. The Queensland rivers and the western NSW portion of the northern Basin experienced average rainfall.

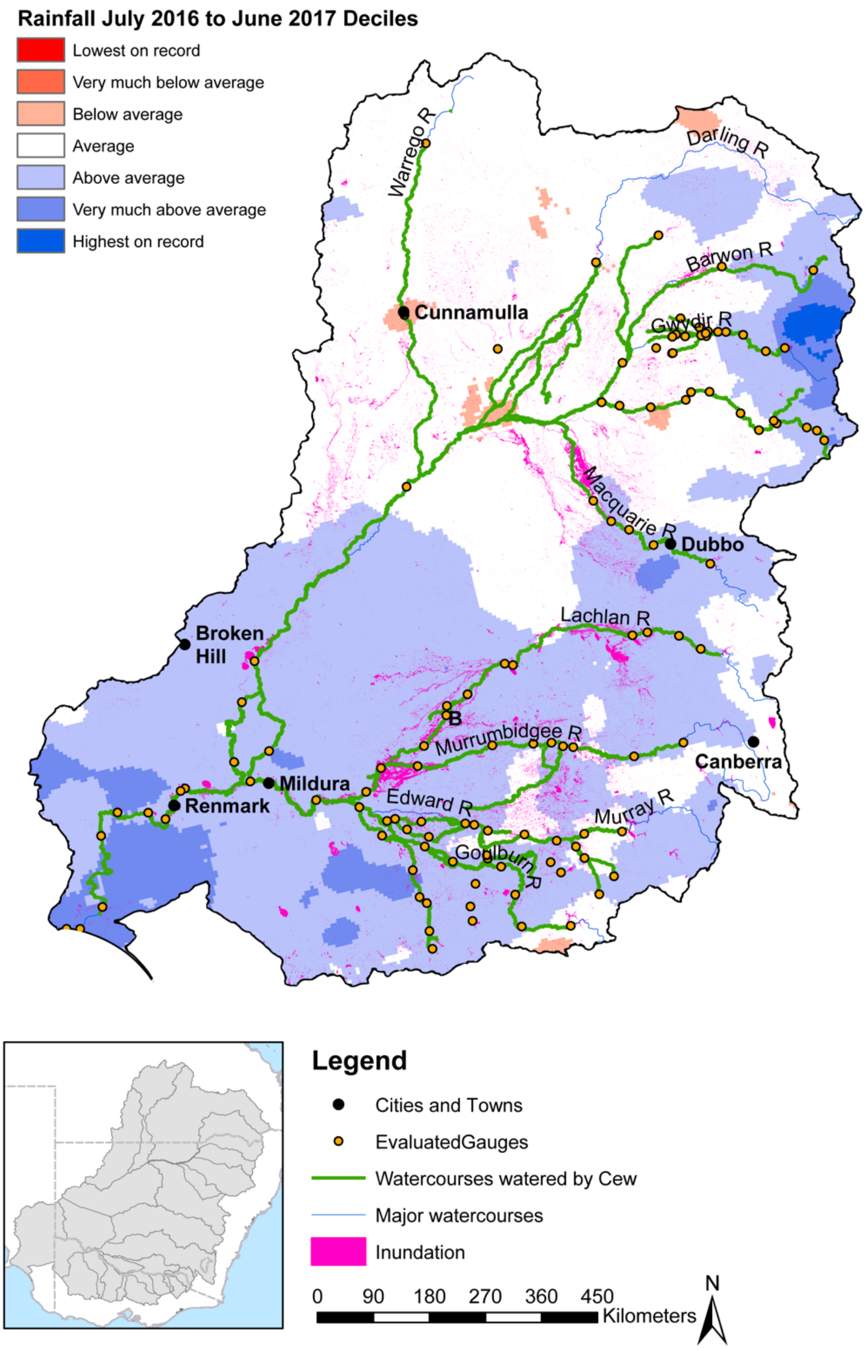


Figure 3. Rainfall, areas inundated and streams watered by Commonwealth environmental water during the 2016–17 watering year.

The Hydrology Basin Matter assessment (Appendix B) identified the resource availability scenarios (RAS) across each of the catchments that received Commonwealth environmental water in 2016–17.

The RAS are based on the availability of held water (including progressive licence acquisitions and allocations) as well as the potential for unregulated or planned environmental flows. For the majority of the catchments that received Commonwealth environmental water, the RAS were considered to be medium to high. There were several exceptions, including three of the Selected Areas (Edward-Wakool, Lachlan and Gwydir valleys) where the RAS was considered to be low to medium (Table 1).

In the context of the relatively wet conditions and the medium to high RAS, Commonwealth environmental water was delivered to facilitate breeding and recruitment of fish, waterbirds and other biota, improve the health and condition of water dependent native vegetation and improve lateral and longitudinal connectivity.

2.3.2 Commonwealth environmental water delivery in 2016–17

Commonwealth environmental water contributed to 93 watering actions across 17 catchments in the 2016–17 watering year (Appendix A). A net total of 1456 gigalitres of Commonwealth environmental water was delivered. Through the use of return flows, Commonwealth environmental water was used and reused, effectively contributing 1788 gigalitres of water. The majority of water (almost 90%) was delivered as base flow or freshes in rivers and streams (Table 1). Many of these watering actions were undertaken collaboratively with state jurisdiction partners and/or sought to piggyback on unregulated flow events to maximise ecological benefits from available water reserves.

Table 1. Summary of Commonwealth environmental watering actions 2016–17 (see Appendix B for further explanation).

Valley	Commonwealth environmental water Resource Availability Scenario (RAS)	Flow type (no. of actions)					
		Base	Fresh	Bankfull	Overbank	Wetland	Fresh & baseflow
Barwon–Darling	Medium-High		3				
Border Rivers	Medium		3	3			
Broken	Medium-High	3					
Central Murray	Medium-High	1	1	1			
Condamine–Balonne	Not classified		1	1			
Edward–Wakool	Low -Medium	4	4				
Goulburn	Medium-High	3	2				
Gwydir	Low	1	1			2	
Lachlan	Low		1			1	
Loddon	Low -Medium	1	1				
Lower Darling	Medium		1				1
Lower Murray	Medium-High		11			11	1
Macquarie	Medium-High		2			4	
Murrumbidgee	High		2			10	
Namoi	Medium	1	1				
Ovens	Medium-High	1	1				
Warrego	Not classified		5	1		2	

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 broad 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 2016–17, the most prevalent expected outcomes of Commonwealth environmental water were to support fish, vegetation and waterbirds (Table 2).

Table 2. Summary of 'expected outcomes' for Commonwealth environmental watering actions 2016–17 (see Appendix A).

Valley	Fish	Vegetation	Birds	Frogs	Other biota	Connectivity	Processes	Resilience	Water quality
Barwon–Darling							3	3	3
Border Rivers	6	1			2	2	1	3	
Broken	2								1
Central-Murray	4	3	1			2	4		2
Condamine–Balonne	1	1	1			1		1	
Edward–Wakool	6	4				1			4
Goulburn	4	3			4		3		2
Gwydir	1	2	2	1	2	4	3	1	2
Lachlan			1						1
Loddon	1	1			2	1			
Lower Darling	2	2	1	1		2			2
Lower Murray	12	20	15	9		1	11		
Macquarie	4	5	3			4	1		
Murrumbidgee	11	11	10	2	2	1	2	1	9
Namoi	2	1			1	1	1		
Ovens						2			
Warrego	2	2	2			6	1	5	
Total (% of all watering actions)	**58**	**54**	**36**	**13**	**13**	**28**	**30**	**14**	**24**

2.3.1 *The first 3 years in context: 2014–17*

Surface water inflows across the Murray-Darling Basin have been low for the four year period mid 2012 to mid 2016 (Figure 4) with magnitudes similar to the less severe years of the Millennium Drought. This period includes the first two years of LTIM, which were characterised by dry conditions and low resource availability scenarios. In 2016-17 (the third LTIM year) surface water inflows in the southern Basin increased to approximately double inflows over the previous four years. For example, the Loddon and Campaspe experienced a five-fold increase on the previous four year average, and the Macquarie inflows were close to twice that of previous years. In other parts of NSW (Namoi, Gwydir and Border Rivers) there have been minor increases in flow in 2016-17, but in the Queensland portion of the Basin (Warrego, and Condamine-Balonne) flows remained low for a fifth consecutive year.

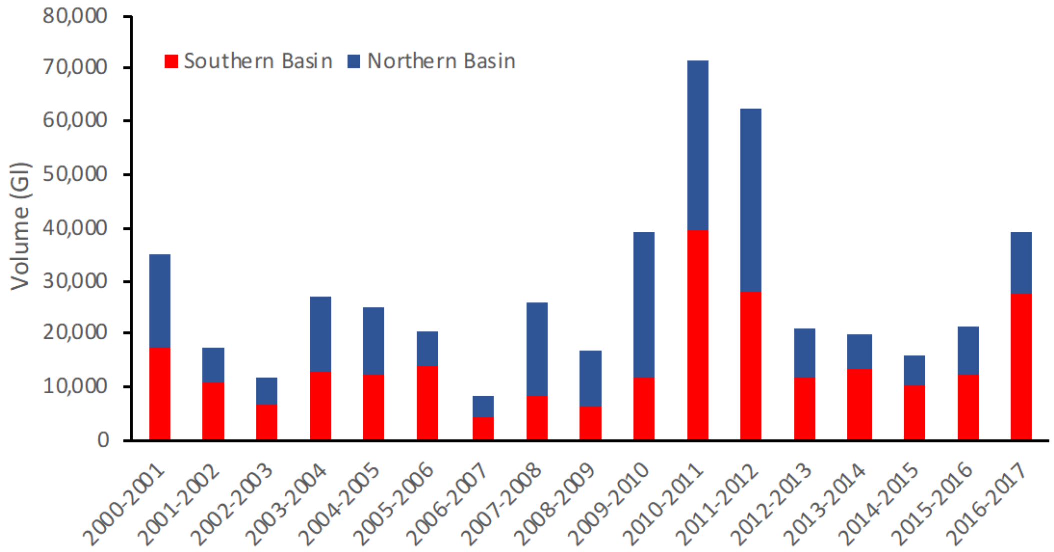


Figure 4: Annual surface water inflows in the Murray-Darling Basin (Source: BoM National Water Account).

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: Generic Diversity.

Provided here is an integrated assessment of the outcomes of Commonwealth environmental water in 2016–17 and cumulatively over the first three years of LTIM (2014–17), 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 three years of LTIM, Commonwealth environmental water inundated half of the wetland types in the Basin and influenced more than 10 % of the mapped extent of five wetland types.
- Plant species diversity increased in response to Commonwealth environmental water in 2016-17 in Selected Area wetland sites. Commonwealth environmental water resulting in wetland inundation across the Basin in 2016-17 is extremely likely to have generated a greater diversity of vegetation communities than would otherwise have been present.
- Commonwealth environmental water contributed to improved Murray cod and golden perch condition in several Selected Areas.
- Commonwealth environmental water has contributed to waterbird diversity by supporting a high abundance of species across the three years, including more than 1% of the populations of 10 species, and improving breeding outcomes for colonial nesting species.
- Thirty-eight species of conservation significance were recorded at sites that received Commonwealth environmental water in the period 2014–17.
- Water has been delivered to nine 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). Generic Diversity (Appendix G) integrates the biodiversity outcomes of these three 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 2016–17*

In the 2016–17 watering year, Commonwealth environmental water was delivered to 17 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 21 600 kilometres of river channel and influenced over 250 000 hectares of mapped wetland and floodplain ecosystems (Figure 5 and Table 3).

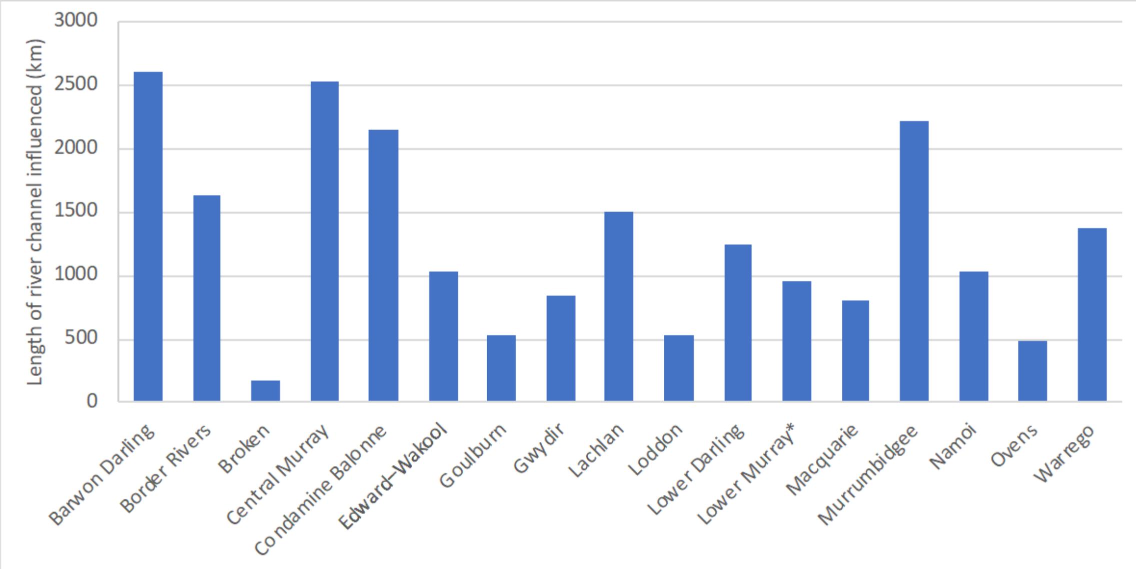


Figure 5. Length of river where flow regimes were enhanced by the delivery of Commonwealth environmental water in the 2016–17 watering year.

Table 3. Area of floodplain and wetland inundation in the 2016–17 watering year.

Catchment name	Lakes and wetland area influenced[6] (ha)	Floodplain area inundated (ha)
Barwon Darling	412	–
Border Rivers	74	48
Central Murray	3372	209
Condamine Balonne	17 341	34
Gwydir	6730	1251
Lachlan	144	2047
Lower Darling	32	11
Lower Murray*	6465*	1158
Lower Murray (Coorong Lakes Alexandrina and Albert and Murray Mouth)	Fresh: 118 148 Estuary: 23 850	66
Macquarie	36 842	6250
Murrumbidgee	6448	3211
Warrego	17 734	186
Total	**237 592**	**14 471**

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

[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.

In terms of vegetation communities, analysis of data collected at the Selected Areas indicated that water regimes were influential on diversity and community composition. Diversity of vegetation communities was promoted within Selected Areas and at a Basin scale by wetting, and to a lesser extent, drying. 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. Inundation mapping showed that large areas and significant proportions of the mapped extent of some vegetation communities were influenced by Commonwealth environmental water in 2016–17, including over 10% of the mapped extent of five wetland types:

- Permanent wetland
- Freshwater meadow
- Temporary sedge/grass/forb marsh
- Temporary lignum swamp
- Temporary river red gum swamp.

Watering by Commonwealth environmental water in 2016–17 contributed significantly to the biodiversity objectives of the Basin Plan associated with vegetation diversity and is likely to have increased species diversity at the Basin scale over the three years. A significant number of plant taxa, mostly native, at each Selected Area (5-11 species), as well as cumulatively across all wetland Selected Areas (10 species), were only present in wetlands that were inundated by Commonwealth environmental water in 2016–17. Consequently, there is a high probability that Commonwealth environmental water significantly enhanced plant species diversity in wetland habitats during 2016–17 as well as across the Basin as a whole.

The outcomes framework (CEWO 2013) identifies two short term (one year) indicators of fish diversity: condition and larval abundance / reproduction. In 2016–17, there were 58 Commonwealth environmental watering actions that targeted fish, including 18 with expected outcomes for fish condition and 21 for reproduction (noting that several watering actions targeted both indicators). Of these watering actions that targeted short term indicators of diversity, only six had any monitoring data collected directly assessing the effects of Commonwealth environmental water. From this limited pool of data, we know that several fish species benefited from Commonwealth environmental water either by stimulating spawning, or providing conditions to improve survival of larval fish, particularly in Gunbower Creek (Bloink & Robinson 2016), the Dumaresq-Macintyre River (NSW DPI & Qld Department of Agriculture and Fisheries 2017), the Lower Warrego River (Southwell *et al.* 2017a) and the Lower Darling River (Sharpe & Stuart 2018). In other areas, the effects of low dissolved oxygen as a result of extensive and infrequent floodplain inundation, impacted the effectiveness of environmental water in maintaining fish condition and facilitating reproduction, with a lack of spawning and / or loss of juvenile and adult fish recorded in several river systems including the Edward-Wakool (Watts *et al.* 2017) and the Lower Murray (Ye *et al.* 2017).

Aggregation of data from Basin Matters, Selected Areas and other observations and monitoring programs indicates that a variety of species were recorded at sites that received Commonwealth environmental water. Species that potentially benefited from Commonwealth environmental water in 2016–17 comprise (see Appendix G):

- 24 species of plants
- 16 species of fish
- 74 species of waterbird
- 9 species of frog
- 3 species of turtle.

3.1.2 *Basin-scale biodiversity outcomes 2014–17*

Cumulative outcomes of Commonwealth environmental water on biodiversity over the first three years of the LTIM project (2014–17) have been integrated into a narrative that crosses themes to highlight outcomes of Basin scale significance:

1. Contributions to maintaining the ecological character of Ramsar sites
2. Benefits to threatened species and communities
3. Maintaining native fish condition through multi-year watering
4. Capitalising on natural inundation to improve ecological outcomes.

Maintaining the ecological character of Ramsar sites

There are 16 Ramsar site in the Basin and over the first three years of the program, Commonwealth environmental water has targeted ecological outcomes at nine of these (Table 4). There are varying degrees of information about the outcomes of these watering actions on the ecological character of each site, but some key outcomes are (see Appendix G for more detail):

- Narran Lakes – A total of 28 870 ML of water, all of which was Commonwealth environmental water, was delivered through the Lower Balonne system into Narran Lakes in spring 2016, contributing to the inundation of approximately 1500 hectares of mapped wetland. This is the most significant inundation at the site since 2013. Although the extent and duration of inundation was insufficient to inundate the colonial nesting waterbird sites, there is good evidence to indicate that large numbers of waterfowl and other waterbirds benefited from the environmental water delivery and the increased habitat and productivity that resulted.
- Macquarie Marshes – has received Commonwealth environmental water each year of the LTIM project. While watering actions in the first two years were focussed on maintaining condition and refuges during dry periods, in 2016–17, Commonwealth environmental water was delivered to extend durations of flooding to improve waterbird outcomes and to aid in the migration of native fish. There is good evidence that these multi-year strategies are contributing to the maintenance of ecological character at the site (Spencer *et al.* 2018).
- Gunbower Forest – water was delivered in 2015–16 and 2016–17 as part of a three year Environmental Water Agreement with the Commonwealth Environmental Water Office (CEWO) to provide the fish hydrograph from 2015–2018 in Gunbower Creek. 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 deleterious effect on fish recruitment and survival with no Murray cod in size classes that represent fish less than three years of age (Sharpe *et al.* 2014). Following the implementation of Commonwealth environmental watering there was evidence of recruitment in five native species: Australian smelt, carp gudgeon, Murray cod, Murray-Darling rainbow fish and unspecked hardy-head. There are now juvenile and sub-adult size classes of Murray cod clearly represented in Gunbower Creek (Bloink & Robinson 2016).

Table 4. Ramsar sites that have been the target of Commonwealth environmental watering actions in the first three years of the LTIM Project.

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

Maintaining fish condition

As mentioned above, only a small percentage of watering actions delivered for indicators of fish diversity are able to be monitored in any given year. The fish Basin Matter is attempting to address this issue by developing models of fish populations and condition in response to Commonwealth environmental water. With just three years of data collected under the LTIM Project, model development is in its infancy and results have a high degree of uncertainty. As time progresses and more data becomes available, our ability to predict the effects of Commonwealth environmental water on native fish diversity will increase. The model results presented here, must be viewed in this light of high uncertainty, but illustrate the progress being made.

There are three target large-bodied native fish species for which data is collected to inform population modelling: bony herring, golden perch and Murray cod. Data for bony herring across Selected Areas in the first three years of LTIM did not indicate a consistent pattern with respect to river flow, recruitment and survival. The models did indicate significant patterns, however, for golden perch and Murray cod.

In terms of flow-ecology relationships, early model results suggest that high spring and summer flows have a significant, positive effect on fish condition for both golden perch and Murray cod. The response of golden perch to these high spring and summer flows is also dependent on the median discharge in the previous years. That is, the condition of golden perch is related to flows spanning more than a single year. It is possible that high autumn flows can have a negative effect on the condition of Murray cod, although the reasons for this are not clear and more data is required to confirm this finding. The condition of golden perch and Murray cod is also dependent on abundance. That is, if the population numbers are high, the average condition of individual fish will be reduced. This pattern suggests food or habitat limitation may decrease individual condition as a result of competition.

In terms of the effect of Commonwealth environmental water we can state with *low confidence* that (see Appendix F for further detail):

- Commonwealth environmental water, together with other environmental water, delivered during 2014–15 and 2015–16, contributed to increases in golden perch condition in the Goulburn, Murrumbidgee, Lachlan and Lower Murray Selected Areas (Figure 6).
- Commonwealth environmental water, together with other environmental water delivered during 2014–15 increased Murray cod condition in the Edward-Wakool and in the Gwydir.
- Delivery of Commonwealth environmental water in autumn within the Goulburn during 2014–15 may have decreased Murray cod condition (Figure 7).

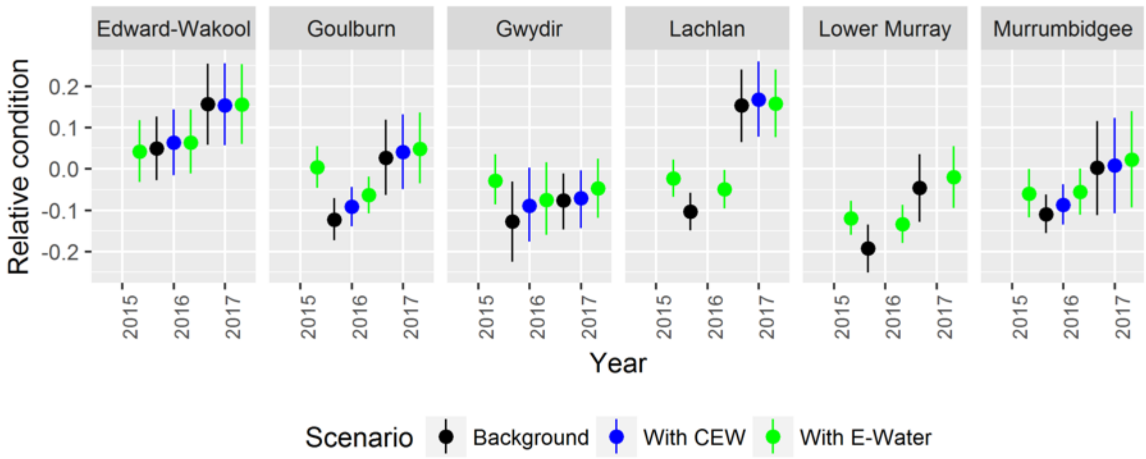


Figure 6. Predicted outcomes for golden perch condition under different hydrological scenarios considering the impact of background and environmental water flows.

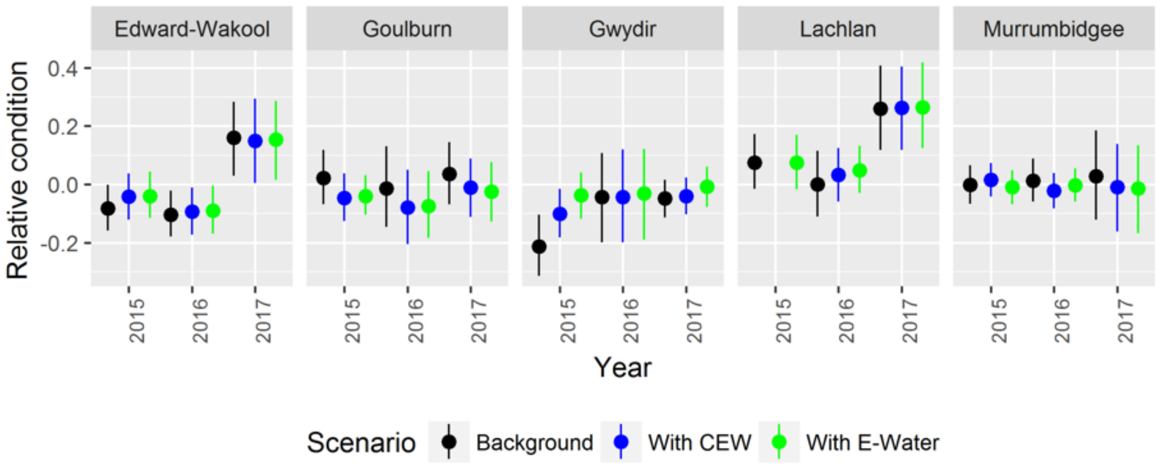


Figure 7. Predicted outcomes for Murray cod condition under different hydrological scenarios considering the impact of background and environmental water flows.

Threatened species

Thirty-eight significant species were recorded at sites that received environmental water in 2014–17 (Table 5). This includes eight international migratory waterbird species, 13 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 benefiting these species across the Basin will also increase.

Two iconic and nationally listed threatened bird species were recorded at sites that received Commonwealth environmental water. The Australasian bittern was recorded in all three years and the Australian painted snipe in 2015–16. Given the cryptic nature of both these species, it is likely that they were present at sites in all years. There is now a good body of evidence suggesting that Commonwealth environmental water is helping to maintain the Australasian bittern (Text box 1).

Table 5. Listed species that were recorded at sites that received Commonwealth environmental water in 2014–17.

Group	Common name	Species name	Significance[1]
Birds	Black-tailed godwit	*Limosa lapponica*	JAMBA, CAMBA, ROKAMBA, V (NSW)
	Common greenshank	*Tringa nebularia*	JAMBA, CAMBA, ROKAMBA
	Common sandpiper	*Actitis hypoleucos*	JAMBA, CAMBA, ROKAMBA
	Latham's snipe	*Gallinago hardwickii*	JAMBA, CAMBA, ROKAMBA
	Marsh sandpiper	*Tringa stagnatilis*	JAMBA, CAMBA, ROKAMBA
	Red-necked stint	*Calidris ruficollis*	JAMBA, CAMBA, ROKAMBA
	Sharp-tailed sandpiper	*Calidris acuminata*	JAMBA, CAMBA, ROKAMBA
	Wood sandpiper	*Tringa glareola*	JAMBA, CAMBA, ROKAMBA
	Australasian bittern	*Botaurus poiciloptilus*	Endangered (EPBC)
	Australian little bittern	*Ixobrychus dubius*	Endangered (VIC)
	Australian painted snipe	*Rostratula australis*	Endangered (EPBC)
	Black-necked stork	*Ephippiorhynchus asiaticus*	Endangered (NSW)
	Blue-billed duck	*Oxyura australis*	Endangered (VIC)
	Brolga	*Grus rubicunda*	Vulnerable (NSW, VIC)
	Comb-crested jacana	*Irediparra gallinacea*	Vulnerable (NSW)
	Eastern great egret	*Ardea modesta*	Vulnerable (VIC)
	Freckled duck	*Stictonetta naevosa*	Vulnerable (SA)
	Hardhead	*Aythya australis*	Vulnerable (VIC)
	Intermediate egret	*Ardea intermedia*	Endangered (VIC)
	Little egret	*Egretta garzetta*	Endangered (VIC)
	Magpie goose	*Anseranas semipalmata*	Vulnerable (NSW)
	Musk duck	*Biziura lobata*	Vulnerable (VIC)
	Regent parrot	*Polytelis anthopeplus*	Vulnerable (EPBC)
	Superb parrot	*Polytelis swainsonii*	Vulnerable (EPBC)
	White-bellied sea-eagle	*Haliaeetus leucogaster*	Vulnerable (NSW, VIC)
Fish	Eel-tailed catfish	*Tandanus tandanus*	Endangered (NSW, VIC)
	Flat-headed galaxias	*Galaxias rostratus*	Critically endangered (EPBC)
	Murray cod	*Maccullochella peelii*	Vulnerable (EPBC)
	Murray hardyhead	*Craterocephalus fluviatilis*	Endangered (EPBC)
	Olive perchlet	*Ambassis agassizii*	Endangered population (NSW)
	Purple-spotted gudgeon	*Mogurnda adspersa*	Endangered (NSW)
	Silver perch	*Bidyanus bidyanus*	Endangered (EPBC)
	Trout cod	*Maccullochella macquariensis*	Endangered (EPBC)
Frogs	Southern bell frog	*Litoria raniformis*	Vulnerable (EPBC)
Plants	Basalt peppercress	*Lepidium hyssopifolium*	Endangered (EPBC)
	Glistening dock	*Rumex crystallinus*	Vulnerable (VIC)
	Rigid water milfoil	*Myriophyllum porcatum*	Vulnerable (EPBC)
	Winged peppercress	*Lepidium monoplocoides*	Endangered (EPBC)

[1] CAMBA = China–Australia Migratory Bird Agreement; JAMBA = Japan–Australia Migratory Bird Agreement; ROKAMBA = Republic of Korea – Australia Migratory Bird Agreement; EPBC = *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Habitat for the Australasian bittern

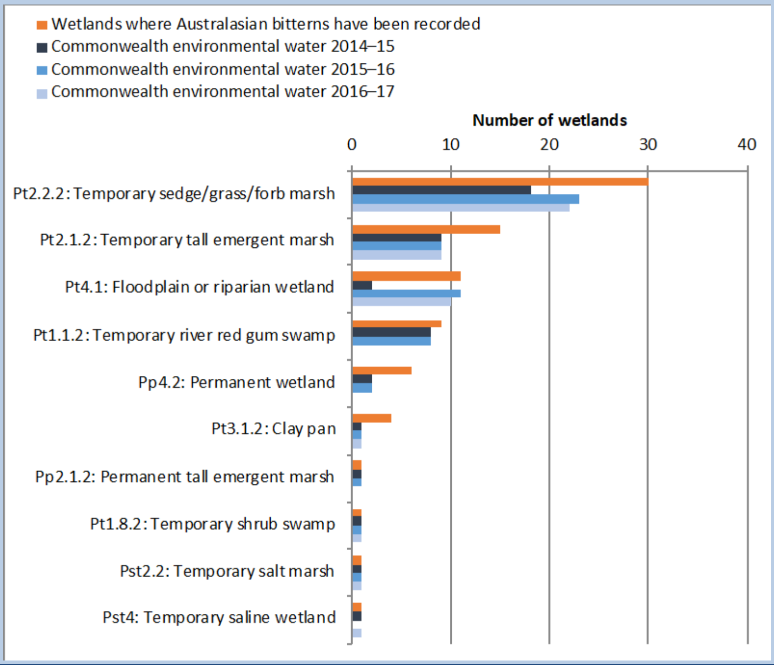
The Australasian bittern is listed as endangered under the EPBC Act and under the International Union for Conservation of Nature (IUCN) Red List. The species occurs also in New Zealand and New Caledonia, within Australia it is largely limited to the Murray—Darling Basin, Tasmania and south-west Western Australia. Population estimates vary, but the total global population is suspected to be 1500 to 4000 individuals (Herring 2016) and Wetlands International (2015) indicate just five individuals represents 1% of the south-eastern Australian population.

Although Australasian bitterns have been observed in many habitat types, including saltmarsh, it is only large, shallow wetlands with emergent vegetation (but not trees) that support them for long periods (Herring 2016). A decline in these habitats and particularly extended drying of these wetlands has been identified as a serious threat and one of the reasons the species is considered endangered (TSSC 2010).

Australasian bitterns are cryptic species and there are many knowledge gaps with respect to lifecycle and behaviours. They were long considered to be sedentary, not moving far from their core wetland (Marchant and Higgins 1990). More recent evidence has indicated that they can and do travel long distances between breeding grounds in the mid to southern Basin to coastal areas (Herring 2016). The limited number of birds that have been tracked to date suggest that birds travel to and from the same wetlands suggesting site fidelity (Herring 2016) but more information is required to confirm this.

Australasian bitterns have been recorded by LTIM and TLM monitoring at six sites in the Basin following the delivery of Commonwealth environmental from the Gwydir in the northern Basin to the Coorong in the south. We also have evidence of Commonwealth environmental water supporting large numbers of bitterns (46 to 48 males) in Barmah-Millewa in 2015–16. If the unheard females were included in the tally, it is possible that the site supported up to one third of the total population (Belcher et al. 2016).

To try and extrapolate benefits of Commonwealth environmental water into sites that were not monitored, all bittern records from the Atlas of Living Australia and LTIM monitoring were overlaid with aquatic ecosystem types and over the past few decades. The species has been recorded in 79 wetlands in the Basin. Of these 58 (73 %) have received Commonwealth environmental water in the first three years of LTIM (see below). While there are still uncertainties with respect to whether bitterns occurred at these sites when environmental water was delivered and if attributes of water delivery such as timing, depth and duration of inundation matched bittern habitat requirements, the high site fidelity of the species provides us with some degree of confidence of the benefit of Commonwealth environmental water to Australian bitterns at the Basin scale.



Wetlands were Australasian bitterns have been recorded in the Basin (Atlas of Living Australia) and those that received Commonwealth environmental water in the first three years of LTIM.

Text box 1. Commonwealth environmental water benefiting Australasian bitterns.

Capitalising on natural inundation for improved ecological outcomes

In the first two years of LTIM, the climate was largely dry and Commonwealth environmental water was delivered in many places with the express aim of maintain condition of long-lived vegetation in a dry landscape and on providing refuges for fauna. This is supported by recent research that indicates that, during dry times, the use of environmental water to maintain key wetland habitats is important for ongoing survival of waterbird populations in the Basin (Bino *et al.* 2015) and can be effective in maintaining other biota, such as frogs and turtles (Howard *et al.* 2017).

In 2016–17, much of the Basin experienced wetter conditions and Commonwealth environmental water was delivered to extend and improve the outcomes of natural floods. This is evident in rivers and streams where Commonwealth environmental water was used to improve connectivity between ecosystems and catchments. For example, in the Lower Darling there were good outcomes for fish in terms of recruitment and dispersal from connecting wetland, and river habitats (Sharpe & Stuart 2018). Similarly, there were reported outcomes for dispersal of fish from connecting flows in the Macquarie – Barwon Rivers and in Gunbower Creek.

Perhaps the most obvious biodiversity outcomes from Commonwealth environmental water in 2016–17 were for waterbirds. 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. Reproductive success was improved through the use of Commonwealth environmental water by maintaining water depths under nesting colonies (Brandis 2017) and by providing adequate foraging habitats in adjacent wetland areas. A summary of measured breeding success at sites that received Commonwealth environmental water indicates success rates of 40 to 66 % (Table 6). Although less well studied, large numbers of waterfowl and other waterbirds would also have bred in response to the floods and drawn benefits from environmental water.

Table 6. Colonial waterbird breeding success at sites that received Commonwealth environmental water in 2016–17 (Brandis 2017; Wassens *et al.* 2017).

Location	Breeding period	Commonwealth environmental water		No. of nests	Success rate (%)
		Volume (ML)	Timing		
Murrumbidgee: Eulimbah	Oct – Mar	2320	28/11/16 - 03/03/17	15 104	59
Murrumbidgee: Telephone B.	Oct - Jan	5425	24/11/16 - 20/03/17	30 779	#
Murrumbidgee: Tori Swamp	Jan - Mar	844	27/10/16 - 13/02/17	6106	40
Lachlan: Booligal	Jan - Mar	1324	09/01/17 - 17/03/17	8000	58
Macquarie: Zoo Paddock	Oct – Jan	17039	24/01/17 - 18/02/17	21 210	66
Macquarie: Monkeygar	Oct – Jan			15 000	63

Not monitored

3.2 Ecosystem function

Basin-scale ecosystem function outcomes

- Commonwealth environmental water has contributed to restoring river flow regimes through provision of base flows across the basin and the contributions to improved frequency and duration of freshes in the southern Basin.
- Commonwealth environmental water has contributed to improving longitudinal connectivity as indicated by an increase in end of system flows across all rivers with substantive consumptive extraction.
- Commonwealth environmental water has contributed to maintaining connectivity through the Murray Mouth, particularly in low flow years.
- There is now evidence to suggest that the delivery of in-channel flows using environmental water can result in increased productivity in the southern Basin.
- There is solid evidence that Commonwealth environmental water is contributing to biological connectivity. In particular, in the third LTIM year, there were two large scale examples of successfully facilitating the movement of golden perch across multiple river systems:
    - the movement of golden perch and spangled perch from the Barwon to the Macquarie River, and
    - the movement of golden perch from the Menindee Lakes nursery to the lower Darling and the Murray River.

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 third 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?

In addition, the Fish Basin Matter considered the effects of Commonwealth environmental water on biological connectivity (the movement of fish along and between ecosystems).

3.2.2 Basin-scale ecosystem function outcomes 2014–17

Restoration of the hydrological regime

Over the first three years of LTIM, 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 8). The full evaluation is provided in Appendix B, with a short summary of highlights presented here.

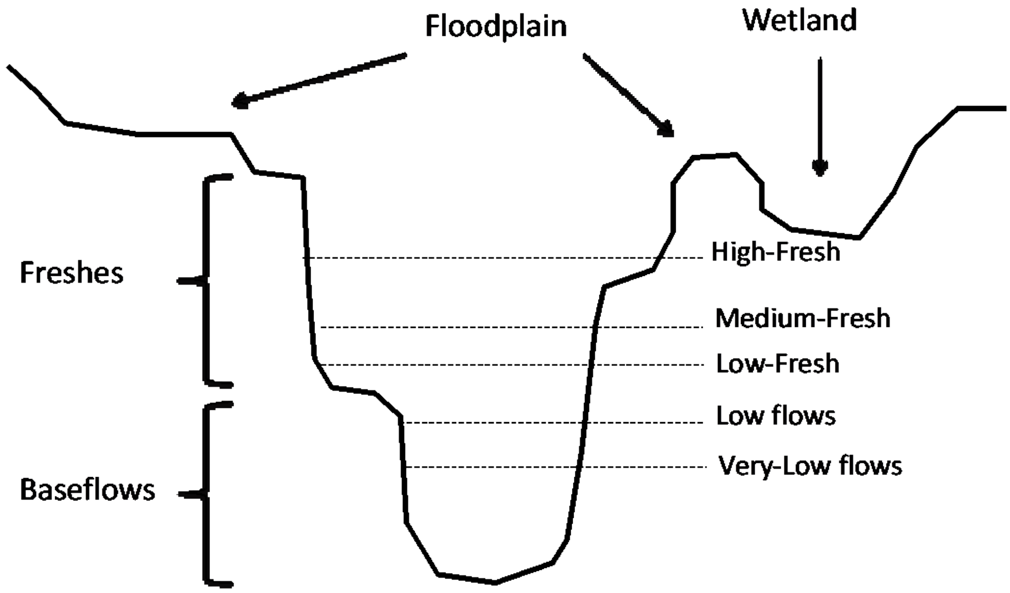


Figure 8. Conceptual diagram indicating water levels corresponding to the flow freshes and base flows used in the hydrological evaluation (for more detail see Appendix B).

Commonwealth environmental water has contributed to maintaining baseflows in all years of LTIM, to varying degrees. Despite a return to normal inflow conditions across much of the Basin in 2016–17, base flow durations were substantially less than those under predevelopment conditions in all rivers except the Central Murray (Figure 9). Environmental water entitlements enhanced base flows across all southern Basin rivers and the Macquarie River in the northern Basin). In NSW rivers, low flow conditions in the previous two years were generally worse than in 2016–17. In contrast, the Victorian rivers have seen similar low flow conditions on average during this third year of monitoring compared to the first year of monitoring (2014–15) but diminished conditions in the middle year (2015–16).

The wetter conditions in 2016–17 resulted in a natural improvement in the occurrence of freshes across the Basin. This was particularly evident in the high fresh category, which raises water levels at least half way up the river bank (see Appendix B). As a consequence, the contribution of Commonwealth environmental water to improving the occurrence of freshes was reduced in 2016–17 compared to the first two years of LTIM, but still important in rivers such as the Darling in NSW. Commonwealth environmental water did contribute to maintaining freshes in the first two years of LTIM, as evidenced by the contribution to medium freshes, particularly in the southern Basin (Figure 10).

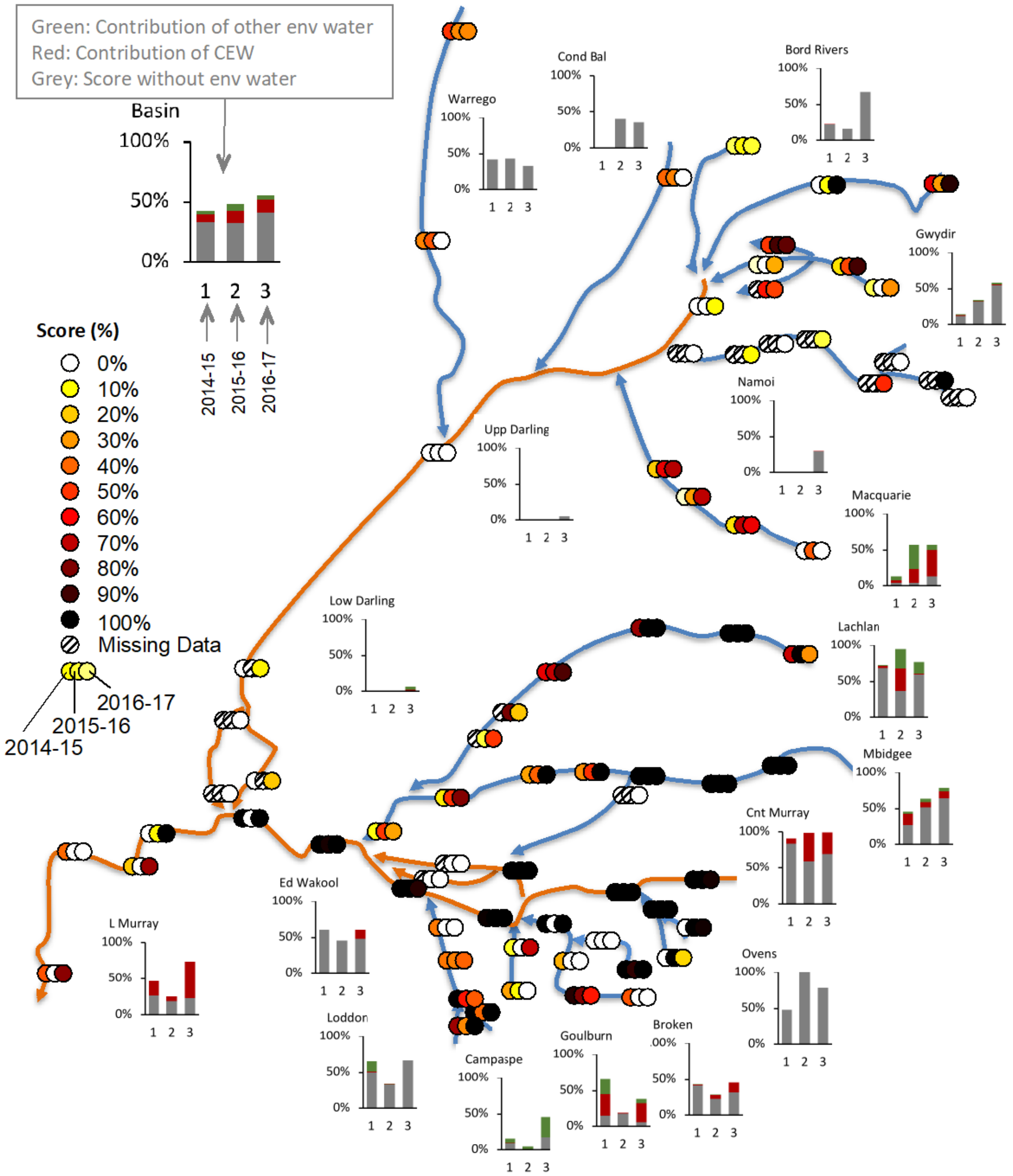


Figure 9. Average contribution of Commonwealth environmental water and other environmental water entitlements to low base flow durations across each valley in the three years of LTIM monitoring. Scores range from 0% (extremely dry) to 100% (normal conditions). See Appendix B for more detailed explanation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

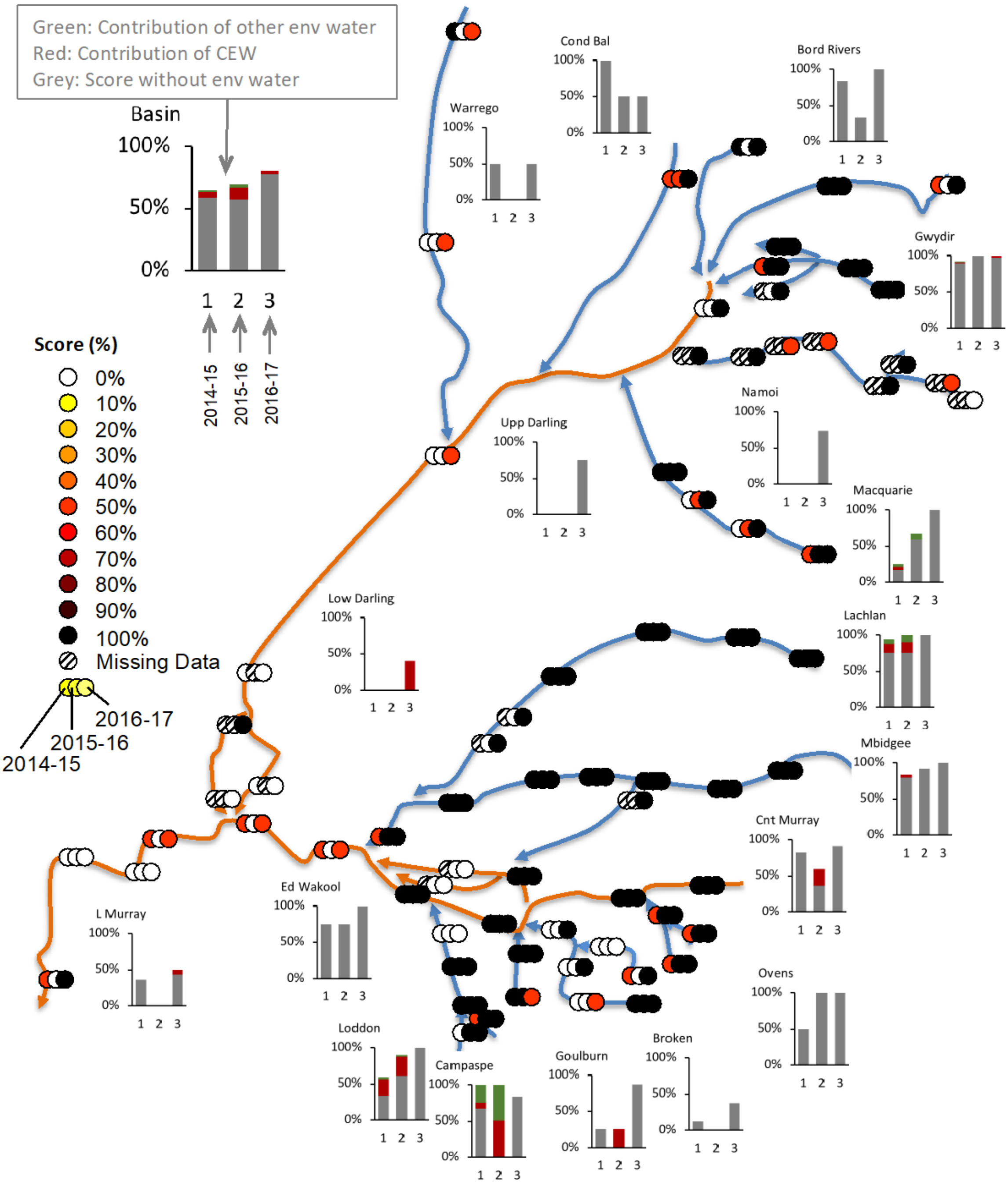


Figure 10. Average contribution of Commonwealth environmental water and other environmental water entitlements to medium fresh durations across each valley in the three years of LTIM monitoring. Scores range from 0% (extremely dry) to 100% (normal conditions). See Appendix B for more detailed explanation on scoring and further details.

Hydrological connectivity

Commonwealth environmental water delivered as in-channel flows has contributed to longitudinal connectivity across the Basin, as evidenced by the effect on end of system flows. Prior to water resources development approximately half of the surface water inflows to the Basin were discharged as end of system flows, the remainder being "lost" to groundwater or evaporation. By the mid to late 20th century, the proportion of inflows that were discharge at the end of the system had reduced to the point that flow ceased at the Murray Mouth in some years.

The effect of Commonwealth environmental water on longitudinal connectivity, as indicated by end of system flows, is illustrated through the comparison of the proportion of mean inflows reaching the end of each system both prior to (2001 to 2008) and after environmental water recovery by the Commonwealth (2013 to 2017). This comparison shows that in almost all rivers where consumptive water withdrawals are large relative to inflows, end-of-valley flows have increased following the environmental water recovery program (Figure 11).

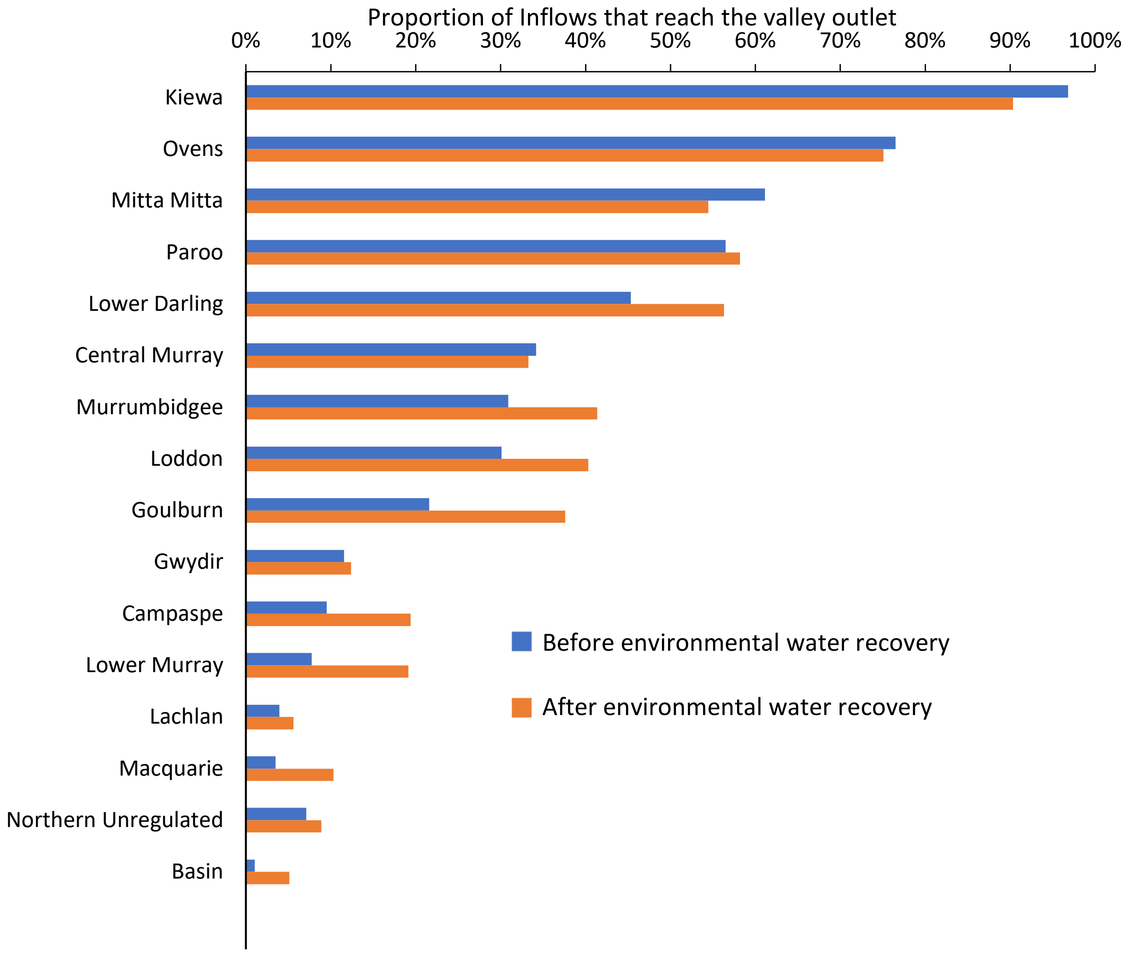


Figure 11. The proportion of mean river flows typically reaching the end of the system in an average year before (2001–2008) and after (2013–2017) Commonwealth environmental water recovery.

Commonwealth environmental water also contributed to connectivity through its effect on the Murray Mouth opening in the first three years of LTIM. 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 first three years of LTIM. In 2015–16, Commonwealth environmental water was the sole contributor to barrage flows, contributing 561 gigalitres. In the absence of Commonwealth environmental water, it is unlikely that there would have been any significant flows over the barrages in 2015–16 and 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. Approximately 802 GL of Commonwealth environmental water was released in 2016–17, which represented 12% of flow through the barrages (Figure 12).

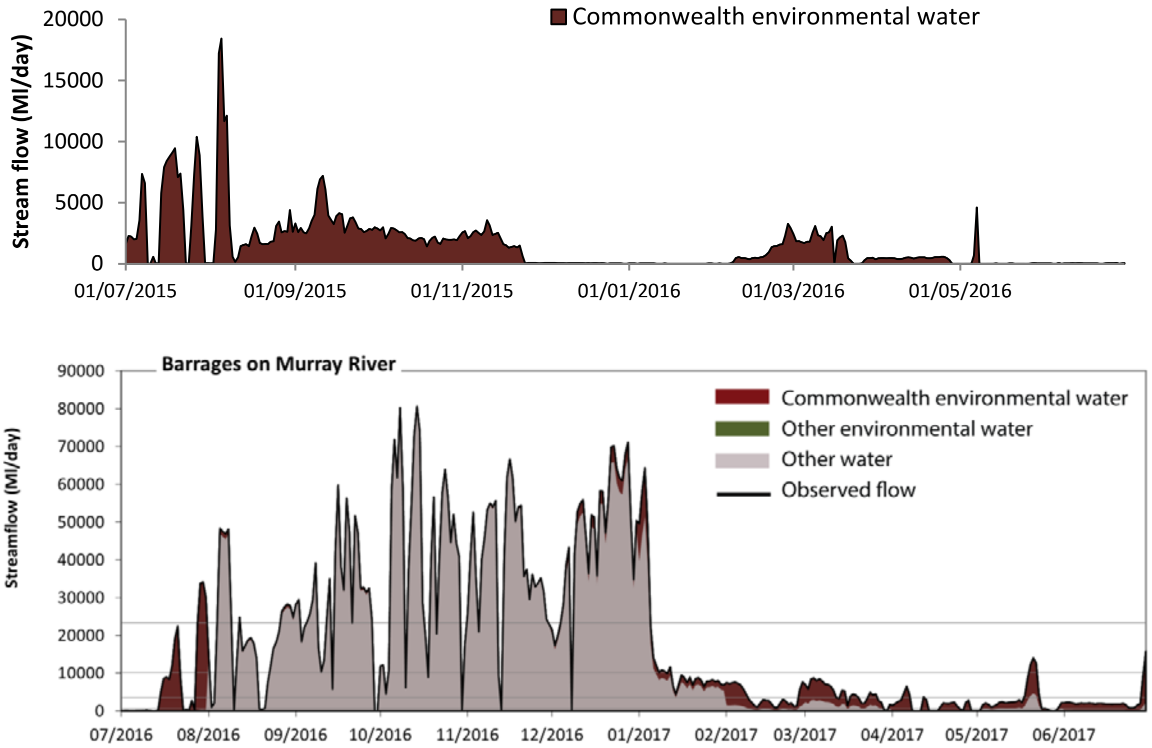


Figure 12. Contribution of Commonwealth environmental water delivery over the barrages in 2015–16 (top) and 2016–17 (bottom). Note that 100% of water flows over the barrages for 2015–16 was contributed by Commonwealth environmental water.

Biological connectivity

Biological connectivity is the movement of biota from one habitat patch to another. It is essential to maintaining several ecological processes in freshwater ecosystems. Longitudinal connectivity (along river networks) is important for dispersal, reproduction and long-term population dynamics in many biota, especially fish (Hermoso *et al.* 2012). Lateral connectivity between rivers and other aquatic habitats (floodplains and wetlands) is important to maintain the exchange of matter and energy and maintain viable populations of many water-dependent species that migrate between the flowing and non-flowing habitats (Koehn *et al.* 2014).

In 2016–17, supporting movement and dispersal of native fish was the primary expected outcome of around one third of the Commonwealth environmental watering actions targeting fish (19 of 58 watering actions). There are several examples that demonstrate the effect of Commonwealth environmental water on biological connectivity in 2016–17:

- Movement of eel-tailed catfish and Murray cod in response to natural flows and environmental water in the Gwydir and Mehi Rivers (Southwell *et al.* 2017b).
- Increases in diversity and abundance of native fish in the connected waterholes of the Lower Warrego River in response to Commonwealth environmental water (Southwell *et al.* 2017).
- Positive effects of "attraction flows" provided by environmental water in the Goulburn River system. Silver perch tagged in the Murray River moved into the Goulburn River in March-April 2017 coinciding with a within-channel environmental flow fresh in the Goulburn River (Webb *et al.* 2017).
- Managed environmental water in autumn 2017 connected the Lower Macquarie to the Barwon River facilitating the upstream movement of golden perch and spangled perch. Monitoring indicated that although the managed flow resulted in movement of native fish, in-channel infrastructure acts as barriers to migration in the lower Macquarie River

downstream of Marebone Weir, limiting the benefits to native fish populations (Davis *et al.* 2017).
- In spring and summer of 2016–17 environmental water, including Commonwealth environmental water, was delivered to complete the nursery function of the Menindee Lakes by dispersing early juvenile golden perch into the LDR, Great Darling Anabranch (GDA) and Murray River populations. Golden perch spawned in the Border Rivers in October 2016, moving downstream into nursery grounds in the Menindee Lakes in late spring. Environmental flows then enabled dispersal of the young golden perch into the lower Darling River and Great Darling anabranch where they made up 50% of the population. It is expected that these young golden perch would then have dispersed into the Murray River demonstrating the effectiveness of environmental water outcomes over large scales and multiple river systems (Sharpe & Stuart 2018).

Stream metabolism

Stream metabolism comprises two ecological processes: primary production (use of light 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, through the movement of organic material:

1. Habitat availability for primary producers and decomposers is strongly influenced by flow, with more habitat being associated with increases in the amount of organic material produced or recycled in the river.
2. Entrainment, in which flow introduces nutrients and organic carbon from external sources to the river or stream, increasing stream metabolism – nutrients and carbon in backwaters, in-channel benches, wetlands and floodplains move into stream channels with inundation.
3. Mixing or resuspending material within the river or stream – organic material may be stored in parts of the stream where they are not readily available (e.g. in the sediment, in a backwater or low flow area, in the bottom water of stratified pools). Increasing flows may mobilise these organic material stores and increase rates of stream metabolism.
4. Disturbance or scour of biofilms – biofilms comprise algae, fungi and bacteria on sediments and plants in the river and can contribute significantly to stream metabolism. Very high flows can scour these biofilms, reducing stream metabolism rates temporarily until the biofilms 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). There has been a general assumption that large out of channel flows that inundate the floodplain and mobilise terrestrial carbon are required to see any effect on primary production and stream metabolism. The evaluation of stream metabolism data collected over the first three years of LTIM, however, has indicated that these in-channel flows can have a positive effect on both carbon production and consumption. There is a clear increase in carbon consumption (and to a lesser extent production) in the southern Basin Selected Areas, with an increase in flows from very low base flows to high freshes (Figure 13).

While there is currently insufficient data to determine the quantitative contribution of Commonwealth environmental water to stream metabolism it is becoming clear that increases in in-channel flow, result in increased stream metabolism.

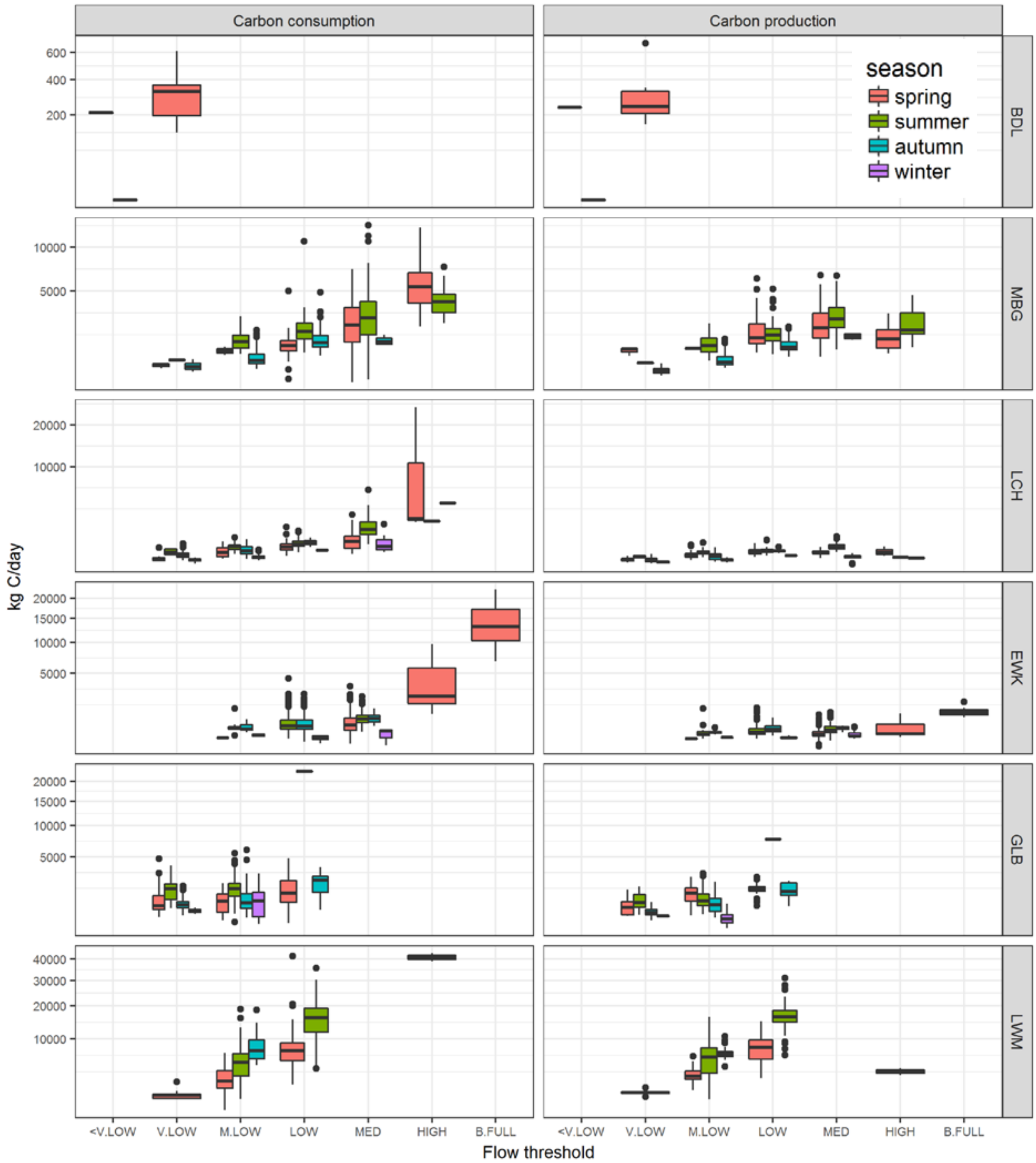


Figure 13. Relationship between flow category (as per Figure 7) and organic carbon production and consumption 2014–17 in the Selected Areas. LWM = Lower Murray, GLB = Goulburn, EWK = Edward-Wakool, LCH = Lachlan, MBG = Murrumbidgee, BDL = (Barwon) Darling. See Appendix C for more detail.

3.3 Resilience

Basin-scale resilience outcomes

- Contributions to resilience were made through both ecosystem diversity and hydrological connectivity.
- The 2016–17 natural floods resulted in decreased dissolved oxygen in a number of Selected Areas, which negatively impacted fish populations, particularly of Murray cod. Although the volumes of environmental water that can be delivered are unlikely to strongly influence the duration and severity of hypoxic events at large scales, it is possible, that enhancing the survival of even very small numbers of Murray cod locally would enhance the resilience of the Murray cod population within the Basin.
- Commonwealth environmental is contributing to improved resilience of waterbirds by supporting substantial (> 1%) of the total population of at least ten 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.

Contributions of Commonwealth environmental water to maintaining ecosystem diversity and hydrological connectivity have been considered under sections 3.1.2 and 3.2.2, respectively. Contributions of Commonwealth environmental water to protecting refuge habitat and maintaining condition of biota in 2014–17 are summarised below.

3.3.1 Protecting refuge habitat

The large natural floods in 2016–17 that occurred in several southern Basin river systems, resulted in incidences of low dissolved oxygen. This occurred where the inundation of dry floodplains resulted in the movement of terrestrial carbon (from leaf litter and other organic matter) into the river system. This boost in carbon rapidly increases bacterial respiration, resulting in a reduction in dissolved oxygen (hypoxia). This can have profound effects on animals that rely on dissolved oxygen to breath, particularly fish. Evaluation of fish community data across Selected Areas and the first three years of LTIM indicated significant shifts in community composition within Selected Areas where hypoxia was observed. This change in composition was not consistent across Selected Areas with the exception of two species (see Appendix F for further details):

- common carp abundance increased in response to flooding, and
- Murray cod abundance decreased by 77% in the Lachlan, 96% in the Edward-Wakool and 56% in the Murrumbidgee.

These two results are consistent with our current knowledge on these two species. Carp are known to be very resistant to environmental hypoxia, having several traits that likely facilitated survival of the large-scale hypoxic flows observed during 2016–17 (Lomholt & Johansen 1979; Zhou *et al.* 2000; Stecyk & Farrell 2006) and are also known to spawn on floodplains during floods (Koehn 2004). Therefore, flooding alone, irrespective of hypoxia, can provide enhanced spawning and recruitment opportunities for carp.

In contrast, Murray cod are known to be susceptible to relatively mild environmental hypoxia (King *et al.* 2012; Small *et al.* 2014), and the reduction in Murray cod abundance observed following the 2016 floods is a consequence of mortality. This result is corroborated by the many observations of Murray cod deaths throughout the Basin during the hypoxic floods.

Given the magnitude of the flood event, volumes of environmental water that can be delivered are likely too small to ameliorate the effects of hypoxia at large scales or for long periods of time. There are also the difficulties of being able to deliver water to the places that are experiencing hypoxia in time to prevent fish deaths, as evidenced by results in the Edward-Wakoool, where environmental water was generally too late to protect the majority of fish (Watts *et al.* 2017). There was evidence, however, from the Lower Murray and Murrumbidgee, where Commonwealth environmental water contributed to maintaining or restoring dissolved oxygen levels above 4 mg/L, potentially providing refuge areas for aquatic organisms including native fish (Wassens *et al.* 2017; Ye *et al.* 2017). Given the magnitude of reductions in Murray cod abundance (up to 96% loss), it is possible that enhancing the survival of even very small numbers of Murray cod locally would enhance the resilience of the Murray cod population within the Basin.

3.3.2 Contributing to resilience through maintaining ecosystems and populations

Over the first three years of LTIM, Commonwealth environmental water has contributed to the inundation of large areas of wetland habitat (Figure 14). 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.

Data to assess the potential effect of Commonwealth environmental water on this large number of ecosystems is limited. We can infer from vegetation mapping and an understanding of the water requirements of inundation dependent species that many vegetation communities and species would have benefited from Commonwealth environmental water, particularly in the first two years of LTIM when conditions were dry. In addition, we can use complementary data to infer outcomes for waterbirds.

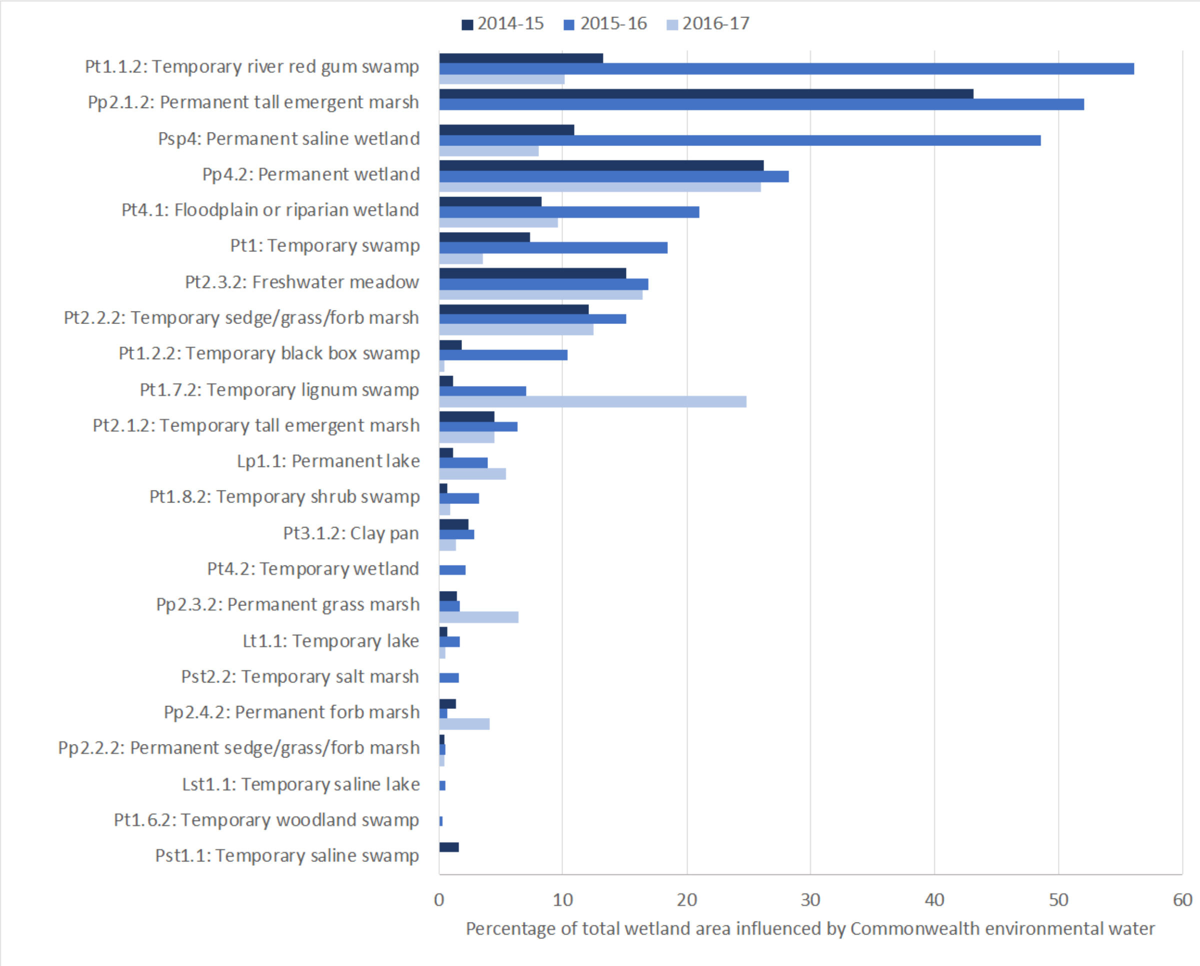


Figure 14. The proportion of the mapped extent of wetland types influenced by Commonwealth environmental water 2014–17 (See Appendix C for more detail).

Although not all of these areas have been monitored, the MDBA Aerial Waterbird Surveys cover the major wetlands in the Basin each year. The total waterbirds at sites that received Commonwealth environmental water in the first three years of LTIM indicates that substantial numbers of waterbirds potentially benefited (Figure 15). It should be noted that the number of waterbirds at sites that received Commonwealth environmental water is likely to be higher for several reasons. Firstly, the aerial survey method under represents certain small and cryptic species that are difficult to see from the air. Secondly, not all sites that received water were monitored by the MDBA program. Finally, the timing of the monitoring may not have coincided with peak abundance. Nevertheless, a total of 370 000 waterbirds have been recorded at sites that received Commonwealth environmental water over the past three years (data from MDBA).

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 several waterbird species (Table 7). By supporting significant proportions of the population of a species, Commonwealth environmental water is contributing to improved resilience at a population scale.

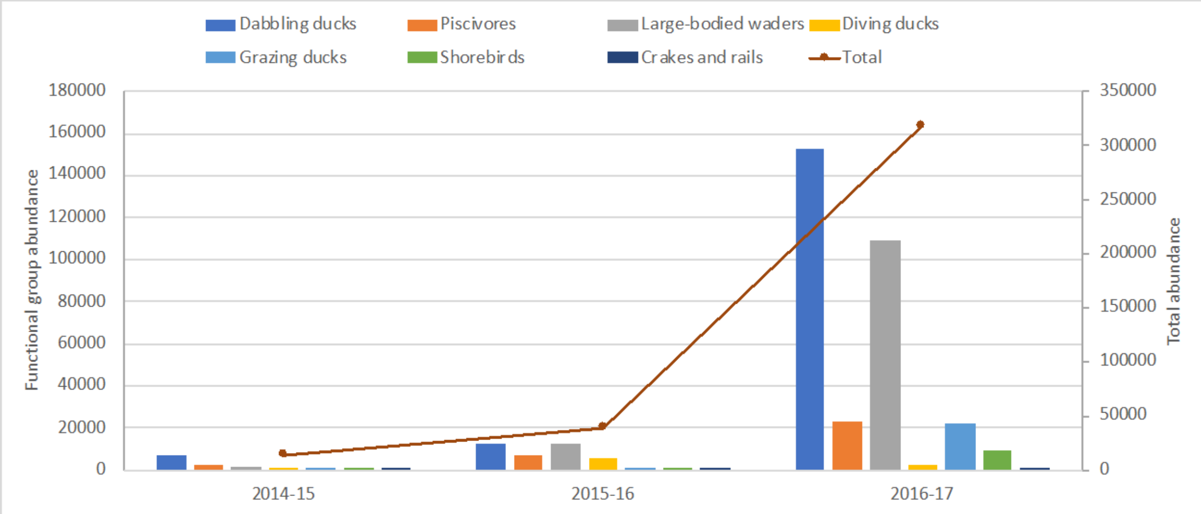


Figure 15. Total abundance of waterbirds from sites that received Commonwealth environmental water (source MDBA Aerial Waterbird Survey (data provided by MDBA).

Table 7. 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 breeding colonies from Selected Area monitoring added).

Species	1% of the population*	Total abundance from multiple sites		
		2014–15	2015–16	2016–17
Australian pelican	1400		4051	13 191
Australian wood duck	10 000			17 658
Banded lapwing	1000			1984
Black-winged stilt	1750			5043
Eastern great egret	1000			2295
Grey teal	20 000			138 795
Straw-necked ibis	10 000			74 725
White-faced heron	1000			2338
White-necked heron	250		302	792
Yellow-billed spoonbill	250	436	2480	

* Population estimates from Wetlands International (2012).

4 Adaptive management

Key adaptive management messages

- A dynamic mosaic of wetting and drying promotes biodiversity
    - Inundation 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.
- Inundation history is an important input to environmental water planning
    - Understanding the water requirements and inundation history of aquatic ecosystems will help to deliver improved diversity at the Basin scale.
- Delivery of water in-channel can, to a certain extent, stimulate productivity.
- Basin scale connectivity is important for native fish
    - Environmental water can be used to facilitate movement of native fish between river systems.
- The 2016–17 floods in the southern Basin have improved our understanding of hypoxia
    - Commonwealth environmental water successfully increased dissolved oxygen concentrations in some river reaches
    - Recommendations for improved planning and water delivery have been identified.
- Timing of flow delivery for fish is important.
    - Flows delivered in spring and summer have the greatest positive impact on golden perch and Murray cod condition.
    - Preliminary results suggest that higher flows in autumn may negatively impact Murray cod (further investigation is warranted)
- When making flow decisions in any given year, flows delivered in the current year may affect how golden perch condition responds to flows in the subsequent year.
    - prioritisation could be given to delivering spring freshes for golden perch in years following above average median flows.

In this first three 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 2016–17 Selected Area Reports

4.1 A dynamic mosaic of wetting and drying promotes biodiversity

At both the wetland and landscape scales, variability in water regime is important for maintaining (and restoring) biodiversity. In the first three 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 histories at multiple scales, and *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 function 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 Inundation history is an important input to environmental water planning

Water regime, the frequency and duration of wetting and drying, is an important driver of wetland ecology and the single biggest determinant of wetland type and vegetation community composition (Roberts & Marston 2011; Webb *et al.* 2012). Inundation dependent plant species and vegetation communities have water regime optimums and tolerances (Brock & Casanova 1997). Too much water, too frequently or consistently missing particular ecosystems types are all scenarios that are potentially deleterious to biodiversity in the Basin. To this end reducing the risk of implementing inappropriate watering regimes is an important consideration in planning for environmental water at small and large spatial scales.

This means not only understanding the inundation history of aquatic ecosystems that are the target of environmental water, but also the water requirements of those systems. Improving understanding of watering requirements at the aquatic ecosystem level should complement and enhance existing approaches that focus on the requirements of key species or communities. Through LTIM, we are assembling a library of Basin wide watering frequencies from Commonwealth environmental water. Ecosystems types (and locations) that are consistently not watered, or watered with too much regularity, can then be identified and an informed assessment of risks can then take place to determine if there is a need and capability to adjust management planning to ensure Basin Plan objectives are met.

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

While out of channel flows result in massively increased rates of ecosystem productivity, there is now evidence that delivering even small increases in flow can introduce more organic carbon into the river and 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 Basin scale connectivity is important for native fish

The movement of native fish between ecosystems is important for sustaining populations in the Basin. For example, it seems likely that the largest recruitment events of golden perch in the Basin are driven by the arrival of juveniles from local nursery grounds rather than from local spawning, with up to 80% of the golden perch in the lower Murry and 60% in the upper Murray being dispersed through the lower Darling (Zampatti *et al.* 2015).

Commonwealth environmental water contributed to several important watering actions aimed at improving large scale connectivity for native fish in 2016–17. The successful movement of fish between river systems (e.g. Murray to Goulburn, Barwon to Macquarie, Menindee Lakes to the lower Darling and Murray River) illustrates the effectiveness of environmental water in improving biological connectivity.

Our understanding of the role that environmental water can play in this important function is currently limited and warrants further investigation. In addition, the impacts on non-flow factors such as instream barriers must be considered when planning to deliver flows for fish movement.

4.5 The 2016–17 floods in the southern Basin have improved our understanding of hypoxia

The natural floods of 2016–17, resulted in low dissolved oxygen in several river systems. While there were examples from some Selected Areas such as the Lower Murray and Murrumbidgee of Commonwealth environmental water successfully improving dissolved oxygen concentrations during and following natural floodplain inundation, the impacts of low dissolved oxygen events were still evident. There were large scale fish deaths, particularly of Murray cod and a reduction in spawning and recruitment attributed to hypoxia in 2016–17.

There were recommendations in several 2016–17 Selected Area reports with respect to improved environmental water management to ameliorate the effects of hypoxia as a result of natural floods. This included the need for real time dissolved oxygen data at key locations and a clear agreed decision process to facilitate implementation of watering actions in a timely manner. A review on the effects of blackwater in the Basin, commissioned by CEWO also recommended the development of a Blackwater Response Plan for the southern Basin that clearly articulates the prioritisation of management interventions where hypoxic conditions may develop (CEWO 2017).

This review, as well as several Selected Area reports and the Fish Basin Matter Report (see Appendix F) recommended exploring novel pro-active approaches to reducing the risk of hypoxia. This could include consideration of more frequent overbank inundation to reduce carbon and nutrient loads on dry floodplains.

Results from the modelling thus far suggest that relatively small changes in the number of hypoxic days can have strong and significant effects on the fish community outcomes. Thus, even if we cannot avoid hypoxic events altogether, if such events occur small reductions in the number of hypoxic days can have very large positive biodiversity outcomes for the Basin.

4.6 Flows delivered in spring and summer may achieve the best ecological outcomes for native fish

The preliminary results of fish population modelling indicate that improved condition of golden perch and Murray cod is achieved with the delivery of freshes in spring and summer. This is consistent with results of monitoring in Selected Areas which identified the spring timing of flows and increasing water temperatures as important for successful spawning and recruitment of golden perch and silver perch (Webb *et al.* 2017; Ye *et al.* 2017). With respect to flow management within the Basin, this result implies that delivery of environmental water in spring may not just be good for spawning of species cued by spring-summer pulses (like golden perch and silver perch), but also good for condition of large-bodied fishes more generally. Even the condition of species like Murray cod, whose spawning is not dependent on spring flow pulses, responds positively to spring pulses. It follows that delivery of spring flows may be a 'win-win', since it may enhance several population processes of native fishes, as well as certain food web processes that fish are dependent on.

The population model also suggested, with low confidence, that autumn flow pulses may decrease Murray cod condition. We have not identified how or why this may occur and this observation requires further investigation. Nevertheless, it may have implications for environmental flow releases delivered for other purposes, as well as for autumn irrigation flows.

4.7 Golden perch outcomes may be maximised with multi-year strategies

Population model results suggest that the condition of golden perch is not only improved with spring freshes, but also when there were higher median flows in the previous year. This suggests that delivering spring freshes to improve golden perch populations could be prioritised for years following naturally high inundation. That is when there is an above average median discharge in one year, environmental watering could target spring freshes in the following year to maximise ecological outcomes.

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 2014–17, 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 4).

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 8. Contribution of Commonwealth Environmental Water Office (CEWO) watering in 2014–17 to Basin Plan objectives.

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2016–17	Measured and predicted 1–3- year outcomes 2014–17
Biodiversity (Basin Plan S. 8.05)	Ecosystem diversity		None identified	None identified	More than 77 500 ha of lakes and wetlands, 14 000 ha of floodplains and 21 000 km of rivers in the Basin upstream of the Lower Lakes were supported by Commonwealth environmental water. 51% of the wetland types and 83% of floodplain types inundated.	72% of the different aquatic ecosystem types inundated with Commonwealth environmental water.
	Species diversity	Vegetation	Vegetation diversity		Increase in plant species diversity with inundation by Commonwealth environmental water.	Presence of some native species likely to be dependent on inundation by Commonwealth environmental water. Decrease in exotic taxa.
				Reproduction		
				Condition		
			Growth and survival	Germination Dispersal	Increased total cover and dominance of inundated vegetation communities and mostly higher species richness (though highly dependent on a range of intrinsic and extrinsic factors).	Greater vegetation cover in plots/transects subjected to at least some wetting during this period.
		Macro-invertebrates	Macroinvertebrate diversity			
		Fish	Fish diversity	Condition		Improved condition in golden perch and Murray cod with environmental water.
				Larval abundance Reproduction	Spawning and recruitment of native fish in response to Commonwealth environmental water in Gunbower Creek, the Dumaresq-Macintyre River, the Lower Warrego River and the Lower Darling River.	Spawning by a range of species facilitated by environmental water across the first three years of LTIM.
			Larval and juvenile recruitment			Clear evidence of recruitment of golden perch in the lower Darling
		Waterbirds	Waterbird diversity		High diversity of waterbirds recorded at sites that received Commonwealth environmental water	Different foraging habitats provided for the full range of waterbird guilds across the three years. 74 species of wetland dependent bird have been recorded at sites

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2016–17	Measured and predicted 1–3- year outcomes 2014–17
						that received Commonwealth environmental water.
			Waterbird diversity and population condition (abundance and population structure)	Survival and condition		Over the first three LTIM years over 1% of the population of 10 water bird species have been supported by Commonwealth environmental water.
				Chicks	Large scale breeding of both colonial nesting species and waterfowl in 2016–17, with 10,000s nests recorded.	Small scale breeding recorded in the first two LTIM years, but the extended duration of inundation by Commonwealth environmental water in 2016–17 contributed to success of colonial nesting events.
				Fledglings	Fledgling recorded in nesting birds at Macquarie Marshes, Lachlan, Murrumbidgee.	Fledgling recorded in nesting birds at Macquarie Marshes, Lachlan, Murrumbidgee, Hattah Lakes in the first three years of LTIM
		Other vertebrate diversity		Young	Frogs recorded breeding at several Selected Areas in response to Commonwealth environmental water.	Breeding of frogs at several locations across the three years, including of southern bell frog in the Murrumbidgee.
			Adult abundance		Twelve species of frog recorded in 2016–17 at sites that received Commonwealth environmental water.	A total of 14 species of frogs recorded at sites that received Commonwealth environmental water over the three years.
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	Evidence of large scale fish movement facilitated by Commonwealth environmental water in the Macquarie-Barwon, Lower Darling, Menindee Lakes and Murray and between the Murray and Goulburn Rivers.	Evidence of longitudinal fish movement in the several river system and lateral movement at Hattah Lakes and the Menindee Lakes.
				Sediment transport		

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2016–17	Measured and predicted 1–3- year outcomes 2014–17
	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		
Resilience (Basin Plan S. 8.07)	Ecosystem resilience		Population condition (individual refuges)	Individual survival and condition (individual refuges)	Refuges in the Warrego and Gwydir were maintained/improved by Commonwealth environmental water.	A number of permanent wetlands inundated with environmental water over the 3 years. Refuges maintained in the first two LTIM years in what would have otherwise been dry landscapes
			Population condition (landscape refuges)			
				Individual condition (ecosystem resistance)		
			Population condition (ecosystem recovery)			Over the first three LTIM years over 1% of the population of 10 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. During the 2016–17 flood events	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 – 2016–17 Commonwealth environmental watering actions

Table A1. Watering actions that included Commonwealth environmental water in 2016–17. 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	111-40	9446	01/07/16 - 15/08/16	Fresh							S	P	S
Barwon Darling: Barwon-Darling River and fringing wetlands	111-40	3631	20/08/16 - 31/08/16	Fresh							S	P	S
Barwon Darling: Barwon-Darling River and fringing wetlands	111-40	13719	13/09/16 - 01/10/16	Fresh							S	P	S
Border Rivers - Severn River	111-33	823.53	01/07/16 - 30/06/17	Bankfull	P	S						P	
Border Rivers - Dumaresq-Macintyre River and Fringing Wetlands	111-34	914.3	07/07/16 - 13/07/16	Fresh	P								
Border Rivers - Dumaresq-Macintyre River and Fringing Wetlands	111-34	14376.8	25/08/16 - 25/10/16	Bankfull	P						S		
Border Rivers - Dumaresq-Macintyre River and Fringing Wetlands	111-34	6492.1	20/03/17 - 03/04/17	Bankfull	P								
Border Rivers - Macintyre Brook and fringing wetlands	111-99	919.23	19/09/16 - 04/10/16 30/04/17 - 04/04/17	Fresh	S				S	S		S	
Border Rivers - Lower Moonie River and fringing wetlands	111-35	1415	25/08/16 - 24/09/16	Fresh	P				P	S		S	
Broken - Lower Broken Creek	10041-03	11893	29/10/16 - 31/12/16	Base flow	P								
Broken - Lower Broken Creek	10041-03	18691	01/01/17 - 31/05/17	Base flow									P
Broken - Lower Broken Creek	10041-03	783	01/06/17 - 30/06/17	Base flow	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: Coorong, Lower Lakes and Murray Mouth	10050-02	618476	01/06/16 - 30/06/17	Fresh, base flow	P	S	S			S	S		S
Central Murray: Barmah-Millewa Forest	10050-01	39170	22/06/16 - 31/12/16	Overbank	S	S					S		
Central Murray: Murray River	10050-01	124754	01/01/17 - 30/06/17	Fresh	S	S					S		
Central Murray - Gunbower Creek	10030-02	23563	01/07/16 - 30/06/17	Base flow	P					P	P		P
Condamine: Lower Balonne floodplain system	111-37	28869.6	21/09/16 - 03/10/16	Bankfull	S	P	P						
Condamine: Lower Balonne floodplain system	111-37	16892.2	06/04/17 - 16/04/17	Fresh						P		S	
Edward Wakool: Wakool River	10054-03	29306.63	31/10/16 - 31/12/17	Fresh	P								P
Edward Wakool: Edward River	10054-04	74822.7	24/10/16 - 08/12/16	Fresh	P								P
Edward Wakool: Colligen-Neimur	10054-05	3240.67	17/10/16 - 16/12/17	Fresh	P								P
Edward Wakool: Colligen-Neimur	10054-06	21542	01/01/17 - 30/06/17	Base flow	S	P							
Edward Wakool: Wakool River	10054-07	2770	01/01/17 - 30/06/17	Base flow		P							
Edward Wakool: Yallakool Creek	10054-08	27581	01/01/17 - 30/03/17	Fresh	P	P							
Edward Wakool: Merran Creek	10054-09	1107	16/02/17 - 28/03/17	Base flow	P								
Edward Wakool: Tuppal Creek	10054-10	1320	30/03/17 - 15/05/17	Base flow		P				P			P
Goulburn - Lower Goulburn River	10051-01	9250	01/07/16 - 05/08/16	Base flow	P				P				S
Goulburn - Lower Goulburn River	10051-01	8200	02/11/16 - 09/01/17	Base flow	P				P				S
Goulburn - Lower Goulburn River	10051-01	64290	01/03/17 - 03/04/17	Fresh	S	P			S		P		
Goulburn - Lower Goulburn River	10051-01	39585	04/04/17 - 25/06/17	Base flow	S	P			S		P		
Goulburn - Lower Goulburn River	10051-01	21119	26/06/17 - 26/06/17	Fresh		P					P		
Gwydir - Gwydir Wetlands	100057-01	9000	27/12/16 - 28/02/17	Wetland	S	P	S		S	S	S	S	
Gwydir - Mallowa Wetlands	100057-02	7496	13/01/17 - 01/04/17	Wetland		S	S	S	S	P			
Gwydir - Carole Creek	100057-03	1351	15/09/16 - 21/09/16	Base flow						S	P		S
Gwydir - Mehi River	100057-04	5000	17/09/16 - 21/09/16	Fresh						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
Lachlan - Lachlan River	10053-02	28168	04/11/16 - 02/01/17	Fresh									P
Lachlan - Booligal Wetlands	10053-02	1324	09/01/17 - 17/03/17	Wetland			P						
Lower Darling- Lower Darling River	10059-01	71248.6	02/10/16 - 08/01/17 24/04/17 - 30/06/17	Fresh, base flow	P	S				S			S
Lower Darling- Great Darling Anabranch	10059-01	89204	16/02/17 - 30/06/17	Fresh	P	S	S	S		P			S
Loddon- Loddon River		479	18/04/17 - 30/04/17	Base flow	S				S	P			
Loddon- Loddon River		1100	13/05/17 - 30/05/17	Fresh		P			S				
Lower Murray - Calperum Station	10050-03	1276.74	01/06/16 - 01/06/17	Wetland		S	S	S					
Lower Murray - Pike River complex	10050-03	5.35	01/11/16 - 01/06/17	Wetland		S	S	S					
Lower Murray - Loxton Riverfront Reserve	10050-03	32.33	01/04/17 - 01/06/17	Wetland		S	S	S					
Lower Murray - Rillis Lagoons	10050-03	35.43	01/04/17 - 01/06/17	Wetland		S	S	S					
Lower Murray - Kroehn’s Landing	10050-03	2.59	01/06/17 - 30/06/17	Wetland		S	S	S					
Lower Murray - Thieles Lagoon	10050-03	11.19	01/04/17 - 01/06/17	Wetland		S	S	S					
Lower Murray - Ramco River Terrace	10050-03	2.71	01/05/16 - 01/06/17	Wetland		S	S	S					
Lower Murray - Gurra Gurra-Lyrup Lagoon	10050-03	110.54	01/04/17 - 01/06/17	Wetland		S	S	S					
Lower Murray - Riversleigh Lagoon	10050-03	180.01	01/04/17 - 01/06/17	Wetland		S	S	S					
Lower Murray - Berri Evaporation Basin	10050-04	707	01/01/17 - 30/06/17	Wetland	P								
Lower Murray - Bookmark Creek	10050-04	239	01/01/17 - 30/06/17	Wetland		P	P						
Lower Murray - Rufus River	10050-06	29570	17/12/16 - 01/01/17	Fresh	P	P					P		
Lower Murray - Lock 15	10050-01	0	04/07/16 - 28/07/16	Fresh	S	P	S			P	S		
Lower Murray - Lock 15	10050-01	0	19/03/17 - 09/05/17	Fresh	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 - Lock 9	10050-01	0	15/07/16 - 30/12/16	Fresh	S	P					S		
Lower Murray - Lock 9	10050-01	0	30/04/17 - 30/06/17	Fresh	S	P					S		
Lower Murray - Lock 8	10050-01	0	20/7/16 - 14/10/16	Fresh	S	P	S				S		
Lower Murray - Lock 8	10050-01	0	26/01/17 - 23/05/17 12/06/17 - 30/06/17	Fresh	S	P					S		
Lower Murray - Lock 7	10050-01	0	01/08/16 - 01/01/17 01/02/17 01/03/17	Fresh	S	P	S				S		
Lower Murray - Lock 7	10050-01	0	01/05/17 - 01/06/17	Fresh	S	P					S		
Lower Murray - Lock 5	10050-02	0	01/07/16 - 01/10/16	Fresh	S	P	S				S		
Lower Murray - Lock 2	10050-02	0	01/07/16 - 01/10/16	Fresh	S	P	S				S		
Murrumbidgee - Murrumbidgee River	10052-02	150978	28/10/16 - 05/01/17	Fresh, bankfull	P						P		P
Murrumbidgee - Yanco-Billabong-Forest Creek system: Wanganella Swamp	10052-03	5000	19/11/16 - 04/01/17	Wetland	S	S	P						S
Murrumbidgee - Nimmie-Caira: Eulimbah	10052-05	2320	28/11/16 - 03/03/17	Wetland	S	S	P						S
Murrumbidgee - Nimmie-Caira: Telephone Bank	10052-06	5425	24/11/16 - 20/03/17	Wetland	S	S	P						S
Murrumbidgee - Yanga National Park	10052-08	2155	29/10/16 - 13/02/17	Wetland	S	S	P						S
Murrumbidgee - North Redbank: Tori Lignum Swamp	10052-09	844	27/10/16 - 13/02/17	Wetland	S	S	P						S
Murrumbidgee - Toogimbie IPA Wetlands	10052-10	998	18/3/17 - 04/04/17 07/05/17 - 24/06/17	Wetland	S	P	S	S	S			P	
Murrumbidgee - Nimmie-Caira: Nap Nap	10052-11	630	03/01/17 - 07/01/17	Wetland	S	S	P						S
Murrumbidgee - Nimmie-Caira: Is-Y-Coed (Kieeta and Kia Lakes)	10052-12	5000	10/02/17 - 20/03/17	Wetland	S	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
Murrumbidgee - Lower Murrumbidgee River	10052-13	47548	01/04/17 - 20/04/17	Fresh	P	S				S	S		S
Murrumbidgee - Lower Murrumbidgee Floodplain	10034-09	15507	04/08/16 - 03/09/16	Wetland	S	S	S	S	S				
Murrumbidgee - Western Lakes	10034-10	5060	07/11/16 - 19/12/16	Wetland		S	S						
Macquarie - Macquarie Marshes	10055-01	17039	24/01/17 - 18/02/17	Wetland	S	S	P				S		
Macquarie - Mid-Macquariue River and Macquarie Marshes	10055-02	2648	04/04/17 - 12/04/17	Fresh	P								
Macquarie - Lower Macquarie River	10055-03	27583	16/04/17 - 15/05/17	Fresh	P	S	S			S			
Macquarie - Macquarie Marshes	10032-02	3000	24/07/16 - 30/07/16	Wetland		P				S			
Macquarie - Macquarie Marshes	10032-02	3500	06/09/16 - 13/09/16	Wetland		P				S			
Macquarie - Macquarie Marshes	10032-02	750	19/12/16 - 21/12/16	Wetland	S	S	P			S			
Namoi - Lower Namoi River	10056-01	7852	28/02/17 - 20/05/17	Base flow	P	S			S	S			
Namoi - Peel River	10063-01	1257	04/06/17 - 30/06/17	Fresh	P						S		
Ovens: Ovens River	10004-03	20	15/02/17 - 23/02/17	Fresh						P			
Ovens: Ovens River	10004-03	50	12/03/17 - 13/03/17	Base flow						P			
Warrego: Upper Warrego River and fringing wetlands.	111-38	795	19/09/16 - 29/09/16	Fresh						S		S	
Warrego: Lower Warrego River and fringing wetlands.	111-39	1912.96	01/07/16 - 07/07/16	Fresh						S		S	
Warrego: Lower Warrego River and fringing wetlands.	111-39	601.99	31/07/16 - 02/08/16	Fresh						S		S	
Warrego: Lower Warrego River and fringing wetlands.	111-39	340.01	06/09/16 - 07/09/16	Fresh						S		S	
Warrego: Lower Warrego River and fringing wetlands.	111-39	5865	23/09/16 - 10/10/16	Bankfull	S					S		S	
Warrego: Lower Warrego River and fringing wetlands.	152-07	7762.5	08/10/16 - 28/10/16	Fresh	P					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
Warrego: Toorale Western Floodplain	152-08	5023	19/07/16 - 12/09/16	Wetland		P	P						
Warrego: Toorale Western Floodplain	152-08	4697	12/09/16 - 20/09/16	Wetland		P	P						

Appendix B – 2016–17 Basin-scale evaluation of Commonwealth environmental water – Hydrology report

Appendix C – 2016–17 Basin-scale evaluation of Commonwealth environmental water – Stream Metabolism & Water Quality report

Appendix D – 2016–17 Basin-scale evaluation of Commonwealth environmental water – Ecosystem Diversity report

Appendix E – 2016–17 Basin-scale evaluation of Commonwealth environmental water – Vegetation Diversity report

Appendix F – 2016–17 Basin-scale evaluation of Commonwealth environmental water – Fish report

Appendix G – 2016–17 Basin-scale evaluation of Commonwealth environmental water – Biodiversity report