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

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Final Report

MDFRC Publication 147/2017

2015–16 Basin-scale evaluation of Commonwealth Environmental Water — Generic Diversity

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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Report Citation: Hale J (2017) 2015–16 Basin-scale evaluation of Commonwealth environmental water – Generic Diversity. Final Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre, MDFRC Publication 147/2017, September, 61pp.

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Document history and status

Version	Date Issued	Reviewed by	Approved by	Revision type
Draft	10 July 2017	Ben Gawne	Ben Gawne	Internal
Draft	11 July 2017	Jenny Hale	Penny Everingham	Internal
Draft	11 July 2017	CEWO & M&E Providers		External
Draft	1 August 2017	Jenny Hale	Penny Everingham	Internal
Draft	14 August 2017	Mary Webb	Jenny Hale	External
Final	27 September 2017	Jenny Hale	Penny Everingham	Internal

Distribution of copies

Version	Quantity	Issued to
Draft	1 x PDF 1 x Word	CEWO and M&E Providers
Final	1 x PDF 1 x Word	Paul Marsh, Sam Roseby and Andrew Lowes

Filename and path: Projects\CEWO\CEWH Long Term Monitoring Project\499 LTIM Stage 2 2014-19 Basin evaluation\Final Reports

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Project Manager: Ben Gawne

Client: Commonwealth Environmental Water Office

Project Title: Basin evaluation of the contribution of Commonwealth environmental water to the environmental objectives of the Murray–Darling Basin Plan

Document Version: Final

Project Number: M/BUS/499

Contract Number: PRN 1213-0427

Acknowledgements:

This project was undertaken using data collected for the Commonwealth Environmental Water Office Long Term Intervention Monitoring project. The assistance provided by the Monitoring and Evaluation Providers into interpretation of data and report review is greatly appreciated. The authors would also like to thank all Monitoring and Evaluation Provider staff involved in the collection and management of data.

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 Introduction

The Murray–Darling Basin (the Basin) contains over 200,000 aquatic ecosystems, including approximately 8000 lakes and 34 000 floodplain wetlands (Brooks *et al*. 2014). Sixteen wetlands of international importance, listed under the Ramsar Convention, are within the Basin, as are over 200 nationally important wetlands (Leblanc *et al.* 2012). These ecosystems support a broad range of species and ecological communities that are inundation dependent, or dependent on vegetation communities that are classified as wetland or floodplain systems. The Basin's aquatic ecosystems also support a large number of nationally and internationally significant plant and animal species, including 95 species listed as threatened under national or state legislation (Leblanc *et al.* 2012).

One objective of the Basin Plan is to protect or restore biodiversity that is dependent on the Basin's water resources. This is achieved through supporting listed threatened species or listed threatened ecological communities and ensuring that representative populations and communities of native biota are protected and, if necessary, restored (Basin Plan, section 8.05(3)).

Species and communities can be dependent on water regimes for all or parts of their life-cycle. Most of the aquatic ecosystem-dependent biota within the Basin are adapted to cycles of wetting and drying, with many important breeding, migration or germination cues linked to water regime (Brock & Casanova 1997; Young *et al.* 2001; Roberts & Marston 2011). In a climate of increasing pressures on water resources, environmental watering actions can play a crucial role in maintaining species and ecosystem diversity (Brandis 2010; Beesley *et al.* 2011).

The Generic Diversity component of the Commonwealth Environmental Water Office's (CEWO's) Long Term Intervention Monitoring (LTIM) Project aims to evaluate the contribution of Commonwealth environmental water to achieving diversity-related objectives of the Basin Plan. This is accomplished through the consolidation of information from multiple sources to provide a summary of species and communities that potentially benefited from Commonwealth environmental water to address the following evaluation question:

- What did Commonwealth environmental water contribute to species diversity?
  - How did Commonwealth environmental water affect the presence, distribution and abundance of plant, fish, waterbird, frog, turtle and aquatic ecosystem dependent mammal species?
  - What listed threatened species and ecological communities benefited from Commonwealth environmental water?
  - What migratory species listed under international agreements (Bonn Convention, CAMBA, JAMBA or ROKAMBA) benefited from Commonwealth environmental water?

1.1 Summary of water actions in 2015–16 with expected outcomes for biota

Commonwealth environmental water contributed to 115 watering actions in the 2015–16 with expected outcomes related to aquatic ecosystem dependent plant and vertebrate species (Annex A). Of these, 60 watering actions had expected outcomes for fish; 91 for plant species or vegetation communities; 62 for waterbirds, 16 for frogs, 2 for reptiles and 2 for mammals (platypus). Monitoring of waterbirds, frogs and turtles in 2015–16 occurred across four Selected Areas – Lachlan river system, Murrumbidgee river system, Gwydir river system and the Junction of the Warrego and

Darling rivers (Table 1). In addition, 8 watering actions were monitored for vegetation (see Capon & Campbell 2017) and 16 for fish (see Stoffels *et al*. 2017).

Table 1. Summary of monitored watering actions related to waterbird, frog and turtle diversity at Selected Areas in 2015–16.

Selected Area (watering action number)	Dates[1]	Commonwealth environmental water volume (ML)[1]	Flow component[1]	Expected ecological outcome[1]	Monitored site(s)[2]	Observed ecological outcome[2]	Influences[2]
Lachlan (1516-Lch-01)	09/08/15 – 15/10/15	24 058.50	Fresh	Secondary: Support the ongoing recovery and resilience of the Great Cumbung Swamp if conditions continue, by providing drought refuge	Great Cumbung Swamp (4 sites)	4 species of frog recorded and all attempted breeding	Duration and extent of inundation favoured breeding
Lachlan (1516-Lch-02)	02/09/15 – 29/10/15	1087.50	Fresh	Secondary: Support the ongoing recovery and resilience of Murrumbidgil Swamp if dry conditions continue, by providing drought refuge	Booligal wetlands (10 sites)	4 species of frog recorded; 2 species recorded breeding	Short duration of inundation limited breeding, particularly for summer breeding species
Murrumbidgee (1516-Mbg-02)	02/09/15 – 20/12/15	1394.30	Wetland	Primary: Support known frog community established in 2014–15	Yarrada Lagoon	6 frog species recorded, high abundance Southern bell frog, calling, tadpoles and metamorphs recorded 2 species of turtle recorded	Percentage of the wetland inundated had a strong effect on calling activity
				Secondary: Provide feeding habitat for waterbirds	Yarrada Lagoon	22 species of waterbird recorded; 3 species breeding	
Murrumbidgee (1516-Mbg-03)	17/10/15 – 09/02/16	18 000.00	Wetland	Primary: Support the habitat requirements of southern bell frogs	Nimmie-Caira	6 species of frog recorded, including southern bell frog	
				Primary: Maintain refuge habitat for a diverse range of turtles	Nimmie-Caira	1 species of turtle recorded	
				Primary: Maintain refuge habitat for a diverse range of native waterbirds Support potential waterbird breeding in Eulimbah (Australasian bitterns and spoonbills)	Nimmie-Caira	33 species of waterbird recorded, including the endangered Australasian bittern Abundance dominated by dabbling ducks, followed by fish-eating species	

Selected Area (watering action number)	Dates[1]	Commonwealth environmental water volume (ML)[1]	Flow component[1]	Expected ecological outcome[1]	Monitored site(s)[2]	Observed ecological outcome[2]	Influences[2]
						Small-scale colonial nesting waterbird breeding	
Murrumbidgee (1516-Mbg-05)	17/11/15 – 11/01/16	10 000.00	Wetland	Secondary: Provide habitat for frogs	Yanga National Park	5 frog species recorded	
				Secondary: Provide habitat for other vertebrates	Yanga National Park	1 species of turtle recorded	
				Primary: To support identified waterbird (egret) breeding event	Yanga National Park	24 species of waterbird recorded	Inundation outside preferred breeding window, small-scale watering
Murrumbidgee (1516-Mbg-11 1516-Mbg-12)	06/05/16 – 30/06/16	7000.00 2557.00	Wetland	Primary: Support the habitat requirements of southern bell frogs	Nap Nap – Wagourah	6 species of frog recorded, including southern bell frog 2 species of turtle recorded	Insufficient duration of inundation to support breeding
				Primary: Support potential waterbird breeding in 2016–17 by improved habitat condition	Nap Nap – Wagourah	7 species of waterbird recorded	Inundation outside preferred breeding window, small-scale watering
Gwydir (1516-Gwyd-01)	09/01/16 – 11/02/16	1350.00	Overbank	Secondary: Provide refuge habitat for waterbirds, fish and other aquatic species	Gwydir Wetlands	22 species of waterbird recorded Low levels of waterbird breeding activity 5 species of frog recorded	Drying phase in multi-watering year strategy
Gwydir (1516-Gwyd-02)	09/11/15 – 05/02/16	3150.00	Overbank	Secondary: Provide refuge habitat for waterbirds and other aquatic species	Mallowa Wetlands	29 species of waterbird recorded	Drying phase in multi-watering year strategy
Gwydir (1516-Gwyd-04)	10/04/16 – 30/05/16	2600.00	Baseflow	Secondary: Provide refuge habitat for waterbirds, fish and other aquatic species	Gingham Wetlands	49 species of waterbird recorded Low levels of waterbird breeding activity	Drying phase in multi-watering year strategy

Selected Area (watering action number)	Dates[1]	Commonwealth environmental water volume (ML)[1]	Flow component[1]	Expected ecological outcome[1]	Monitored site(s)[2]	Observed ecological outcome[2]	Influences[2]
						6 species of frog recorded	
Junction of Warrego and Darling	01/07/15 01/11/15 01/06/16	0		Primary: Maintain waterbird habitat	Boera Dam Booka Dam Western Floodplain	32 species of waterbird recorded; 3 species with evidence of breeding 3 species of frog recorded	Low levels of water inflowing; no significant watering of Western Floodplain.

[1] As reported by the Commonwealth Environmental Water Office (CEWO).

[2] As reported by the Monitoring and Evaluation (M&E) team for each Selected Area in Selected Area reports for 2015–16.

2 Methods

2.1 General approach

The main output of the Generic Diversity evaluation is an aggregated list of species and communities that potentially benefited from Commonwealth environmental water each year. This list has been derived from a number of sources, including: other Basin Matter reports, Selected Area reports, and other monitoring programs (external to LTIM).

Determining if a species or community benefited from Commonwealth environmental water is not straightforward. The presence of a species at a site that received Commonwealth environmental water does not necessarily indicate that the species benefited, nor does it provide any indication of the temporal or spatial scale over which that species may have benefited. The Generic Diversity Basin Matter undertakes a qualitative evaluation of expected outcomes of watering actions undertaken by CEWO. The approach uses information from different sources to identify species that potentially benefited from Commonwealth environmental water. The sources of information include (Figure 1):

- evaluations from other Basin Matters (Vegetation, Fish, Ecosystem Diversity)
- monitoring at Selected Areas
- monitoring/observations at sites watered but not monitored
- a case study approach for wetlands that are nationally or internationally recognised as important (i.e. listed on the Directory of Important Wetlands in Australia (DIWA) or under the Ramsar Convention).

General information about a species life-history or habitat requirements and broad assumptions about the hydraulic outcomes are used to infer benefit. Increased confidence in the assessment that a species or community benefited from environmental water is assigned as a result of repeated observations over space and time. That is, as a species or community is observed at sites that receive Commonwealth environmental water at different locations in the Basin and in multiple years, confidence that the species benefited from environmental water is increased.

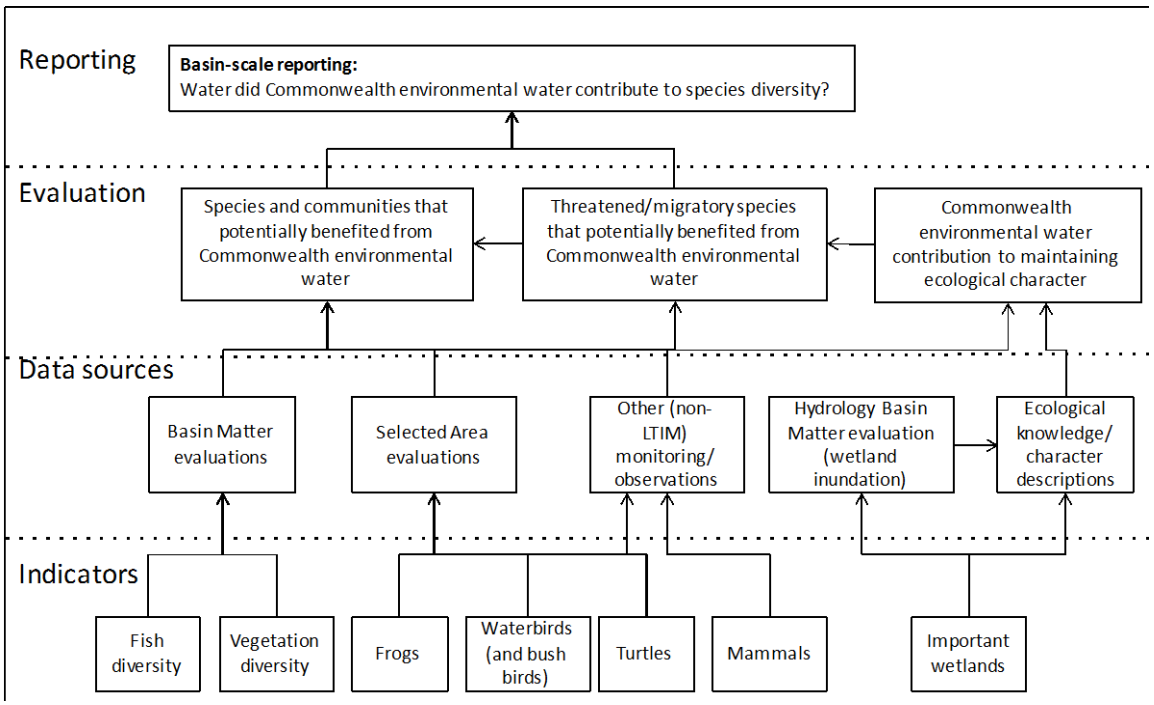

Figure 1. Basin evaluation of generic diversity.

2.2 Other Basin Matters

The effects of Commonwealth environmental water on vegetation, fish and ecosystem diversity have been evaluated as other Basin Matters (Brooks 2017; Capon & Campbell 2017; Stoffels *et al.* 2017). These evaluations adopted different approaches and methods for assessing the effect of Commonwealth environmental water, which are documented in each report. Species and communities that were identified in each of these evaluations as benefiting (or potentially benefiting) from Commonwealth environmental water have been extracted and included in the aggregated list of species in Annex B.

2.3 Waterbirds, frogs, turtles and mammals

2.3.1 Selected Area outcomes

In the 2015–16 watering year, several Selected Areas were monitored for waterbirds, frogs and/or turtles (Figure 2) (noting that aquatic ecosystem–dependent mammals were not included in any LTIM monitoring):

- Gwydir river system – waterbirds, frogs
- Lachlan river system – frogs
- Murrumbidgee river system – waterbirds, frogs and turtles
- Junction of the Warrego and Darling rivers – waterbirds and frogs.

Information collected from Selected Area monitoring has been reviewed and summarised to identify species that potentially benefited from Commonwealth environmental water in 2015–16.

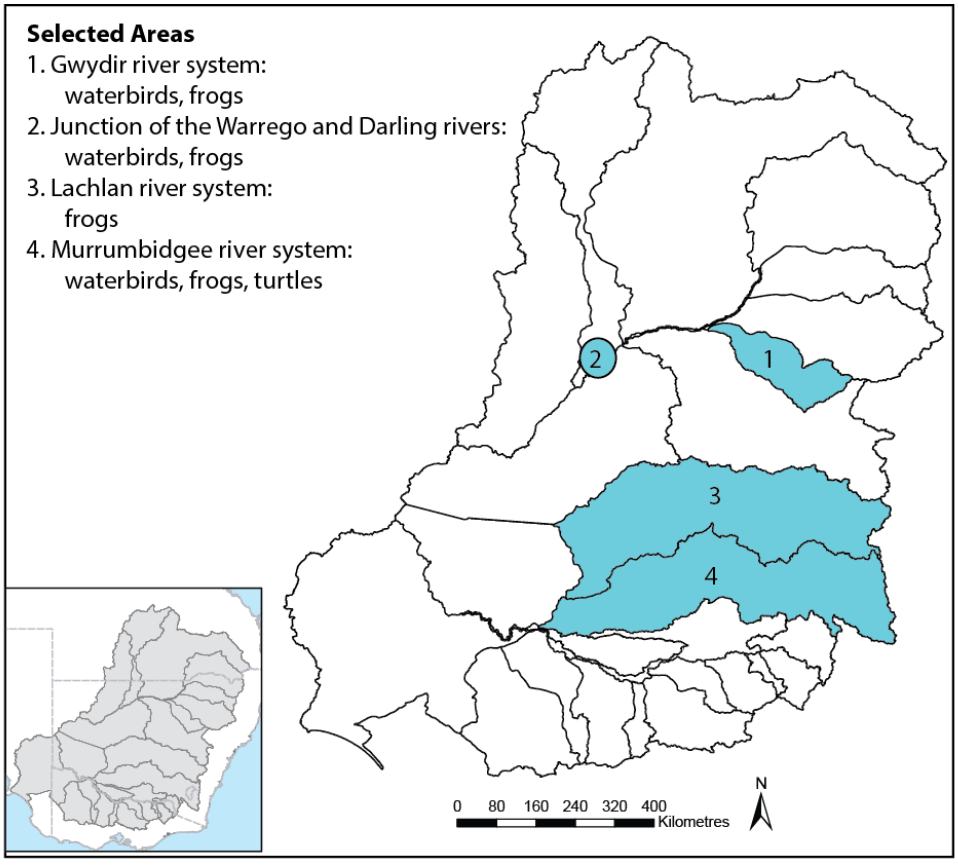

Figure 2. Locations of Selected Area monitoring for waterbirds, frogs and turtles 2015–16.

2.3.2 Unmonitored sites

In this report 'unmonitored' refers to sites that received Commonwealth environmental water, but were not measured as part of LTIM. These sites had varying degrees of information available relevant to ecological responses to watering. There are sites that were monitored under state or Murray–Darling Basin Authority (MDBA) programs (e.g. The Living Murray program); sites at which there are observations documented in CEWO acquittal reports (unpublished); and sites at which there may be general information available on the species likely to be present, but at which no direct information related to the ecological outcomes of environmental watering could be sourced.

Where information on the effects of environmental watering in the 2015–16 watering year was available, this has been extracted and aggregated into a list of species and communities for each aquatic ecosystem.

In addition, several case studies have been explored for internationally recognised Ramsar wetland sites, and nationally recognised wetlands listed in DIWA. These sites are identified as being significant at national or international scales because of the species and communities they support. They are some of the most diverse and species-rich wetlands in the Basin. As case studies, they provide examples of the benefits of environmental watering and contributions to meeting Basin Plan objectives for both diversity and for maintaining the ecological character of Ramsar wetlands.

For case study sites, information related to the watering action, known species and habitats at the site and any complementary monitoring data were used to evaluate the effects of the watering action through the following questions:

- What was the expected outcome?
- What information is available about the watering action?
- What evidence is available to evaluate the outcome?
- What species and communities potentially benefited from Commonwealth environmental water?

3 Synthesis of Selected Area outcomes (waterbirds, frogs and turtles)

3.1 Highlights

- Smaller volumes of water were delivered to wetlands in the Gwydir river system and Murrumbidgee river system Selected Areas in 2015–16 than the previous watering year. Despite the decreases in extent and duration of inundation in these two Selected Areas, waterbird diversity in terms of species richness increased and all waterbird functional guilds were represented.
- Shallow water in the Gwydir system provided feeding habitat for Australian and internationally migratory waterbirds, including five species listed under international agreements.
- The nationally listed endangered Australasian bittern (*Botaurus poiciloptilus*) was recorded at wetlands in the Murrumbidgee river system that received Commonwealth environmental water.
- There was some small-scale colonial nesting waterbird breeding activity at sites that received Commonwealth environmental water in the Murrumbidgee system.
- The nationally listed vulnerable southern bell frog (*Litoria raniformis*) was recorded in wetlands in both the Lachlan river system and Murrumbidgee system at sites that received Commonwealth environmental water, with some evidence of breeding.

Information on waterbirds, frogs and turtles from monitoring within the Selected Areas is summarised in Table 1.

3.1.1 Waterbirds

Waterbirds were monitored in three Selected Areas in both 2014–15 and 2015–16; Murrumbidgee river system, Gwydir river system and the Junction of the Warrego and Darling rivers. A total of 65 wetland-dependent species were recorded across the 2 years (Table 2). This included several species that are listed as threatened. The nationally listed endangered Australasian bittern was recorded at wetlands in the Murrumbidgee that received Commonwealth environmental water. Three species listed as vulnerable in New South Wales (NSW) were also recorded: brolga (*Grus rubicunda*), freckled duck (*Stictonetta naevosa*) and magpie goose (*Anseranas semipalmata*). In addition, a number of species listed under international migratory bird agreements were present at sites that received Commonwealth environmental water, including seven species that are part of the East Asian–Australasian Flyway.

Twelve of the 65 species were recorded in sites that received Commonwealth environmental water in all three Selected Areas across both years, including several species of duck, black swans (*Cygnus atratus*), Eurasian coot (*Fulica atra*), Australian pelican (*Pelecanus conspicillatus*), Australian white ibis (*Threskiornis molucca*) and white-faced heron (*Egretta novaehollandiae*). By contrast, 13 species were recorded at only 1 Selected Area and in 1 year. This list includes four species of international migratory shorebirds, the two Australian bittern species, black-necked stork (*Ephippiorhynchus asiaticus*) and spotless crake (*Porzana tabuensis*).

Table 2. Maximum counts of aquatic ecosystem–dependent waterbirds recorded in Selected Area monitoring at sites that received Commonwealth environmental water in 2014–15 (Yr1) and 2015–16 (Yr2). Shaded cells indicate evidence of breeding.

Functional group	Species	Gwydir		Murrumbidgee		Warrego–Darling		Significance[1]
		Yr1	Yr2	Yr1	Yr2	Yr1	Yr2	
Australian shorebirds	Australian pratincole		1		1			
	Black-fronted dotterel	16	12			6	14	
	Black-winged stilt	4	14		2	1	7	
	Masked lapwing	12	20	2	2	3	4	
	Red-capped plover						8	
	Red-kneed dotterel	3	11				16	
	Red-necked avocet		8				3	
Migratory shorebirds	Black-tailed godwit		2					J, C, R
	Common greenshank	1	1					J, C, R
	Common sandpiper						1	J, C
	Latham's snipe	19	2					J, R
	Marsh sandpiper		31					J, C, R
	Sharp-tailed sandpiper	13	20					J, C, R
	Wood sandpiper						1	J, C, R
Dabbling ducks	Australasian shoveler	2		6		3	2	
	Chestnut teal		2					
	Freckled duck					1	1	V (NSW)
	Grey teal	137	89	312	383	97	130	
	Pacific black duck	203	77	52	100	73	10	
	Pink-eared duck	6	11	259	16	23	35	
Diving ducks	Black swan	5	2	57	31	2	3	
	Dusky moorhen		4		3			
	Eurasian coot	83	14	204	575	3	2	
	Hardhead		20	32	16	44		
Grazing ducks	Australian shelduck			3	2			
	Australian wood duck	32	58	38	23	15	42	
	Magpie goose	176	1					V (NSW)
	Plumed whistling-duck	399	80				8	
	Wandering whistling-duck	7						
Fishers	Australasian bittern				2			E (EPBC)
	Australasian darter	12	5		19	21	2	
	Australasian grebe	12	5	45	20	6		
	Australian little bittern	1						

Functional group	Species	Gwydir		Murrumbidgee		Warrego–Darling		Significance[1]
		Yr1	Yr2	Yr1	Yr2	Yr1	Yr2	
	Australian pelican	10	21	64	20	8	14	
	Cattle egret	20	168					
	Eastern great egret	19	10	4	32	2	1	J
	Great cormorant	5	7	38	65			
	Hoary-headed grebe	2		110	24	8	5	
	Intermediate egret	107	10		16			
	Little black cormorant	61	25	21	75	1		
	Little egret	2			4	1		
	Little pied cormorant	19	100	17	56			
	Nankeen night-heron		1	5				
	Pied cormorant	5	4		1		3	
	Red-backed kingfisher						2	
	Sacred kingfisher	3	3	2	2	2	3	
	Whiskered tern	2	2		120		1	
	White-faced heron	23	11	2	4	4	2	
	White-necked heron	29	17		4	4	1	
Large wading birds	Australian white ibis	60	43	10	135	5	1	
	Black-necked stork		1					E (NSW)
	Brolga	22	3			4	2	V (NSW)
	Glossy ibis	40	101					
	Royal spoonbill		21		12	6		
	Straw-necked ibis	120	65	40	28	29		
	Yellow-billed spoonbill	11	8		16	4	5	
Crakes and rails	Black-tailed native-hen	10			36		27	
	Purple swamphen	10	5		8			
	Spotless crake		1					
Raptors	Swamp harrier	4	1		3			
	White-bellied sea-eagle	2		2	2		1	C
Other wetland species	Australian reed warbler	20	16		6			
	Golden-headed cisticola	11	20		1			
	Little grassbird	4	3		1	2		
	Tawny grassbird	3						

[1] C = CAMBA (China–Australia Migratory Bird Agreement); J = JAMBA (Japan–Australia Migratory Bird Agreement); R = ROKAMBA (Republic of Korea – Australia Migratory Bird Agreement); E (EPBC) = endangered under national legislation (*Environment Protection and Conservation Act 1999*); E (NSW) = endangered under New South Wales (NSW) state legislation; V (NSW) = vulnerable under NSW state legislation.

Species richness varied across the Selected Areas and the 2 years, but was greatest in the Gwydir river system (Figure 3). The number of aquatic ecosystem–dependent bird species increased in each of the Selected Areas from 2014–15 to 2015–16; noting that monitoring locations within a Selected Area may have changed between the two periods. In terms of species richness, fish-eating species ('fishers' in Table 2 and Figure 3) were the dominant functional group in all locations and years (Figure 3). In terms of abundance, dabbling and diving ducks were dominant in the Murrumbidgee river system and the Junction of the Warrego–Darling rivers, while grazing ducks dominated the Gwydir river system in 2014–15 as did fish-eating species in 2015–16 (Table 2).

Habitat, with respect to vegetation community and broad aquatic ecosystem type, is recorded with each waterbird count. In order to determine whether monitoring results from Selected Areas could be extrapolated to sites that received Commonwealth environmental water, but are not monitored, an assessment of functional group by habitat was attempted (Figure 4). While it is evident that shorebirds do not generally occur in wooded aquatic ecosystems, there is little pattern to the data, suggesting that species do not have strong habitat affinities. This is consistent with our understanding of waterbirds, where factors such as water depth and extent and duration of inundation are important; and that these birds use different habitats for different functions (e.g. breeding, foraging, roosting).

Evidence of breeding was recorded for 24 species over the first 2 years of the program (Table 2). Waterbird breeding was not undertaken as part of LTIM monitoring in 2014–16. NSW Office of Environment and Heritage (OEH), however, did undertake operational monitoring and waterbird breeding observations. A summary of outcomes at sites that received Commonwealth environmental water is provided in Table 3.

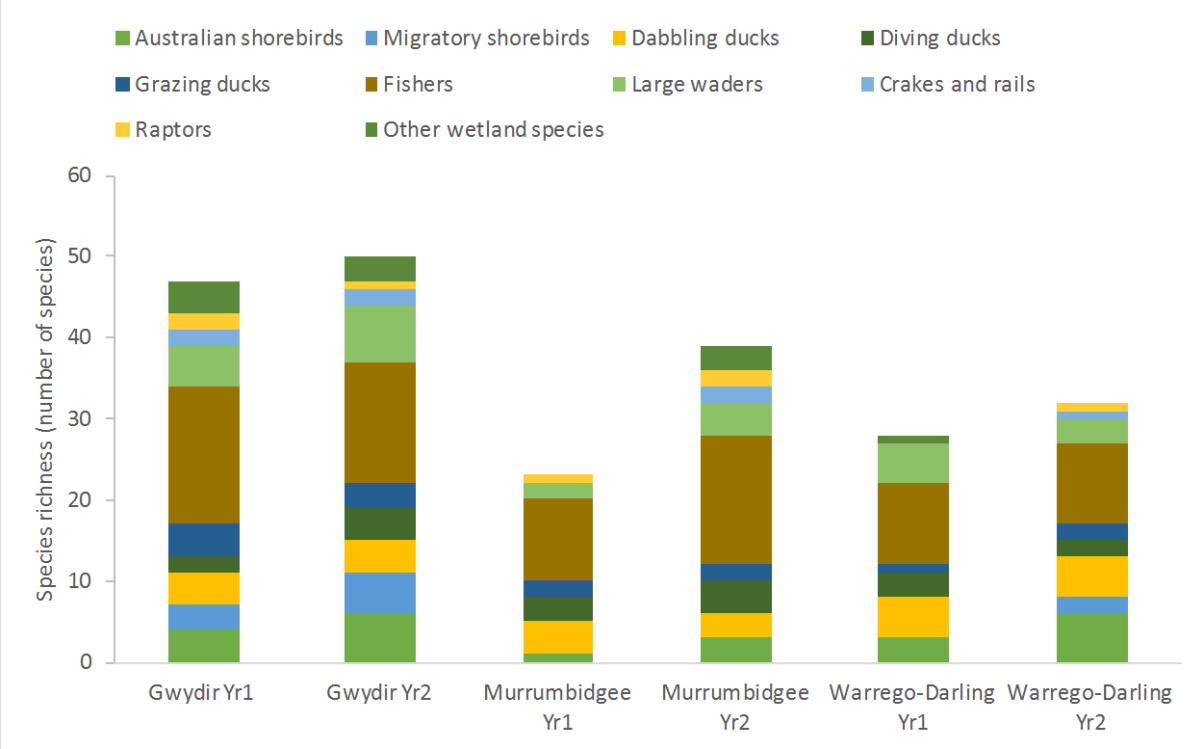

Figure 3. Species richness of functional groups in the three Selected Areas monitored for waterbirds as part of the LTIM project in 2014–15 (Yr1) and 2015–16 (Yr2).

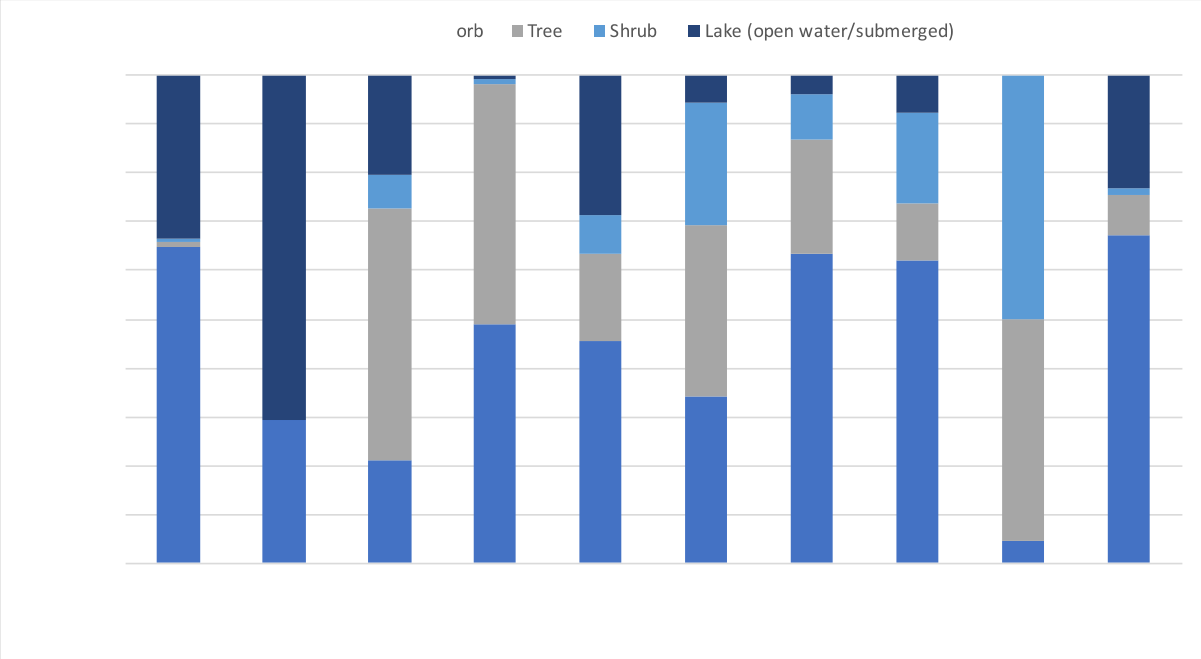

Figure 4. Habitat in which waterbirds were recorded. Data pooled from the three Selected Areas and the two monitoring years.

Table 3. Colonial nesting waterbird observations by the New South Wales Office of Environment and Heritage (as reported in the Commonwealth Environmental Water Officer (CEWO) unpublished acquittal report), provided as number of active nests.

Species	Yanga National Park	Nimmie-Caira		Yarrada
		Telephone Creek	Eulimbah	
Australasian darter	12	22		30+
Australian white ibis	30+	1	100+	
Eastern great egret	250+	18		
Great cormorant		2		12+
Little black cormorant	20+	19		50+
Little egret	At least 1			
Little pied cormorant	50+	9		50+
Royal spoonbill			20+	
Yellow-billed spoonbill	At least 1			

3.1.2 Frogs

Frogs were monitored in four Selected Areas in 2015–16: the Lachlan river system, the Murrumbidgee river system, the Gwydir river system and the Junction of the Warrego and Darling rivers. Two of these Selected Areas were also monitored in 2014–15 (Table 4). A total of 11 species of frog have been recorded at sites that received Commonwealth environmental water, including the nationally listed vulnerable southern bell frog.

Table 4. Frog species recorded at sites in Selected Areas that received Commonwealth environmental water.

Common name	Species name	Lachlan	Murrumbidgee		Gwydir	Warrego–Darling	
		Yr2	Yr1	Yr2	Yr2	Yr1	Yr2
Desert froglet	*Crinia deserticola*					x	
Plains froglet	*Crinia parinsignifera*	x	x	x	x		x
Striped burrowing frog	*Cyclorana alboguttata*				x		
Barking marsh frog	*Limnodynastes fletcheri*		x	x	x	x	
Inland banjo frog	*Limnodynastes interioris*	x		x			
Spotted marsh frog	*Limnodynastes tasmaniensis*	x	x	x	x	x	x
Green tree frog	*Litoria caerulea*					x	
Broad-palmed rocket frog	*Litoria latopalmata*				x		
Peron's tree frog	*Litoria peronii*	x	x	x	x	x	x
Southern bell frog[1]	*Litoria raniformis*	x		x			
Desert tree frog	*Litoria rubella*					x	

[1] Listed as vulnerable nationally under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Monitoring methods varied between Selected Areas and so a comparison of breeding and recruitment success is not possible. The frogs recorded in Table 4 represent calls and could be considered to represent attempts at breeding. In the Murrumbidgee, tadpole abundance was recorded, with three species recorded at sites receiving Commonwealth environmental water in both 2014–15 and 2015–16: plains froglet (*Crinia parinsignifera*), inland banjo frog (*Limnodynastes interioris*) and Peron's tree frog (*Litoria peronii*). In addition, tadpoles of the vulnerable southern bell frog were recorded in Yarrada Lagoon in 2015–16. Tadpoles and metamorphs were also recorded in several sites that received Commonwealth environmental water in the Lachlan in 2015–16 including the inland banjo frog, Peron's tree frog and southern bell frog.

3.1.3 Turtles

Turtles were monitored in the Murrumbidgee river system in 2014–15 and 2015–16, with two species recorded at sites that received Commonwealth environmental water:

- eastern long-necked tortoise (*Chelodina longicollis*)
- broad shell tortoise (*Chelodina expansa*).

There was evidence of recruitment in the eastern long-necked tortoise (Wassens *et al.* 2016); however, the relationship with Commonwealth environment water is unclear.

4 Unmonitored area outcomes

In this report, 'unmonitored' refers to sites that received Commonwealth environmental water, but were not measured as part of the LTIM Project. It includes information from other monitoring programs as well as observations.

4.1 Highlights

- Monitoring at several Ramsar-listed wetlands in the Basin (Hattah–Kulkyne Lakes, Macquarie Marshes, Barmah Forest and Central Murray Forests) indicated benefits to vegetation, fish, frogs and waterbirds. At each of these sites, environmental water (contributed to by the Commonwealth) was the major water source. Although inundation was limited in extent and duration, it is likely that environmental water sustained these important wetland systems, which otherwise would have remained largely dry. As these sites dried down, habitat for wading species, including several international migratory shorebirds, was provided.
- The Barmah–Millewa Forest supported a significant proportion (at least 10% and potentially up to 30%) of the total population of Australasian bittern (listed as endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Habitat for the species was maintained by Commonwealth environmental water.
- Monitoring of the fish species Murray hardyhead (*Craterocephalus fluviatilis*), listed as endangered under the EPBC Act, indicated a strong positive response to Commonwealth environmental water in Brickworks Billabong, although there was a potential negative effect at Cardross Lakes in Victoria.
- Inundation of wetlands along the Lower Murray provided habitat for a range of waterbird species, including the NSW-listed vulnerable freckled duck.

4.2 Aggregation of data from other sources

4.2.1 Effects of Commonwealth environmental water on waterbird, frog, turtle and mammal species diversity at unmonitored sites

Information on the ecological responses of waterbirds, frogs, turtles and mammals is summarised in Table 5. This table does not include important wetland sites such as Hattah–Kulkyne Lakes, Barmah–Millewa Forest and Macquarie Marshes, which are considered in more detail in Section 4.3. The majority of the information collated is qualitative and includes very little additional evidence about the site that received Commonwealth environmental water or how species or communities responded to water regime.

Table 5. Summary of observations and other information from unmonitored watering actions related to waterbird, frog, turtle and mammal diversity in 2015–16. Note that many of these actions involved multiple water sources (in addition to Commonwealth environmental water). Additional information on the portfolio of environmental water can be found in the Basin Matter Hydrology report (Stewardson & Guarino 2017).

Surface water region/asset (watering action number)[1]	Commonwealth environmental water volume (GL)[1]	Dates[1]	Flow component[1]	Expected ecological outcome[1]	Observed ecological outcome	Source of information
Lower Murray wetlands (NFSA) – Mundic Wetland (1516-NFSA-02)	104.00	01/10/15 – 30/11/15	Wetland	Improve habitat for waterbirds to assist maintenance of their abundance and diversity.	Most abundant species were grey teal, red-kneed dotterel, black-tailed native-hen, black-fronted dotterel, Australian white ibis.	Summary of environmental watering event at Duck Hole, Mundic Wetland and Inner Mundic Wetland on the Pike Floodplain (CEWO, unpublished)
Lower Murray wetlands (NFSA) – Duck Hole (1516-NFSA-03)	271.00	01/10/15 – 30/11/16	Wetland	Improve habitat for waterbirds to assist maintenance of their abundance and diversity.	Most abundant species were Australian shelduck, black-fronted dotterel, chestnut teal, grey teal, Australian pelican. Also, the New South Wales (NSW) vulnerable species freckled duck recorded.	
Lower Murray wetlands (NFSA) – Johnson's Waterhole (1516-NFSA-05)	117.00	01/09/15 – 30/04/16	Wetland	Improve habitat for waterbirds to assist maintenance of their abundance and diversity.	Over 200 black swans feeding. Other species included grey teal, Australian white ibis, straw-necked ibis, Australian shelduck, Australasian grebe, masked lapwing and Australian pelican.	Johnsons Waterhole monitoring report (2013–16) (CEWO, unpublished)
Lower Murray wetlands (NFSA) – South Teringie (1516-NFSA-06)	79.00	01/12/15 – 30/05/16	Wetland	Improve habitat for waterbirds to assist maintenance of their abundance and diversity.	15 species of waterbird recorded including 10 EPBC migratory species. Most common species were sharp-tailed sandpiper.	Teringie South monitoring report (2013–16) (CEWO, unpublished)
Lower Murray wetlands (NRM Board) – Piggy Creek (1516-NRMB-06)	201.00	20/10/15 – 05/11/15	Wetland	Provide waterbird habitat.	25 species of wetland-dependent bird recorded. Most abundant species were grey teal, Australian wood duck, pink-eared duck and hardhead. The SA-listed vulnerable freckled duck was also recorded.	Hoffman *et al.* 2016
Lower Murray wetlands (NRM Board) – Carpark Lagoons (1516-NRMB-07)	229.00	21/10/15 – 31/01/16	Wetland	Provide waterbird habitat.	25 species of wetland-dependent bird recorded. Most abundant species were grey teal, Australian wood duck and hardhead. The SA-listed vulnerable freckled	Hoffman *et al.* 2016

Surface water region/asset (watering action number)[1]	Commonwealth environmental water volume (GL)[1]	Dates[1]	Flow component[1]	Expected ecological outcome[1]	Observed ecological outcome	Source of information
					duck was also recorded. Pacific black duck observed breeding.	
Lower Murray wetlands (NRM Board) – Morgan Conservation Park Bird & Meeting Lagoons (1516-NRMB-11)	306.00	11/01/16 – 29/04/16	Wetland	Provide waterbird habitat.	19 species of wetland recorded. Most common species were Australasian grebe, Eurasian coot, grey teal and hardhead. Musk muck observed breeding.	Hoffman *et al.* 2016
Lower Murray wetlands (NRM Board) – Hogwash Bend South (1516-NRMB-12)	420.00	20/01/16 – 18/02/16	Wetland	Provide waterbird habitat.	26 species of wetland bird recorded. Most common species were grey teal, Eurasian coot and pink-eared duck. The SA-listed vulnerable freckled duck was also recorded.	Hoffman *et al.* 2016
Lower Murray wetlands (NRM Board) – Maize Island (1516-NRMB-14)	213.00	04/02/16 – 24/04/16	Wetland	Provide waterbird habitat.	17 species of wetland-dependent bird recorded. Most common species were grey teal, Eurasian coot and pink-eared duck. The SA-listed vulnerable freckled duck was also recorded.	Hoffman *et al.* 2016
Lower Murray: Mallee Wetlands Brickworks Billabong (1516-VicW-03)	200.00	01/10/15 – 30/11/15	Wetland	Increase the abundance and distribution of Murray hardyhead.	Multiple Murray hardyhead cohorts recorded, indicating that successful recruitment and early indications of self-sustaining population.	Huntley 2016
Mid Murray Valley – Carrs, Capitts and Bunberoo Creek System (1516-Mur-08)	115.00	19/01/16 – 7/03/16	Wetland	Provide areas of aquatic habitat for fauna including birds and frogs.	16 species of waterbird recorded. Most common species were Australian wood duck, grey teal, black swan and white-faced heron. No observations of breeding.	Sunraysia Environmental 2016
Mid Murray Valley – Wingillie Station (1516-Mur-09)	950.00	04/04/16 – 16/05/16	Wetland	Support suitable habitat conditions and food resources for waterbird growth and survival and southern bell frog.	Six frog species identified, including the threatened southern bell frog. Waterbirds were immediately attracted to the site and included pelicans, little black cormorants, pied cormorants, royal spoonbills, ibis, yellow-billed spoonbills, teals, black ducks, dotterels and egrets.	CEWO acquittal report (unpublished)

[1] As reported by the Commonwealth Environmental Water Office (CEWO) (unpublished).

Note: Sites for which no information could be sourced have been excluded; EPBC = endangered or vulnerable under the national *Environment Protection and Biodiversity Conservation Act 1999*; NFSA = Nature Foundation SA; NRM = Natural Resource Management; SA = South Australia.

4.3 Important wetland case studies

Thirteen DIWA/Ramsar sites were the target of Commonwealth environmental water in 2015–16 and had expected outcomes related to diversity. These included several sites within Selected Areas (e.g. Gingham and Lower Gwydir (Big Leather) watercourses, Lowbidgee wetlands) as well as several sites for which little information on the effects of environmental water could be sourced (e.g. Pike–Mundic wetland system, Gunbower Creek). Five sites were selected as case studies to assess the effects of Commonwealth environmental water on important wetlands:

- Banrock Station – DIWA and Ramsar
- Barmah–Millewa Forest – DIWA and Ramsar
- Cardross Lakes – DIWA
- Hattah–Kulkyne Lakes – DIWA and Ramsar
- Macquarie Marshes – DIWA and Ramsar.

4.3.1 Banrock Station

What was the expected outcome?

The expected outcomes related to biodiversity were to:

- *Protect the extent and condition of native riparian vegetation communities and provide reproduction and recruitment opportunities.*
- *Improve cover and condition of understorey vegetation including lignum.*
- *Enhance survival of seedlings arising from 2011 flood event.*
- *Establish more diverse healthy habitat for other native species including the southern bell frog.*
- *Improve the condition of the associated river red gum woodland vegetation communities that are hosting one of the few colonies of regent parrot in South Australia.*
- *Establish more diverse and healthy habitat for both wetland and migratory bird species found in the surrounding Ramsar area.*

What information is available about the watering action?

A total of 2000 megalitres (ML) of environmental water was delivered to Banrock Station, all of which was Commonwealth environmental water. Water was delivered to five sites within the Ramsar site via pumping: Herons Bend, Banrock's Bend, Wiggley Reach Central Channel, Wiggley Reach Depression and Eastern Lagoon. The water was delivered sequentially and photo point evidence indicates dry conditions prior to water delivery, followed by inundation for a period of weeks to months and then a gradual drawdown. Inundation of approximately 375 hectares (ha) of floodplain woodland and shrubland occurred within the Ramsar site boundary (Figure 5 and Table 6). The wetland sites had been dry since 2011 and had suffered a decline in condition as a result. Environmental water in 2015–16 was part of a multi-year strategy to restore the ecological character of the Ramsar site.

What evidence is available to evaluate the outcome?

Banrock Station was listed as a Ramsar site in 2002, primarily for its role in supporting threatened species – the endangered regent parrot (*Polytelis anthopeplus monarchoides*) and the vulnerable southern bell frog – as well as supporting a variety of waterbirds during critical life stages of migration, breeding and moulting (Butcher *et al*. 2009).

A brief observational report was prepared as part of the environmental watering actions (Tourenq 2016) which reported on the response of vegetation, fish, frogs and waterbirds. These amount to snapshot observations with no quantitative data. The confidence in attributing benefits from environmental water to species must be considered in this context.

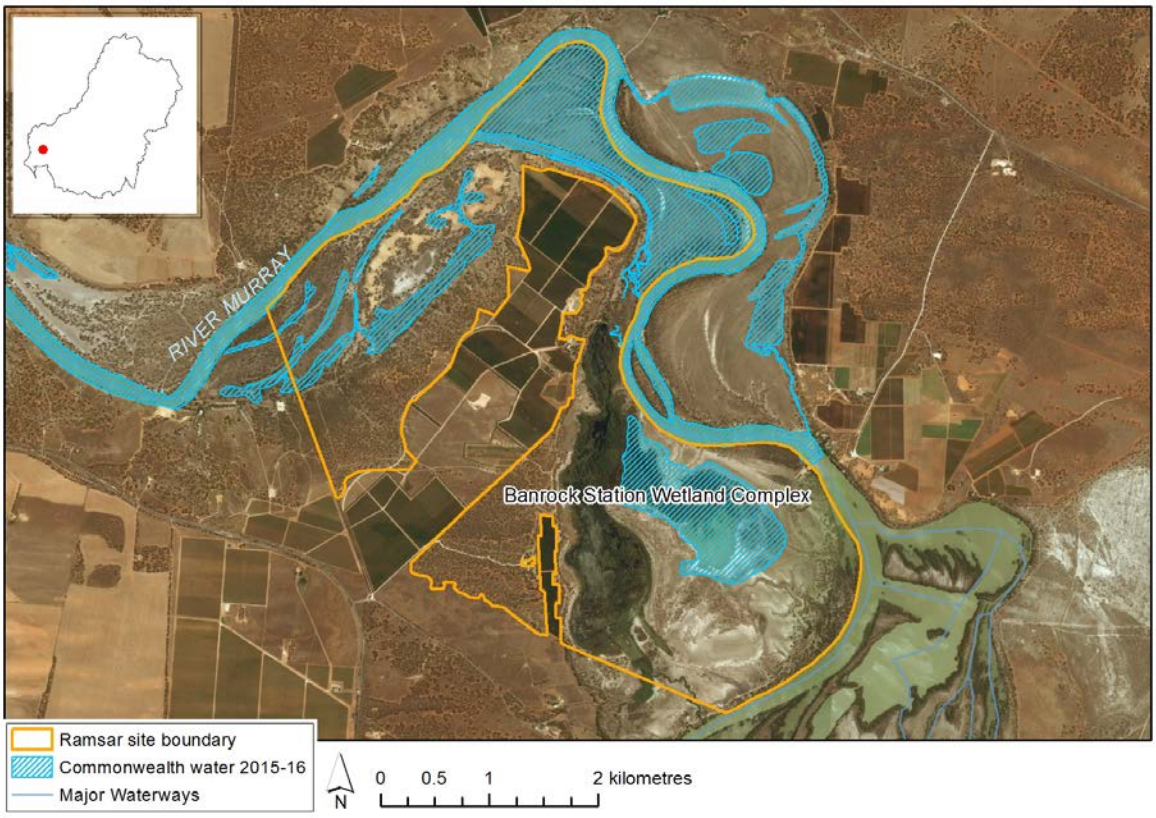

Figure 5. Extent of inundation at Banrock Station during environmental watering in 2015–16.

Table 6. ANAE wetland and floodplain types inundated from environmental watering in 2015–16 at Banrock Station Ramsar site.

Australian National Aquatic Ecosystem (ANAE) wetland type	Area inundated (hectares)
F.1.8: Black box woodland floodplain	22
F2.2: Lignum shrubland floodplain	146
F2.4: Shrubland floodplain	110
Pp4.1: Permanent floodplain wetland	78
Pt1: Temporary swamps	19
Total	**375**

What species/communities potentially benefited?

There is some observational evidence to suggest that a range of species benefited from Commonwealth environmental water at Banrock Station in 2015–16 (Table 7). Monitoring over subsequent years would improve confidence in these assessments.

Table 7. Species and communities that potentially benefited from Commonwealth environmental water at Banrock Station in 2015–16 (Toureq 2016).

Community/species	Evidence
Riparian vegetation communities	Germination of 42 native plant species, including river red gum (*Eucalyptus camaldulensis*), black box (*Eucalyptus largiflorens*) and lignum (*Duma florulenta*).
Fish	Bony bream (*Nematalosa erebi*) and unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*) recorded in the inundated wetlands.
Frogs	Spotted marsh frog (*Limnodynastes tasmaniensis*), eastern banjo frog (*Limnodynastes dumerili*), Peron's tree frog (*Litoria peroni*) and plains froglet (*Crinia parinsignifera*) were heard at all the sites.
Waterbirds	40 species of waterbird recorded in the inundated ponds, including the nationally endangered Australian painted snipe (*Rostratula australis*). Potential breeding of clamorous reed warbler (*Acrocephalus stentoreus*).
Regent parrot	Regent parrot recorded in the woodlands adjacent to the site. If the watering over years results in improved nesting habitat (river red gum) then there will be more confidence in suggesting this species benefited from Commonwealth environmental water.

4.3.2 Barmah–Millewa Forest

What was the expected outcome?

The expected outcomes for this watering action were described in terms of the broader objectives of environmental water across the entire River Murray system (CEWO, unpublished). Specific objectives for environmental water in 2015–16 for the Barmah–Millewa Forest are provided in the intervention monitoring report (Borrell & Webster 2016a):

- *Use low flows (<15 000 ML/day) to preserve certain characteristics of the Ramsar wetlands; in particular, floodplain marshes and river red gum forests (critical wetland vegetation categories).*
- *Achieve sufficient water depths to promote the growth of moira grass in Barmah–Millewa Forest.*
- *Promote floodplain connectivity to support large-bodied native fish movement, in species such as Murray cod (Maccullochella peelii peelii) and Trout cod (Maccullochella macquariensis)*
- *Provide suitable habitat and resources for water birds.*
- *Ensure water quality is a maintained at an appropriate level.*

What information is available about the watering action?

The delivery of water to the Barmah–Millewa Forest is complex and was part of a broader watering action designed to affect the River Murray and associated floodplains and wetlands from Hume Dam to the Murray Mouth. Water commenced flowing overbank into the floodplain forest and wetlands in August 2015 and continued until the end of October 2015 (Figure 6). An additional 8000 ML of Commonwealth environmental water was delivered together with water from The Living Murray and NSW OEH to Reed Bed Swamp from November 2015 to February 2016, specifically to maintain water levels for waterbird breeding.

Inundation mapping indicates around 12 400 ha of ANAE wetland types within the Ramsar sites were inundated (Figure 7 and Table 8). This is slightly less than the 14 500 ha of inundation calculated by Borrell & Webster (2016a) which may be due to mapping inconsistencies and inundation outside the Ramsar boundaries.

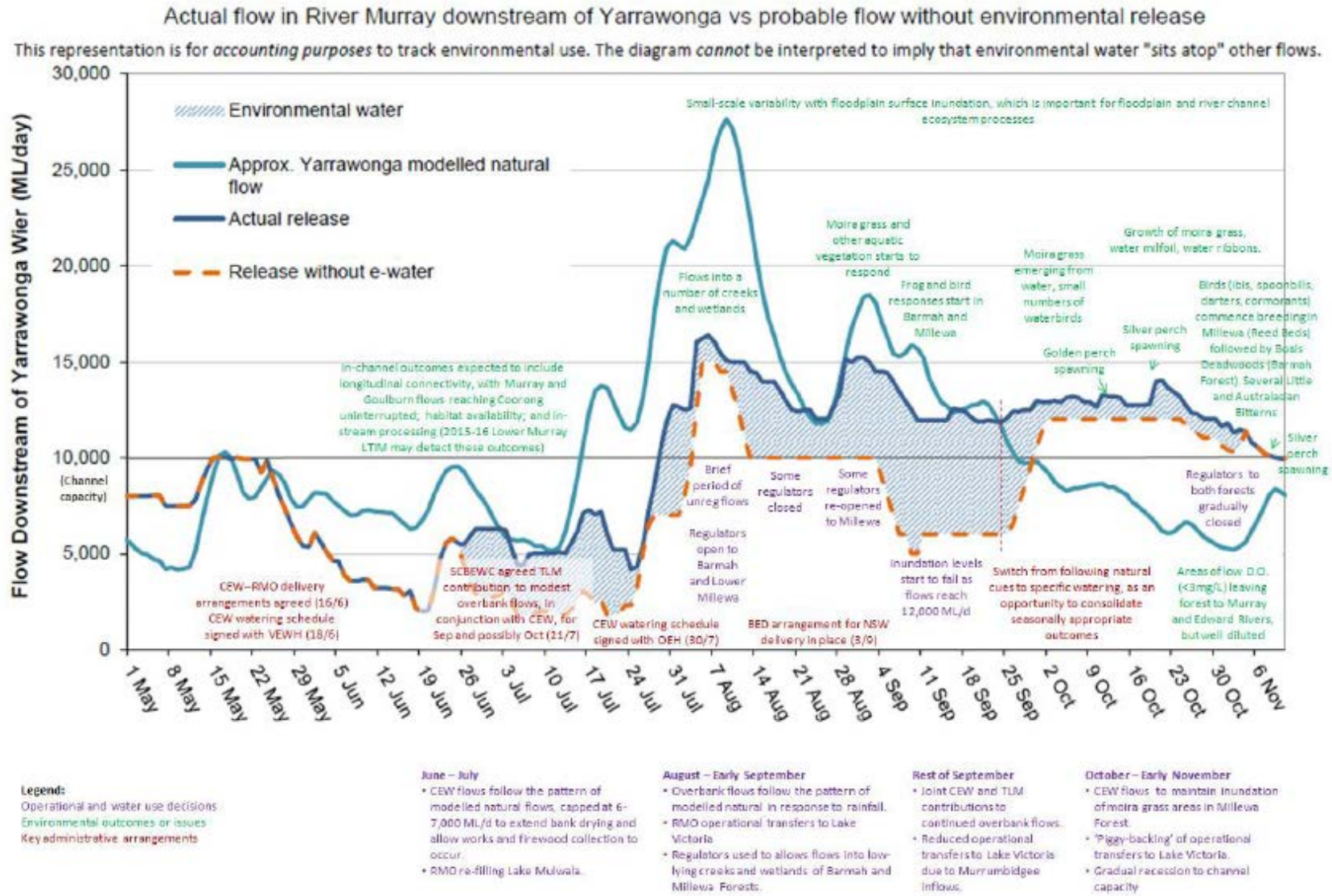

Figure 6. Environmental water releases downstream of Yarrawonga (Commonwealth Environmental Water Office (CEWO), unpublished).

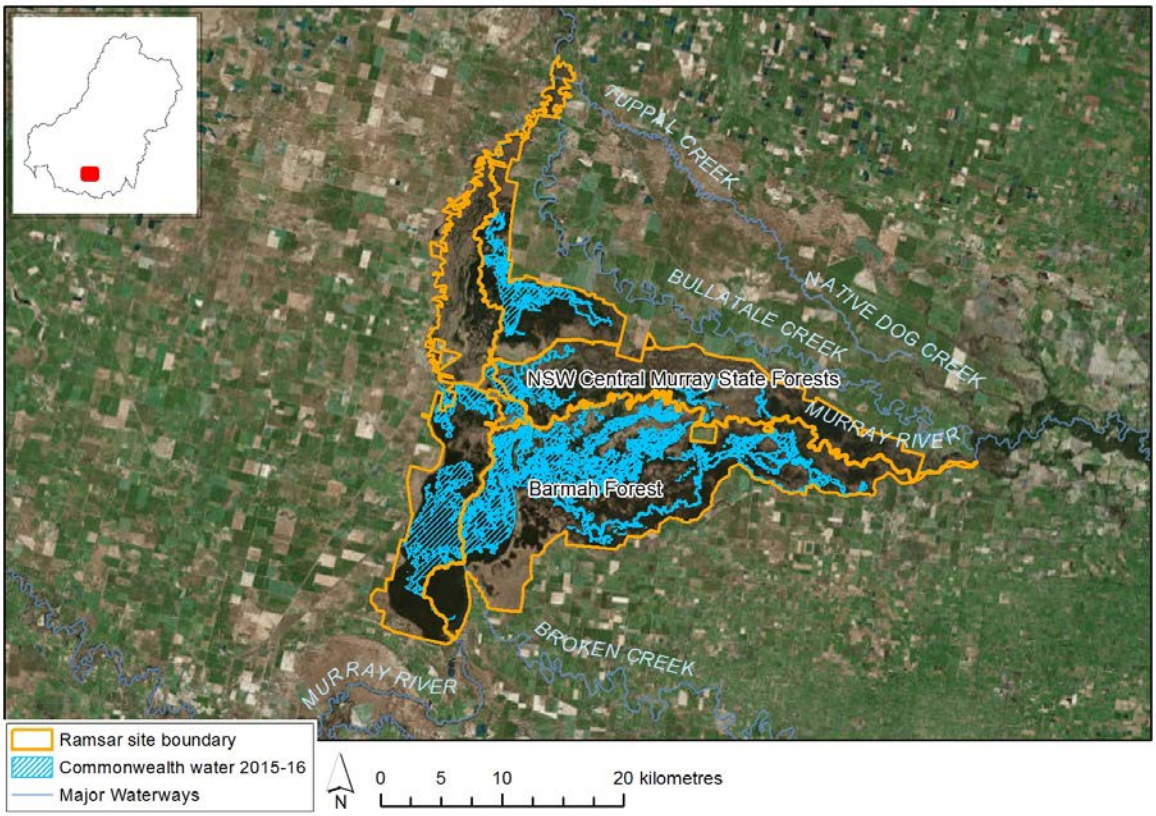

Figure 7. Extent of inundation at Barmah–Millewa Forest during environmental watering in 2015–16.

Table 8. ANAE wetland and floodplain types inundated from environmental watering in 2015–16 at Barmah–Millewa Forest.

Australian National Aquatic Ecosystem (ANAE) wetland type	Area inundated (hectares)
F1.2: River red gum forest floodplain	5275
F1.4: River red gum woodland floodplain	3
Lst2.1: Temporary saline floodplain lakes	122
Lt2.1: Temporary floodplain lakes	155
Pp4.1: Permanent floodplain wetland	322
Psp4: Permanent saline wetland	594
Pst4: Temporary saline wetland	138
Pt1.1.1: Intermittent River red gum floodplain swamp	5424
Pt1.6.1: Temporary woodland floodplain swamp	253
Pt2.3.1: Floodplain freshwater meadow	47
Pt4.1: Temporary floodplain wetland	44
Total	12 377

What evidence is available to evaluate the outcome?

Barmah–Millewa Forest is listed as a single DIWA site, but is part of two separate Ramsar sites: Barmah Forest, which lies in Victoria, and Millewa Forest, which is part of the NSW Ramsar site

'Central Murray Forests'. Barmah Forest was listed as a Ramsar site in 1982 and Central Murray Forests in 2003. The reasons for designation of the two sites are largely the same, in that together they form the largest intact floodplain forest in the bioregion; they support several threatened species, including Australasian bittern, superb parrot (*Polytelis swainsonii*), Murray cod, silver perch (*Bidyanus bidyanus*) and trout cod; and are important for breeding waterbirds, particularly colonial nesting species.

Aspects of biodiversity were monitored as part of the long-term icon site monitoring of the Barmah–Millewa Forest and included vegetation (Borrell & Webster 2016a), fish (Raymond *et al.* 2016) and waterbirds (Belcher *et al*. 2016). The 2015–16 watering year was dry and the responses of biota to environmental watering across the Barmah–Millewa Forest need to be considered in this context.

Monitoring of moira grass (*Pseudoraphis spinescens*) indicated that the species was not present at Porter's Plain in Millewa Forest in 2015–16, despite the site supporting extensive areas of the community in the past. Moira grass was present at Moira Lake, but its extent was reduced from previous years and there were some indications that condition had also declined (Borrell & Webster 2016a). Moira grass at Barmah–Millewa Forest has been declining in extent and condition for several years, due to a combination of factors including encroachment by river red gum (*Eucalyptus camaldulensis*) seedlings and giant rush (*Juncus ingens*), grazing (particularly by feral horses) and altered water regimes (Colloff *et al.* 2014). Watering in 2015–16 may have been of insufficient extent and duration to result in measurable outcomes for this vegetation community. Recent studies have suggested that without appropriate grazing management, environmental watering is unlikely to result in improvements in the extent of moira grass in Barmah Forest (Nicol *et al*. 2017).

Monitoring of tree condition in 2014–15 indicated that 32% of the trees in Barmah Forest were in good condition, 64% were in moderate condition and less than 5% were in poor or degraded condition (MDBA 2016). While results for tree condition in 2015–16 are not yet available it is likely that environmental watering of over 10 000 ha of river red gum forest and woodland would have maintained or improved tree condition.

The overall condition of fish in the Barmah–Millewa Forest was assessed as being 'good' and to have remained stable or improved in the past 2 years (Raymond *et al*. 2016). Eleven native and five alien fish species were recorded in 2014–15, including all three threatened species: Murray cod, silver perch and trout cod. Movement of several large-bodied species, including Murray cod and trout cod, was observed from the river into the wetland habitats (CEWO, unpublished).

Native fish recruitment in river habitats was high and approximately 60% of native species within flowing habitats successfully recruited individuals into their respective populations in 2015–16. There was some evidence that in-channel pulses as a result of environmental water increased golden perch (*Macquaria ambigua*) spawning intensity and may have benefited silver perch spawning. The relationship between water regime, environmental water and fish population and community condition was, however, recognised as a knowledge gap (Raymond *et al*. 2016).

Monitoring in Millewa Forest indicated a range of waterbird species utilising the wetlands during the period of environmental water delivery. Thirty species of waterbird were recorded with over 1000 nesting pairs (Borrell & Webster 2016b):

- straw-necked ibis (*Threskiornis spinicolis*) – 430 pairs
- Australian white ibis (*Threskiornis molucca*) – 325 pairs
- little pied cormorant (*Microcarbo melanoleucos*) – 41pairs
- eastern great egret (*Ardea modesta*) – 65 pairs
- royal spoonbill (*Platalea regia*) – 238 pairs
- Australasian darter (*Anhinga novahollandiae*) – 6 pairs.

In addition, a colony of approximately 400 pairs of ibis and spoonbills were observed nesting in Boals Deadwoods, Barmah Forest. Although this was fewer than previous large-scale breeding events, it is a direct benefit of Commonwealth environmental water in a dry year.

Surveys also recorded at least 46 male Australasian bitterns within the Barmah–Millewa Forest in 2015–16 (Belcher *et al*. 2016). The inundation of wetlands by environmental water provided feeding and suspected breeding habitat for this endangered species. The number of males represents nearly 10% of the total population of this species (estimated at 500 individuals – Wetlands International 2015). Given that males are suspected to be polygamous (breeding with more than one female) it is possible that the site supported more than a third of the total population during environmental watering.

What species/communities potentially benefited?

Environmental water significantly extended the duration and extent of inundation across the site. In the absence of Commonwealth environmental water, many aquatic habitats would not have been inundated and duration would have likely been insufficient to complete cycles of breeding. There is good evidence to suggest that a number of species benefited from Commonwealth environmental water at Barmah–Millewa Forest in 2015–16 (Table 9).

Table 9. Species and communities that potentially benefitted from Commonwealth environmental water at Barmah–Millewa Forest in 2015–16.

Community/species	Evidence
River red gum forest and woodland	No empirical evidence, but it is likely that inundation of over 10 000 hectares of river red gum forest and woodland would have helped maintain or improve tree condition.
Silver perch and golden perch	Monitoring indicates that flow variability provided by environmental water increased spawning.
Murray cod and trout cod	Some evidence of movement of these species into the wetland system.
Australasian bittern	Significant proportion of the total population of the species recorded within the inundated wetland habitats.
Straw-necked ibis, Australian white ibis, little pied cormorant, eastern great egret, royal spoonbill and Australasian darter	Colonial nesting breeding event supported by environmental water.

4.3.3 Cardross Lakes

What was the expected outcome?

The expected outcomes related to biodiversity were to:

- *Increase the abundance and distribution of Murray hardyhead, an endangered fish species, by providing suitable habitat that will support the establishment of self-sustaining populations along the lower River Murray.*
- *Maintain and/or improve the condition, diversity and extent of native floodplain and wetland vegetation.*
- *Support the recruitment and improved condition of native vegetation, waterbirds, frogs, native fish and other biota through maintaining suitable aquatic habitat and providing opportunities for breeding and recruitment.*

What information is available about the watering action?

A total of 953.23 ML of environmental water was delivered to Cardross Lakes, 476.61 ML of which was Commonwealth environmental water. The water extended across the lower basin, (Basin 1) which is also called Cardross Lake (Figure 8), covering approximately 80 ha of predominantly open water habitat (Australian National Aquatic Ecosystem (ANAE) wetland type: temporary saline lakes). Environmental water has been used for the past several years to maintain water levels (permanence) of Cardross Lakes and salinity has remained below 5000 µS cm^{-1} since 2010 (Huntley 2016).

What evidence is available to evaluate the outcome?

The Cardross Lakes DIWA site comprises a chain of wetlands that, when fully inundated, are interconnected. Basin 1 (Cardross Lakes) is the southernmost wetland and was the target of the environmental watering action. The site was identified as a nationally important wetland, largely on the basis of supporting threatened fish populations; in particular, EPBC-listed endangered Murray hardyhead (Directory of Important Wetlands in Australia http://www.environment.gov.au/node/25064).

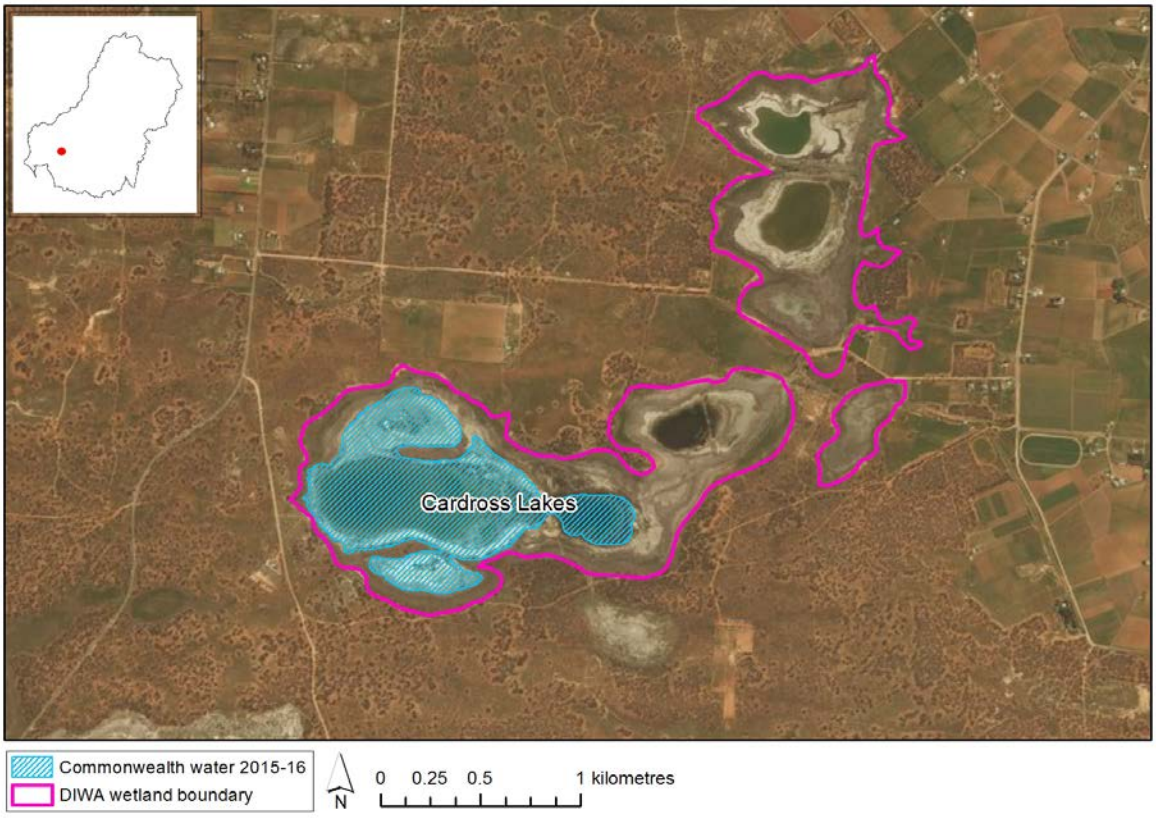

Figure 8. Extent of inundation at Cardross Lakes during environmental watering in 2015–16.

There is a population monitoring program for Murray hardyhead (Ellis *et al.* 2014; Huntly 2016), which was the target of this environmental watering action. Murray hardyhead are recorded most often in wetlands with brackish salinity (>4000 µS cm^{-1}, although they have a wide salinity tolerance (Ellis *et al.* 2014). Monitoring indicates that there was low abundance of Murray hardyhead in 2014–15 in Cardross Lakes following environmental watering and no individuals were recorded in 2015–16 (Huntley 2016). It was suggested that high freshwater inflows lowered salinity and may have negatively impacted Murray hardyhead through: increased abundance of competing small-bodied fish species; and a decline in the saline submerged plant *Ruppia* spp. which provides spawning

habitat (Huntly 2016). The abundance of Murray hardyhead at Cardross Lakes has declined from peaks of >100 catch per net in 2011 to isolated records in 2015. In addition, there has been an expanse of the emergent macrophyte *Typha orientalis* at Lake Cardross in response to higher water levels and lower salinity (Huntley 2016).

What species/communities potentially benefited?

The endangered Murray hardyhead has undoubtedly benefited from environmental water over the past 2 decades. It seems likely, however, that there was little benefit, and possibly a negative impact, in both the 2014–15 and 2015–16 watering years. A good adaptive management program is in place at the site, with lessons learned from 2015–16 environmental watering resulting in a revised watering regime for future years, with a drawdown planned for 2016–17 (Huntley 2016).

4.3.4 Hattah–Kulkyne Lakes

What was the expected outcome?

The expected outcomes were:

- *Provide hydrological connectivity with the River Murray to promote:*
  - *movement of mature native fish to the River Murray (including new recruits supported by watering in 2014) (relevant to 2015–16 Basin Annual Watering Priority for fish movement)*
  - *exchange and cycling of nutrients and carbon between the river and the lakes*
  - *exchange and dispersal of biota, including seeds and fish eggs/larvae.*
- *Provide improved habitat and food resources for fish and waterbirds.*
- *Maintain deeper water to support potential breeding of piscivorous waterbirds, leading to localised increases in cormorant and darter populations (2015–16 Basin Annual Watering Priority).*
- *Maintain potential breeding habitat for fish, including small-bodied natives and golden perch (2015–16 Basin Annual Watering Priority).*
- *Support the ongoing reestablishment of water-dependent vegetation in wetlands and waterways.*

What information is available about the watering action?

A total of 6619 ML of environmental water was delivered to Hattah–Kulkyne Lakes, 5347 ML of which was Commonwealth environmental water. Water was delivered to the site via pumping from the River Murray for 2 weeks in October 2015. All 12 lakes that comprise the Hattah–Kulkyne Lakes Ramsar site were inundated (Figure 9).

The Ramsar site boundary follows the wetland boundaries and excludes much of the surrounding floodplain. Watering in 2014–15 inundated an extensive area of floodplain outside the Ramsar site boundary, while the smaller watering action in 2015–16, was largely within the beds of the lakes. Total inundation was of around 1140 ha of lake and wetland (Table 10).

There is a good record of inundation in the Hattah–Kulkyne Lakes. The lakes filled from natural floods in 2010–11 and were dry in 2011–12 and 2012–13. In 2013, environmental works were completed which included the construction of a permanent pump station, regulators and environmental levees to allow for more effective environmental watering at the site. The lakes were inundated in 2013–14 and the 2014–15 watering represented a second-large scale watering action at the site (Henderson *et al.* 2014). Inundation in 2015–16 was considerably less than in previous years and several of the wetlands dried to residual pools (or completely) over summer and autumn.

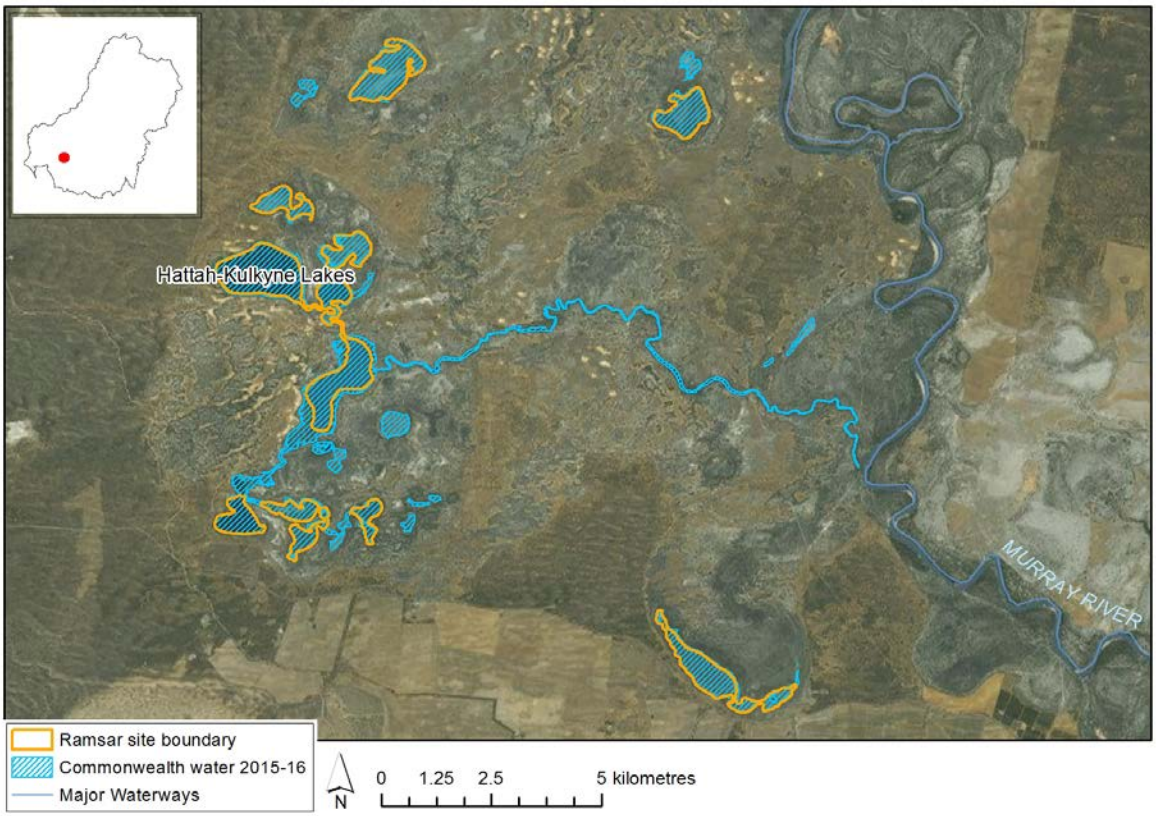

Figure 9. Extent of inundation at Hattah–Kulkyne Lakes during environmental watering in 2015–16. Note that the orange line indicates the Ramsar boundary, which includes only the lake beds of the wetlands.

Table 10. ANAE wetland and floodplain types inundated from environmental watering in 2015–16 at Hattah–Kulkyne Lakes Ramsar Site.

Australian National Aquatic Ecosystem (ANAE) wetland type	Area inundated (hectares)
Lt1.1: Temporary lakes	2
Lt2.1: Temporary floodplain lakes	1070
Pt1.1: Temporary swamp	46
Pt4: Temporary wetland	15
Pt1.1.1: Intermittent River red gum floodplain swamp	10
Total	**1143**

What evidence is available to evaluate the outcome?

Hattah–Kulkyne Lakes were listed as a Ramsar site in 1982 for a high diversity of wetland-dependent plant species, breeding of waterbirds and fish and supporting threatened species: Australasian bittern, Australian painted snipe, regent parrot, silver perch, Murray cod, flat-headed galaxias (*Galaxias rostratus*) and winged peppercress (*Lepidium monoplocoides*) (Butcher & Hale 2011).

Hattah–Kulkyne Lakes are an example of a site where there is a large amount of information available, primarily through other monitoring programs conducted on behalf of the Mallee Catchment Management Authority (CMA) and MDBA. Monitoring outcomes of environmental water were available for 2015–16 for vegetation, fish and birds (Loyn & Dutson 2016; Smales 2016; Wood *et al*. 2016).

The assessment of vegetation in the Hattah Lakes is part of a longer term project looking at the portfolio of water management since the commissioning of infrastructure at the Ramsar site in 2013. The results do not necessarily reflect the outcomes of the environmental watering action in 2015–16, but rather the combined effects of environmental water management at the site from 2013 to 2016 (Moxham & Kenny 2016). The key outcomes of vegetation monitoring related to environmental water were (Wood *et al.* 2016):

- a reduction in mortality and an increase in growth of river red gum as a result of increased water availability
- maintenance of the health of black box (*Eucalyptus largiflorens*) communities
- restoration of a wetland vegetation habitat mosaic with a variety of functional groups represented and a low proportion of non-native species, attributed to the diversity of water regimes as maintained by environmental watering actions over the past 3 years
- the seven most abundant plant species in wetland surveys were water responsive, with the most abundant species in 2015–16 being red water-milfoil (*Myriophyllum verrucosum*)
- presence of the Victorian-listed vulnerable species glistening dock (*Rumex crystallinus*) for the first time at the Hattah Lakes in the 2015–16 surveys
- lignum at Hattah Lakes was in moderate condition in 2015–16, but was in decline on long-dry areas of the floodplain (noting that these areas are outside the Ramsar site boundary).

Monitoring of fish within the Hattah Lakes in 2015–16 indicated that several small-bodied native wetland fish species, carp gudgeon (*Hypseleotris* spp.), flathead gudgeon (*Phylipnodon grandiceps*) and Australian smelt (*Retropinna semoni*) have increased in abundance, which indicates that environmental watering has contributed to self-sustaining populations of these species (Wood *et al*. 2016). The low level of watering and the drawdown of wetlands in 2015–16 resulted in only a single species of large-bodied native fish being caught in wetlands, bony herring (*Nematalosa erebi*). Studies also indicated that large-bodied native fish, such as golden perch, that use the wetlands as nursery habitat, return to the River Murray through the regulator when the water is drained as part of environmental water management (Wood & Brown 2016).

A total of 43 species of waterbird were recorded in the Hattah Lakes in 2015–16. This represents an increase in diversity over recent years, largely as the drawdown of water in several lakes provided habitat for small waders and shorebirds (Smales 2016). Abundance in June 2016 was relatively high, with over 4000 waterbirds across 3 lakes, largely due to substantial numbers of grey teal (*Anas gracilis*) and hoary-headed grebe (*Poliocephalus poliocephalus*) (Mallee CMA 2016). There is evidence of successful breeding and recruitment of small numbers of Australasian darter and little pied cormorant on 2015–16 (Smales 2016).

Monitoring indicated that environmental watering benefited a number of species of bush birds, which were markedly more abundant on sites that had been inundated or were in flood recession than on sites that did not receive environmental water (Loyn & Dutson 2016). Increases in productivity and food resources benefited several species of insectivores, nectivores and seed-eating species. Numbers of bush birds either remained stable or increased in abundance in previously inundated floodplain woodland despite the time since wide-scale inundation. Species that benefited included the EPBC-listed vulnerable regent parrot.

What species/communities potentially benefited?

There is evidence to suggest that a wide range of species benefited from Commonwealth environmental water at Hattah–Kulkyne Lakes in 2015–16 (Table 11).

Table 11. Species and communities that potentially benefited from Commonwealth environmental water at Hattah–Kulkyne Lakes in 2015–16.

Community/species	Evidence
River red gum woodland	Good canopy condition and evidence of growth and increased population structure.
Black box woodland	Good canopy condition and evidence of growth and increased population structure.
Wetland vegetation communities	Variability in water regime supports a diversity of wetland plant species.
Small-bodied native fish	Increase in abundance of carp gudgeon, flathead gudgeon and Australian smelt. Water regimes allow for self-sustaining populations.
43 species of waterbird	High waterbird diversity and relatively high abundance of some species. Increase in the number of small waders (albeit in small numbers).
A range of bush birds (see Annex B for full list)	High abundance in previously inundated sites suggesting increased productivity benefits.
Regent parrot	Increased seed abundance providing food resources, high abundance in previously flooded sites.

4.3.5 Macquarie Marshes

What was the expected outcome?

The expected outcomes were:

- *Avoid loss, and maintain the resilience of permanent and semi-permanent wetland ecosystems in core wetland areas of the northern and southern Macquarie Marshes, particularly targeting some areas in the northern marshes which were not adequately inundated in 2014–15.*
- *Provide river conditions that allow for the movement and improvement of condition of native fish by providing winter flows, hydrological connectivity and access to habitat.*
- *Provide refuge habitat for waterbirds, fish and other aquatic species.*
- *Recharge shallow groundwater system in core areas of the northern and southern Macquarie Marshes.*
- *Allow for sediment transport, nutrient and carbon cycling.*

What information is available about the watering action?

A total of 52 554 ML of environmental water was delivered to the Macquarie Marshes, 12 114 ML of which was Commonwealth environmental water. Water was delivered in two pulses; the first in August – September 2015 and the second from mid-September to mid-October 2015. The timing of inundation in 2015–16 was earlier (winter–spring) than in 2014–15, when water was delivered in late spring into early summer. Although water inundated a significant proportion of the northern and southern Macquarie Marshes, water did not persist and the area started to dry from mid-spring.

Water inundated approximately 10 000 ha of the Macquarie Marshes, including around a quarter of the mapped wetlands within the 19 850 ha Ramsar site (Figure 10 and Table 12). The Ramsar site comprises the northern and southern sections of the Macquarie Marshes Nature Reserve as well as two additional disjunct areas, ‘U-block’ and ‘Wilgara’. Within the Ramsar site, the inundation was predominantly of ANAE wetland type ‘permanent floodplain wetland’. It should be noted, however, that ANAE classifications are broad, and the ecological character description for the site indicates

that the area described as ‘permanent floodplain wetland’ in Table 12 is more accurately described as intermittent marsh with emergent vegetation, such as common reed (*Phragmites australis*), cumbungi (*Typha* spp.) and water couch (*Paspalum distichum*) (OEH 2012).

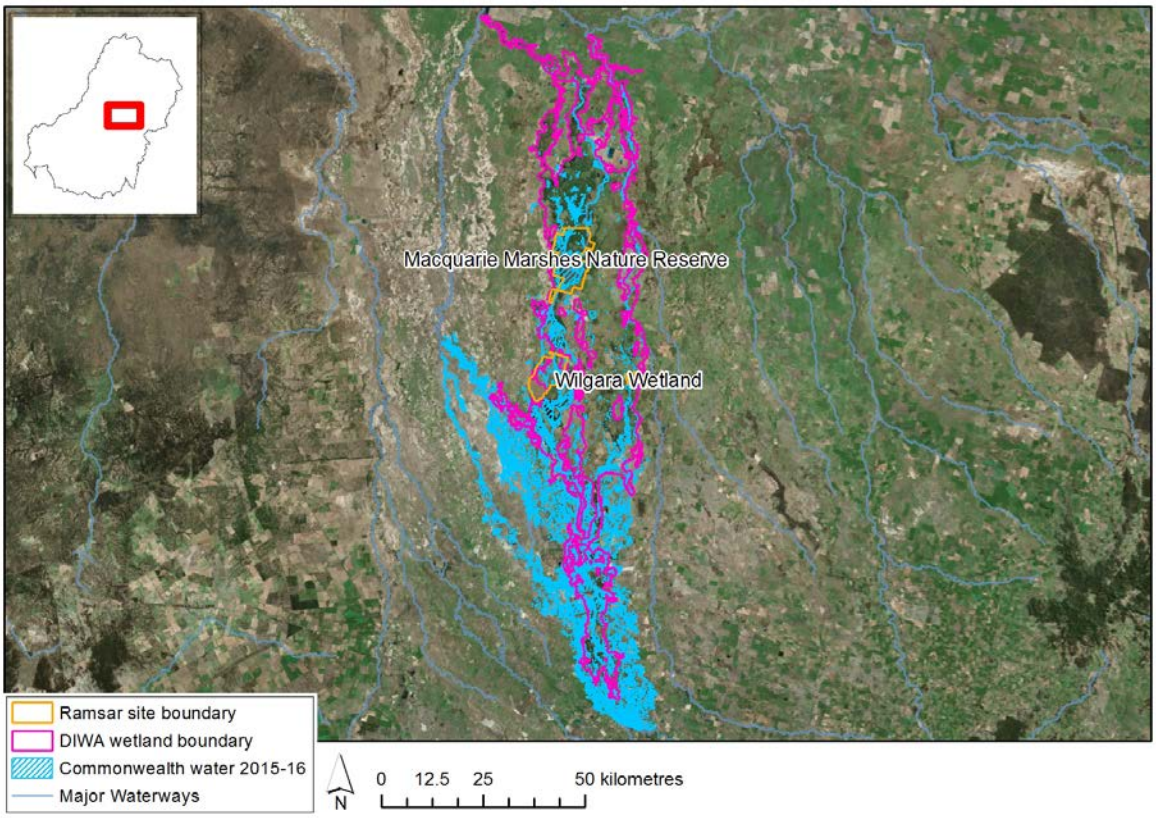

Figure 10. Total extent of inundation at the Macquarie Marshes by all sources of water, including Commonwealth environmental water and New South Wales environmental entitlements during environmental watering in 2015–16.

Table 12. ANAE wetland and floodplain types inundated from Commonwealth and New South Wales environmental watering in 2015–16 at the Macquarie Marshes Ramsar site.

Australian National Aquatic Ecosystem (ANAE) wetland type	Area inundated (hectares)
Pp4.1: Permanent floodplain wetland	4524
F3.2: Sedge/forb/grassland floodplain	473
Pt3.1.2: Clay pans	38
Rp1.4: Permanent lowland streams	33
Pt2.2.1: Temporary sedge/grass/forb floodplain marsh	29
Pp2.1.2: Permanent tall emergent marshes	22
Pt2.3.1: Floodplain freshwater meadow	16
Pp4.2: Permanent wetland	11
Pp2.3.2: Permanent grass marshes	7
Total	5153

What evidence is available to evaluate the outcome?

The Macquarie Marshes was listed as a Ramsar site in 1986 for its extensive wetland vegetation communities; abundance of waterbirds; supporting migratory birds listed under international treaties; supporting waterbird breeding, particularly colonial nesting species; the native fish community and supporting threatened species – Australasian bittern, Australian painted snipe, superb parrot, Murray cod and basalt peppercress (*Lepidium hyssopifolium*) (OEH 2012).

Available data included monitoring of frogs and waterbirds by NSW OEH (Ocock & Spencer 2016; Spencer *et al*. 2016) as well as preliminary observations as detailed in the CEWO acquittal report (unpublished). Key ecological outcomes were:

- winter response from wetland vegetation with sprouting of common reed and flowering of water couch
- maintenance of river red gum condition, but not of tree species such as black box and coolabah (*Eucalyptus coolabah*) which occur higher on the floodplain where inundation did not reach
- moderate diversity of waterbirds, with 45 species recorded in spring, including the nationally listed species Australian painted snipe and Australasian bittern
- good foraging habitat in shallow waters for wading species of birds, including international migrant species Latham's snipe (*Gallinago hardwickii*) and sharp-tailed sandpiper (*Calidris acuminata*), albeit in low numbers
- no recorded nesting activity largely due to the short duration and early timing of inundation
- 14 species of frog recorded and some opportunistic breeding of marsh species. The duration and timing of inundation was insufficient for successful breeding and recruitment of spring–summer species.

What species/communities potentially benefited?

There is evidence to suggest that a number of species and communities potentially benefited from Commonwealth environmental water at the Macquarie Marshes in 2015–16 (Table 13).

Table 13. Species and communities that potentially benefitted from Commonwealth environmental water in the Macquarie Marshes in 2015–16.

Community/species	Evidence
River red gum forest and woodland	Maintained or improved condition of river red gum trees in areas that were inundated.
Emergent marsh vegetation	Growth and flowering of emergent marsh vegetation in response to watering.
Australian painted snipe and Australasian bittern	Observed foraging in inundated wetland areas.
Waterbirds (general)	45 species recorded, comprising wetland generalists as well as a diversity of wading species feeding in shallow wetlands.
Frogs	14 species recorded with some limited breeding opportunities.

4.4 Effect of Commonwealth environmental water on species diversity

Commonwealth environmental water contributed to the inundation of approximately 64% of the wetland types in the Basin (as determined by the interim ANAE classification of wetlands and floodplains in the Basin; Table B1 (Annex B); Brooks 2017). This has contributed to maintaining (or restoring) ecosystem diversity and the species and communities supported by those ecosystems.

Lists of species that potentially benefited from Commonwealth environmental water in 2015–16 are provided in Annex B and comprise:

- 15 species of plants
- 11 species of fish
- 44 species of bush bird
- 70 species of waterbird
- 15 species of frog
- 2 species of turtle.

5 Long-term (1–5-year) outcomes

5.1 Highlights

- The number of species that have potentially benefited from Commonwealth environmental water increased, with a higher species richness of waterbirds and frogs recorded in 2015–16.
- There is evidence that the smaller scale watering in 2015–16 contributed to maintaining condition and refuges at several sites.
- There is a lack of information on the outcomes of environmental water in the Northern Basin and this may be limiting the list of species and communities that potentially benefited.

5.2 Cumulative (2014–16) short-term responses

Lists of ecosystems, species and communities that potentially benefited from Commonwealth environmental water in the first 2 years of LTIM (2014–16) are provided in Annex B and comprise:

- 23 species of native plants
- 14 species of native fish
- 48 species of bush bird
- 74 species of waterbird
- 18 species of frog
- 2 species of turtle.

Areas such as the Gwydir Wetlands, Hattah Lakes, Macquarie Marshes and Lower Murrumbidgee received Commonwealth environmental water in both 2014–15 and 2015–16. Watering was, however, of a shorter duration and reduced extent in 2015–16; with site-specific objectives related primarily to maintaining condition of vegetation communities and providing refuges for aquatic fauna. Despite this, diversity of waterbirds (and frogs in some areas) increased in 2015–16 as shallow water habitat provided foraging for small wading bird species. An additional 14 species of waterbird were recorded in sites that received Commonwealth environmental water, largely Australian resident and international migratory shorebirds. These birds (usually in small numbers) opportunistically foraged in the shallow water inland habitats.

Commonwealth environmental water also contributed to the inundation of several additional areas in 2015–16, including the Barmah–Millewa Forest. The watering actions at Barmah–Millewa were, again, of a relatively short duration and designed largely to maintain condition between large flood events. Although not specifically reported, inundation of over 10 000 ha of river red gum forest and woodland is likely to have contributed to maintaining tree condition and understorey diversity.

The assessment of fish responses to Commonwealth environmental water suggests a high degree of nativeness in the Basin fish community and the provision of refuge habitat in areas such as the Gwydir river system and the Warrego River (Stoffels *et al*. 2017).

While there was some moderate-scale breeding of waterbirds in the Barmah–Millewa Forest and Murrumbidgee in 2014–15 and evidence of breeding of some frog species in several areas that received Commonwealth environmental water in both years, large-scale breeding is yet to be recorded. The first 2 years of the LTIM Project have been moderate in terms of inundation duration and extent and have focused on maintaining populations and ecosystems during dry periods. Larger scale breeding events can be expected in years of significant inundation, mostly likely driven by natural events, which could be augmented by environmental water to maximise benefits.

There is a lack of information describing watering actions delivered in the Northern Basin. While there is monitoring at the Junction of the Warrego–Darling, there was very little water provided to the Warrego–Darling ecosystems in 2014–16 and only some inchannel water in 2015–16. There were several Commonwealth environmental watering actions in the Border Rivers and Condamine Balonne, which included end of system flows in the Culgoa River and Narran Lakes. However, there is little indication of the species and communities that may have benefited from environmental water in these systems and in the Queensland portion of the Basin in particular. The Northern Basin supports several species and communities that are either not represented in the south or have restricted distributions. Data collected from the Northern Basin in the future will most likely increase the list of species and communities that have potentially benefited from Commonwealth environmental water.

6 Basin-scale outcomes

6.1 Highlights

- 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-two 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 during a period that, without environmental water, would have remained largely dry.

6.2 Synthesis

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 are 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.

6.2.1 Maintaining the ecological character of Ramsar sites

Three case studies have been selected for an assessment of the effects of Commonwealth environmental water on maintaining the ecological character of Ramsar sites in the Basin: Barmah–Millewa Forest (which comprises two Ramsar sites: Barmah Forest and Central Murray Forests), Hattah–Kulkyne Lakes and Macquarie Marshes. Although Banrock Station is also a Ramsar site that received Commonwealth environmental water, the extent and duration of watering was limited and information available on the outcomes insufficient at this stage to comment on the effects to ecological character. Watering in 2015–16 of Banrock Station was the first in a series of planned watering actions and as time progresses and increased information becomes available, an assessment of the effects of environmental water on maintaining this site will be possible.

For each case study, consideration has been given to the relationship of Commonwealth environmental water and the components, processes and services identified as critical to maintaining ecological character.

The ecological character description for the Hattah–Kulkyne Lakes Ramsar site identifies four components / process and five services as critical to ecological character (Butcher & Hale 2011). The potential contribution of Commonwealth environmental water to maintaining each of these identified critical components, processes and services is provided in Table 14.

Table 14. Contribution of Commonwealth environmental water in 2014–16 to maintaining the ecological character of the Hattah–Kulkyne Lakes Ramsar site.

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
Hydrology	Lakes are filled via Chalka Creek (now via modified infrastructure). While the majority of the lakes dry within 12 months after inflows cease, lakes Mournpall and Hattah can retain water for several years post flooding.	Environmental water delivered to Hattah Lakes is designed to meet the hydrological needs at the site. This critical process is directly maintained by environmental water. There was wide-scale inundation in 2014–15 and then smaller watering in 2015–16 with wetlands allowed to dry down.
Lake bed herbland vegetation	Dominant vegetation across all lakes is lake bed herbland. It shifts from being dominated by aquatic and amphibious species with some terrestrial species on the edges in the wet phase, to being dominated by terrestrial species in the dry phase.	Evidence of aquatic species dominance during the wet phase of environmental watering, and an increase in diversity and complexity in 2015–16 when the site started to dry and water regimes were more variable across the site.
Fish	Fish fauna is dominated by small-bodied native species. Site regularly supports Australian smelt, bony herring, carp gudgeon and unspecked hardyhead.	Evidence that Commonwealth environmental water benefited a range of fish species and, in 2015–16, there was strong evidence that small-bodied native fish (Australian smelt, carp gudgeon and unspecked hardyhead) were breeding at the site and maintaining populations. Also, evidence of the movement of large-bodied native fish back into the river in response to flow cues.
Waterbirds	Supports 70 species of waterbirds, 12 of which are covered by international migratory bird treaties. 34 species have been recorded breeding at the site.	49 species of waterbird recorded at the site over the 2 years 2014–16 following environmental watering. High abundances of fish-eating species and >1% of the population of great cormorant in 2014–15 when water levels were high and a greater number of wading species and shorebirds as the lakes dried in 2015–16.
Supports near-natural wetland ecosystems	The site represents the largest series of floodplain lakes along the River Murray and is in relatively good condition.	Strong evidence to suggest the environmental water contributed to maintaining the site in good condition across both years.
Provides physical habitat (for breeding waterbirds)	Hattah–Kulkyne Lakes provide habitat that supports waterbird breeding and feeding.	Habitat suitable for breeding of at least three species of fish-eating birds.
Supports threatened wetland species	Australasian bittern, Australian painted snipe, regent parrot, silver perch, Murray cod, flat-headed galaxias and winged peppercress.	Good evidence that environmental water in 2014–15 supported silver perch, Murray cod and regent parrot. No dedicated surveys for the cryptic

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
		species Australasian bittern and Australian painted snipe.
Biodiversity	The site supports regionally significant range and number of species comparable to other sites within the Murray–Darling Basin. This includes supporting a large number and variety of waterbirds, including breeding habitat for many waterbird species and a rich and diverse flora and seed bank.	Large number of species and communities potentially benefited from Commonwealth environmental water in 2014–16 (see Table 11).
Ecological connectivity	Hattah–Kulkyne Lakes are hydrologically and ecologically connected and provide semipermanent surface water in a semi-arid environment, thus ensuring ecological persistence of aquatic habitats.	Evidence of connectivity (hydrological and biological) through the delivery of environmental water and return flows in both years, with good evidence from fish tracking that large-bodied native fish, such as golden perch move back into the river if provided the correct flow cues.

Barmah–Millewa Forest is listed as two separate Ramsar sites – Barmah Forest and Central Murray Forests. However, the ecological character descriptions for both sites identify largely the same critical components, processes and services for the site (Hale & Butcher 2011; Harrington & Hale 2011). The potential contribution of Commonwealth environmental water to maintaining each of these identified critical components, processes and services is provided in Table 15.

Table 15. Contribution of Commonwealth environmental water in 2014–16 to maintaining the ecological character of the Barmah Forest and Central Murray Forests Ramsar sites.

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
Hydrology	Inundation of the site is driven largely by flows within the River Murray. Large-scale floods that inundate the forest are generally the result of catchment-scale rainfall events. Moderate- and small-scale inundation is managed through regulators and environmental water.	There is evidence to suggest that Commonwealth environmental water contributed to small/moderate-scale inundation of the site in 2015–16.
Vegetation	The 2 critical wetland vegetation categories are river red gum forests and floodplain marshes. Approximately 85–90% of the 2 sites are covered by inundation-dependent forest and woodland. Floodplain marshes include moira grass plains which are regionally significant.	While it is likely that environmental water contributed to maintaining river red gum health, there is an ongoing decline in moira grass within the Barmah–Millewa Forest. This is largely a result of grazing and the presence of feral horses.
Fish	17 native species of fish have been recorded from within the site.	11 native species recorded within the site with evidence that environmental

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
		water was maintaining habitat for these species.
Waterbirds	67 species of wetland bird have been recorded from the site. This includes 11 species listed under international migratory agreements. The site is significant for supporting breeding of colonial nesting waterbirds and contains a significant breeding population of superb parrot.	30 species of waterbird recorded and over 1000 pairs of colonial nesting waterbirds breeding.
Supports diversity of wetland types	The site supports part of the largest remaining river red gum forest and provides a mosaic of vegetated wetland habitats.	Some evidence that the short-term watering maintained the diversity of wetland types in what would otherwise have been a dry year.
Provides physical habitat (for waterbirds)	The site provides habitat that supports waterbird breeding and feeding.	Small-scale waterbird breeding supported and evidence of some foraging provided. Aerial surveys recorded several thousand waterbirds in November 2015.
Supports threatened wetland species	Australasian bittern, Australian painted snipe, superb parrot, silver perch, Murray cod, trout cod.	Very large numbers of Australasian bittern recorded in inundated vegetated marshes. Superb parrot recorded feeding and nesting in river red gums. All 3 threatened fish species recorded at the site with evidence of spawning of silver perch.
Biodiversity	The site supports regionally significant range and number of species comparable to other sites within the Murray–Darling Basin. This includes supporting a large number and variety of waterbirds, including breeding habitat for many waterbird species and a rich and diverse flora and seed bank.	The small-scale, short-term environmental watering of the Barmah–Millewa Forest is likely to have helped maintain the diversity of plants and animals at the sites in what would otherwise have been a dry period.
Ecological connectivity	The site provides important migratory routes between riverine, wetland and floodplain habitats for fish spawning and recruitment.	There is evidence that fish moved in and out of the sites in response to environmental watering; maintaining ecological connectivity.

The ecological character description for the Macquarie Marshes Ramsar site identifies seven components/process and services as critical to ecological character (OEH 2012). Potential contribution of Commonwealth environmental water to maintaining each of these identified critical components, processes and services is provided in Table 16. While the watering actions inundated only a portion of the Ramsar site and for a relatively short duration, there is some evidence of contributions to maintaining ecological character, especially in terms of drought refuge in a dry landscape.

Table 16. Contribution of Commonwealth environmental water in 2014–16 to maintaining the ecological character of the Macquarie Marshes Ramsar site.

Critical components, processes and services	Description	Contribution of Commonwealth environmental water
Wetland types and vegetation	River red gum woodland and forests (6500 hectares; ha) Common reed beds (3350 ha) Cumbungi rushland (280 ha) Water couch marsh (1100 ha) Mixed marsh grasslands (50 ha) Lagoons (90 ha) Coolibah woodland and black box woodland (720 ha) Lignum (200 ha)	Environmental water inundated a range of vegetation communities in both 2014–15 and 2015–16 and, although for only a relatively short duration, would have contributed to maintaining condition during a regionally dry period. There is evidence of maintaining tree condition, particularly river red gum communities that were inundated in both years and of growth and reproduction in common reed and water couch emergent marshes.
Aquatic invertebrates	High densities of microinvertebrates, which are am important food source for fish. Also supports a diversity of macroinvertebrate species.	Possible that the inundation of the wetland and floodplain systems resulted in increased productivity and abundance of microinvertebrates for a short period in both years.
Fish species diversity	11 species of native fish recorded. Provides rich productive feeding habitats, and spawning habitat for several species.	Some evidence of spawning of bony bream, and potential increase in productivity from inundation of the Ramsar site in 2014–15. However, very high abundance of exotic fish species.
Waterbird abundance and diversity	Supports over 70 species of waterbirds, with between 10 000 and 30 000 adult waterbirds reliant on the site each season.	Although high abundances were not observed, 43 species of waterbird recorded using the site.
Waterbird breeding	16 species of colonial nesting waterbirds, with colonies of more than 500 nests on average in 9 in every 15 years.	No evidence of colonial nesting breeding in 2014–15 or 2015–16.
Migratory birds and waders	17 species listed under international migratory agreements have been recorded at the site.	4 international migratory waders recorded at the site, albeit in small numbers.
Supports threatened wetland species	Australasian bittern, Australian painted snipe, superb parrot, Murray cod and basalt peppercress.	Australasian bittern and Australian painted snipe both recorded using the inundated habitats of the site in 2015–16.

6.2.2 Threatened species

Thirty-three significant species were recorded at sites that received environmental water in 2014–16 (Table 17). This includes 8 international migratory waterbird species, 11 nationally listed threatened species and 14 species listed under state legislation. It is anticipated that as LTIM progresses and more data become available, this list will not only grow, but our understanding of how Commonwealth environmental water is benefiting these species across the Basin will also increase.

Two iconic and nationally listed threatened bird species were recorded at sites that received Commonwealth environmental water. The Australasian bittern was recorded in both years and the Australian painted snipe in 2015–16. Given the cryptic nature of both these species, it is likely that they were present at sites in both years. Although there are several other waterbird species listed as threatened under the EPBC Act that can occur in the Basin, these are largely shorebirds that rely mostly on coastal habitats and would not be expected in these inland wetlands on a regular basis. Two species of parrot that are listed nationally as vulnerable (regent parrot and superb parrot) are often considered 'wetland dependent' for their reliance on river red gum as nesting trees. These two species were recorded in sites that received Commonwealth environmental water in both years and watering actions aimed at maintaining tree health would be sustaining nesting habitat. In addition, there is evidence from Hattah Lakes that the regent parrot has benefited over the past 2 years from watering of the floodplain and the resulting increase in productivity and food resources (Loyn & Dutton 2016).

The olive perchlet (*Ambassis agassizii*), which is listed as an endangered population in the NSW 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 (Stoffels *et al*. 2017).

6.2.3 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 that indicates that, during dry times, the use of environmental water to maintain key wetland habitats is important for ongoing survival of waterbird populations in the Basin (Bino *et al*. 2015) and can be effective in maintaining other biota, such as frogs and turtles (Howard *et al.* 2017).

Table 17. Listed species that were recorded at sites that received Commonwealth environmental water in 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)
	Rigid water milfoil	*Myriophyllum porcatum*	Vulnerable (EPBC)
	Winged peppercress	*Lepidium monoplocoides*	Endangered (EPBC)

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

7 Contribution to achievement of Basin Plan objectives

The environmental water outcomes framework is a hierarchy of expected outcomes based around the Basin environmental watering objectives. Expected outcomes are matters that best available science indicates can be achieved from environmental watering (CEWH 2013):

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

The outcomes framework provides a template for synthesising outcomes of environmental water and progress towards meeting Basin Plan objectives. There is evidence across the Basin that Commonwealth environmental water is contributing to Basin Plan objectives for ecosystem and species diversity (Table 18).

Table 18. Contribution of Commonwealth environmental water in 2014–16 to Basin Plan objectives associated with generic diversity.

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	Reproduction	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.
				Condition		
			Growth and survival	Germination Dispersal	Increased total cover and dominance of inundated vegetation communities and mostly higher species richness (though highly dependent on range of intrinsic and extrinsic factors).	Greater vegetation cover in plots/transects subjected to at least some wetting during this period.
		Macro-invertebrates	Macroinvertebrate diversity	-	-	-
		Fish	Fish diversity	Condition	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		Evidence of Murray hardyhead recruitment.	Evidence of Murray hardyhead recruitment.
		Waterbirds	Waterbird diversity		Foraging habitat provided at a number of locations, including several large wetland complexes, particular 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 on nesting birds at Hattah Lakes	Fledgling recorded on nesting birds at Hattah Lakes
		Other vertebrate diversity		Young	Limited breeding of frogs.	Breeding of frogs at several locations across the 2 years.
			Adult abundance		Foraging habitat provided in several areas.	Foraging habitat provided in several areas.

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Annex A. Watering actions contributed to by Commonwealth environmental water in 2015–16 with expected outcomes for fish, vegetation, waterbirds, frogs or other vertebrates

Table A1. Watering actions contributed to by Commonwealth environmental water in 2015–16 with expected outcomes for fish, vegetation, waterbirds, frogs or other vertebrates. 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; X = unassigned)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lachlan - Great Cumbung Swamp	1516-Lch-01	24,058.50	9/08/2015 - 15/10/15	Fresh		P				P	P	S	
Lachlan - Booligal Wetlands - Merrimajeel and Muggabah Creek	1516-Lch-02	1,087.50	2/09/15 - 29/10/15	Fresh		P	P			P		S	
Lachlan Booligal wetlands – waterbird contingency	1516-Lch-03	1,497.00	29/10/15 - 10/11/15	Fresh			P					S	
Lower Lachlan River channel	1516-Lch-04	9,378.50	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	7/11/15	Fresh	P				P	P	S	P	
QLD Border Rivers - Dumaresq-Macintyre River and Fringing Wetlands	1516-BrdR-04	137.10	1/2/16	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	

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected Outcomes (P = primary; S = secondary; X = unassigned)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
QLD Condamine-Balonne - Nebine Creek	1516-CndBal-01	997.78	23/06/15 - 27/06/15	Fresh	S	S			S	P	P	P	
QLD Condamine-Balonne - Lower Balonne floodplain system	1516-CndBal-02	9,454.90	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	2,702.36	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	3,481.13	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	1,456.67	1/06/2016 - 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	5,000.00	08/03/16 - 29/3/16	Fresh	S	S	S	S	P		P		
Murrumbidgee - Yarradda Lagoon	1516-Mbg-02	1,394.30	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	8,075.00	15/10/2015 - 11/11/15	Fresh	P								
Murrumbidgee - Waldaira Wetlands (Junction Wetlands)	1516-Mbg-08	2,000.00	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					

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected Outcomes (P = primary; S = secondary; X = unassigned)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Murrumbidgee - Nap Nap - Wagourah	1516-Mbg-12	7,000.00	06/05/16 - 30/06/16	Wetland		P	P	P					
Murrumbidgee - Nap Nap - Wagourah	1516-Mbg-11	2,557.00	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	1,444.90	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	2,000.00	17/09/15 - 22/11/15	Base flow and Fresh		P				P			P
Goulburn - Lower River Channel	1516-Gbn-01	190,563	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	1,476.70	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						

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected Outcomes (P = primary; S = secondary; X = unassigned)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray - Banrock Station - Wigley Reach Central	1516-Brock-05	52.49	20/01/16 - 01/02/16	Wetland	P	P	P						
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	1,340.43	17/11/15 - 11/03/16	Wetland	P	P	P						
Lower Murray wetlands (NRM Board) - Berri Evaporation Basin	1516-NRMB-03	1,255.00	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					

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected Outcomes (P = primary; S = secondary; X = unassigned)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
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						
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	1,290.00	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	1/12/15 - 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						

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected Outcomes (P = primary; S = secondary; X = unassigned)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Lower Murray wetlands (NFSA) - Yarra Creek	1516-NFSA-12	593.00	01/10/15 - 30/01/16	Wetland		P	P	P					
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	1/02/16 - 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	12/8/15 - 22/5/16	Base flow	P	S							
Lower Broken Creek - Reach 3	1516-Brkn-02		18/8/15 - 30/11/16	Base flow	S	S							P
Lower Broken Creek - Reach 3	1516-Brkn-04		1/10/15 - 16/5/16	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 - 9/11/15 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		

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected Outcomes (P = primary; S = secondary; X = unassigned)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
Mid Murray - River Murray Channel	1516-Mur-03	172,600.00	25/07/15 - 10/09/15	Overbank	P	P	P			P			
Mid Murray - River Murray Channel, Barmah and Millewa	1516-Mur-04	63,900.00	11 /9/15 - 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	8,000.00	11 /11/15 - 10/2/16	Overbank		P	S						
Mid-Murray - Gunbower Creek	1516-Mur-02	13,606.00	01/7/15 –30/6/16	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	6/08/15 - 17/10/15	Fresh	P	P	S		S	S	S		
Macquarie - Macquarie River System, including floodplain	1516-Macq-02	2,125.00	25/06/16 - 30/06/16	Fresh	P	P	P	P	P	P	P		
Gwydir - Gwydir Wetlands	1516-Gwyd-01	1,350.00	09/01/16 - 11/02/16	Overbank	S	P	S		S	S	S		
Gwydir - Mallowa Wetlands	1516-Gwyd-02	3,150.00	09/11/15 - 5/02/16	Overbank		P	S		S	P			

Surface water region/asset	Watering Action Number	Commonwealth environmental water volume (ML)	Dates	Flow component	Expected Outcomes (P = primary; S = secondary; X = unassigned)								
					Fish	Veg	Birds	Frogs	Other biota	Con.	Proc.	Res.	WQ
		336.00											
Gwydir - Mehi River	1516-Gwyd-03	964.00	09/11/15 - 11/11/15	Fresh	P					S	P	S	
Gwydir - Gwydir River System	1516-Gwyd-04	2,600.00	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 9/03/16 - 3/06/16	Wetland	P	P			S			P	P
Lower Murray - Mallee wetland Sites - Cardross Wetlands	1516-VicW-02	476.61	9/09/15 - 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	5,347.50	12/10/15 - 23/10/15	Wetland	P	P	P		S	P	S		

Note: IPA = Indigenous Protected Area; NFSA = Nature Foundation South Australia; NRM = Natural Resource Management.

Annex B. Species and communities that potentially benefited from Commonwealth environmental water in 2014–16.

Table B1. ANAE wetland types likely to have been influenced by Commonwealth environmental water 2014–16 (Brooks 2017).

Australian National Aquatic Ecosystem (ANAE) wetland type	Total area (ha)	Area influenced 2014–15 (%)	Area influenced 2015–16 (%)
Pt1.4.2: Intermittent river cooba swamp	104	0	97.1
Pp2.3.1: Permanent floodplain grass marshes	431	5.8	50.3
Pp2.1.1: Permanent floodplain tall emergent marshes	7809	54.8	45.6
Pp4.1: Permanent floodplain wetland	42 004	51.2	44.4
Pt2.2.1: Temporary sedge/grass/forb floodplain marsh	51 081	12.7	35.6
Pp2.1.2: Permanent tall emergent marshes	134	23.1	23.1
Pt1.1.1: Intermittent river red gum floodplain swamp	63 396	43.2	15.8
Lst2.1: Temporary saline floodplain lakes	10 636	22	13
Rp1.3: Permanent low energy upland streams	286	9.1	8.4
Pt1: Temporary swamps	3766	18.7	7.4
Rp1.4: Permanent lowland streams	74 534	19.2	5.2
Pt3.1.2: Clay pans	51 074	6.4	4.1
Psp4: Permanent saline wetland	3965	56	4
Pp2.3.2: Permanent grass marshes	183	3.8	3.8
Pt1.2.1: Intermittent black box floodplain swamp	33 916	3.8	3.5
Pst1.1: Temporary saline swamp	17 020	12.5	3.2
Pt3.1.1: Floodplain clay pans	49 329	4.6	3.2
Pt2.3.1: Floodplain freshwater meadow	11 138	1.5	2.9
Pt1.7.2: Intermittent lignum swamps	17 967	<0.1	1.8
Rt1: Temporary streams	294	33.7	1.7
Pt4.1: Temporary floodplain wetland	122 885	5.8	1.3
Pt1.1.2: Intermittent river red gum swamps	8480	0.1	1.1
Pst4: Temporary saline wetland	11 912	8.2	0.9
Rt1.4: Temporary lowland streams	223 362	0.9	0.9
Pt1.3.2: Intermittent coolibah swamp	1019	0	0.9
Pt1.7.1: Intermittent Lignum floodplain swamp	27 356	<0.1	0.7
Lp2.1: Permanent floodplain lakes	137 406	61.8	0.5
Lt1.1: Temporary lakes	306 351	0.7	0.5
Pt2.2.2: Temporary sedge/grass/forb marsh	30 527	2.1	0.3
Lt2.1: Temporary floodplain lakes	198 459	1.3	0.3
Lp1.1: Permanent lakes	47 669	0.7	0.3
Pp4.2: Permanent wetland	22 388	0.1	0.2
Pp2.2.2: Permanent sedge/grass/forb marshes	2564	0	0.2
Pt1.2.2: Intermittent Black box swamp	16 470	0.5	<0.1
Pt2.1.1: Temporary tall emergent floodplain marsh	50 687	0.4	0.1
Pt1.6.1: Temporary woodland floodplain swamp	179 804	0.2	<0.1
Lst1.1: Temporary saline lakes	12 759	<0.1	<0.1
Pt1.3.1: Intermittent coolibah floodplain swamp	5173	0.1	0.1
Pt1.6.2: Temporary woodland swamp	44 406	0	<0.1
Psp2.1: Permanent salt marsh	3	66.7	0
Pt2.1.2: Temporary tall emergent marsh	18 381	40.6	0
Rp1: Permanent streams	1428	28.4	0
Lsp1.1: Permanent saline lakes	8225	25.3	0
Rt1.3: Temporary low energy upland streams	712	22.9	0
Pst2.2: Temporary salt marsh	8575	4.8	0
Pp2.4.1: Permanent floodplain forb marshes	157	1.9	0
Pst3.2: Salt pans and salt flats	13 186	1.2	0
Rt1.2: Temporary transitional zone streams	5957	0.6	0
Pt4.2: Temporary wetland	130 760	0.1	0

Table B2. Plant species that potentially benefited from Commonwealth environmental water (restricted to wet plots) in 2014–16 (Capon & Campbell 2017).

Grasses	Subshrubs/shrubs	Sedges/rushes
Aristida leptopoda *Echinochloa* spp. *Eragrostis leptostachya* *Leptochloa* spp.	*Eremophila debilis* *Lycium australe*	*Carex bichenoviana*
Forbs	**Trees**	**Mistletoes**
*Arctotheca calendula** *Chrysocephalum apiculatum* *Dichondra* spp. *Eichhornia crassipes** *Emex australis** *Gnaphalium* spp. *Goodenia* spp. *Gratiola pedunculata* *Medicago lupulina** *Persicaria hydropiper* *Persicaria* spp. *Rhaponticum repens** *Spirodela polyrhiza* *Veronica catenata**	*Myoporum acuminatum*	*Dendrophthoe* spp.

Note: asterisks (*) indicate exotic species.

Table B3. Fish species that potentially benefited from Commonwealth environmental water in 2014–16 (extracted from Stoffels *et al.* 2017, augmented with species recorded in monitoring outside LTIM).

Common name	Species name	Listing
Australian smelt	*Retropinna semoni*	
Bony bream	*Nematalosa erebi*	
Carp gudgeon	*Hypseleotris* spp.	
Eel-tailed catfish	*Tandanus tandanus*	Endangered (NSW, Vic)
Flathead gudgeon	*Phylipnodon grandiceps*	
Golden perch	*Macquaria ambigua*	
Murray cod	*Maccullochella peelii*	Vulnerable (EPBC)
Murray–Darling rainbowfish	*Melanotaenia fluviatilis*	
Murray hardyhead	*Craterocephalus fluviatilis*	Endangered (EPBC)
Olive perchlet	*Ambassis agassizii*	Endangered population (NSW)
Silver perch	*Bidyanus bidyanus*	Endangered (EPBC)
Spangled perch	*Leiopotherapon unicolor*	
Trout cod	*Maccullochella macquariensis*	Endangered (EPBC)
Unspecked hardyhead	*Craterocephalus stercusmuscarum*	

Note: EPBC = listed under the *Environment Protection and Biodiversity Conservation Act 1999*; NSW = New South Wales, Vic = Victoria.

Table B4. Frog species that potentially benefited from Commonwealth environmental water in 2014–16.

Common name	Species name	Listing
Barking marsh frog	*Limnodynastes fletcheri*	
Broad-palmed frog	*Litoria latopalmata*	
Crucifix frog	*Notaden bennetti*	
Desert froglet	*Crinia deserticola*	
Desert tree frog	*Litoria rubella*	
Eastern banjo frog	*Limnodynastes dumerilii*	
Green tree frog	*Litoria caerulea*	
Inland banjo frog	*Limnodynastes interioris*	
Painted burrowing frog	*Neobatrachus sudelli*	
Peron's tree frog	*Litoria peronii*	
Plains froglet	*Crinia parinsignifera*	
Salmon-striped frog	*Limnodynastes salmini*	
Southern bell frog	*Litoria raniformis*	Vulnerable (EPBC)
Spotted marsh frog	*Limnodynastes tasmaniensis*	
Striped burrowing frog	*Litoria alboguttata*	
Water-holding frog	*Litoria platycephala*	
Warty water-holding frog	*Litoria verrucosa*	
Wrinkled toadlet	*Uperoleia rugosa*	

Note: EPBC = listed under the *Environment Protection and Biodiversity Conservation Act 1999*.

Table B5. Turtle species that potentially benefited from Commonwealth environmental water in 2014–16.

Common name	Species name	Listing
Eastern long-necked tortoise	*Chelodina longicollis*	-
Broad shell tortoise	*Chelodina expansa*	-

Table B6. Bush bird species that potentially benefited from Commonwealth environmental water at Hattah Lakes (extracted from Loyn & Dutson 2016, showing species whose abundance increased during or after environmental watering 2014–15 and those that continued to use the previously flooded site in 2015–16).

Common name	Species name	2014–15	2015–16
Apostlebird	*Struthidea cinerea*	X	X
Australian raven	*Corvus coronoides*	X	X
Australian ringneck	*Barnardius zonarius*	X	X
Black-faced cuckoo-shrike	*Coracina novaehollandiae*	X	X
Blue bonnet	*Northiella haematogaster*	X	X
Blue-faced honeyeater	*Entomyzon cyanotis*	X	
Brown falcon	*Falco berigora*	X	X
Brown treecreeper	*Climacteris picumnus*	X	X
Chestnut-rumped thornbill	*Acanthiza uropygialis*	X	X

Common name	Species name	2014–15	2015–16
Common bronzewing	*Phaps chalcoptera*	X	X
Eastern rosella	*Platycercus eximius*	X	X
Galah	*Eolophus roseicapilla*	X	X
Grey fantail	*Rhipidura albiscapa*	X	X
Grey shrike-thrush	*Colluricincla harmonica*	X	X
Laughing kookaburra	*Dacelo novaeguineae*	X	X
Little corella	*Cacatua sanguinea*	X	X
Little eagle	*Hieraaetus morphnoides*	X	X
Little friarbird	*Philemon citreogularis*	X	X
Magpie-lark	*Grallina cyanoleuca*	X	X
Major Mitchell's cockatoo	*Lophochroa leadbeateri*	X	X
Noisy miner	*Manorina melanocephala*	X	X
Rainbow bee-eater	*Merops ornatus*	X	X
Red-capped robin	*Petroica goodenovii*	X	X
Regent parrot (vulnerable; EPBC)	*Polytelis anthopeplus*	X	X
Restless flycatcher	*Myiagra inquieta*	X	X
Rufous whistler	*Pachycephala rufiventris*	X	X
Sacred kingfisher	*Todiramphus sanctus*	X	X
Singing honeyeater	*Lichenostomus virescens*	X	X
Spiny-cheeked honeyeater	*Acanthagenys rufogularis*	X	X
Spotted pardalote	*Pardalotus punctatus*	X	X
Striated pardalote	*Pardalotus striatus*	X	X
Striped honeyeater	*Plectorhyncha lanceolata*	X	X
Tree martin	*Petrochelidon nigricans*	X	X
Varied sittella	*Daphoenositta chrysoptera*	X	X
Weebill	*Smicrornis brevirostris*	X	X
Welcome swallow	*Hirundo neoxena*	X	
Whistling kite	*Haliastur sphenurus*	X	X
White-backed swallow	*Cheramoeca leucosterna*	X	X
White-bellied sea-eagle (FFG listed)	*Haliaeetus leucogaster*	X	X
White-browed woodswallow	*Artamus superciliosus*	X	X
White-plumed honeyeater	*Lichenostomus penicillatus*	X	X
White-winged chough	*Corcorax melanorhamphos*	X	X
White-winged triller	*Lalage tricolor*	X	X
Willie wagtail	*Rhipidura leucophrys*	X	
Yellow rosella	*Platycercus elegans flaveolus*	X	X
Yellow thornbill	*Acanthiza nana*	X	X
Yellow-rumped thornbill	*Acanthiza chrysorrhoa*	X	X
Yellow-throated miner	*Manorina flavigula*	X	

Note: EPBC = listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwth); listed under the FFG = *Flora and Fauna Guarantee Act 1988* (Vic).

Table B7. Waterbird species that potentially benefited from Commonwealth environmental water in 2014–15 Across river systems for which data was available. Number represents the number of years that the species was recorded.

Species	Gwydir	Murrum-bidgee	Warrego–Darling	Lower Murray	Goulburn	Mid-Murray	Macquarie
Australasian bittern[1]		1			1	2	1
Australasian darter	2	1	2	1		2	1
Australasian grebe	2	2	1	1		2	1
Australasian shoveler	1	1	2	1		2	1
Australian little bittern[3]	1					2	
Australian painted snipe[2]							1
Australian pelican	2	2	2	2		2	1
Australian pratincole	1	1					
Australian reed warbler	2			1		2	
Australian shelduck		2		1		2	1
Australian white ibis	2	2	2	1		2	1
Australian wood duck	2	2	2	2		2	1
Banded lapwing				1		2	1
Black swan	2	2	2	2	1	2	1
Black-fronted dotterel	2		2	1		2	1
Black-necked stork[3]	1						1
Black-tailed godwit[4]	1						
Black-tailed native-hen	2		1	1		1	1
Black-winged stilt	2	1	2	1		1	1
Blue-billed duck[3]						1	
Brolga[3]	2		2	1	1		1
Caspian tern				2		2	
Cattle egret	2						1
Chestnut teal	1			1		2	1
Common greenshank[4]	1						1
Common sandpiper[4]			1				
Dusky moorhen	1	1		2		2	1
Eastern great egret[3]	2	2	2	1		2	1
Eurasian coot	2	2	2	1		2	1
Freckled duck[3]			2	1			
Glossy ibis	2						1
Golden-headed cisticola	2						
Great cormorant	2	2		1		2	1
Great crested grebe						1	
Grey teal	2	2	2	2		2	1
Hardhead[3]	1	2	1	1		2	1
Hoary-headed grebe	1	2	2	1		2	1
Intermediate egret[3]	2	1				1	1
Latham's snipe[4]	2						2
Little black cormorant	2	2	1	1		2	1
Little egret[3]	1	1	1			2	1

Species	Gwydir	Murrum-bidgee	Warrego–Darling	Lower Murray	Goulburn	Mid-Murray	Macquarie
Little grassbird	2		1	1		1	
Little pied cormorant	2	2		1		2	1
Magpie goose	2						1
Marsh sandpiper	1					1	1
Masked lapwing	2	1	2	2		2	1
Musk duck[3]				1		2	
Nankeen night-heron	1	1				2	
Pacific black duck	2	2	2	2		2	1
Pied cormorant	2	1	1	1		2	
Pink-eared duck	2	2	2	2		1	1
Plumed whistling-duck	2		1				1
Purple swamphen	2			1			1
Red-backed kingfisher			1				
Red-capped plover			1			1	
Red-kneed dotterel	2		1	1		1	1
Red-necked avocet	1		1			1	
Red-necked stint[4]						1	
Royal spoonbill	1	1	1				1
Sacred kingfisher	2	2	2			2	
Sharp-tailed sandpiper[4]	2			1		1	2
Silver gull						2	
Spotless crake	1						
Straw-necked ibis	2	2	1	1		2	1
Superb parrot						1	
Swamp harrier	2			1		1	
Tawny grassbird	1						
Wandering whistling-duck	1						
Whiskered tern	2	1	1				1
White-bellied sea-eagle	1	2	1			2	
White-faced heron	2	2	2	1		2	1
White-necked heron	2	1	2	1		2	1
Wood sandpiper[4]			1				
Yellow-billed spoonbill	2		2	1		2	1

[1] Listed as endangered nationally under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

[2] Listed as vulnerable nationally under the EPBC Act.

[3] Listed as threatened under state legislation.

[4] Listed under international migratory agreements JAMBA (Japan–Australia Migratory Bird Agreement); CAMBA (China–Australia Migratory Bird Agreement); ROKAMBA (Republic of Korea– Australia Migratory Bird Agreement).