2015–16 Basin-scale evaluation of Commonwealth environmental water – Synthesis Report

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Final Report

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2015–16 Basin-scale evaluation of Commonwealth environmental water – Synthesis Report

Final Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre.

This report was prepared by The Murray–Darling Freshwater Research Centre (MDFRC). The aim of the MDFRC is to provide the scientific knowledge necessary for the management and sustained utilisation of the Murray–Darling Basin water resources. The MDFRC is a joint venture between La Trobe University and CSIRO. Additional investment is provided through the University of Canberra.

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The Murray–Darling Freshwater Research Centre 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 Murray–Darling 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.

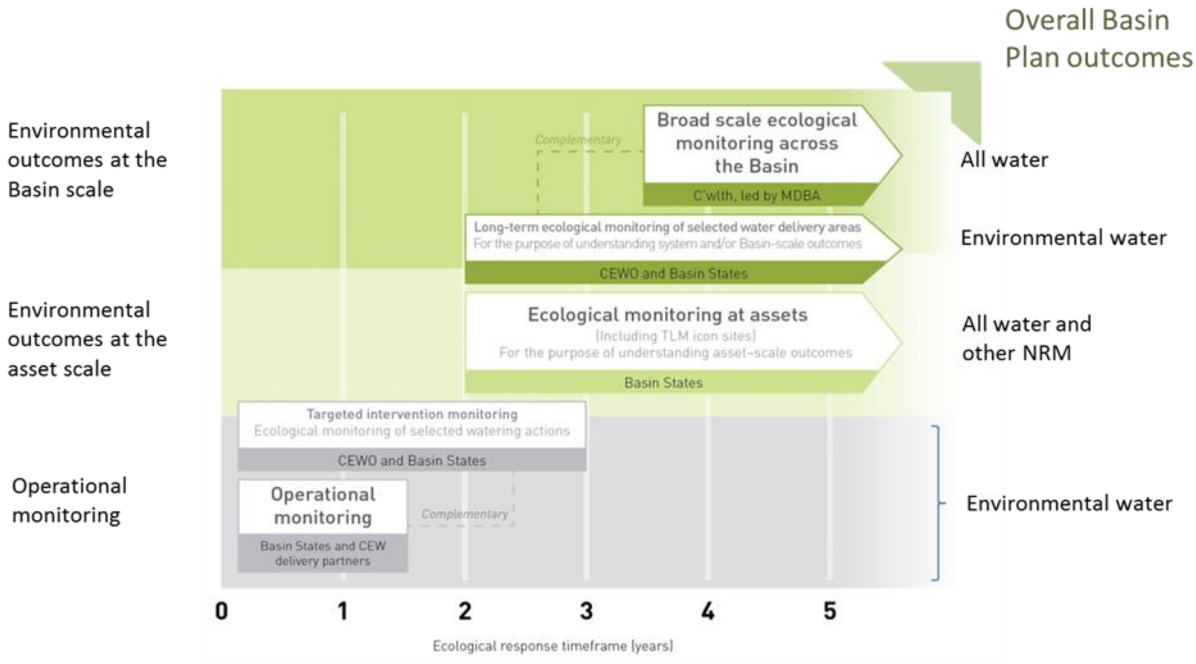

Figure 1. Monitoring and evaluation reporting obligations (Source: Commonwealth Environmental Water Office).

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 is reporting obligations and demonstrate both value for money from the Australian Government's investment and support adaptive environmental flow management over time.

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

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

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

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

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

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

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

The Basin-wide 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 Commonwealth Environmental Water Office (CEWO) Long Term Intervention Monitoring (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.

LTIM Project Selected Areas were chosen to be representative of areas where environmental flows will occur; to complement but not duplicate areas where other monitoring activities are undertaken; to be in catchments where 90% of Commonwealth environmental water entitlements are held; and which enable results to be used to infer outcomes at areas not monitored with:

- the support of dose–response models that will be progressively improved over time
- an understanding of the existing science and knowledge of how ecosystems respond to changes in hydrological parameters
- modelling of with and without environmental water hydrological scenarios.

[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

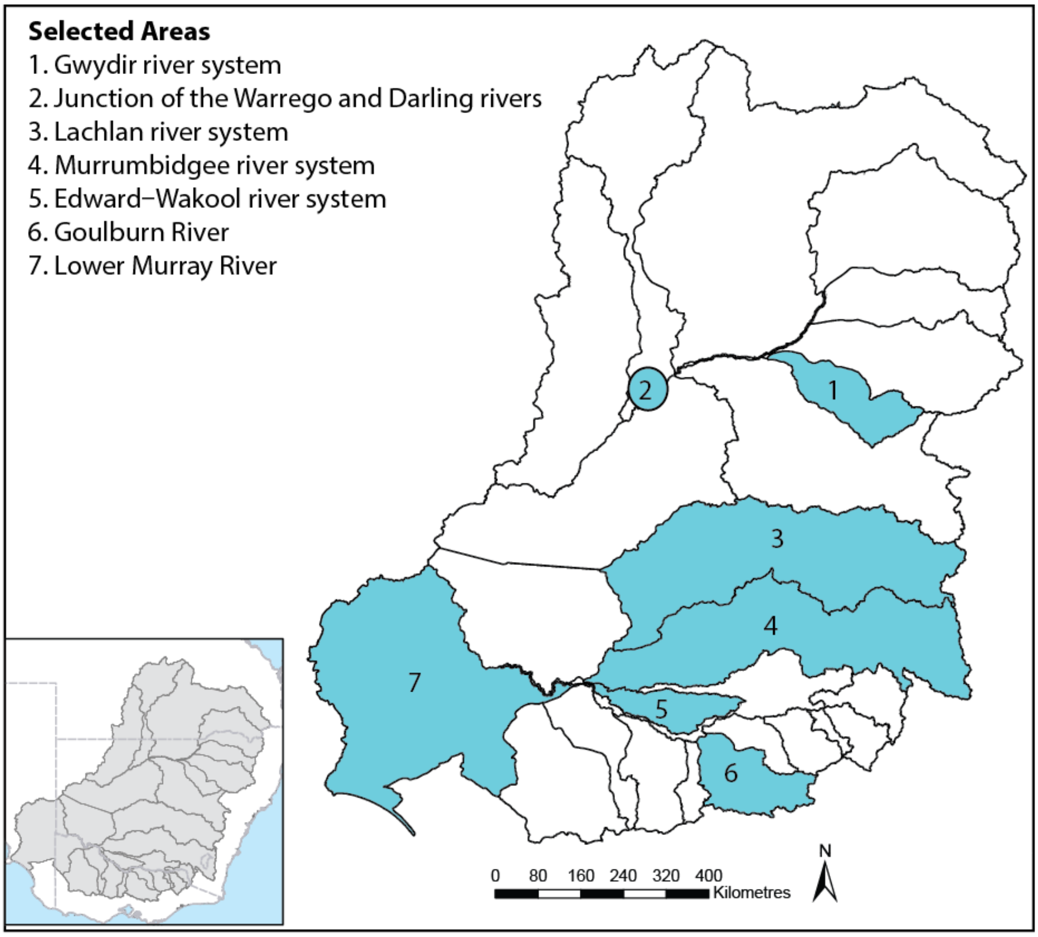

Figure 2. General location of the seven Selected Areas where the LTIM Project is measuring the effects of Commonwealth environmental water.

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.

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 2 years of the LTIM Project (2014–16), with a focus on the outcomes from Year 2 (2015–16) and cumulative outcomes from 2014–16. Outcomes from the first year (2014–15) are synthesised in Gawne *et al.* (2016).

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

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
- **generic diversity** – effects on diversity of all biota from monitoring and observations.

Standard methods have been adopted for these Basin Matters to allow for integration and analysis of data across Selected Areas. Over the course of the 5 years of the LTIM Project, this will provide a unique opportunity for evaluation of environmental watering at a large spatial scale and, in many respects, represents a world first in intervention monitoring.

The general approach is based on a conceptual understanding of how water regimes affect aquatic ecosystems and the communities and species that depend on them. This conceptual understanding represents the current state of knowledge, but the evaluation process is designed to both generate and incorporate new knowledge about the influence of water regimes on aquatic ecosystems.

The monitoring data from the six Basin Matters are used to evaluate outcomes of the management of Commonwealth environmental water at the Basin scale, building upon the Selected Area–scale evaluations provided in the individual Selected Area reports. For monitored watering actions, this requires a comparison between the observed outcome and a prediction of what would have happened in the absence of the environmental flow.

Predictions of what would have happened in the absence of the environmental flow can be derived from a number of sources, including reference sites, conceptual models and quantitative models. Due to limitations associated with identifying suitable reference sites, the Basin evaluation will, over the next 5 years, develop quantitative models that predict the outcomes of Commonwealth environmental watering based on the characteristics of the event and the condition prior to watering. The next step is to make a judgement about whether the observed outcome matches the expected outcome. The evaluation then considers the factors that contributed to success, and which could be modified to lead to improved outcomes or to ensure success next time. This process once again relies on our conceptual understanding of how water regimes affect aquatic ecosystems.

For unmonitored watering actions, any available evidence is used to inform an evaluation of the likelihood that the watering action achieved its objectives. The next step is to consider the factors that may have contributed to the watering action's outcomes. This process is reliant on both the available evidence and our capacity to predict responses to flow. The development of quantitative

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[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

models by the LTIM Project will significantly increase the capacity to evaluate unmonitored watering actions.

Evaluation at the Basin scale requires both an estimation of the overall outcomes across the Basin and then a judgement of their significance and contribution to Basin Plan objectives. This process synthesises the evaluations from the Selected Areas and then uses the CEWO Outcomes Framework to link these to Basin Plan objectives, by translating local or site-scale outcomes into the four high-level environmental objectives under the Basin Plan generically described as Biodiversity, Ecosystem Function, Resilience and Water Quality (see Table 4).

The LTIM Project is a 5-year project and evaluation of the effects of Commonwealth environmental water at the Basin scale will be progressively developed over this time, with each year's data adding to the analysis and contributing to both improvements in our conceptual understanding and development of models to support improved predictions of the outcomes of environmental flows. It is anticipated that this process will see significant improvements in the scope and rigour of the evaluation process over the life of the LTIM Project.

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 in the second LTIM year, 2015–16. Although, quantitative models are still in the early stages of development, Basin evaluation is cumulative for 2014–16 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 2 years
3. **adaptive management** – a summary of key 'lessons learned' for both improved environmental water outcomes and the LTIM Project.

2.3 Context: the 2015–16 watering year

2.3.1 Climate and water availability

Rainfall conditions were variable across the Basin in 2015–16 (Figure 3). The centre of the Basin (Barwon–Darling, Lachlan, Macquarie and Murrumbidgee valleys) experienced above average rainfall conditions; the majority of the northern Basin had average rainfall. In contrast, parts of the southern Basin in Victoria experienced below-average rainfall conditions (Campaspe, Goulburn and Loddon valleys).

The Hydrology Basin Matter assessment (Appendix B) identified the resource availability scenarios (RAS) across each of the catchments that received Commonwealth environmental water in 2015–16. 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, including all of the Selected Areas, the RAS were considered to be low–moderate. Under these conditions, water was predominantly delivered to maintain ecological health and ecosystem resilience.

2.3.2 Commonwealth environmental water delivery in 2015–16

Commonwealth environmental water contributed to 115 watering actions across 16 catchments in the 2015–16 watering year (Appendix A). A net total of 1662 gigalitres of Commonwealth environmental water was delivered, with the largest volumes allocated to the Lower Murray and the Central Murray. The majority of water was delivered as base flow or freshes in rivers and streams and approximately a quarter of Commonwealth environmental water was used in watering actions that delivered water out of the river channel (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.

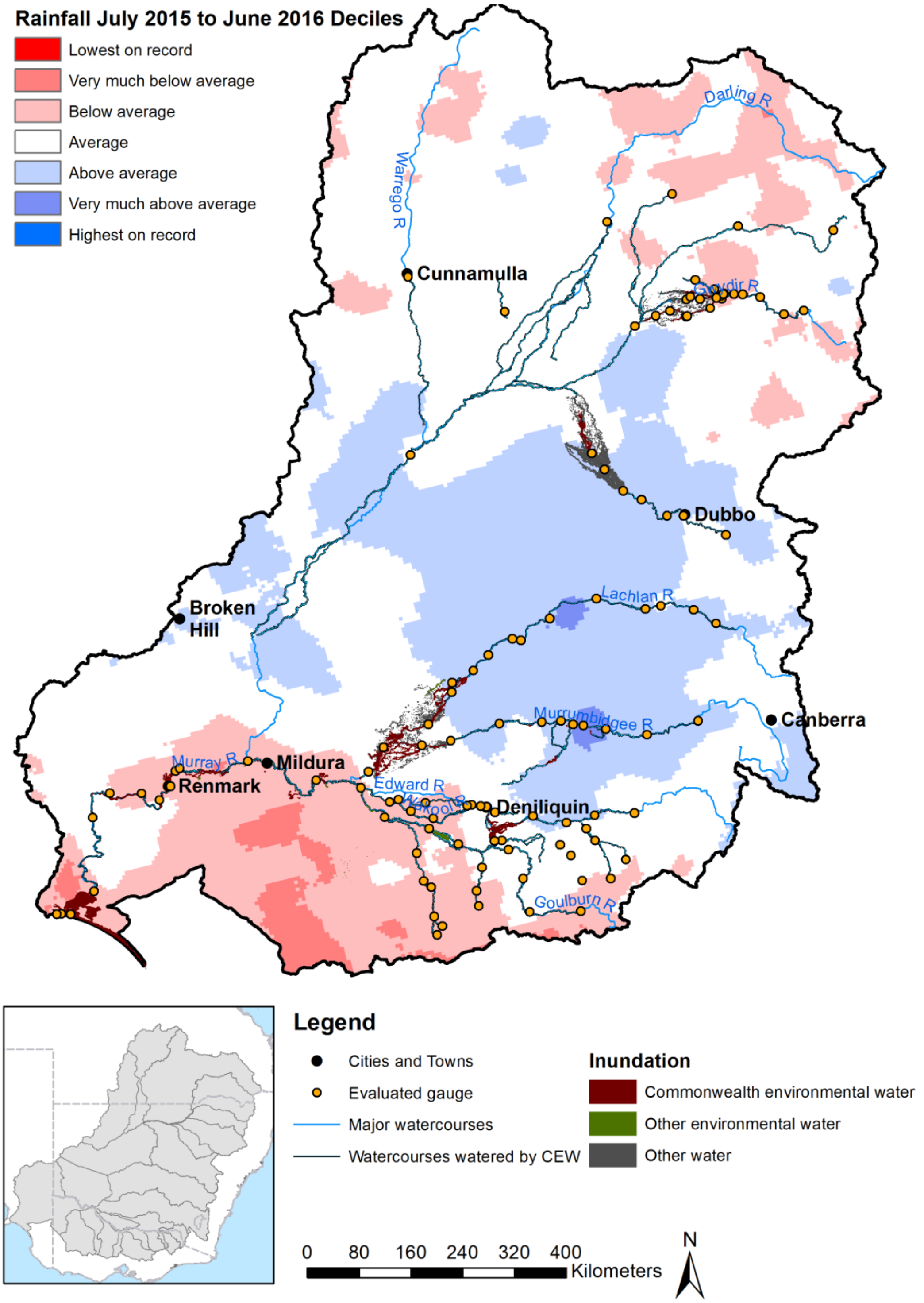


Figure 3. Rainfall, areas inundated and streams watered by Commonwealth environmental water during the 2015–16 watering year.

Table 1. Summary of Commonwealth Environmental Water Office (CEWO) watering actions by valley (see Appendix B for further explanation).

Valley	Number of actions	Commonwealth environmental water volume (GL)	Total active environmental volume (GL)	CEW volume as % of total	Flow components							
					Cease to flow	Baseflow	Fresh	Base flow and fresh	Bankfull	Overbank	Wetland inundation	Fresh and wetland
Barwon–Darling	3	7.6	7.6	100			3					
Border Rivers	6	1.2	1.2	100		1	5					
Broken	5	29.5	30.3	97		4	1					
Campaspe	2	3.3	9.8	34			2					
Central Murray	12	399.9	NA	NA		1	1	1		4	5	
Condamine–Balonne	2	10.5	10.5	100			2					
Edward–Wakool	4	32.2	34.5	93				4				
Goulburn	6	190.6	228.2	84		4	2					
Gwydir	4	8.1	13.2	61		1	1			2		
Lachlan	4	36.0	48.0	75			4					
Loddon	1	1.5	3.9	38			1					
Lower Murray	48	817.7[a]	NA	NA		2	5				40	1
Macquarie	2	14.2	55.1	26			2					
Murrumbidgee	13	108.3	200.8	54			2				11	
Ovens	2	0.1	0.1	100		2						
Warrego	1	0.9	0.9	100					1			
Total count	115				0	15	31	5	1	6	56	1
Component volume as % of total					0.0	62.3	6.1	7.9	0.1	16.8	6.8	0.1

[a] This volume includes water delivered in the Central Murray so total Commonwealth environmental water is less than sum of Central Murray and Lower Murray volumes.

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 2015–16, the most prevalent expected outcomes of Commonwealth environmental water were to support vegetation, fish and waterbirds (Table 2).

Table 2. Summary of 'expected outcomes' for Commonwealth environmental watering actions 2015–16 (see Appendix A).

Valley	Fish	Vegetation	Birds	Frogs	Other biota	Connectivity	Processes	Resilience	Water quality
Barwon–Darling						3	3	3	
Border Rivers	6	1			4	6	5	6	
Broken	5	5				1			3
Campaspe	2	2			2				2
Central-Murray	6	8	7	3	1	5	1		2
Condamine–Balonne	2	1			2	2	1	2	
Edward–Wakool	2	4				1			1
Goulburn	4	3			3	3	6		3
Gwydir	3	3	3		3	4	3	2	
Lachlan	1	3	3		1	3	1	3	1
Loddon	1								
Lower Murray	17	50	36	3	4	7	7	2	4
Macquarie	2	2	2	1	2	2	2		
Murrumbidgee	7	9	11	9	4	1	3		1
Ovens	2				2		2		
Warrego	1					1		1	
Total (% of all watering actions)	**61**	**91**	**62**	**16**	**28**	**39**	**34**	**19**	**17**

2.3.1 The first 2 years in context: 2014–16

The first 2 years of LTIM were similar in many respects, with dry conditions and low resource availability scenarios identified for most catchments where Commonwealth environmental water was delivered. The overarching objectives of environmental watering across the Basin were to support threatened species and maintain refuges, communities and functions. While in 2014–15 there were two large-scale watering actions in both Hattah Lakes and the Gwydir river system, where large areas of the floodplain were inundated for substantial periods, in 2015–16 water was delivered to wetland and floodplain systems for shorter periods of time and at a reduced extent.

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 at site, Selected Area and Basin scales 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 2015–16 and cumulatively over the first 2 years of LTIM (2014–16), across the three broad themes of the Basin Plan as defined by the CEWO Outcomes Framework: 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 2 years of LTIM, Commonwealth environmental water inundated two-thirds of the wetland types in the Basin and influenced more than one-quarter of the mapped extent of 13 wetland types.
- Good evidence was provided to suggest that Commonwealth environmental water contributed to maintaining the ecological character of four Ramsar sites – Barmah Forest, Central Murray Forests, Hattah–Kulkyne Lakes and Macquarie Marshes.
- Thirty-three species of conservation significance were recorded at sites that received Commonwealth environmental water in the period 2014–16.
- Commonwealth environmental water contributed to maintaining complex wetland ecosystems between natural flood events in a time that, without environmental water, these systems would have remained largely dry.
- Commonwealth environmental water promoted the diversity of water regimes experienced across the Basin; it is highly likely, therefore, to have enhanced the diversity and heterogeneity of vegetation communities across the Basin during 2015–16 in both unmonitored areas and LTIM Selected Areas.

3.1.1 Basin Matter evaluations related to biodiversity 2015–16

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) all report the outcomes of LTIM Project monitoring at the Selected Area and Basin scales. 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.

In the 2015–16 watering year, Commonwealth environmental water was delivered to 16 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 20 000 kilometres of river channel and inundated aver 270 000 hectares, of which approximately 200 000 hectares was mapped wetland and floodplain ecosystems (Figures 4 and 5).

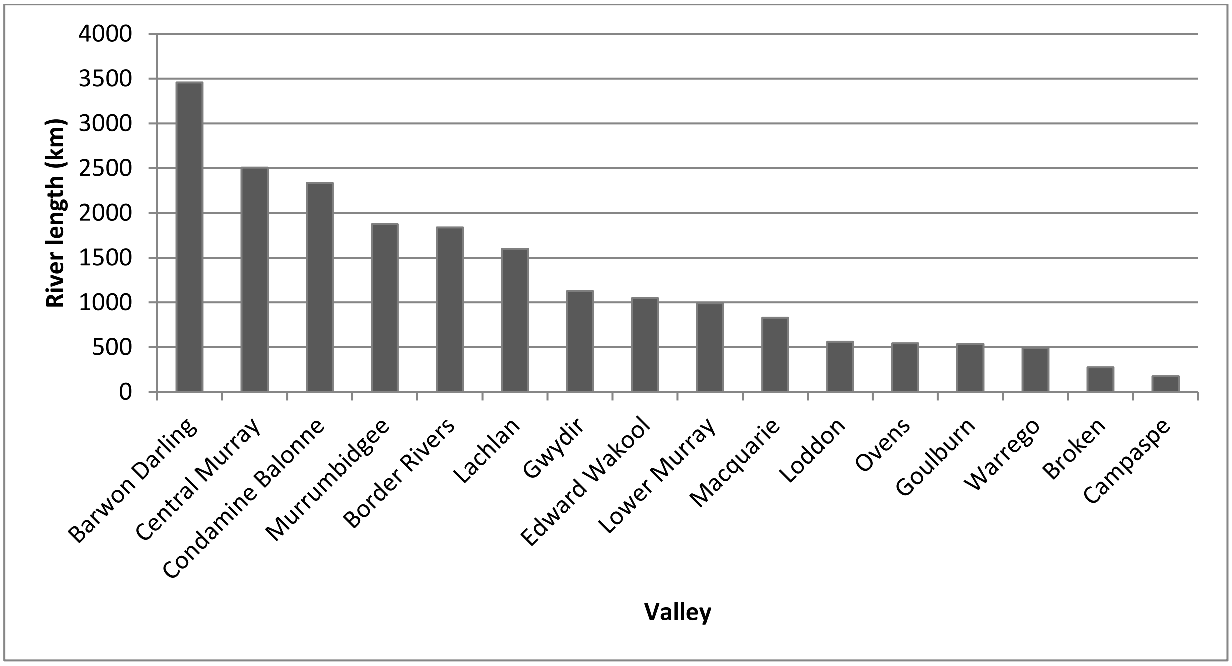


Figure 4. Length of river where flow regimes were enhanced by the delivery of Commonwealth environmental water in the 2015–16 watering year.

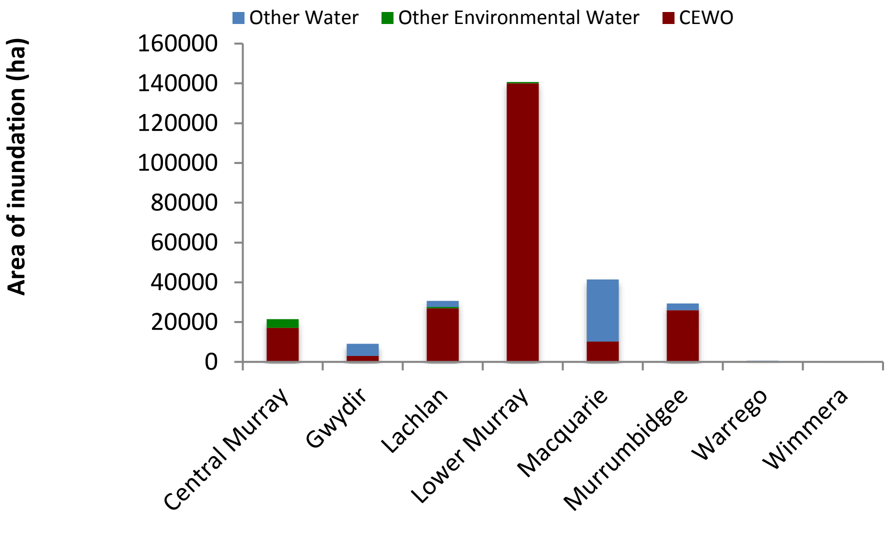


Figure 5. Area of floodplain and wetland inundation in the 2015–16 watering year.[6]

[6] Area of inundation shows the total cumulative inundation area of wetlands and floodplains where Commonwealth environmental water made a contribution. That is, inundation area reflects the total inundation and not the net area contribution of Commonwealth environmental water. The extremely large inundation area recorded in the Lower Murray reflects that Commonwealth environmental water made a contribution in the Coorong and Lower Lakes, but the net inundation area attributed to Commonwealth environmental water (which was not calculated) would be lower.

In terms of vegetation communities, results of analysis of data collected at the Selected Areas indicated that those communities that received Commonwealth environmental water were more diverse at the landscape scale than those that remained dry. In addition, inundation mapping showed that large areas and significant proportions of the mapped extent of some vegetation communities were influenced by Commonwealth environmental water in 2015–16, including over 30% of the mapped extent of five wetland types:

- Temporary sedge/grass/forb floodplain marsh
- Permanent floodplain tall emergent marshes
- Permanent floodplain grass marshes
- Permanent floodplain wetland
- Intermittent river cooba swamp.

Watering by Commonwealth environmental water in 2015–16 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 2 years. Where Commonwealth environmental water generated wetland and floodplain inundation, it is also likely to have promoted greater total cover, dominance and species richness of inundated vegetation communities as well as shifts in composition, including a reduction in the proportionate cover and richness of exotic taxa. The diversity and heterogeneity of vegetation communities present across the Basin in 2015–16 was almost certainly promoted by the delivery of Commonwealth environmental water through its contribution to spatial and temporal variability in water regimes. Specifically, these include positive effects on plant species diversity and an increased heterogeneity of vegetation communities at both Selected Area and Basin scales. The resilience of plant species and vegetation communities to drought is also likely to have been enhanced by the delivery of Commonwealth environmental water.

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 2015–16 comprise (see Appendix G):

- 15 species of plants
- 11 species of fish
- 45 species of bush birds
- 70 species of waterbird
- 15 species of frog
- 2 species of turtle.

3.1.2 Basin-scale biodiversity outcomes 2014–16

Assessing the significance of Commonwealth environmental water at the Basin scale has a high degree of uncertainty. As the portfolio of watering actions increases over time and we have results from multiple years at a larger number of locations, confidence will increase in our evaluation of Basin-scale outcomes. At this stage, the assessment of Basin-scale outcomes is focused on three more certain pathways:

1. Contributions to maintaining the ecological character of Ramsar sites is of international significance and so can be considered significant at the Basin scale.
2. Benefits to threatened species and communities are, by definition, also considered significant at the Basin scale.
3. Maintaining condition of important sites between large-scale flood events is contributing to diversity at the Basin scale.

Maintaining the ecological character of Ramsar sites

There are 16 Ramsar site in the Basin and over the first 2 years of the program, Commonwealth environmental water has targeted ecological outcomes at eight of these: Gingham and Lower Gwydir, the Coorong and Lakes Alexandrina and Albert, Barmah Forest, Gunbower Forest, Central Murray Forests, Hattah–Kulkyne Lakes, Banrock Station and the Macquarie Marshes. 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):

- Hattah–Kulkyne Lakes – almost all of the water entering the site in the past 2 years has been environmental water, with Commonwealth environmental water comprising the greatest contribution. Monitoring has indicated that the ecological character of the site has been maintained with positive outcomes for vegetation, fish, waterbirds and bush birds (see Box 1 for case study example).
- Macquarie Marshes – again, a substantial portion of the water within the Macquarie Marshes from 2014–16 was from environmental watering actions. There is some evidence from local monitoring and observations indicating that Commonwealth environmental water contributed to maintaining the ecological character of the Macquarie Marshes Ramsar site, especially in the context of a regionally dry period.
- Barmah–Millewa Forest – water was delivered to the two Ramsar sites that extend across the Barmah–Millewa Forest in spring 2015, inundating over 10 000 hectares of river red gum forest and woodland as well as several wetland and stream ecosystems. This water supported a moderate colonial nesting waterbird breeding event with over 1000 nests as well as providing foraging habitat for a wide range of birds, fish and frogs.

Maintaining the ecological character of Hattah–Kulkyne Lakes – patterns of wet and dry

The Hattah–Kulkyne Lakes Ramsar site comprises 12 Lakes on the floodplain of the Murray River that vary from semi-permanent to temporary and episodic. During and following the 'Millennium Drought', inundation extent and frequency of the Ramsar site had declined. To address this, The Living Murray (TLM) program commissioned significant environmental works, which included a permanent pump station, regulators and environmental levees, which are being used to deliver environmental water to return a more natural water regime to the lakes.

The Ecological Character Description of the site, which describes the hydrological regime required to maintain the condition of the Ramsar site, includes more frequent inundation of semi-permanent wetlands, such as lakes Lockie and Hattah, and less frequent flooding of more temporary and episodic wetlands such as lakes Bitterang and Kramen (Butcher & Hale 2011).

Environmental water delivered over the first 2 LTIM years marked the beginning of managing the water regime at the site to match these requirements of ecological character, with the CEWO, together with the Victorian Environmental Water Holder (VEWH) and TLM, delivering a large allocation of water (106 GL) in 2014–15 which inundated all 12 lakes and a large area of the floodplain. Water delivery in 2015–16 was of a smaller volume (6.6 GL) and duration, and allowed some of the temporary and episodic wetlands to dry down. These two periods (one wet and one of drying) provided different and complementary functions to the system that together resulted in the maintenance of ecological character:

- Deeper water habitats supported submerged and floating aquatic vegetation, wetland generalist waterbirds, such as diving and dabbling ducks, as well as fish–eating species, such as Australasian darter and great cormorant.
- As wetlands started to dry down, a mosaic of wetland vegetation formed with an increase in diversity across the diverse wetland habitats. Similarly, the number of waterbird species increased as shallow water habitats provided foraging opportunities for wading species, including several listed international migratory shorebirds.
- Large numbers of bush birds, including the threatened regent parrot, benefited from increased productivity in the floodplain, which extended into 2015–16, a year after inundation and flood recession.
- Provision of habitat for native fish supported resident small–bodied species and larger bodied species that move between the wetlands and the river.


Box 1. Case study example of effects of Commonwealth environmental water on Ramsar sites in 2015–16 (photo of red water milfoil (left) and jerry jerry (right) at Hattah Lakes in 2015–16 by F Freestone).

Threatened species

Under the low water availability scenarios experienced across much of the Basin in the first 2 LTIM years, protecting threatened species through environmental water management was a priority. In 2014–16, 35 species of conservation significance were recorded at sites that received Commonwealth environmental water; 24 bird, 7 fish, 1 frog and 4 plant species (Table 3).

Table 3. Listed species recorded at sites that received Commonwealth environmental water 2014–16.

Group	Common name	Species name	Significance[1]
Birds	Black-tailed godwit	*Limosa lapponica*	JAMBA, CAMBA, ROKAMBA
	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)
	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 (VIC)
Fish	Eel-tailed catfish	*Tandanus tandanus*	Endangered (NSW, VIC)
	Flat-headed galaxias	*Galaxias rostratus*	Critically endangered (EPBC)
	Murray hardyhead	*Craterocephalus fluviatilis*	Endangered (EPBC)
	Silver perch	*Bidyanus bidyanus*	Endangered (EPBC)
	Trout cod	*Maccullochella macquariensis*	Endangered (EPBC)
	Murray cod	*Maccullochella peelii*	Vulnerable (EPBC)
	Olive perchlet	*Ambassis agassizii*	Endangered population (NSW)
Frogs	Southern bell frog	*Litoria raniformis*	Vulnerable (EPBC)
Plants	Basalt peppercress	*Lepidium hyssopifolium*	Endangered (EPBC)
	Glistening dock	*Rumex crystallinus*	Vulnerable (VIC)

Group	Common name	Species name	Significance[1]
	Rigid water milfoil	*Myriophyllum porcatum*	Vulnerable (EPBC)
	Winged peppercress	*Lepidium monoplocoides*	Endangered (EPBC)

[a] 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); NSW = listed under New South Wales legislation; VIC = listed under Victorian legislation.

While presence of a species is not necessarily evidence of that species having benefited, there is clear evidence of the effect of Commonwealth environmental water on several threatened species. For example:

- Australasian bittern (*Botaurus poiciloptilus*) – this species was recorded at several locations including the Lowbidgee wetlands, Macquarie Marshes and Moodies Swamp in the Goulburn River. A very large number of Australasian bitterns were recorded in Barmah–Millewa Forest, possibly comprising over 10% of the total population of this nationally listed endangered species (Belcher *et al.* 2016). Commonwealth environmental water contributed significantly to the inundation of vegetated marshes where the species forages and breeds.
- Regent parrot (*Polytelis anthopeplus*) at Hattah–Kulkyne Lakes – monitoring after inundation in black box forests indicated that increases in productivity and food resources benefited several species of insectivores, nectivores and seed-eating species, including the vulnerable regent parrot, with effects extending across the 2 years (2014–16).
- Monitoring of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC-) listed endangered fish species Murray hardyhead (*Craterocephalus fluviatilis*) indicates a strong positive response to Commonwealth environmental water in South Australia. High abundances of the species were recorded at the Berri Saline Water Disposal Basin in February 2015 (MDBA 2015) and in Brickworks Billabong in 2016 (Huntley 2016) after receiving Commonwealth environmental water. There is evidence to suggest that Commonwealth environmental water is helping to restore this species through provision of appropriate habitat.
- The olive perchlet (*Ambassis agassizii*), which is listed as an endangered population in the New South Wales portion of the Basin, was recorded in the Gingham Waterhole in the Gwydir river system. Without Commonwealth environmental water, key refuge pools such as the Gingham Waterhole would have dried, water quality within those pools would have deteriorated, and longitudinal connectivity between those pools would have ceased (Appendix F).

It is also likely that a number of water-dependent threatened species that were not observed or recorded in monitoring programs also benefited from Commonwealth environmental water in 2014–16. Threatened species are, by definition, rare and, unless the target of dedicated monitoring programs, are less likely to be observed or recorded than more common species.

Maintaining condition between floods

Commonwealth environmental water contributed to the inundation of several large wetland complexes over the past 2 years where environmental water comprised all or most of the water to the sites. This included watering of Hattah Lakes, the Gwydir and Gingham watercourses and Macquarie Marshes in both years and Barmah–Millewa Forest and Banrock Station in 2015–16. While the extent and duration of inundation in many of these watering actions was limited, the environmental water contributed to important functions in maintaining condition of long-lived vegetation and providing refuge habitat for aquatic biota. While very large-scale responses to water are only provided by large, natural floods (e.g. significant colonial nesting events for waterbirds, booms in productivity from floodplain inundation), maintaining condition and habitat between flood events is an important aspect of environmental water and one, arguably, where environmental water can have the greatest effect. This is supported by recent research which 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).

3.2 Ecosystem function

Basin-scale ecosystem function outcomes

- The effects of Commonwealth environmental water on ecosystem function were limited by the dry conditions that occurred across most of the Basin in 2014–16, which limited environmental flows mostly to base flows and freshes as is expected under low to moderate resource availability scenarios.
- The contribution of Commonwealth environmental water to maintaining flow regimes was similar in the first 2 years of LTIM. Areas where Commonwealth environmental water was delivered maintained either a good base flow (for hydraulic diversity) or fresh flow (for fish movement) regime.
- Commonwealth environmental water contributed to lateral connectivity through floodplain inundation and coordinated weir pool management in 6 of the 12 weirs along the Murray River from Euston to Blanchetown.
- Commonwealth environmental water contributed to connectivity between the Murray River and the Southern Ocean through the opening of the Murray Mouth.
- LTIM monitoring did not detect any effect of Commonwealth environmental water on stream metabolism in the southern Selected Areas, which can, in part, be attributed to water being delivered as in-channel flows (base flows and freshes) in the dry years 2014–16.

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 second 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).[7] 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?

[7] Note that in future years the Fish Basin Matter will consider aspects of biological connectivity through fish movement monitoring and evaluation.

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

3.2.2 Basin-scale ecosystem function outcomes 2014–16

Restoration of the hydrological regime

The Basin Plan seeks to ensure there is no loss of, or degradation in, flow regimes that include relevant flow components. The flow components are classified into five discrete types (Figure 6). Four valleys experienced above average rainfall conditions (Barwon–Darling, Lachlan, Macquarie and Murrumbidgee), while nine valleys experienced average rainfall conditions (Central Murray, Border Rivers, Broken, Condamine–Balonne, Gwydir, Lower Murray, Ovens, Warrego and Edward–Wakool) and three valleys (Campaspe, Goulburn and Loddon – all in Victoria) experienced below average rainfall conditions (Figure 3). Almost two-thirds of the Commonwealth environmental water delivered in 2015–16 was used in 15 baseflow watering actions across the Murray River, northern Victoria, Gwydir and Border Rivers. A smaller portion, only 14% of the Commonwealth environmental water, contributed to the 41 actions involving freshes or actions that combined both freshes and base flows across 16 LTIM valleys.

The contribution of Commonwealth environmental water to restoration of the flow regime has been evaluated by comparing the base flow and fresh components of the water regime in 2014–16 to what would have occurred in the absence of water resource development and extraction (Figures 7 and 8). Commonwealth environmental water contributed significantly to maintaining base flows and freshes in the southern Basin.

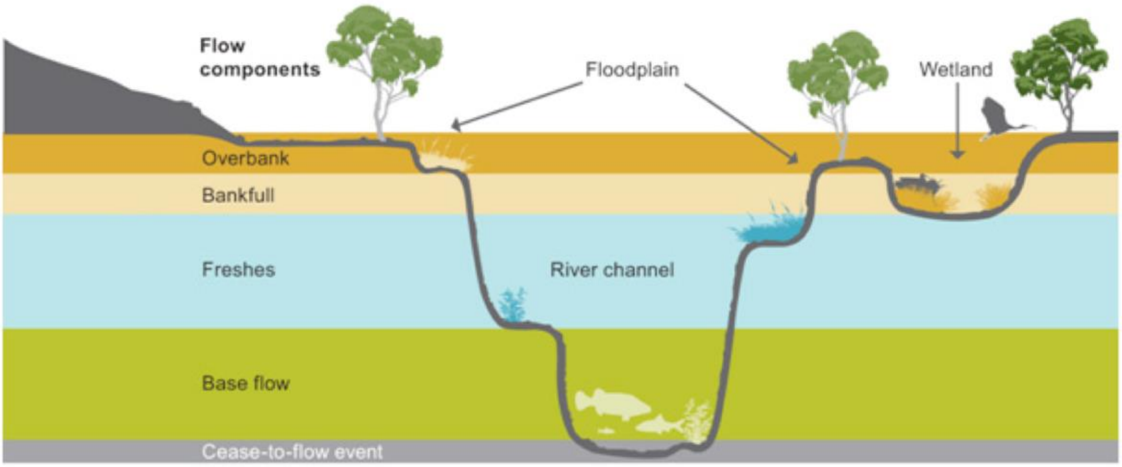


Figure 6. Five flow types and their influence on different parts of the river channel, wetlands and floodplains (MDBA 2011).

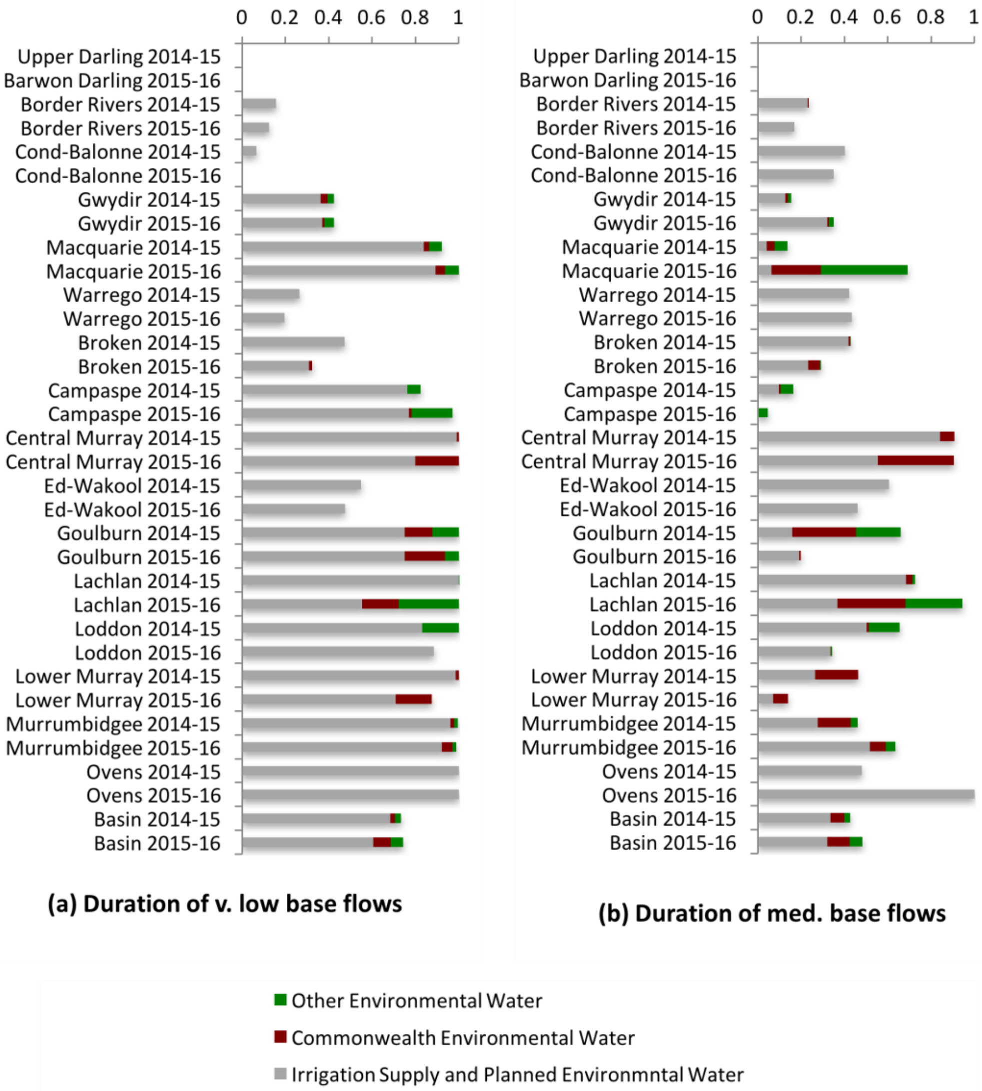
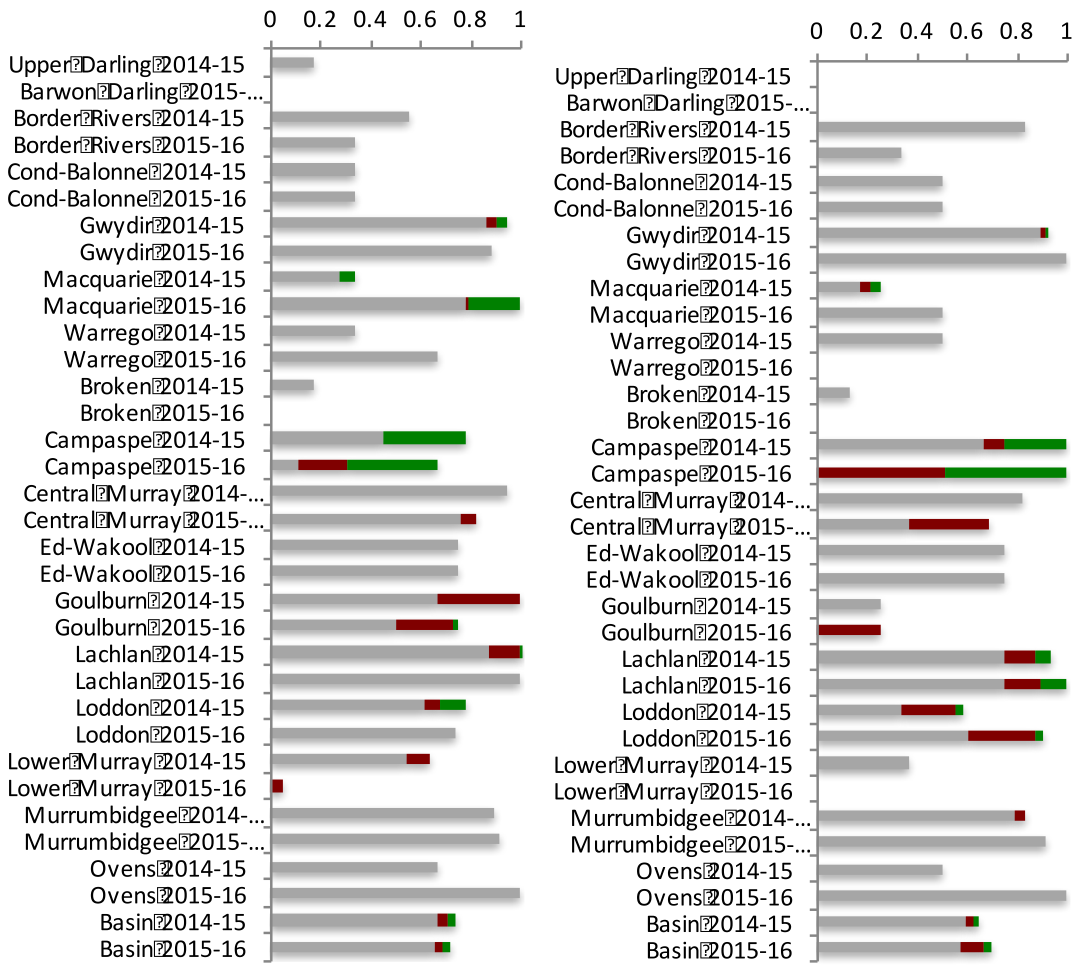


Figure 7. Average contribution of Commonwealth environmental water and other environmental water entitlements to base flow durations across each valley in the 2 years of LTIM monitoring. Presented as the average score for each valley; the horizontal axis ranges from a score of 0, which is severely altered, and 1, which indicates an adequate frequency of the flow type. See Appendix B for more detailed explanation on scoring and further details.



(a) Occurrence of low freshes **(b) Occurrence of med. freshes**

Figure 8. Average contribution of Commonwealth environmental water and other environmental water entitlements to low and medium freshes across each valley in the 2 years of LTIM monitoring. Presented as the average score for each valley; the horizontal axis ranges from a score of 0, which is severely altered, and 1, which indicates an adequate frequency of the flow type. See Appendix B for more detailed explanation on scoring and further details.

Hydrological connectivity

Commonwealth environmental water delivered as in-channel flows contributed to longitudinal connectivity across 16 river valleys in the Basin over the 2014–16 period. In 2015–16, the Commonwealth contributed to watering approximately 20 000 kilometres of river channels. Improvements in longitudinal connectivity were generated by freshes that would have contributed to longitudinal connectivity by providing opportunities for native fish to disperse. This was observed in the Goulburn River in 2015–16, where a fresh flow promoted downstream movement by adult golden perch (*Macquaria ambigua*) (Webb *et al.* 2016). Base flow watering actions also contributed to longitudinal connectivity that, in the northern Basin, would have helped sustain refuges by maintaining their depth and water quality.

Commonwealth environmental water also contributed to connectivity through its effect on the Murray Mouth opening in the first 2 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). To this end, there is a target in the Basin-wide Watering Strategy (MDBA 2014) for the Murray Mouth to remain open 90% of the time to an average depth of 1 metre. Modelling has shown that Commonwealth environmental water, together with other management options such as dredging, has contributed to maintaining a depth of greater than 1 metre compared with conditions that would have occurred in the absence of the buyback of water in both 2014–15 and 2015–16.

In 2015–16, Commonwealth environmental water was the sole contributor to barrage flows, contributing 561 gigalitres (Figure 9). 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 (Figure 10).

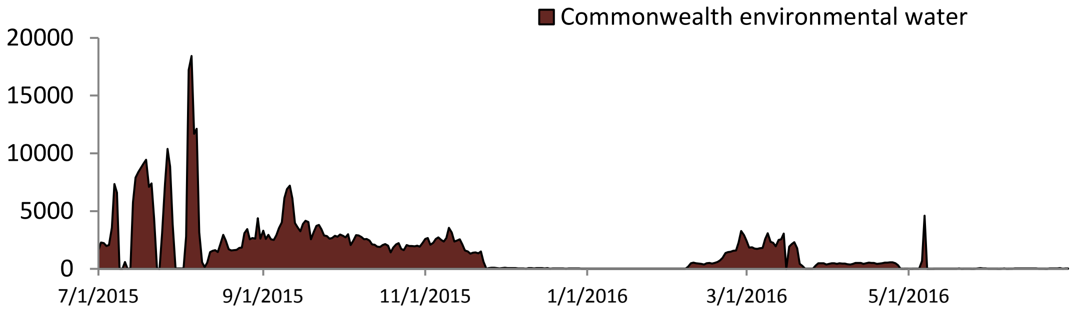


Figure 9. Contribution of Commonwealth environmental water delivery over the barrages (100% of water flows over the barrages for 2015–16 was contributed by Commonwealth environmental water).

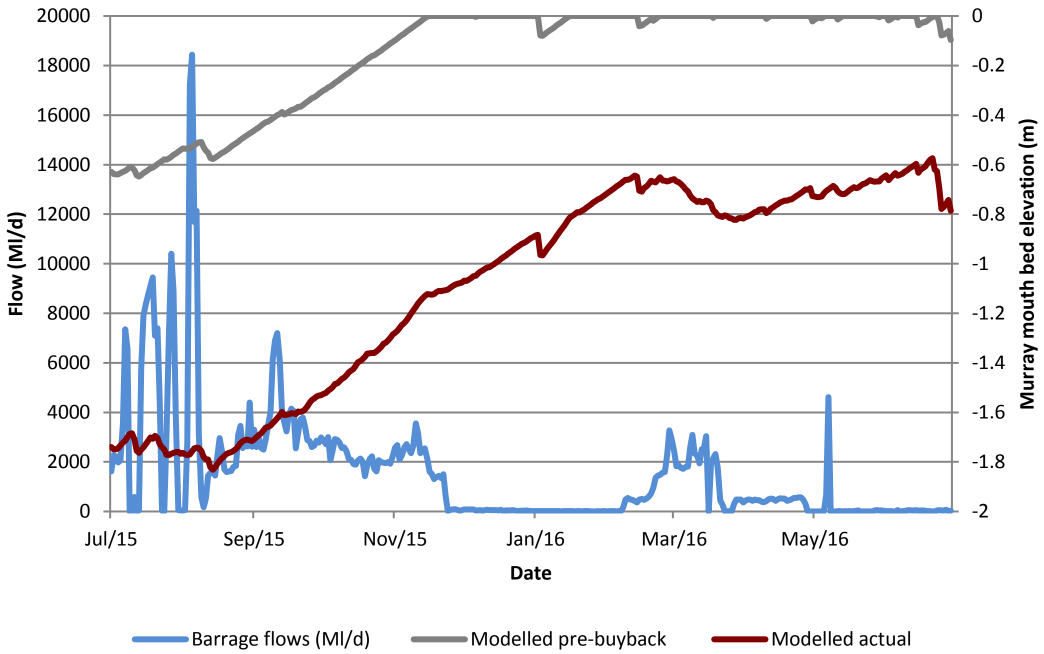
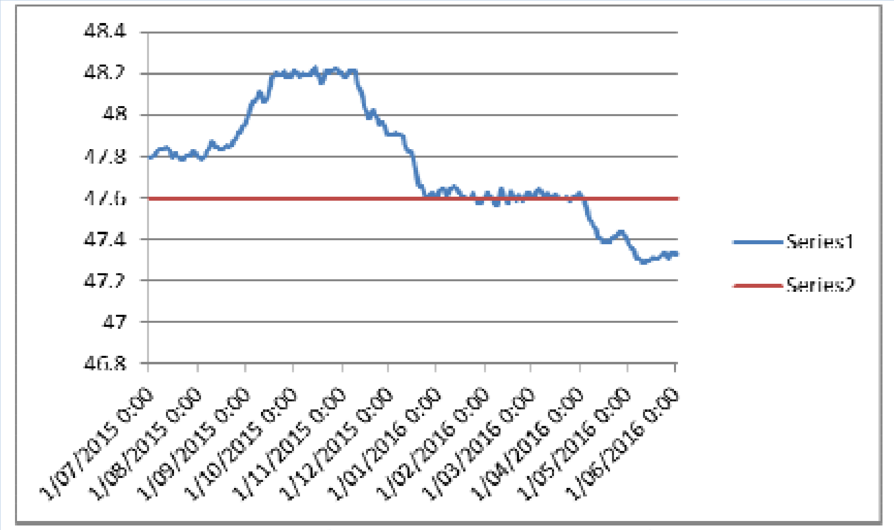


Figure 10. Modelled change in the height of the Murray Mouth bed with and without (before the purchase of water entitlements for the environment) Commonwealth environmental water. The model shows that Commonwealth environmental water is responsible for the scouring of close to a metre's worth of sediment from the Murray Mouth bed elevation for the counterfactual scenario (modelled pre-buyback) and an actual scenario (modelled actual).

Commonwealth environmental water made a major contribution to the inundation of 273 000 hectares of wetland and floodplain over 2015–16 (see Box 2 for case study example). In addition, Commonwealth environmental water contributed to floodplain and wetland connectivity through the delivery of water to terminal wetland systems, such as the Great Cumbung Swamp, and infrastructure-assisted wetland inundation, particularly in the Murray.

Connecting rivers and floodplains: weir pool manipulation in the Lower Murray

In 2015–16, Commonwealth environmental water was used as part of coordinated weir pool management in the Murray River from Euston to Blanchetown. The aim was for weir pool levels to be raised in order to inundate low-lying wetlands and floodplains, flood runners and tributaries that are influenced by the locks and weirs; and lowered to create additional stream variability (see example hydrograph below from Lock 15). Ten manipulations were implemented across six weirs (Locks 2, 5, 7, 8, 9 and 15).



Water level in Lock 15 (blue) and full supply level (red).

Outcomes of the weir pool manipulations included (CEWO, unpublished):

- lateral connectivity with inundation of several wetlands, flood runners and anabranches at each of the six weirs
- some improvements in stream metabolism (although small and short lived)
- improvements in wetland and floodplain vegetation and some recruitment of species such as river red gum
- some evidence of improved fish condition.

Box 2. Case study of connecting rivers and floodplains in the Lower Murray.

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).

There are several examples that demonstrate the effect of Commonwealth environmental water on biological connectivity in the first 2 LTIM years (2104–16):

- Wetland inundation within the Gwydir River network has had clear positive impacts on water quality within wetlands, as well as on lateral connectivity. Commonwealth environmental water contributed greatly to these lateral connectivity events. Fishes of high conservation concern, such as eel-tailed catfish (*Tandanus tandanus*), have been identified in some of the inundated wetlands, and thus Commonwealth environmental water is likely to be contributing to conservation outcomes for these species.
- Opening of the gates at Boera Dam on the Warrego River resulted in the reconnection of waterholes. Following this watering action, strong recruitment of golden perch, bony herring (*Nematalosa erebi*) and spangled perch (*Leiopotheron unicolor*) was observed, and Hyrtl's tandan (*Neosilurus hyrtlii*), a relatively rare catfish, was recorded in the waterholes of the lower Warrego during 2015–16. Although the extent to which Commonwealth environmental water contributed to the observed recruitment is currently unknown, in the absence of Commonwealth environmental water and the decision to open the gates, the system would have remained dry and waterholes isolated, threatening the important assemblage of self-recruiting, large-bodied native fishes.
- Return flows from Hattah Lakes to the Murray River were managed to allow for the passage of native fish. There was evidence that large-bodied native fish, such as golden perch, that use the wetlands as nursery habitat, returned to the Murray River through the regulator when the water was drained as part of environmental water management (Wood & Brown 2016).

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).

Estimates of river metabolism are derived from daily measurements of changes in dissolved oxygen, temperature and light in open water (Figure 11). The open water measurements average out all metabolic activity occurring in the channel and these data are then used to generate estimates of gross primary production, community respiration and the re-aeration coefficient per litre of water (Figure 12). The estimates of gross primary production and community respiration can then be scaled up to provide an estimate of reach-scale metabolism using an estimate of the volume of water in the monitored reach (Figure 11). See the Stream Metabolism and Water Quality Foundation Report (Grace 2015) for more detail on the method. In this second Basin-scale evaluation of metabolism, quantitative evaluations could only be undertaken on the influence of flow on entrainment affecting metabolism rates per unit volume. More complete quantitative evaluations will be undertaken in future years once additional hydraulic data and modelled predictions of what would have happened in the absence of environmental flows become available. Given this, base flows were evaluated qualitatively using our conceptual understanding of the influence of flow on metabolism.

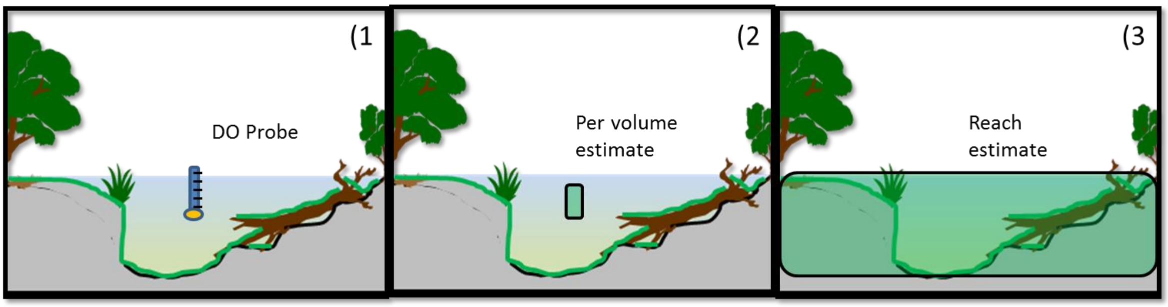


Figure 11. Illustration of the three steps in generating a reach-scale estimate of stream metabolism: (1) monitoring open water dissolved oxygen; (2) using data to develop a per unit volume measure; and (3) scaling up to the reach.

The quantitative evaluation of outcomes yielded very similar results to those recorded in Year 1. The greatest influences on metabolism across the Selected Areas were day length and temperature (Figure 12). Understanding the influence of day length and temperature is important for the development of the models that will be used to predict outcomes in the absence of environmental flows. These relationships will also be important in informing managers about the potential effects of changes in the timing of delivery of environmental flows.

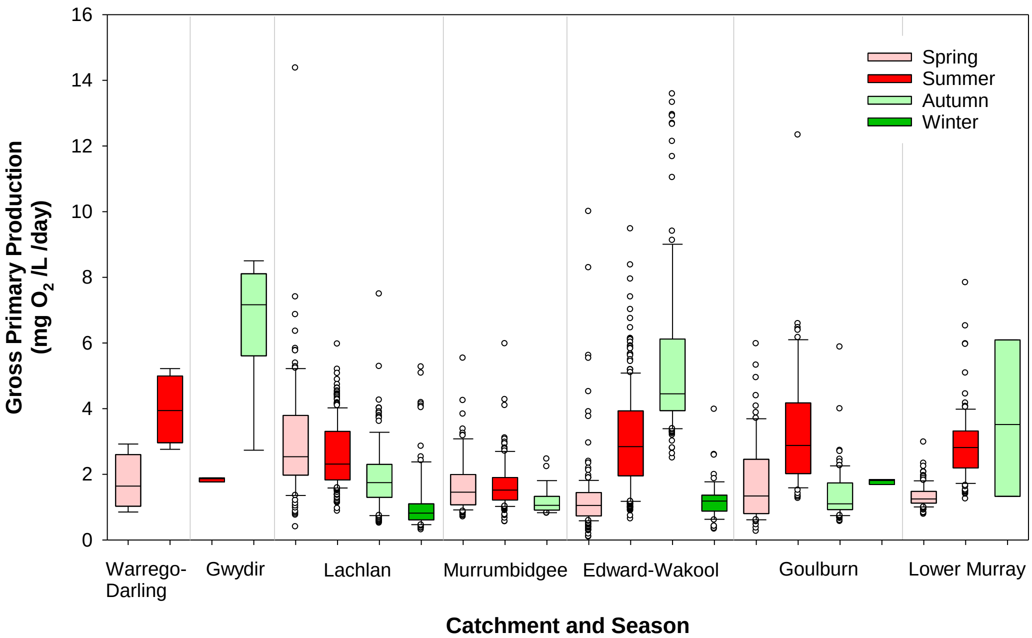


Figure 12. Box plots representing seasonal gross primary productivity (left) in the seven Selected Areas 2015–16. See Appendix C for more detail.

Fresh flows were allocated in the Goulburn and Gwydir systems in 2015–16. In the Goulburn River, monitoring revealed freshes were associated with no change or a depression in rates of primary production and ecosystem respiration per unit volume, which is most likely the result of dilution. From a conceptual point of view, it is not clear what the overall outcome would have been in the Goulburn as the counteracting forces of a decrease in the rate per unit volume may have been offset by the overall increase in water within the reach, and the longer the fresh lasted and the warmer the water, the more likely it is that the fresh would have increased overall metabolism. The fresh delivered in the Gwydir was may also have had an effect on metabolism, but the evaluation is subject to the same uncertainties as outlined for the Goulburn River.

A qualitative evaluation of base flows was undertaken on the basis that increasing base flows are likely to influence the amount of habitat available for primary producers and decomposers. Any increase in available habitat is likely to increase the supply of organic carbon, the energy source driving and sustaining aquatic food webs and essential nutrient recycling via ecosystem respiration. For flowing systems in which environmental flows have had a significant influence on base flows, it is likely that there will have been an associated effect on metabolism for the whole river. The systems where Commonwealth environmental water increased base flows included the Central Murray, Goulburn, Lachlan and Macquarie rivers (Stewardson & Guarino 2017) and given their duration (multiple weeks), these watering actions are likely to have provided base levels of organic carbon and nutrients – the quantities of these essential components are determined by primary producer biomass and the amount of organic carbon available.

The situation in impounded rivers is likely to be different as changes to base flows may not affect the amount of habitat. In 2015–16, the allocation of Commonwealth environmental water to base flows through the Lower Murray were associated with weir pool manipulations which promoted lateral connectivity and the possibility of entrainment. As a result of these watering actions, primary production and ecosystem respiration increased by a factor of up to 2–3 above baseline values, while there was an even larger (five-fold) increase in ecosystem respiration, but not primary production, in the Chowilla Creek anabranch (Punkah Creek) and associated wetlands (Wallace & Cummings 2016).

3.3 Resilience

Basin-scale resilience outcomes

- Contributions to resilience were made through both ecosystem diversity and hydrological connectivity.
- Commonwealth environmental water contributed to resilience through maintaining refuges in a dry landscape in wetlands and, to a lesser extent, by maintaining in-channel waterholes.
- Inundation contributed to improving the condition of vegetation, fish, waterbirds and other biota, making them more resilient to adverse events in the future. The role of Commonwealth environmental water in promoting resilience through improved condition will be explored over the following years.

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 2014–16 are summarised below.

3.3.1 Protecting refuge habitat

In-channel waterholes are recognised as important refuge habitat, particularly for native fish, and their persistence is strongly linked to their depth (MDBA 2014). Consequently, environmental flows that replenish waterholes by increasing their depth and improving water quality would be expected to contribute to the system's resilience. In the dry conditions that prevailed over much of the Basin in the first 2 LTIM years (2014–16), maintaining refuges was considered a priority for environmental water (Table 2) and was the target of a number of watering actions, particularly in the northern Basin, including the Border Rivers, Moonie River, Lower Balonne Floodplain, Warrego River, Gwydir River and Barwon–Darling River. The effectiveness of environmental water in achieving objectives related to providing waterhole refuge habitat varied.

As illustrated in Figure 13, Commonwealth environmental water can comprise the majority of total discharge within sections of the major rivers during dry periods. Within the Gwydir river system Selected Area, there is good evidence that, without Commonwealth environmental water, key refuge pools supporting native fish biodiversity would have dried, water quality within those pools would have deteriorated, and longitudinal connectivity between those pools wold have ceased (Southwell *et al*. 2016). These flows have contributed to maintaining Gingham Waterhole, within which the olive perchlet, a threatened species, was recorded during 2015–16 LTIM.

In other parts of the northern Basin, there were very low flow conditions across both years (2014–15 and 2015–16), with environmental water contributing little to maintaining base flows and freshes in many locations. It is likely that expected outcomes for maintaining refuges in several northern Basin rivers, such as the Condamine–Balonne and Border Rivers, were not achieved.

Wetlands and floodplains may also represent important refuges for some biota, with permanent wetlands acting as refuges when temporary wetland systems are dry. The ecosystem diversity analysis revealed that Commonwealth environmental water contributed to the inundation of over 60% (85 000 hectares) of permanent floodplain lakes in 2015–16. In addition, around half of the permanent floodplain wetlands and tall emergent marshes were influenced by Commonwealth environmental water in both years. Given the dry conditions that persisted across large areas of the Basin in 2014–16, it is assumed that these permanent wetland and lake areas provided refuge habitat for a wide range of aquatic biota.

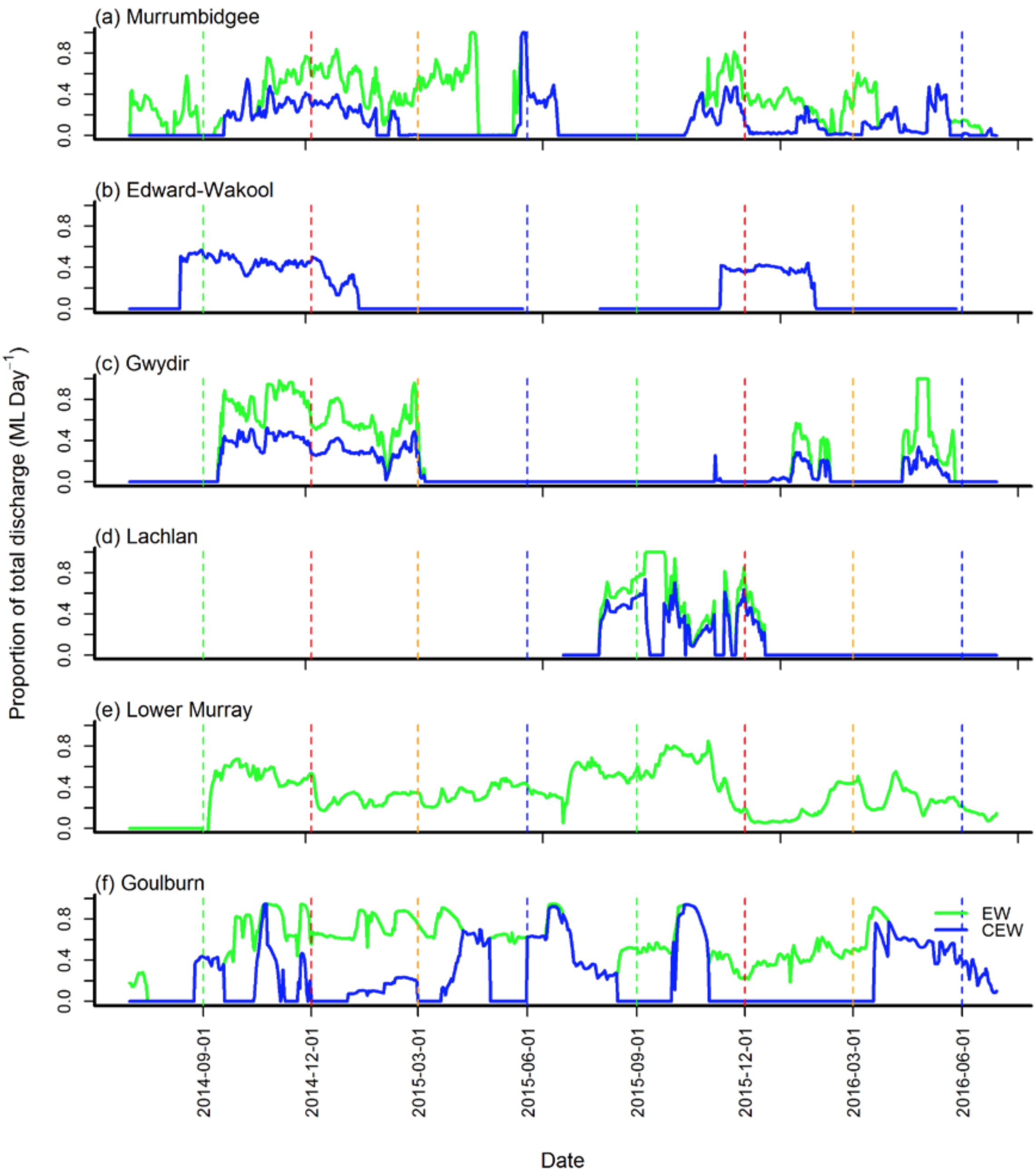


Figure 13. The proportion of total discharge in LTIM fish focal zones comprised of Commonwealth environmental water (blue) and all environmental water (green) in the 2014–16 period. See Appendix F for more details.

3.3.2 Contributing to resilience through improved condition

Fish condition across the Basin in 2014–2016 exhibited species-specific trends with respect to condition. The condition of bony herring remained consistent in most Selected Areas, but increased between 2014–15 and 2015–16 in the Gwydir river system. The median condition of golden perch and Murray cod (*Maccullochella peelii*), however, were at or below average across most Selected Areas, with a statistically significant decline observed in median Murray cod condition within the Edward–Wakool, Lachlan and Murrumbidgee (Figure 14).

This average or below average condition may reflect the two predominantly dry years that occurred 2014–2016. This does not mean Commonwealth environmental water isn't having positive impacts on fish condition, because it is possible condition would have been worse in the absence of Commonwealth watering actions.

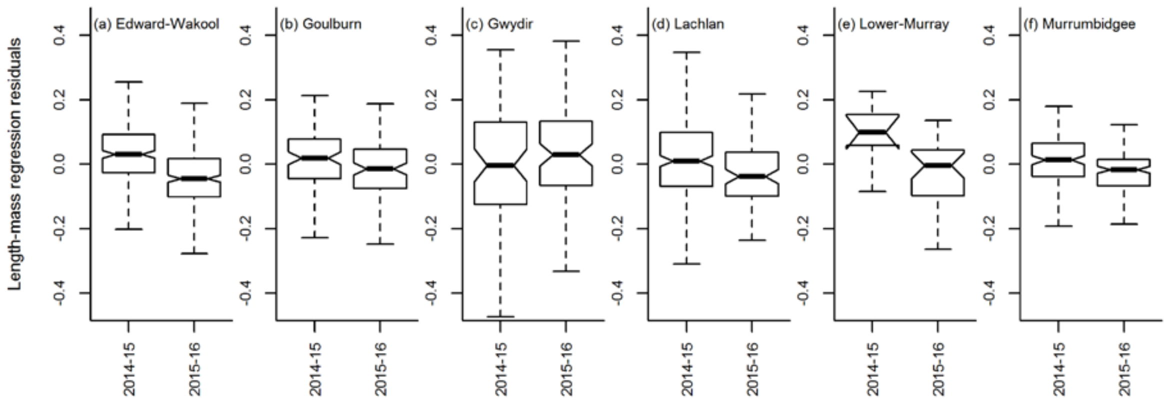


Figure 14. Variation in relative Murray cod condition (2014–15 and 2015–16). Positive values indicate 'above average condition' and negative values 'below average condition'. See Appendix F for more detail.

4 Adaptive management

Key adaptive management messages

- Timing of water delivery is important for biota, with limited responses observed to winter watering in wetlands and river systems.
- Variable water regimes promote diversity in vegetation communities and waterbirds.
- Slow rates of recession are beneficial for promoting vegetation germination.
- LTIM will be improved by:
  - more detailed hydrological information
  - changes to the way expected outcomes are reported
  - inundation mapping with and without Commonwealth environmental water.

In this first 2 years of the LTIM Project there are a small number of lessons learned related to two aspects of environmental watering:

1. improvements in our understanding of flow–ecology relationships that could inform future environmental watering actions
2. identification of information needs that are required for monitoring and evaluation of the outcomes of environmental water.

4.1 What we have learned about the effects of environmental water?

4.1.1 Timing of water delivery affects outcomes for biota

The CEWO allocated winter and early spring flows in the Lachlan river system, Murrumbidgee river system, Barmah–Millewa Forest and Macquarie Marshes in 2015–16. These flows were a Basin annual watering priority and sought to reinstate winter flows and counteract the seasonal reversal of flows common across the southern connected Basin. In some instances, these flows sought to maintain patterns of natural flow variation believed to be important in some systems. These winter flows were delivered to both rivers (flowing systems) and wetlands, with potentially different outcomes.

Water delivered in winter inundated a portion of floodplain wetlands in target systems, persisting until late spring. As a result of low temperatures, the responses of waterbirds, fish and frogs and metabolism were limited during inundation. Water then did not persist for sufficient time for spring and summer biota responses and the benefits of this watering for wetland systems was not clear. Given the opportunity costs associated with reducing the water available to be allocated later in the season, there are disbenefits associated with watering actions undertaken in winter, particularly in wetlands. In many systems, there are constraints that limit water managers' capacity to deliver water in late spring and summer; however, the evidence is accumulating that getting the timing of watering actions right will have a significant influence on whether the stated objectives are achieved, particularly breeding and recruitment outcomes.

In flowing systems, the outcomes may be different, but initial monitoring data did not indicate a direct benefit from winter environmental flows in 2015–16. The evaluation of fish at the Basin scale reported that evidence from the Goulburn River indicated that flows delivered in November–December that coincided with warmer water had a greater impact on spawning in golden perch and silver perch (*Bidyanus bidyanus*) than flows delivered during the cooler period of October–November. This finding is consistent with previous studies on spawning and movement of these two species (O'Connor *et al.* 2005; Roberts *et al.* 2008; King *et al.* 2009, 2010; Zampatti & Leigh 2013), strengthening the argument for consideration of temperature and timing on environmental water targeting these species.

4.1.2 Rate of fall is important for vegetation

The evaluation of vegetation at the Basin scale considered that there was evidence across several Selected Areas that benefits to vegetation diversity may be enhanced by changes to the timing, depth and duration of inundation. In particular, slower recession of water levels would likely enhance germination and growth of inundation-dependent vegetation by prolonging the time that soil moisture conditions are optimal. Most aquatic plants in Australia have the capacity to tolerate a range of habitat conditions associated with cycles of wetting and drying. The capacity of some aquatic plants to deal with the changes associated with drying, however, is limited. The rate of recession influences the depth and area of standing or flowing water habitat as well as soil moisture conditions. For species reliant on the presence of water, such as ribbonweed (*Vallisneria australis*), slower rates of recession enable colonisation of areas further down the bank, as these areas become suitable habitat in terms of depth and light penetration. Rapid rates of recession are likely to strand and desiccate these species prior to colonisation of other potentially suitable habitat. For species reliant on high levels of soil moisture for germination and growth, slower rates of recession prolong the time that soil moisture conditions are optimal, thus increasing the likelihood of successful germination, growth, flowering and seed set. The completion of plant life-cycles is important in ensuring the replenishment of soil seed banks, facilitating an increase in abundance and cover of vegetation through successive flow events.

4.1.3 Fish spawning cues

Comparisons of spawning responses across the Basin for flow cued-spawners, including golden perch, revealed variation in responses to freshes that are difficult to explain with any level of confidence at this time. The collection of additional data over the next 3 years should help reduce this uncertainty. Currently there are six flow characteristics that have been proposed as important in triggering spawning: temperature; rate of increase in discharge; adult condition; current velocity, occurrence of a pre-conditioning fresh; and water source and chemical cues (Appendix F). From an adaptive management perspective, there are two ways that this list may influence future efforts to trigger spawning; first would be to ensure that they are all given some consideration when designing the watering action to try and maximise the chances of success. Second would be to use situations in which constraints limit options to undertake watering actions that would allow the influence of individual factors to be evaluated. The factors that could be evaluated include rate of rise, current velocity, pre-conditioning freshes and the water source. Incorporating these considerations into flow planning will help accelerate learning and improve future outcomes through increased certainty of the influence of different flow characteristics.

4.1.4 Variable water regimes promote biodiversity

At both the wetland and landscape scales, variability in water regime is important for maintaining (and restoring) biodiversity. In the first 2 years of LTIM, this has been evidenced by the responses observed in both vegetation and waterbirds.

At the wetland scale, responses to watering depend, in part, on the prior watering history, with continuous inundation resulting in different responses to those triggered by variable wetting and drying regimes. In many wetlands, repeated or continuous watering over periods longer than 1 year appears likely to generate vegetation communities that are dominated by a few aquatic plant species with relatively high cover. With respect to waterbirds, permanent inundation of wetlands results in fewer species of mostly wetland generalists (e.g. dabbling ducks).

At the landscape scale, vegetation diversity is extremely likely to be enhanced by watering actions that promote spatial variation in water regimes over both the short term (i.e. <1 year) and longer time frames (i.e. variable flow histories). Therefore, to address Basin Plan objectives, annual watering decisions should prioritise actions that increase the diversity of annual and longer term water regimes experienced at both local and regional scales. This might firstly include actions which inundate wetlands and floodplains, where this is possible, that have not been watered for the longest periods. Secondly, maintaining regular watering in at least some wetland areas within each valley may also be important for promoting landscape vegegation heterogeneity and vegetation resilience over the longer term as these wetlands may provide reservoirs of propagules (e.g. vegetative fragments, short-lived seed etc.) which can disperse into other wetland habitats when broader scale wetting occurs, potentially enabling a faster response to re-wetting. Finally, ensuring that some variable wetting and drying regimes are also experienced in landscapes (e.g. allowing some wet areas to dry and vice versa) may generate the greatest vegetation diversity at a landscape (i.e. Selected Area) scale in terms of both species presence and community composition and structure.

4.1.5 Improving native fish condition

The first 2 years of LTIM were characterised by low flows in many parts of the Basin (www.bom.gov.au/water/nwa/; noting this report covers data collected before the large-scale floods of winter–spring 2016). We have presented some evidence that these extended low flow periods may erode condition and survival of Murray cod and golden perch populations. Suppose the models we develop over the next couple of years add confirmation that multi-year low flow periods erode the condition, recruitment and survival of large-bodied native fish populations. If this is the case, then the question arises: what types of watering actions during low flow periods yield the greatest *long-term* (thinking beyond that watering year) outcomes for large-bodied native fishes? During the first 2 years of LTIM, freshes were delivered to promote spawning (e.g. in the Lachlan) but, given the prevailing conditions at the time, perhaps those quantities of water may be better used to maintain flows above the low flow threshold throughout summer, maintaining condition and survival rates of populations. Perhaps freshes are best delivered during years when we do not expect particularly dry summer–autumn periods.

4.2 How can we improve the LTIM Project?

4.2.1 More detailed hydrological information would be beneficial

The availability of hydrological information with respect to watering actions is highly variable and is limiting both the assessments of hydrological outcomes as well as ecological responses. Predicting responses to environmental watering at places that are not monitored is predicated on having information on the key aspects of the water regime that are important to target biota, including aspects such as depth and duration of inundation, and rates of rise and fall at both sites where monitoring data are collected and unmonitored sites. Specific examples from the first 2 years include:

- Documentation of weir pool manipulations in the Murray River is variable; in particular, the hydrological outcomes in terms of the extent and duration of flooding produced by weir pool raising. These should be reported along with an account of the extent to which they are consistent with targeted outcomes for particular habitat types.
- Reporting on hydrological outcomes for wetland watering achieved through pumping or use of weirs and other infrastructure is quite limited. For example, the hydraulic outcomes for watering actions during the 2015–16 year that delivered water into Toogimble Wetlands, Nap Nap Wetland and Sandy Creek in the mid Murrumbidgee Valley are uncertain. Some thought is required to identify hydrological targets for these watering events and then reporting against these targets.

4.2.2 Expected outcomes are needed at multiple scales

Increasingly the CEWO is moving toward coordinated large-scale watering actions that influence multiple assets and rivers. Within the context of this change, it is important that the monitoring and evaluation process be adapted to ensure the adaptive management can be undertaken at this large scale.

Planning for delivery of environmental water is a complex, interactive process with objectives and expected outcomes increasingly being developed at multiple scales. For example, there may be expected outcomes set in a holistic sense for the watering year within a given valley aimed at restoring part of the flow regime. The overarching objective may be to restore part of the winter flow regime in a regulated river system that currently has higher flows in summer due to irrigation deliveries. At the individual site scale, however, there may be more specific expected outcomes, such as providing habitat for frogs, waterbirds or fish.

Currently, the communication of these multiple-scale expected outcomes is imperfect and the full range of expected outcomes that have guided environmental water delivery may not be clear to monitoring teams. This hampers the effectiveness of evaluation and limits the ability of the LTIM project to provide advice on adaptive management of environmental water. Better communication between delivery teams and those reporting on the outcomes of environmental water will improve this in the future.

4.2.3 Setting excepted outcomes for ecosystem types would help our predictive capacity

The increasing focus on multi-scale watering actions discussed above also has implications for the ecological scale of expected outcomes; that is, consideration of ecosystems in addition to species and populations. Understanding how key ecosystem types influence Basin biodiversity, resilience, ecosystem function and ecosystem services paves the way towards delivering Commonwealth environmental water for ecosystem objectives that move beyond counting the ecosystem types watered or whether some types have had watering targets met. This includes, for example, shaping flow regimes to preserve patterns of spatio-temporal variability along a river or delivering water at critical times to maintain life forms or processes *because* they characterise ecosystem types that are to be preserved or improved. Managing to prevent or promote ecosystem turnover to new types may require long-term management frameworks with institutional memory and conviction to stay the course over decadal time scales. The Commonwealth currently does not have 1-year or 5-year expected outcomes for ecosystem diversity but it is hoped that, within the LTIM Project, we can develop thinking towards an appropriate approach to developing draft ecosystem diversity expected outcomes. Current planning that links ecosystem types to water availability scenarios, such as directing water to maintain permanent water systems in dry years, and augmenting overbank flows to the floodplain in wet years, may be a good starting point that is already implicitly considering ecosystem diversity, albeit often without explicit ecosystem outcomes.

4.2.4 Inundation mapping with and without Commonwealth environmental water is crucial

Our ability to evaluate the contribution of Commonwealth environmental water to achieving objectives of the Basin Plan is currently limited by high uncertainty in the fate of water in the landscape after it is released. The volumes in storage and the rates and timing of delivery are well known, but the physical extent of water covering the land and the duration it persists in wetlands and on floodplains is much more poorly understood. In addition, much of the inundation information used in the first 2 years of the LTIM Project was provided by individuals who were willing to share data. This is a significant risk for the program if the activities generating these data are discontinued.

Initial planning for Basin evaluation was contingent on good inundation data both with and without Commonwealth environmental water. The Basin Evaluation Plan considered that for much analysis there would be an assessment of the types and extent of wetlands inundated by Commonwealth environmental water and the use of conceptual modelling to infer ecological responses based on the timing, duration and wetland type inundated (Gawne *et al.* 2014).

In the absence of this information, Basin-scale evaluations for several Basin Matters (Ecosystem Diversity, Vegetation Diversity, Generic Diversity) in 2014–16 are limited. It is expected that ongoing development of the hydrological and ecological information base by Basin jurisdictions will increase the accuracy of Basin-scale evaluations in subsequent years of the LTIM Project.

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 2014–16, 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 4. Contribution of Commonwealth Environmental Water Office (CEWO) watering in 2014–16 to Basin Plan objectives.

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2015–16	Measured and predicted 1–2- year outcomes 2014–16
Biodiversity (Basin Plan S. 8.05)	Ecosystem diversity		None identified	None identified	Total of over 200 000 hectares of mapped wetland inundated. 65% of the different aquatic ecosystem types.	67% of the different aquatic ecosystem types inundated with Commonwealth environmental water.
	Species diversity	Vegetation	Vegetation diversity		Presence of some native species likely to be dependent on inundation by Commonwealth environmental water. Decrease in exotic taxa.	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				
		Fish	Fish diversity	Condition	Comparatively high level of nativeness in fish assemblages.	Comparatively high level of nativeness in fish assemblages. Golden perch, silver perch, Australian smelt, carp gudgeon and bony herring exhibited species-specific responses to flows.
				Larval abundance Reproduction	Spawning by golden perch and bony bream.	Spawning by golden perch and bony bream.
			Larval and juvenile recruitment			
		Waterbirds	Waterbird diversity		Foraging habitat provided at a number of locations, including several large wetland complexes, particularly for shorebirds and other wading species.	Different foraging habitats provided for the full range of waterbird guilds across the 2 years

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2015–16	Measured and predicted 1–2- year outcomes 2014–16
			Waterbird diversity and population condition (abundance and population structure)	Survival and condition		
				Chicks	Some evidence of breeding of waterbird species and small-scale colonial nesting in Barmah–Millewa.	Some evidence of small-scale breeding at several locations: Hattah, Barmah–Millewa, Murrumbidgee.
				Fledglings	Fledgling recorded in nesting birds at Hattah Lakes.	Fledgling recorded in nesting birds at Hattah Lakes.
		Other vertebrate diversity		Young	Limited breeding.	Breeding of frogs at several locations across the 2 years.
			Adult abundance		Foraging habitat provided in several areas.	Foraging habitat provided in several areas.
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 longitudinal fish movement in the Gwydir river system and lateral movement at Hattah Lakes.	Evidence of longitudinal fish movement in the Gwydir river system and lateral movement at Hattah Lakes.
				Sediment transport		
	Process			Primary productivity (of aquatic ecosystems)	Little evidence, under dry conditions, of effects on these processes.	Little evidence, under dry conditions, of effects on these processes.
				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 2 years.

Basin Plan objectives	Basin outcomes		5-year expected outcomes	1-year expected outcomes	Measured and predicted 1-year outcomes 2015–16	Measured and predicted 1–2- year outcomes 2014–16
			Population condition (landscape refuges)			
				Individual condition (ecosystem resistance)	Some evidence of improved condition of vegetation communities and fish populations with a high degree of nativeness.	Some evidence of improved condition of vegetation communities and fish populations with a high degree of nativeness.
			Population condition (ecosystem recovery)			
Water quality (Basin Plan S. 9.04)	Chemical			Salinity		
				Dissolved oxygen		Evidence from the Edward–Wakool of maintained dissolved oxygen.
				pH		
				Dissolved organic carbon		
	Biological			Algal blooms		

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Appendix A – 2015–16 Commonwealth environmental watering actions

Table A1. Watering actions that included Commonwealth environmental water in 2015–16. 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
Lachlan – Great Cumbung Swamp	1516-Lch-01	24,058.50	09/08/15 – 15/10/15	Fresh		P				P	P	S	
Lachlan – Booligal Wetlands – Merrimajeel and Muggabah Creek	1516-Lch-02	1087.50	02/09/15 – 29/10/15	Fresh		P	P			P		S	
Lachlan Booligal wetlands – waterbird contingency	1516-Lch-03	1497.00	29/10/15 – 10/11/15	Fresh			P					S	
Lower Lachlan River channel	1516-Lch-04	9378.50	11/11/15 – 15/12/15	Fresh	P	P	P		P	S			S
Qld Border Rivers – Severn River (Qld)	1516-BrdR-01	22.22	31/01/16 – 01/02/16	Base	P	S				P		P	
QLD Border Rivers – Dumaresq–Macintyre River and Fringing Wetlands	1516-BrdR-02	409.30	26/07/15 – 07/08/15	Fresh	P					P	S	P	
QLD Border Rivers – Dumaresq–Macintyre River and Fringing Wetlands	1516-BrdR-03	234.90	26/08/15	Fresh	P				P	P	S	P	
QLD Border Rivers – Dumaresq–Macintyre River and Fringing Wetlands	1516-BrdR-05	243.50	07/11/15	Fresh	P				P	P	S	P	
QLD Border Rivers – Dumaresq–Macintyre River and Fringing Wetlands	1516-BrdR-04	137.10	01/02/16	Fresh	P				P	P	S	P	
QLD Moonie – Lower Moonie River and Fringing Wetlands	1516-Moon-01	200.98	28/08/15 – 02/09/15	Fresh	S				P	P	P	P	
QLD Condamine–Balonne – Nebine Creek	1516-CndBal-01	997.78	23/06/15 – 27/06/15	Fresh	S	S			S	P	P	P	

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
QLD Condamine–Balonne – Lower Balonne floodplain system	1516-CndBal-02	9454.90	09/02/16 – 16/02/16	Fresh	S				S	P		P	
QLD Warrego – Lower Warrego River and fringing wetlands	1516-Warr-02	859.29	17/01/16 – 19/01/16	Bankfull/ fresh	P					S		P	
NSW Barwon–Darling – Barwon–Darling River and fringing wetlands (Mungindi to Menindee)	1516-BarDar-01	2702.36	01/07/15 – 30/09/15	Fresh						P	S	P	
NSW Barwon–Darling – Barwon–Darling River and fringing wetlands (Mungindi to Menindee)	1516-BarDar-02	3481.13	28/01/16 – 01/03/16	Fresh						P	S	P	
NSW Barwon–Darling – Barwon–Darling River and fringing wetlands (Mungindi to Menindee)	1516-BarDar-03	1456.67	01/06/16 – 30/06/16	Fresh						P	S	P	
Murrumbidgee – Redbank	1516-Mbg-06	25 000.00	21/10/15 – 10/02/16	Wetland	P	P	P						
Murrumbidgee – Yanga National Park waterbird support	1516-Mbg-05	10 000.00	17/11/15 – 11/01/16	Wetland	S		P	S	S		S		
Murrumbidgee – Nimmie Caira	1516-Mbg-03	18 000.00	17/10/15 – 09/02/16	Wetland	P		P	P	P				S
Murrumbidgee – Juanbung	1516-Mbg-07	10 000.00	04/11/15 – 17/02/16	Wetland		P	S	S					
Murrumbidgee – Hobblers Lake – Penarie Creek	1516-Mbg-01	5000.00	08/03/16 – 29/03/16	Fresh	S	S	S	S	P		P		
Murrumbidgee – Yarradda Lagoon	1516-Mbg-02	1394.30	02/09/15 – 20/12/15	Wetland	P	P	S	P					
Murrumbidgee – Yanco Creek Wetland inundation	1516-Mbg-13	18 263.00	21/07/15 – 13/08/15	Wetland	S	P	S		S	P	S		
Murrumbidgee – Yanco Creek trout cod supoort flow	1516-Mbg-04	8075.00	15/10/2015 – 11/11/15	Fresh	P								
Murrumbidgee – Waldaira Wetlands (Junction Wetlands)	1516-Mbg-08	2000.00	09/02/16 – 30/06/16	Wetland		P	S	S					
Murrumbidgee – Toogimbie IPA	1516-Mbg-09	933.00	15/03/16 – 01/05/16	Wetland		P	S	P					
Murrumbidgee – Nap Nap – Wagourah	1516-Mbg-12	7000.00	06/05/16 – 30/06/16	Wetland		P	P	P					

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Murrumbidgee – Nap Nap – Wagourah	1516-Mbg-11	2557.00	06/05/16 – 30/06/16	Wetland		P	P	P					
Murrumbidgee – Sandy Creek	1516-Mbg-10	105.00	01/04/16 – 30/06/16	Wetland									
Edward–Wakool – Colligen–Niemur system	1516-EdWak-03	15,740.00	04/09/15 – 30/01/16	Base flow and Fresh		P							
Edward–Wakool – Upper Wakool River	1516-EdWak-02	1444.90	04/09/15 – 30/01/16	Base flow and fresh	P	P							
Edward–Wakool – Yallakool Creek	1516-EdWak-01	13,004.10	04/09/15 – 30/01/16	Base flow and fresh	P	P							
Edward–Wakool – Tuppal Creek	1516-EdWak-04	2000.00	17/09/15 – 22/11/15	Base flow and fresh		P				P			P
Goulburn – Lower River Channel	1516-Gbn-01	190,563.00	01/07/15 – 08/07/15	Fresh		P					S		
Goulburn – Lower River Channel	1516-Gbn-02		09/07/15 – 02/10/15	Base flow	P				P	P	S		P
Goulburn – Lower River Channel	1516-Gbn-03		03/10/15 – 29/10/15	Fresh	S	P					S		
Goulburn – Lower River Channel	1516-Gbn-04		30/10/15 – 12/03/16	Base flow	P				P	P	S		P
Goulburn – Lower River Channel	1516-Gbn-06		06/04/16 – 30/06/16	Base flow	P				P	P	S		P
Goulburn – Lower River Channel	1516-Gbn-05		15/03/16 – 05/04/16	Base flow		P					S		
Ovens River – Buffalo River	1516-Ovn-02	20.00	25/04/16 – 26/04/16	Base flow	P				P		P		
Ovens River – King River	1516-Ovn-01	50.00	05/04/16 – 07/05/16	Base flow	P				P		P		
Loddon reach 4	1516-Ldn-01	1476.70	24/08/15 – 07/09/15	Fresh	P								
Lower Murray and Coorong	1516-SA-01	556 000.00	01/07/15 – 30/11/15	Base flow	P	P	P						P
Lower Murray and Coorong	1516-SA-02	242 000.00	01/12/15 – 01/07/16	Base flow	P	P	P						P
Lower Murray – Banrock Station – Herons Bend	1516-Brock-01	20.41	10/11/15 – 27/11/15	Wetland	P	P	P						
Lower Murray – Banrock Station – Banrock Bend	1516-Brock-04	15.48	03/12/15 – 18/12/15	Wetland	P	P	P						
Lower Murray – Banrock Station – Wigley Reach Central	1516-Brock-05	52.49	20/01/16 – 01/02/16	Wetland	P	P	P						

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray – Banrock Station – Wigley Reach Depression	1516-Brock-02	571.91	10/11/15 – 18/01/16	Wetland	P	P	P						
Lower Murray – Banrock Station – Eastern Lagoon	1516-Brock-03	1340.43	17/11/15 – 11/03/16	Wetland	P	P	P						
Lower Murray wetlands (NRM Board) – Berri Evaporation Basin	1516-NRMB-03	1255.00	25/09/15 – 30/06/16	Wetland	P								
Lower Murray wetlands (NRM Board) – Bookmark Creek	1516-NRMB-01	424.00	25/08/15 – 30/06/16	Wetland		P	P						
Lower Murray wetlands (NRM Board) – Martin Bend	1516-NRMB-02	56.00	31/08/15 – 03/09/15	Wetland		P							
Lower Murray wetlands (NRM Board) – Old Parcoola (West)	1516-NRMB-04	353.00	30/09/15 – 28/11/15	Wetland		P	P						
Lower Murray wetlands (NRM Board) – Piggy Creek	1516-NRMB-06	201.00	20/10/15 – 05/11/15	Wetland		P	P						
Lower Murray wetlands (NRM Board) – Carpark Lagoons	1516-NRMB-07	229.00	21/10/15 – 31/01/16	Wetland		P	P						
Lower Murray wetlands (NRM Board) – Molo Flat (Western and Eastern channels)	1516-NRMB-05	105.00	08/10/15 – 21/10/15	Wetland		P							
Lower Murray wetlands (NRM Board) – Wiela	1516-NRMB-08	375.00	04/11/15 – 11/12/15	Wetland		P							
Lower Murray wetlands (NRM Board) – Hogwash Bend North	1516-NRMB-10	28.00	14/01/16 – 06/04/16	Wetland		P	P						
Lower Murray wetlands (NRM Board) – Hogwash Bend South	1516-NRMB-12	420.00	20/01/16 – 18/02/16	Wetland		P	P						
Lower Murray wetlands (NRM Board) – Morgan East	1516-NRMB-09	200.00	12/11/15 – 30/01/16	Wetland		P		P					
Lower Murray wetlands (NRM Board) – Morgan Conservation Park Bird & Meeting Lagoons	1516-NRMB-11	306.00	11/01/16 – 29/04/16	Wetland		P	P						

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray wetlands (NRM Board) – Maize Island Conservation Park	1516-NRMB-14	213.00	04/02/16 – 24/04/16	Wetland		P	P						
Lower Murray wetlands (NRM Board) – Yabby Creek	1516-NRMB-13	1290.00	10/03/16 – 18/05/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Lyrup Lagoon	1516-NFSA-01	284.00	01/09/15 – 30/01/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Mundic Wetland	1516-NFSA-02	104.00	01/10/15 – 30/11/15	Wetland		P	P						
Lower Murray wetlands (NFSA) – Duck Hole	1516-NFSA-03	271.00	01/10/15 – 30/11/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Inner Mundic Creek	1516-NFSA-04	42.00	01/11/15 – 30/11/15	Wetland		P	P						
Lower Murray wetlands (NFSA) – Johnson's Waterhole	1516-NFSA-05	117.00	01/09/15 – 30/04/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – South Teringie	1516-NFSA-06	79.00	01/12/15 – 30/05/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Calperum Station	1516-NFSA-07	837.00	01/11/15 – 30/06/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Lescheid Pikes	1516-NFSA-08	19.00	01/12/15 – 30/12/15	Wetland		P	P						
Lower Murray wetlands (NFSA) – Loxton Riverfront Reserve	1516-NFSA-09	19.00	01/08/15 – 30/05/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Clark's Floodplain	1516-NFSA-10	105.00	01/08/15 – 30/03/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Waikerie Ferry	1516-NFSA-11	6.00	01/12/15 – 30/01/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Yarra Creek	1516-NFSA-12	593.00	01/10/15 – 30/01/16	Wetland		P	P	P					

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray wetlands (NFSA) – Thiele's Flat	1516-NFSA-13	43.00	01/08/15 – 30/03/16	Wetland		P							
Lower Murray wetlands (NFSA) – Rilli Reach – Stanitzkis	1516-NFSA-14	27.00	01/11/15 – 30/05/16	Wetland		P							
Lower Murray wetlands (NFSA) – Westbrooks	1516-NFSA-15	14.00	01/10/15 – 30/04/16	Wetland		P							
Lower Murray wetlands (NFSA) – Rilli Reserve	1516-NFSA-16	2.00	01/08/15 – 30/09/15	Wetland		P							
Lower Murray wetlands (NFSA) – Riversleigh	1516-NFSA-17	569.00	01/01/16 – 30/06/16	Wetland		P		P					
Lower Murray wetlands (NFSA) – Greigers @ Sugar Shack	1516-NFSA-18	59.00	01/12/15 – 30/04/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Greenways	1516-NFSA-19	39.00	01/02/16 – 30/03/16	Wetland		P	P						
Lower Murray wetlands (NFSA) – Warnoch Lescheid	1516-NFSA-20	32.00	01/02/16 – 30/02/16	Wetland		P	P						
Campaspe – Reach 4	1516-Cmpe-01	1700.00	26/08/15 – 06/09/15	Fresh	P	P			P				P
Campaspe – Reach 4	1516-Cmpe-02	1588.70	27/10/15 – 04/11/15	Fresh	P	P			P				P
Lower Broken Creek – Reach 3	1516-Brkn-01	29 519.50	12/08/15 – 22/05/16	Base flow	P	S							
Lower Broken Creek – Reach 3	1516-Brkn-02		18/08/15 – 30/11/16	Base flow	S	S							P
Lower Broken Creek – Reach 3	1516-Brkn-04		01/10/15 – 16/05/16	Base flow	S	S							P
Lower Broken Creek – Reach 3	1516-Brkn-03		18/08/15 – 12/09/15 28/09/15 – 30/11/15	Fresh	S	S							P
Lower Broken Creek – Reach 3	1516-Brkn-05		25/10/15 – 09/11/15 29/11/15 – 31/12/15	Base flow	S	S				P			
Mid Murray – River Murray Channel	1516-Mur-01	99 400.00	22/06/15 – 24/07/15	Base flow	P	P				P	P		
Mid Murray – River Murray Channel	1516-Mur-03	172 600.00	25/07/15 – 10/09/15	Overbank	P	P	P			P			

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Mid Murray – River Murray Channel, Barmah and Millewa	1516-Mur-04	63 900.00	11 /09/15 – 03/10/15	Overbank	P	P	P			P			
Mid Murray – River Murray Channel, Barmah and Millewa	1516-Mur-05	30 900.00	04/10/15 – 31/10/15	Overbank	P	P	P			P			
Mid Murray – Gulpa Creek and Reed Beds Swamp (Millewa Forest)	1516-Mur-07	8000.00	11 /11/15 – 10/02/16	Overbank		P	S						
Mid-Murray – Gunbower Creek	1516-Mur-02	13 606.00	01/07/15 – 30/06/16	Base flow	P					P			P
Mid Murray Valley – Wingillie Station	1516-Mur-06	192.00	09/10/15 – 17/10/15	Wetland		P	P	P	P				
Mid Murray Valley – Carrs, Capitts and Bunberoo Creek System	1516-Mur-09	950.00	04/04/16 – 16/05/16	Wetland		P	P	P					P
NSW Murray – Barham Lake	1516-Mur-08	115.00	19/01/16 – 7/03/16	Wetland	P	P	P	P					
Lower Murray – Lock 15	1516-Weir-01	5249.00	01/07/15 – 30/12/15 01/04/16 – 30/06/16	Fresh	P	P	S			P	S		
Lower Murray – Lock 9	1516-Weir-02	0.00	01/10/15 – 30/02/16	Fresh	P	P				P	S		
Lower Murray – Lock 8	1516-Weir-03	0.00	01/12/15 – 30/05/16	Fresh	P	P				P	S		
Lower Murray – Lock 7	1516-Weir-04	2739.00	01/08/15 – 30/01/16 01/01/16 – 30/05/16	Fresh	P	P	S			P	S		
Lower Murray – Lock 5	1516-Weir-05	4346.00	01/08/15 – 30/11/15	Fresh	P	P	S			P	S		
Lower Murray – Lock 2	1516-Weir-06	738.00	01/09/15 – 30/11/15	Fresh	P	P	S			P	S		
Macquarie – Macquarie Marshes	1516-Macq-01	12 114.00	06/08/15 – 17/10/15	Fresh	P	P	S		S	S	S		
Macquarie – Macquarie River System, including floodplain	1516-Macq-02	2125.00	25/06/16 – 30/06/16	Fresh	P	P	P	P	P	P	P		
Gwydir – Gwydir Wetlands	1516-Gwyd-01	1350.00	09/01/16 – 11/02/16	Overbank	S	P	S		S	S	S		
Gwydir – Mallowa Wetlands	1516-Gwyd-02	3150.00 336.00	09/11/15 – 05/02/16	Overbank		P	S		S	P			
Gwydir – Mehi River	1516-Gwyd-03	964.00	09/11/15 – 11/11/15	Fresh	P					S	P	S	

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected outcomes (P = primary; S = secondary)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Gwydir – Gwydir River System	1516-Gwyd-04	2600.00	10/04/16 – 30/05/16	Base flow	P	S	S		S	P	S	P	
Lower Murray – Mallee wetland Sites – Brickworks Billabong	1516-VicW-01	200.00	01/10/15 – 30/11/15 09/03/16 – 03/06/16	Wetland	P	P			S			P	P
Lower Murray – Mallee wetland Sites – Cardross Wetlands	1516-VicW-02	476.61	09/09/15 – 24/12/15	Wetland	P	P			S			P	P
Lower Murray – Mallee wetland Sites – Cowanna Billabong	1516-VicW-03	125.00	10/06/15 – 30/11/15	Wetland		P			S				
Lower Murray – Hattah Lakes	1516-HattL-01	5347.50	12/10/15 – 23/10/15	Wetland	P	P	P		S	P	S		

Appendix B – 2015–16 Basin-scale evaluation of Commonwealth environmental water – Hydrology report

Appendix C – 2015–16 Basin-scale evaluation of Commonwealth environmental water – Stream Metabolism & Water Quality report

Appendix D – 2015–16 Basin-scale evaluation of Commonwealth environmental water – Ecosystem Diversity report

Appendix E – 2015–16 Basin-scale evaluation of Commonwealth environmental water – Vegetation Diversity report

Appendix F – 2015–16 Basin-scale evaluation of Commonwealth environmental water – Fish report

Appendix G – 2015–16 Basin-scale evaluation of Commonwealth environmental water – Generic Diversity report