



research for a sustainable future



Murrumbidgee Selected Area Monitoring, Evaluation and Research Plan 2019



Prepared by: Wassens, S^a., Michael, D.R^a., Spencer, J^c., Thiem, J^d., Kobayashi, T^c., Bino, G^b., Thomas, R^c., Brandis, K^b., Hall, A^a and Amos, C^{a, c}.



^a Institute for Land, Water and Society- Charles Sturt University, PO Box 789, Albury, NSW 2640



^b Centre for Ecosystem Science, University of New South Wales, Sydney, NSW, 2052



^c Water, Wetlands & Coasts Science Branch, NSW Office of Environment and Heritage, PO Box A290, Sydney South, NSW 1232

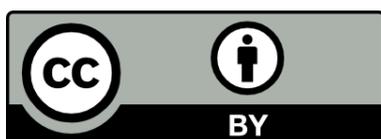


^d NSW Trade and Investment Narrandera Fisheries Centre, PO Box 182, Narrandera NSW 2700

This MER Plan was commissioned and funded by Commonwealth Environmental Water Office with additional in-kind support from Charles Sturt University, University of NSW, NSW Office of Environment and Heritage, NSW Department of Primary Industries

Copyright

© Copyright Commonwealth of Australia, 2019



Murrumbidgee Monitoring, Evaluation and Research Plan is licensed by the Commonwealth of Australia for use under a Creative Commons By Attribution 3.0 Australia licence with the exception of the Coat of Arms of the Commonwealth of Australia, the logo of the agency responsible for publishing the report, content supplied by third parties, and any images depicting people. For licence conditions see: <http://creativecommons.org/licenses/by/3.0/au/>

This report should be attributed as 'Murrumbidgee Monitoring, Evaluation and Research Plan Commonwealth of Australia 2019'.

The Commonwealth of Australia has made all reasonable efforts to identify content supplied by third parties using the following format '© Copyright'.

Disclaimer

The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the Australian Government or the Minister of the Environment.

While reasonable efforts have been made to ensure that the contents of this publication are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

1	Introduction	1
1.1	About the MERP	3
1.2	MERP development and rational	4
2	Murrumbidgee Selected Area description	7
2.1	Monitoring Zones.....	7
2.1.1	Riverine zones.....	8
2.1.2	Wetland zones	10
2.1.3	Hydrology of the Murrumbidgee Selected Area	13
3	Commonwealth environmental watering.....	16
3.1	Overview of environmental watering options for the catchment	16
3.2	Flow Objectives.....	20
3.3	Water holdings in the Murrumbidgee Selected Area	22
3.4	Practicalities of watering	23
4	Monitoring and research priorities.....	26
4.1.1	Process for prioritisation of hydrological zones.....	26
4.1.2	Outline monitoring priorities	27
4.1.3	Contingency monitoring	31
4.1.4	Research priorities.....	32
5	Indicators.....	35
5.1	Wetland hydrology (Category 3 Selected area).....	36
5.1.1	Monitoring.....	36
5.1.2	Research.....	39
5.2	Stream Metabolism.....	40
5.2.1	Monitoring.....	40
5.2.2	Evaluation.....	41
5.2.3	Research.....	44
5.3	Fish Communities (River)	45
5.3.1	Monitoring.....	45
5.3.2	Evaluation.....	46
5.3.3	Research.....	49

5.4	Larval Fish	50
5.4.1	Monitoring.....	50
5.4.2	Evaluation	51
5.4.3	Research	53
5.5	Vegetation Diversity	54
5.5.1	Monitoring.....	54
5.5.2	Evaluation	54
5.5.3	Research	56
5.6	Wetland Fish Communities	57
5.6.1	Monitoring.....	57
5.6.2	Evaluation	58
5.6.3	Research	60
5.7	Frogs, tadpoles and turtles	61
5.7.1	Monitoring.....	61
5.7.2	Evaluation	62
5.7.3	Research	65
5.8	Waterbird Diversity	66
5.8.1	Monitoring.....	66
5.8.2	Evaluation	66
5.8.3	Research	69
6	Integrated research	70
7	Summary of monitoring, evaluation and research activities ...	72
7.1	Timeline.....	74
8	Engagement and communication	79
8.1	Purpose.....	79
8.2	Communications goals	79
8.3	Stakeholders and tools of engagement	81
8.4	Communication activities	83
8.4.1	Communication products.....	83
8.4.2	Community engagement activities.....	85
8.5	Communication protocols	87
8.5.1	Protocols around colonial breeding waterbird sites.	87
8.5.2	Culturally sensitive sites	88

8.5.3	Social media protocols.....	88
9	Reporting	90
9.1	Written reports	90
9.2	Annual Forum	91
10	Project management	92
10.1	Governance, leadership and administration	92
10.2	Landholder and land manager relationships	92
10.3	Data management	95
11	References.....	96
12	Detailed Budgets.....	105
13	Appendices.....	106
	Appendix 1 - Workplace Health & Safety Plan.....	106
	Appendix 2 - Risk Assessment	106
	Appendix 3 - Standard operating procedures for indicators monitored	107
	Appendix 4 - Progress report template.....	Error! Bookmark not defined.
	Appendix 5 - Waterbird Breeding.....	112

1 Introduction

The Commonwealth Environmental Water Holder (CEWH) is responsible under the *Water Act 2007* (Cth) for managing Commonwealth environmental water holdings. The holdings must be managed to protect or restore the environmental assets of the Murray-Darling Basin, and other areas where the Commonwealth holds water, so as to give effect to relevant international agreements. The Basin Plan (2012) further requires that the holdings must be managed in a way that is consistent with the Basin Plan's Environmental Watering Plan. The *Water Act 2007* (Cth) and the Basin Plan also impose obligations to report on the contribution of Commonwealth environmental water to the environmental objectives of the Basin Plan.

Monitoring and evaluation are critical for supporting effective and efficient use of Commonwealth environmental water. They provide important information to support the CEWH to meet their reporting obligations in addition to demonstrating overall effectiveness at achieving ecological objectives.

The Monitoring, Evaluation and Research program (MER program) builds on the previous Long Term Intervention Monitoring (LTIM) program (2014 - 2019). In order to protect the integrity of the long-term dataset that was developed under the LTIM program (Wassens *et al.* 2018) much of the methodology employed in this program is a direct continuation of the previous LTIM program. This new MER program will therefore be the primary mechanism to evaluate the outcomes of Commonwealth Environmental Water (CEW) actions undertaken between 2019 and 2022. The MER program will continue to be implemented at seven Selected Areas over a three year period (2019 - 2020 to 2021 - 2022) to deliver five high-level outcomes (in order of priority):

- Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authority's (MDBA) Environmental Watering Plan.
- Evaluate the ecological outcomes of Commonwealth environmental watering at each of the seven Selected Areas.

- Infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin not monitored.
- Support the adaptive management of Commonwealth environmental water.
- Monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

This Monitoring, Evaluation and Research Plan (MERP) provides details of activities that will be implemented across the **Murrumbidgee Selected Area** between 2019 and 2022. This MERP includes:

- A description of the Murrumbidgee Selected Area including hydrological zones
- Monitoring and research priorities
- Monitoring indicator methods and evaluation questions relevant to the Basin-scale and Selected Area
- A summary of MER activities
- A communications and engagement plan
- Project and data management
- A detailed budget

A Workplace health and safety plan and risk assessment are provided as standalone documents, whereas the standard operating procedures for CAT 3 indicators monitored, a reporting template and (optional) waterbird breeding sections are provided in the Appendix (1-5).

1.1 About the MERP

The Murrumbidgee catchment in southern NSW is one of the largest river catchments in the Murray-Darling Basin (MDB) (87,348 km²). The Murrumbidgee River is one of the most regulated rivers in Australia, controlled by multiple major reservoirs including the Snowy Mountains Hydro-electric Scheme, the Australian Capital Territory (ACT) Water Supply Scheme, and, in NSW, primarily by two large dams: Burrinjuck Dam (1,026,000 ML capacity, operational in 1911) on the Murrumbidgee River and Blowering Dam (part of the Snowy River scheme) (1,628,000 ML capacity, operational since 1968) located on the Tumut River (CSIRO 2008b). The Murrumbidgee has an extremely high level of water resource development with an average diversion rate of 53% (2257 GL/year) of all available water (CSIRO 2008b).

The Murrumbidgee Selected Area covers the lowland section of the Murrumbidgee catchment and largely encompasses the Murrumbidgee portion of the "aquatic endangered ecological community of the Natural Drainage System of the Lower Murray River Catchment", identified under the (*Fisheries Management Act 1994* (NSW)). The Murrumbidgee Selected Area contains three significant regions: the Murrumbidgee River main channel, the mid-Murrumbidgee wetlands and the Lowbidgee floodplain. The Murrumbidgee Selected Area provides critical habitats for a number of federally-listed threatened species, including Australasian bittern (*Botaurus poiciloptus*), trout cod (*Maccullochella macquariensis*), Murray cod (*Maccullochella peelii*), silver perch (*Bidyanus bidyanus*), Macquarie perch (*Macquaria australasica*), and southern bell frog (*Litoria raniformis* (*Commonwealth Environment Protection and Biodiversity Conservation Act, 1999* - EPBC), as well as well as state listed species including the southern myotis (fishing bat) (*Myotis macropus*) (*NSW Biodiversity Conservation Act, 2016*) and nationally significant population of the endangered Grey Snake (*Hemiapsis damelii*) (IUCN). The Lowbidgee floodplain also contains some of the Murray-Darling Basin's largest breeding sites for colonially-nesting waterbirds and waterbird species listed under bilateral migratory bird agreements that Australia has signed with Japan (*Japan-Australia migratory bird agreement (JAMBA), 1974*), China (*China - Australia migratory bird agreement (CAMBA), 1986*) and the Republic of Korea (*Republic of Korea - Australia migratory bird agreement (ROKAMBA), 2007*).

This MERP has been developed to provide a comprehensive Monitoring, Evaluation and Research program, capable of supporting adaptive management and Basin wide evaluation in the Murrumbidgee Selected Area. The plan takes into account the significant environmental water holdings in the Selected Area, flexible delivery options and high diversity of important aquatic habitats, and leverages on extensive datasets and collaborations developed under the Long Term Intervention Monitoring (LTIM) program (Wassens *et al.* 2014) and the Murray-Darling Basin Environmental Water Knowledge and Research project (MDB EWKR). The focus of the MERP is on large-scale cost-effective monitoring activities, rather than intensive small-scale monitoring within a single habitat type. The benefit of the large-scale approach is that it provides a more robust framework upon which to base Selected Area evaluation of the contribution of Commonwealth environmental water and build on the significant amount of data and information that was collected under the previous above mentioned projects.

1.2 MERP development and rational

As mentioned above, the MERP builds on monitoring and evaluation questions formulated under the previous Long Term Intervention Monitoring (LTIM) program (Wassens *et al.* 2014), which was developed to follow five guiding principles of the outcomes framework underpinning the management of Commonwealth environmental water (Commonwealth Environmental Water 2013). The five guiding principles include:

The need to provide a robust evaluation of the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authority's (MDBA) Environmental Watering Plan:

- To protect and restore water-dependent ecosystems of the Basin;
- To protect and restore the ecosystem functions of water-dependent ecosystems;
- To ensure that water-dependent ecosystems are resilient to risks and threats; and
- To ensure that environmental watering is coordinated between managers of planned environmental water, owners and managers of environmental assets, and holders of held environmental water.

Acquire the capacity to evaluate ecological outcomes of Commonwealth environmental watering in the Murrumbidgee Selected Area.

We have developed the MERP to evaluate the ecological outcomes of Commonwealth environmental water for a consistent number of different indicators (e.g. fish, frogs, waterbirds and vegetation). In addition, Selected Area evaluation of key ecological responses was based on a series of statistical process models designed to quantify the relative contribution of Commonwealth Environmental water.

Develop and inform robust models that can infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin.

The MER plan uses a framework that has been established to evaluate relationships and patterns that have generality and transferability at two spatial scales. At the basin scale, the MER program will contribute data to Basin evaluations led by CSIRO and University of Canberra, with CSU, UNE, La Trobe and other agencies as partners. Within the Murrumbidgee Selected Area, the MER program has been established to enable ecological outcomes to be inferred across twelve monitored wetlands within three zones. This is achieved by maintaining sufficient replication within each of the three target zones to account for spatial variability, allowing for cross validation and testing of modelled predictions.

Support the adaptive management of Commonwealth environmental water.

A key goal of the Murray-Darling Basin Authority's (MDBA) Environmental Watering Plan is to "*ensure that environmental watering is coordinated between managers of planned environmental water, owners and managers of environmental assets, and holders of held environmental water*". The MERP has been developed in consultation with NSW environmental water managers, landholders and managers of NSW and Commonwealth estates, including the Murrumbidgee Valley National and Regional Parks, Yanga National Park and Nature Reserve, and the Nimmie-Caira System Enhanced Environmental Water Delivery Project.

In highly regulated systems, such as the Lowbidgee floodplain, water is actively managed in order to achieve the desired ecological objectives, and monitoring is a critical component of this process. Active water management is particularly important in supporting waterbird breeding. For example, the Nimmie-Caira floodplain supports some of Australia's largest breeding colonies of straw-necked ibis (*Theskiornis*

spinicollis) that are particularly sensitive to sudden changes in water level around their nests. Information on the status of nesting birds and water levels is needed during breeding events to support real-time adaptive management of environmental water (Brandis *et al.* 2011). In previous water years, colonies of egret and cormorant species in Yanga National Park (Redback zone) were initiated and successfully managed using Commonwealth and NSW environmental water, with monitoring actions playing a critical role in informing the need for top-up flows (Childs *et al.* 2010). Top-up flows are also critical in maintaining successful breeding by the vulnerable southern bell frog (EPBC Act 1999) across the Lowbidgee floodplain (see Wassens *et al.* 2018). During return flows from wetland and/or floodplain to the river, monitoring activities are also critical in providing real time information on risks associated with hypoxic black water, exotic fish movement into the river channel, as well as identifying needs for return and reconnection flows when significant recruitment of native fish is observed on the floodplain. Adaptive management and frequent communication between monitoring providers and a range of stakeholders are critical for the success of environmental watering actions.

2 Murrumbidgee Selected Area description

Wetlands make up over 4% (370,000 ha) of the Murrumbidgee Catchment, with over 1000 wetlands identified (Murray 2008). Nationally important wetlands, including the mid-Murrumbidgee and Lowbidgee floodplain, cover over 208,000 ha (2.5% of the catchment area). For the purposes of the assessment of environmental water requirements and identification of monitoring zones, three key areas were identified in the Murrumbidgee LTIM project (Gawne *et al.* 2013a). Each area was identified by the MDBA as a “*key environmental asset within the Basin*” and “*important site for the determination of the environmental water requirements of the Basin*”. They include:

- The Lower Murrumbidgee River (in-channel flows) (Murray-Darling Basin Authority 2012a),
- The mid-Murrumbidgee River wetlands (Murray-Darling Basin Authority 2012b), and
- The lower Murrumbidgee floodplain (Murray-Darling Basin Authority 2012c).

2.1 Monitoring Zones

Monitoring zones represent areas with common ecological and hydrological attributes. Under the LTIM project, separate zones were identified for riverine and wetland habitats across the Murrumbidgee Selected Area. In most cases, the zones were selected to align with existing classifications by MDBA and NSW Office of Environment and Heritage (OEH). In order to align closely with established management units across the Murrumbidgee Selected Area, a broad scale approach to the selection of zones was taken, focusing on large scale differences in hydrology, vegetation and faunal communities. It should be noted that the selected zones cover large areas, and, in the case of wetland zones, there remains considerable heterogeneity within as well as between zones. As a result, higher levels of replicate monitoring locations are required in some zones to enable statistical evaluation of ecological outcomes.

2.1.1 Riverine zones

The Murrumbidgee River is over 1 600 km long, with the Murrumbidgee Selected Area covering the lowland section (approximately 786 km). In the Murrumbidgee River, three zones were identified that have a degree of hydrological uniformity and could be accurately estimated using the existing gauge network. The zone classification also takes into account key inflows (tributaries) and outflows (distributaries and irrigation canals) (Figure 2-1). The three river zones include:

- **Narrandera reach (187.3 km)** – Includes major irrigation off-takes, also key populations of Murray Cod.
- **Carrathool reach (358.0 km)** – Downstream of Tom Bullen storage and major irrigation off-takes, reduced influence of irrigation flows, target for in-channel Commonwealth environmental watering actions.
- **Balranald reach (241.4 km)** – Aligns with the Lowbidgee floodplain, it is associated with three major weirs (Maude, Redbank and Balranald). Target for in-channel and floodplain Commonwealth environmental watering actions.

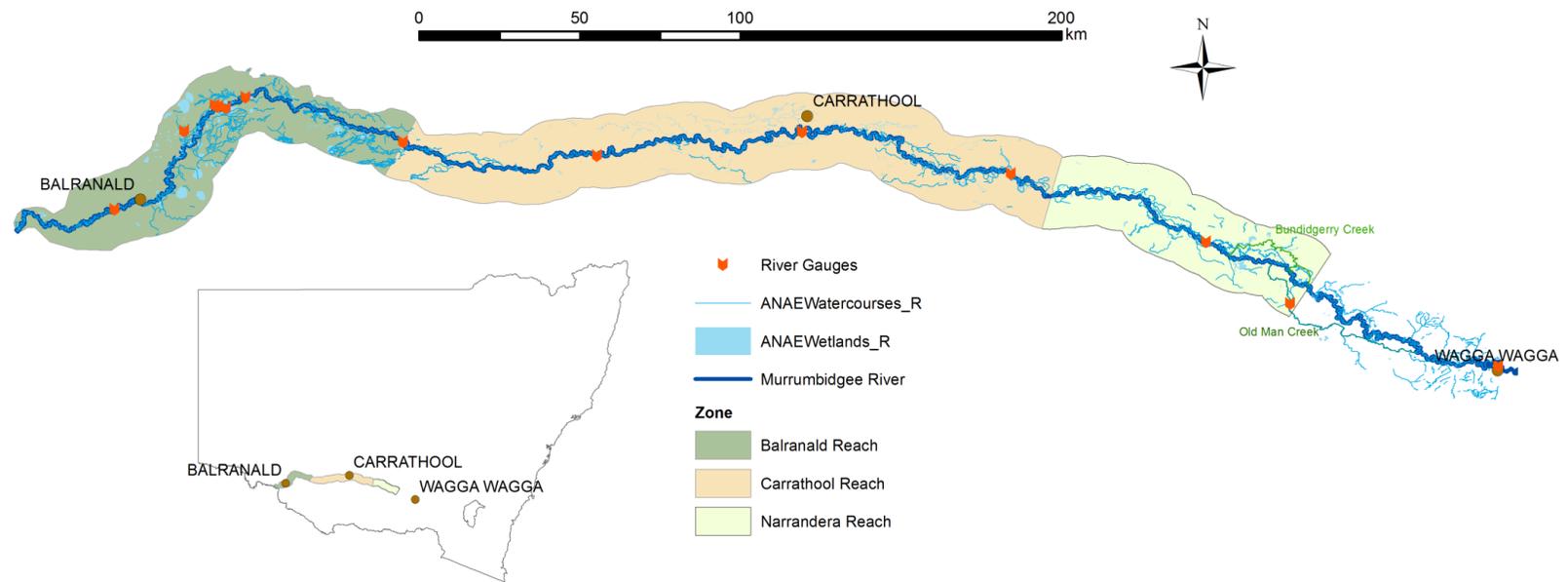


Figure 2-1 Distribution of riverine zones in the Murrumbidgee Selected Area.

2.1.2 Wetland zones

The identification of zones across floodplain habitat is more complex than in riverine systems, due to the diversity of aquatic habits, complexity of hydrological regimes (spatiotemporal variability of flows), diversity of vegetation types and presence of flow control structures (e.g. water management units). Ultimately, six very broad zones were identified under the LTIM project based on dominant vegetation type, faunal communities and expected ecological responses (Figure 2-2). These six zones aligned with the management units identified by NSW OEH and are recognised by MDBA and the Commonwealth Environmental Water Office (CEWO). Zones were classified for two key regions: the mid-Murrumbidgee River (Murray 2008) and the lower Murrumbidgee floodplain (Murrumbidgee Catchment Management Authority 2009).

These regions are split into six broad zones (see Figure 2-2):

- **mid-Murrumbidgee wetlands (82,800 ha)** – River red gum forest interspersed with paleochannels and oxbow lagoons
- **Pimpara–Wagourah (55,451 ha)** – Mosaic of creek lines, paleochannels and wetlands, with River red gum and black box mostly north of the Murrumbidgee River
- **Redbank (92,504 ha)** – Mosaic of river red gum forest and woodland, spike rush wetlands - divided into two management subzones (north and south Redbank)
- **Nimmie-Caira (98,138 ha)** – Mosaic of creek lines, paleochannels, open wetlands and lakes dominated by lignum and lignum-black box communities
- **Fiddlers-Uara (75,285 ha)** – Paleochannels and creek lines bordered by black box
- **The Western Lakes (3459 ha)** – Open quaternary lakes with inactive lunettes west of the Lowbidgee floodplain

Under the MER program (2019 – 2022), we will continue to monitor and evaluate key indicators, key indicators, identified under the LTIM project, within the mid-Murrumbidgee, Nimmie-Caira Nimmie-Caira and Redbank zones (

Figure 2-2). Descriptions of all wetland sites for which key indicators will be monitored is provided in Table 2-1.

Table 2-1 Summary of core wetland monitoring locations following on from the Murrumbidgee LTIM project across three zones in the Murrumbidgee Selected Area, including proposed new monitoring sites in the mid-Murrumbidgee.

Site name	Site abbreviation	Zone	ANAE classification
Gooragool Lagoon	GOO	mid-Murrumbidgee	Permanent floodplain wetland
McKennas Lagoon*	MCK		Intermittent River red gum floodplain swamp
Sunshower Lagoon*	SUN		Intermittent River red gum floodplain swamp
Yarradda Lagoon	YAR		Intermittent River red gum floodplain swamp
Darlington Lagoon**	DAR		Intermittent River red gum floodplain swamp
Matangry**	MAN		Intermittent River red gum floodplain swamp
Avalon Swamp	AVA	Nimmie-Caira	Temporary floodplain lakes
Eulimbah Swamp	EUL		Temporary floodplain wetland
Nap Nap Swamp	NAP		Intermittent River red gum floodplain swamp
Telephone Creek	TEL		Permanent floodplain wetland
Mercedes Swamp	MER	Redbank	Intermittent River red gum floodplain swamp
Piggery Lake	PIG		Permanent floodplain tall emergent marshes
Two Bridges Swamp	TBR		Intermittent River red gum floodplain swamp
Waugorah Lagoon	WAG		Permanent floodplain wetland

* Note: some indicators (e.g. wetland fish, frogs, tadpoles and waterbird diversity) will no longer be routinely monitored at McKennas Lagoon or Sunshower Lagoon unless they commence to fill. **Alternate monitoring sites.

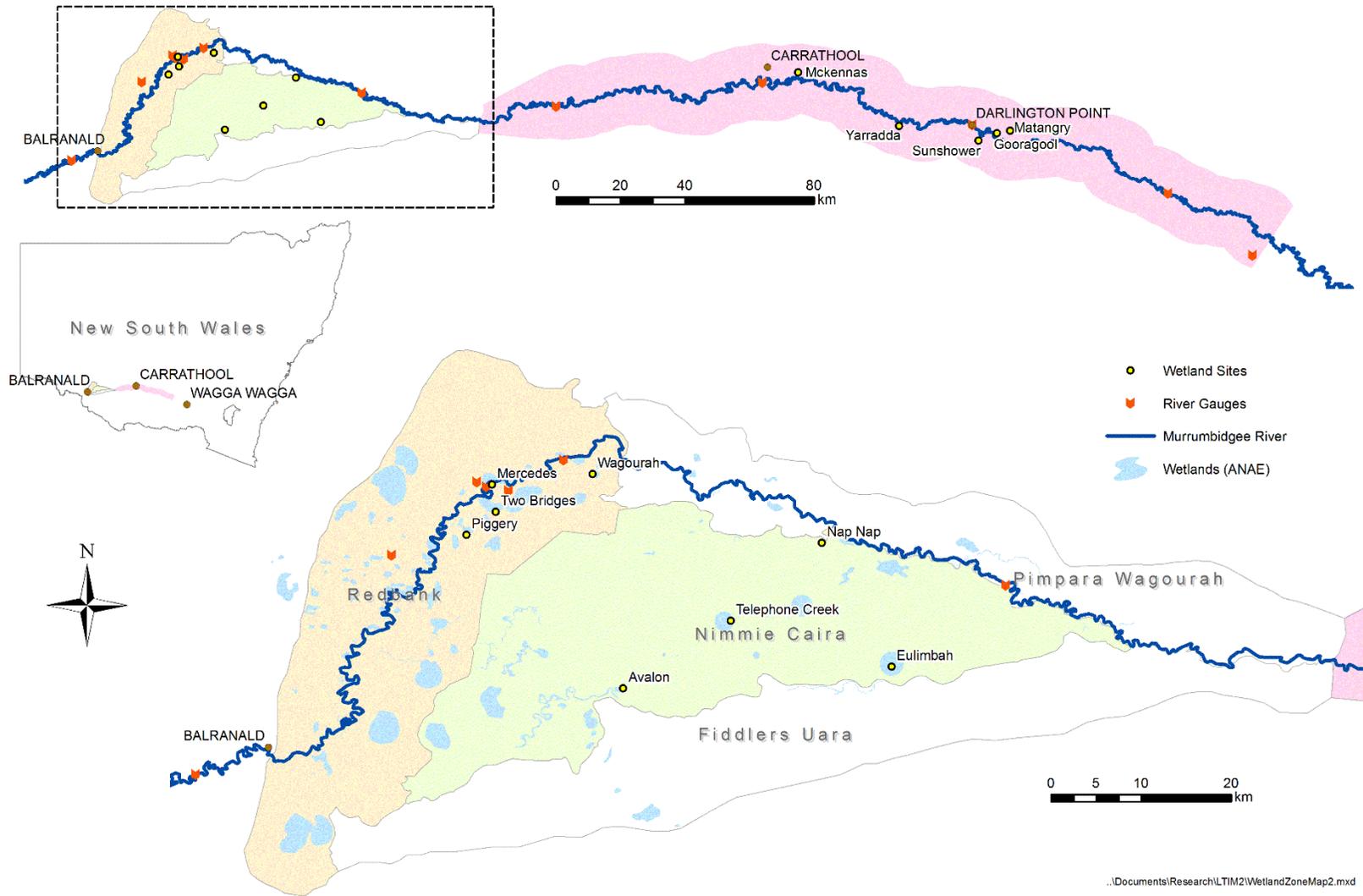


Figure 2-2 Distribution of wetland zones in the Murrumbidgee Selected Area and locations of key wetlands.

2.1.3 Hydrology of the Murrumbidgee Selected Area

The Murrumbidgee River and connected wetlands receive regular inflows as a result of spring snow melt and rainfall in the upper catchment (Murray 2008) (Figure 2-3). Prior to the millennium drought, the majority of wetlands through the mid-Murrumbidgee were considered to be permanent, with others exhibiting fluctuating seasonal water levels that rarely resulted in complete drying (Chessman 2003). Likewise, the Lowbidgee floodplain once received considerable inundation each year with overbank flows in spring and summer maintaining over 200,000 ha of lignum, black box and river red gum wetland complexes (Kingsford & Thomas 2001). However, flows within the Murrumbidgee River have undergone significant long-term changes since the construction of large headwater dams and in-channel weirs which allow the river flows to be regulated and diverted to meet agricultural and consumptive needs. The timing of high flow periods, in particular, has shifted from winter to spring to meet irrigation demands and there have been significant reductions in the frequency of minor and moderate flow pulses (Frazier *et al.* 2005; Frazier & Page 2006). Between 2000 and 2010 a significant drought event coupled with increasing consumptive water demand exacerbated the effects of river regulation (Dijk *et al.* 2013) leading to significant declines in the condition of floodplain vegetation (Wen *et al.* 2009). Large-scale flooding occurred in 2010 and 2011 which was followed by moderate water availability between 2012 and mid-2016. In 2016-17, there was above average rainfall in the catchment contributing to increasing tributary inflows and unregulated river flows which inundated significant areas of wetland through the mid-Murrumbidgee and Lowbidgee floodplains between September and November 2016. The 2017-2018 water year, saw below average rainfall across much of the MDB. In the twelve-month period, rainfall across the Murrumbidgee catchment was closer to the long-term average, with about 80% of the mean annual total falling in the upper regions of the catchment. However, reasonable water levels in storage dams contributed to moderate water availability. Dry conditions have continued into 2018-19 with 'very dry' and 'extreme dry' and below average dam levels.

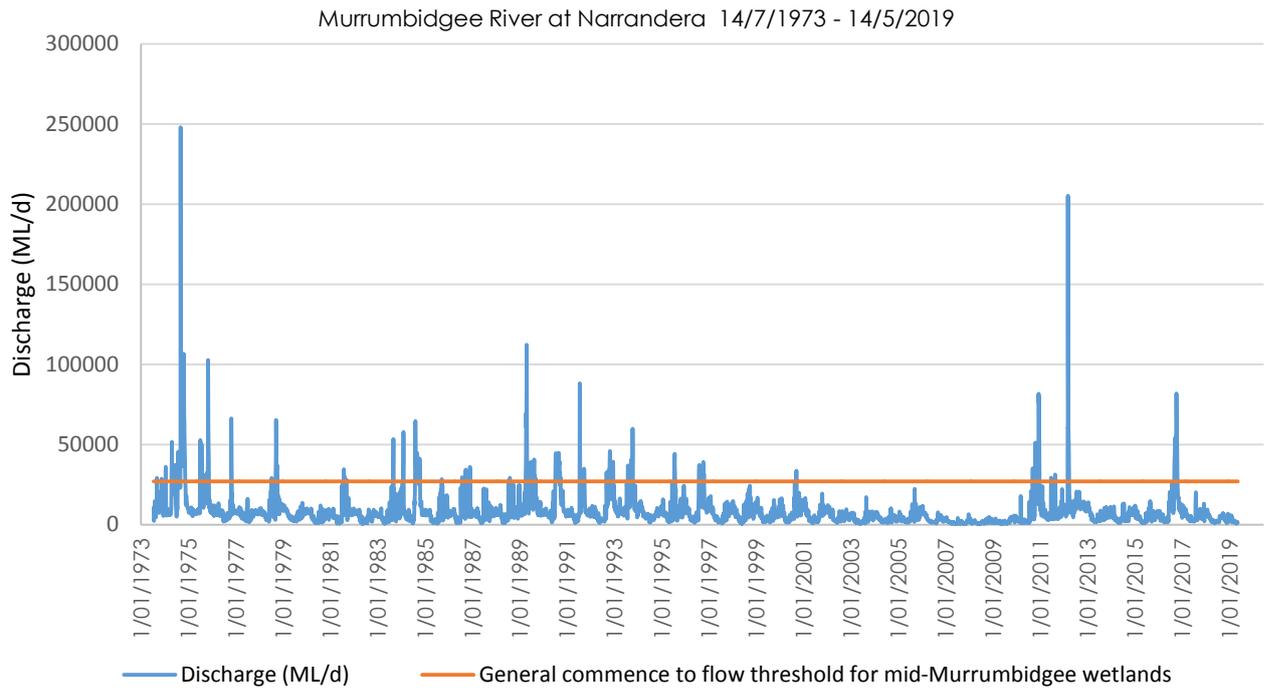


Figure 2-3 Flows in the mid-Murrumbidgee area (Narrandera) between 1973 and 2019 (<https://realtimedata.watersw.com.au> Gauge Number: 41005). Red line indicates commence to fill for mid-Murrumbidgee wetlands.

River Hydrology

The Murrumbidgee River is heavily regulated and has a very well developed network of gauges maintained by WaterNSW within the main river channel and key off-takes (Sinclair Knight Merz 2011). River zones in the Murrumbidgee Selected Area were specifically defined with a view to reducing hydrological heterogeneity and aligning key monitoring activities with the existing gauge network (Table 2-2). As a result, we are of the view that the current gauging network will be sufficient to provide hydrological information to maintain Category 1 monitoring activities.

Table 2-2 Summary of Gauges in the Selected Area (from WaterNSW). <https://realtimedata.watersw.com.au/water.stm>

Zone	Number	Name	Lat	Long	Zero Elevation (m)
Wagga Wagga	410001	Murrumbidgee River At Wagga Wagga	-35.1006	147.3674	170.05
Narrandera	410005	Murrumbidgee River At Narrandera	-34.7554	146.5489	137.39
	410007	Yanco Creek At Offtake	-34.7061	146.4094	134.80
	410013	Main Canal At Berembed	-34.8779	146.836	149.07
	410023	Murrumbidgee River At D/S Berembed Weir	-34.8797	146.836	147.88
	410036	Murrumbidgee River At D/S Yanco Weir	-34.6953	146.4007	132.48
	410093	Old Man Creek At Kywong (Topreeds)	-34.9274	146.7844	152.37
Carrathool	410002	Murrumbidgee River At Hay	-34.5169	144.8418	-
	410021	Murrumbidgee River At Darlington Point	-34.5664	146.0027	117.86
	410040	Murrumbidgee River At D/S Maude Weir	-34.4790	144.2996	-
	410078	Murrumbidgee River At Carrathool	-34.4493	145.4174	97.231
Balranald	410041	Murrumbidgee River At D/S Redbank Weir	-34.3813	143.7804	-
	410130	Murrumbidgee River At D/S Balranald Weir	-34.6665	143.4904	54.253
	41000236	Talpee Creek D/S Pee Vee Creek Junction	-34.5284	143.7305	60.35
	41000240	Waugorah Creek U/S Regulator	-34.3549	143.8580	65.33
	41000241	Weather Station At North Of Woolshed Creek Regulator	-34.5619	143.6645	-
	41000244	Woolshed Creek D/S Of Regulator	-34.5627	143.6697	61.79
	41000246	Yanga Creek At D/S Offtake	-34.3854	143.8029	65.26
	41000255	North Redbank Channel At Glendee	-34.3766	143.7712	65.126
	41000256	North Redbank Channel At Athen	-34.4491	143.6861	63.775

3 Commonwealth environmental watering

3.1 Overview of environmental watering options for the catchment

The Commonwealth Environmental Water Office (CEWO) manages environmental water in the Murrumbidgee Catchment in partnership with the MDBA, NSW OEH (including the National Parks and Wildlife Service), WaterNSW, NSW Office of Water, the Riverina Local Land Services, the Murrumbidgee Environmental Water Allowance Reference Group, Traditional Owners, and local land managers and water users. Environmental watering actions are determined by a combination of catchment and climate conditions, the environmental demand and the volume of water holdings. Multiple large scale watering actions have been undertaken since 2009 with the use of substantial Commonwealth and NSW environmental water holdings (Table 3-1). These normally include a combination of flows targeting a range of aquatic habitats, to address unique ecological objectives. For example: 1) in-channel flows in the Murrumbidgee River, 2) wetland watering actions across multiple zones within the Lowbidgee floodplain, 3) in-channel flows managed to allow for connection to the mid-Murrumbidgee wetlands, 4) reconnection flows to the mid-Murrumbidgee River from the wetlands, and 5) in-channel freshes managed as piggy-back flows associated with The Living Murray (TLM) releases or periods of tributary inflows. In any given water year, Commonwealth watering options and related monitoring activities are required to be flexible to accommodate changing flow priorities and climatic conditions, opportunities and risks.

In the Murrumbidgee catchment, there is considerable public scrutiny of Commonwealth watering actions and risk management during environmental flows. In particular, management of hypoxic black water, algal blooms, and taste and odour issues (real or perceived) is critical. Likewise flows across the Lowbidgee floodplain are highly regulated and managed. While the presence of extensive infrastructure provides significant flexibility in water actions in a given year, it also requires high levels of adaptive management with top-up flows frequently required to sustain waterbird and southern bell frog breeding populations across the floodplain.

Table 3-1 Summary of watering actions undertaken in the Murrumbidgee Selected Area

Watering Action	In-channel/floodplain	Zone	CEW delivered (ML)
2009 - 2010 (48,741 ML)			
North Redbank	Floodplain	Redbank	1,600
Yanga National Park	Floodplain	Redbank	47,141
2010 - 2011 (193,347 ML)			
Barren Box Swamp	Floodplain	Murrumbidgee Irrigation Area	3000
Lowbidgee - North Redbank	Floodplain	Redbank	2525
Lowbidgee - Yanga National Park	Floodplain	Redbank	7533
Lowbidgee - Yanga Nature Reserve/Park	Floodplain	Redbank	13,287
Mid-Murrumbidgee wetlands and the Yanco-Colombo-Billabong Creek system	In-channel and floodplain	Mid-Murrumbidgee	109,250
Murrumbidgee river replenishment	In-channel	Carrathool-Balranald	57,752
2011 - 2012 (82,978.6 ML)			
Lower Murrumbidgee in-stream fresh	In-channel	Balranald	33,749
Lower Murrumbidgee River - blackwater dilution flow	In-channel	Balranald	26,744.90
North Redbank wetlands, including return flows	In-channel and floodplain	Redbank	22,484.70
2012 - 2013 (156,000 ML)			
Hobblers Lake, Cherax Swamp and associated wetlands.	Floodplain	Western Lakes	6000
Murrumbidgee River fish recruitment flow	In-channel	Carrathool-Balranald	150,000
2013 - 2014 (136,600 ML)			
Lower Murrumbidgee floodplain	Floodplain	Redbank	127,233
Lower Murrumbidgee floodplain (supplementary flows)	Floodplain	Nimmie-Caria	9367
2014 - 2015 (152,560.2 ML)			
Juanbung (North Redbank)	Floodplain	Western Lakes	5688.2
Mid North Redbank and return flows	In-channel and floodplain	Mid-Murrumbidgee	40,000
Paika Lake	Floodplain	Western Lakes	8498
Sandy Creek	In-channel	Yanco-Billabong	250
Upper North Redbank	Floodplain	Junction	20,000
Yanco Creek system	In-channel and floodplain	Yanco-Billabong	2462
Yanga National Park	Floodplain	Redbank	74,512
Yarradda Lagoon	Floodplain	Mid-Murrumbidgee	1150

Table 3-2 Continued summary of watering actions undertaken in the Murrumbidgee Selected Area

2015 – 2016 (108,328 ML)			
Junction Wetlands (Waldaira)	Floodplain	Junction	2000
Nimmie-Caira	Floodplain	Nimmie-Caria	27,557
North Redbank	Floodplain	Redbank	35,000
Sandy Creek	In-channel	Yanco-Billabong	105.7
Toogimbie IPA	Floodplain	Nimmie-Caria	933
Western Lakes	Floodplain	Western Lakes	5000
Yanco Creek native fish flow	In-channel	Yanco-Billabong	8075
Yanco Creek wetland inundation	In-channel and floodplain	Yanco-Billabong	18,263
Yanga National Park	Floodplain	Redbank	10,000
Yarradda Lagoon	Floodplain	Mid-Murrumbidgee	1394.3
2016 – 2017 (241,465 ML CEW)			
Junction Wetlands: no take of LBG SAL	n/a	Junction	n/a
Lower Murrumbidgee Floodplain: Nimmie-Caira to South Yanga (Nimmie Creek to Yanga Lake)	In-channel	Balranald	15,507
Lower Murrumbidgee River: Autumn fish pulse	In-channel	Balranald	47,548
Murrumbidgee River Fresh: Flood recession and dissolved oxygen management	In-channel	Carrathool-Balranald	150,978
Nimmie-Caira: Nap Nap waterbird breeding support	Floodplain	Nimmie-Caria	630
Nimmie-Caira: Telephone Bank waterbird breeding support	Floodplain	Nimmie-Caria	5425
Nimmie-Caira: Eulimbah waterbird breeding support	Floodplain	Nimmie-Caria	2320
Nimmie-Caira: Is-Y-Coed pelican breeding support	Floodplain	Nimmie-Caria	5000
North Redbank: Tori Lignum Swamp waterbird support	Floodplain	Redbank	844
Toogimbie IPA Wetlands	Floodplain	Nimmie-Caria	998
Western Lakes	Floodplain	Yanco-Billabong	5060
Yanco-Billabong Creek System: Water Quality	In-channel	Yanco-Billabong	
Yanco-Billabong- Forest Creek system: Wanganella Swamp waterbird breeding support	In-channel and floodplain	Yanco-Billabong	5000
Yanga National Park: waterbird support	Floodplain	Redbank	2155

Table 3-3 Continued summary of watering actions undertaken in the Murrumbidgee Selected Area

2017 – 2018 (266,270.64 ML)			
Gooragool Lagoon – Forego Kooba Ag Water	Floodplain	Mid-Murrumbidgee	1500
mid-Murrumbidgee wetlands reconnection (Yarradda & Gooragool pumping)	Both in-channel and floodplain	Mid-Murrumbidgee	161,035
Murrumbidgee River and Floodplain Wetlands: Coonancoocabil Lagoon	Both in-channel and floodplain	Mid-Murrumbidgee	900
Murrumbidgee River and Floodplain Wetlands: Oak Creek	Both in-channel and floodplain	Mid-Murrumbidgee	620
Nimmie-Caira Refuge	Floodplain	Nimmie-Caria	13,850
Nimmie-Caira Refuge Flow	Floodplain	Nimmie-Caria	1738
North Redbank Refuge Flows	Floodplain	Redbank	5528
Sandy Creek	In-channel	Yanco-Billabong	400
Toogimbie IPA Wetlands	Floodplain	Nimmie-Caria	1000
Tuckerbil Swamp	Floodplain	MIA	600
Waldaira Lagoon	Floodplain	Junction	1500
Yarradda Lagoon Pumping	Floodplain	Mid-Murrumbidgee	177

3.2 Flow Objectives

In identifying flow objectives we found it informative to consider the objectives, ecological values and expected outcomes presented in key published documents, e.g. (Murray-Darling Basin Authority 2012a; Murray-Darling Basin Authority 2012b; Murray-Darling Basin Authority 2012c; Gawne *et al.* 2013a; NSW Commissioner for Water 2013, CEWO annual watering plans 2011-2019 and the Murrumbidgee Long-Term Water Plan) (Office of Environment and Heritage 2019). The Long-Term Water Plan (LTWP) sets out planning objectives under five key themes: 1) Native vegetation, 2) Native fish, 3) Waterbirds, 4) Ecosystem function, and 5) other species (e.g. Frogs) (Office of Environment and Heritage 2019) (Table 3-4). CEWO are required to have regard to the LTWP while developing planning objectives.

Table 3-4 Summary of ecological objectives related to the five themes (ecosystem function, vegetation, other species (frogs), waterbirds and native fish) adapted from the draft Murrumbidgee Long Term Water Plan (Office of Environment and Heritage 2019).

Group	Ecological objective
Ecosystem function	Provide and protect a diversity of refugia across the landscape
	Create quality instream, floodplain and wetland habitat
	Provide movement and dispersal opportunities for water-dependent biota to complete lifecycles and disperse into new habitats
	Support instream and floodplain productivity
	Support nutrient, carbon and sediment transport along channels, and between channels and floodplains/wetlands
	Support groundwater conditions to sustain groundwater-dependent biota
Native vegetation	Increase the contribution of flows into the Murray from tributaries
	Maintain the extent and viability of non-woody vegetation communities occurring within channels
	Maintain or increase the extent and maintain the viability of non-woody vegetation communities occurring in wetlands and on floodplains
	Maintain the extent and improve the condition of river red gum communities closely fringing river channels
Other species (Frogs)	Maintain or increase the extent and maintain or improve the condition of native woodland and shrubland communities on floodplains
	Maintain species richness and distribution of flow-dependent frog communities
	Maintain successful breeding opportunities for flow-dependent frog species
Waterbirds	Maintain and increase number of wetland sites occupied by the endangered southern bell frog
	Maintain the number and type of waterbird species
	Increase total waterbird abundance across all functional groups
	Increase opportunities for non-colonial waterbird breeding
Native Fish	Increase opportunities for colonial waterbird breeding
	Maintain the extent and improve condition of waterbird habitats
	No loss of native fish species
	Increase the distribution and abundance of short to moderate-lived generalist native fish species
	Increase the distribution and abundance of short to moderate-lived floodplain specialist native fish species
	Improve native fish population structure for moderate to long-lived flow pulse specialist native fish species
	Improve native fish population structure for moderate to long-lived riverine specialist native fish species
	A 25% increase in abundance of mature (harvestable sized) golden perch and Murray cod
Increase the prevalence and/or expand the population of key short to moderate-lived floodplain specialist native fish species into new areas (within historical range)	
	Increase the prevalence and/or expand the population of key moderate to long-lived riverine specialist native fish species into new areas (within historical range)

3.3 Water holdings in the Murrumbidgee Selected Area

River regulation and consumptive water use in the Murrumbidgee has reduced water flows into both the mid-Murrumbidgee wetlands and Lowbidgee floodplain and altered the seasonality of riverine flow peaks. However, the combined Commonwealth and NSW environmental water holdings are significant (Table 3-5) with over 939,906 ML of combined Commonwealth and NSW water holdings. In combination with the substantial investment in infrastructure to assist in the delivery of environmental water under the NSW Rivers Environmental Restoration Program (RERP) these water holdings are expected to make significant progress toward restoring key beneficial attributes of the hydrograph and reducing the frequency on extreme drying events.

Table 3-5 Summary of Commonwealth and NSW environmental watering holdings as of 28th February 2019: For modifications see:

<http://www.environment.gov.au/topics/water/commonwealth-environmental-water-office/southern-catchments/murrumbidgee>

Account			Security	Registered entitlements (ML)
Environmental (EWA)	Water Allowance		EWA ¹	30,000
NSW Environmental (EWH)	Water Holdings		General	28,508
			Unregulated (event based)	5,679
			Supplementary access	155,000
Commonwealth Water (CEW)	Environmental		High	14,340
			General	283,200
			Unregulated (event based)	164
			Supplementary access	21,986
			Conveyance	36,420
			Lowbidgee supplementary water access licence (long-term annual diversions) (pending transfer to CEWO)	393,117
Total availability (full allocation)				939,906 ML

3.4 Practicalities of watering

Flow management

Compared to other catchments in the Murray-Darling Basin, ecological characteristics and water requirements of aquatic communities in the Murrumbidgee Selected Area are well documented (CSIRO 2008a; Murray 2008; Sinclair Knight Merz 2011; Hardwick & Maguire 2012; Murray-Darling Basin Authority 2012a; Murray-Darling Basin Authority 2012b; Murray-Darling Basin Authority 2012c; Spencer *et al.* 2012; Gawne *et al.* 2013a; Gawne *et al.* 2013b; Murray-Darling Basin Authority 2014). There is also an established framework for environmental watering throughout the Murrumbidgee Selected Area with considerable investment in infrastructure-improved water management through the Lowbidgee floodplain under the RERP. In 2011, Sinclair Knight Mertz undertook a comprehensive assessment of water delivery options through the Murrumbidgee Selected Area, including detailing major infrastructure, and flow volumes required to fill key environmental assets (Sinclair Knight Merz 2011).

The Basin Plan currently lists four major flow types that have been used to develop the sustainable diversion limit: 1) Base flow, 2) Freshes, 3) Bank full, and 4) Overbank (Gawne *et al.* 2013b). In the Murrumbidgee Selected Area, a range of capacity constraints limit the extent to which water levels in the Murrumbidgee River can be increased above 23,000 ML at Wagga Wagga (fresh) and Commonwealth and NSW watering options targeting the mid-Murrumbidgee wetlands typically focus on achieving 23,000 ML (1/3 bank full) at Wagga Wagga to 15000 ML at Darlington Point to allow reconnections to important oxbow lagoons. Across the Lowbidgee floodplain, there are also considerable opportunities to create infrastructure facilitated overbank flows through the Lowbidgee floodplain during both base flow conditions and even in dry years (e.g. less than 20% of the Commonwealth's allocation as of 2011).

Due to the disconnect between flow types outlined in the Basin Plan and watering opportunities in the Murrumbidgee Selected Area, the identification of Commonwealth and NSW environmental watering options are typically based on the Water allocations set by Department of Industry – Water under the Murrumbidgee

water sharing plan. A summary of the watering options with a given environmental watering allocation is provided in Table 3-3.

Operational Constraints

Water delivery through the Lowbidgee floodplain is highly complex as water can be moved via a well-developed network of canals, regulators and other structures. Water infrastructure available to deliver Commonwealth environmental watering across the floodplain is detailed in the NSW Adaptive Environmental Water Use Plan for the Murrumbidgee Water Management Area (NSW Commissioner for Water 2013) and summarised in Table 3-6.

Water levels at Maude and Redbank Weir can be raised to allow for diversions into the Nimmie-Caira and Redbank systems respectively even when river levels are low. There are a number of constraints that limit daily delivery volumes via canal and regulator structures across the Lowbidgee floodplain, including the presence of private structures, and channel capacity constraints. During very dry years carriage losses along canals can be significant, and as a result, watering actions may be restricted to areas closer to the offtakes to limit losses. The mid-Murrumbidgee wetlands have limited infrastructure. The exceptions being Yanco Agricultural High School Lagoon, Turkey Flats and Gooragool Lagoon which can be filled via Murrumbidgee Irrigation Area (MIA) infrastructure. Inflows into these wetlands are dependent on river heights exceeding their commence-to-fill (around 23,000 ML/day at Narrandera) (see Murray (2008) and Sinclair Knight Merz (2011) for commence-to-fill values for individual wetlands). Since 2014, capacity to pump wetlands in the mid-Murrumbidgee has been developed and pumping actions are likely to expand to include a number of additional wetlands in the mid and lower Murrumbidgee.

Recent earthworks have been undertaken in the Gayini-Nimmie section of the Nimmie-Caira as part of a large scale Sustainable Diversion Limits (SDL) program. These earthworks are likely to increase the volume of water that can be transferred via the Nimmie-Caira system into Yanga National Park.

Table 3-6 Summary of key infrastructure (including Asset numbers) and flow constraints in the Murrumbidgee (CSIRO 2008a; Murray 2008; Sinclair Knight Merz 2011; Hardwick and Maquire 2012; Murray-Darling Basin Authority 2012a; Murray-Darling Basin Authority 2012b; Murray-Darling Basin Authority 2012c; Spencer *et al.* 2012; Gawne *et al.* 2013a; Murray-Darling Basin Authority 2014).

Zone	Important infrastructure and gauges to support water delivery and monitoring	Indicative Constraints
Nimmie Caira Fiddlers-Uara	Nimmie Creek Off-take Regulator (87019) North Caira Bridge Regulator (87021) South Caira Bridge Regulator (87035) Uara Creek Fiddlers	Above 650 ML/day the South Caira channel spills in various directions through recently constructed cuttings. Likely to increase due to completion of Gayini Nimmie SDL adjustment works. The offtake channel to Uara Creek currently has a private structure which limits diversions to 300 ML/day. Fiddlers has two 500 ML/day offtakes (Suez and Warwaegae offtakes). However, this is not utilised fully as have to raise weir pool to reach 1000 ML/day target and no target watering occurs at this level.
South Redbank	Yanga Regulator (Asset 87084) Waugorah Regulator (87059), Mercedes Pipe Regulator IAS regulator IES regulator	1AS – Aquatic vegetation growth limits average daily flows to 400 ML/day at 5.64 M or up to 600 ML/day @ 5.75 M Redbank weir pool. 1ES – 70 ML/day @ 5.64 or 150 at 5.75 M Redbank weir pool.
North Redbank and Western Lakes	Glenn Dee Regulator (87000) Juanbung Regulator (87005) Athen Gauging Station (41000256) Patto's Pipe Bill's Pipe	The new flume gated Glen Dee regulator will only run about 700 ML/day down the North Redbank channel at 5.75 M. If Lake Marimley have irrigation orders. channel share reducing capacity of e-water diversion to as low as 200-300 ML/day.
Murrumbidgee River	Murrumbidgee River downstream Burrinjuck at Gundagai	Private land access and inundation (Mundarlo Bridge) limits flow to max 32,000 ML/day.
	Mid-Murrumbidgee wetlands aligned with Narrandera zone at Darlington Point	Minor flood level 23,000 ML/day at Wagga Wagga and minor flood level 15,000 ML/day at Darlington Point.
	Murrumbidgee River at Balranald	Channel capacity and delivery of flows to downstream locations on River Murray - 9,000 ML/day.

4 Monitoring and research priorities

4.1.1 Process for prioritisation of hydrological zones

There are over 2000 individual wetlands, creek lines and anabranches within the Murrumbidgee Selected Area (Murray 2008), as well as extensive areas within the Murrumbidgee River that can be targeted with Commonwealth environmental water. The MER program aims to continue to develop the long-term dataset that commenced in 2014 under the LTIM program (see Wassens *et al.* 2014). Considering the range of key flow objectives and watering activities undertaken since 2009, the proposed monitoring sites represent the majority of wetland sites presented previously under LTIM (Wassens *et al.* 2014). These sites have therefore been retained for inclusion in the monitoring program on the bases of:

- Their ecological character and representativeness of wetlands within the zone;
- Their ecological significance (e.g. presence of threatened species);
- Their hydrology (e.g. selected sites contain water for at least three months to allow for repeat sampling and are of sufficient depth to allow surveys);
- Their accessibility for vehicle or boat access; and
- Their capacity to receive Commonwealth environmental water.

For wetlands, twelve fixed sites will be monitored continuously across the three year period, to provide data allowing the evaluation of long-term outcomes of Commonwealth environmental watering at the Basin (Category 1 and 2) and Selected Area scales. The MERP includes capacity for the twelve fixed sites across three of the six wetland zones (Nimmie-Caira, Redbank, and mid-Murrumbidgee) with provision to incorporate alternate sites within the same monitoring zones in the event that any of the selected core wetlands are not targeted with Commonwealth environmental water (CEW), or they remain dry throughout the monitoring period. Focusing on the fixed sites allows for the deployment of water depth loggers and associated analysis of LIDAR data to support calculation of wetland hydrology metrics, and reducing costs associated with continuous redeployment across other wetlands.

In the riverine zone, budget constraints have necessitated the removal of the Narrandera reach from the MER program, with stream metabolism, larval fish and fish community monitoring focusing on the Category 1 Carrathool reach only.

4.1.2 Outline monitoring priorities

The MERP has been designed to build on the framework developed under the previous LTIM program (see Wassens *et al.* 2014) and reflect current stakeholder and LTWP priorities. The MERP is also aligned with basin evaluation activities (Category 1 and 2 activities). Accordingly, the MERP includes a similar range of monitoring activities under the three broad objectives relating to hydrology, ecosystem function, and flora and fauna communities. The MERP has also been developed to contribute data to allow for the evaluation of Category 1 indicators at the Basin scale and evaluate ecological outcomes of Commonwealth environmental watering within the selected area (Figure 4-1). In consultation with the CEWO and key stakeholders, further refinement of the previous monitoring activities have been developed and some components of the original LTIM program have been removed from the current MER program due to budget constraints (Table 4-1). The most significant change that was required was the removal of larval fish sampling (Category 3) and stream metabolism (Category 3) from the Narrandera reach, with larval fish and stream metabolism only continuing at the Category 1 (Basin evaluation site) in the Carrathool reach. While there are significant benefits of replicated sampling in a second river reach, budget limitations mean that this activity is no longer feasible.

Other major changes to the program include removal of additional selected area (Category 3) activities, including microinvertebrate monitoring and evaluation, and wetland nutrient monitoring and evaluation.

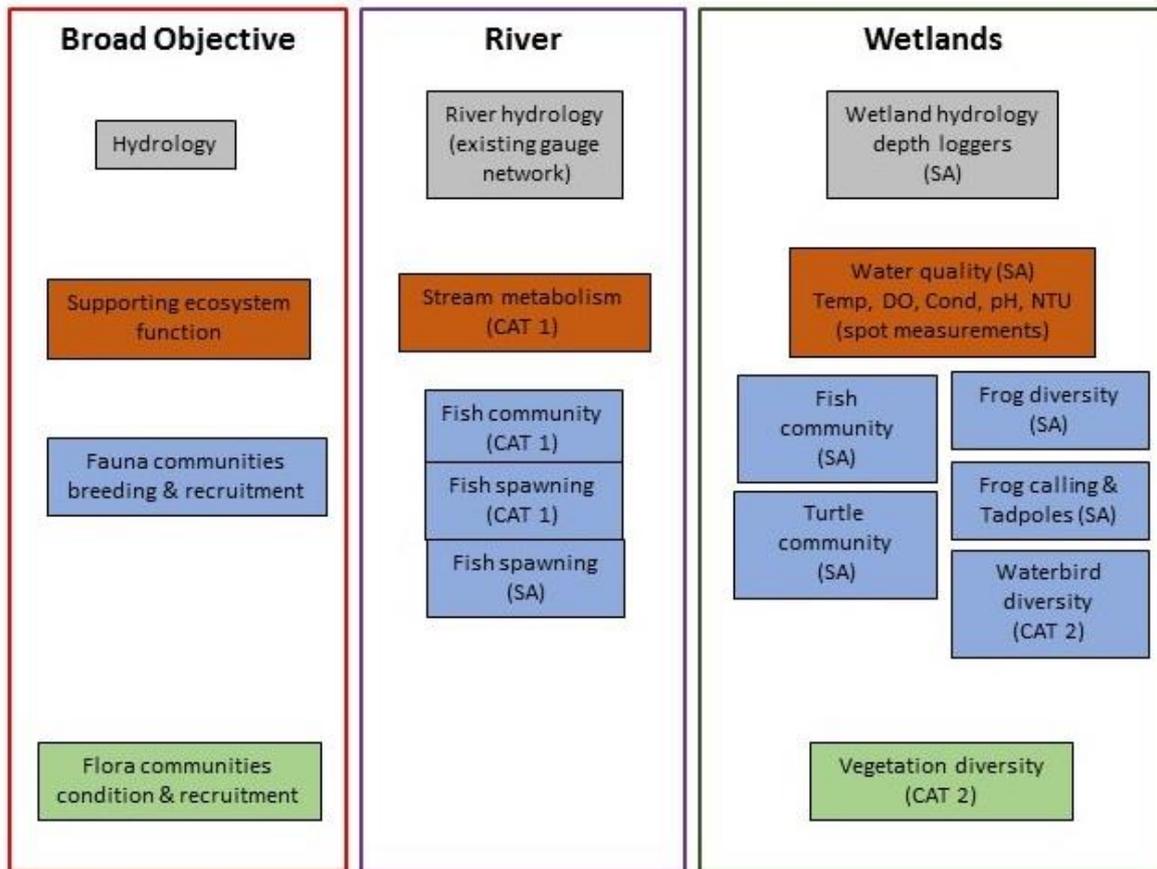


Figure 4-1 Generalised MERP framework and indicators proposed for the Murrumbidgee Selected Area (SA) and Cat 1 (Category 1 Basin scale).

Table 4-1 Summary of indicators, LTIM methodology and proposed changes.

LTWP Objective	Component	LTIM 2014-19 methodology	Proposed changes and justification
Native Fish	Fish spawning (River)(Cat1) Carrathool reach	In-channel light traps (10) and drift nets (8) (flowing sites 100 m apart), and wetland light traps (10) and larval trawls (3 × 5 min).	None
	Fish community (River) (Cat1) Carrathool reach	Annual sampling (Mar-May) consisting of electro fishing (n=16 × 2 x 90 sec shots), and small mesh fyke nets (n=10/site).	None
	Fish Spawning (River) (Cat 3)	In-channel light traps (10) and drift nets (8) (flowing sites 100 m apart), and wetland light traps (10) and larval trawls (3 × 5 min).	Yes - discontinue sampling of Cat 3 indicators for larval fish and stream metabolism in the Narrandera zone. Current available data is sufficient to generate predicted relationships between flow and fish spawning in the Narrandera reach.
	Fish, Tadpole and Turtle community (Wetland) (Cat 3) (frog and turtle data used in Diversity theme at Basin scale)	2 x replicate sets of 12 mm double winged large fyke (80 cm hoops) and 2 x replicate sets of 2 mm (double wing) small fyke nets (50 cm hoops), four surveys per year.	Yes - change net mesh size to 19 mm for large fykes and reduce number of individuals measured from 50 per net (200 individuals) to 20 per net (80 individuals) to improve sampling efficiency. Replace McKennas Lagoon as a core site and with Darlington Point Lagoon to increase replication of watered sites.
Ecosystem Function	Stream metabolism (River) (Cat1) Carrathool reach	Cat 1 standard method, including collection of continuous dissolved oxygen, temperature, discharge, PAR and barometric pressure, and monthly duplicate water samples to be analysed for nutrients (TN, TP, FRP, NOx, NH ₄ , PO ₄), dissolved organic carbon (DOC) and Chlorophyll-a.	None
	Stream metabolism (Cat 3)	Cat 3 standard method, including collection of continuous dissolved oxygen, temperature, discharge, PAR and barometric pressure, and monthly duplicate water samples to be analysed for nutrients (TN, TP, FRP, NOx, NH ₄ , PO ₄), dissolved organic carbon (DOC) and Chlorophyll-a.	Yes - remove from program. Current available data is sufficient to generate predicted relationships between flow and stream metabolism in the Narrandera reach.
	Nutrients (Wetland)	Water samples assayed for: dissolved organic carbon (DOC), Chlorophyll-a, nutrients (TN, TP, NOx, NH ₄ , PO ₄),	Yes - remove from program. Current available data is sufficient to generate predicted relationships between flow and wetland nutrients.
	Wetland water quality (spot measurements)	Spot measurements of pH, NTU, conductivity and DO.	None

Table 4-1 Continued. Summary of indicators, LTIM methodology and proposed changes.

LTWP Objective	Component	LTIM 2014-19 methodology	Proposed changes
Ecosystem Function	Microinvertebrates (River)	Collection of benthic core and pelagic samples at fixed LTIM sites.	Yes - discontinue sampling of this group. Current available data is sufficient to generate predicted relationships between flow and microinvertebrates in the Narrandera reach.
	Microinvertebrates (Wetland)	Collection of benthic core and pelagic samples.	Yes – remove from program. Current available data is sufficient to generate predicted relationships between flow and microinvertebrates in wetlands.
Waterbirds	Waterbird Diversity	Cat 2 methods – biannual ground surveys (spring and autumn) at fixed locations. Timing of spring surveys aligned with long-term aerial survey. Cat 3 methods undertaken quarterly alongside fish-frog wetland surveys (fixed sites within water year).	Yes - surveys will be conducted twice per year (October and Feb) and will integrate data collected by NSW OEH. This will allow for increased spatial replication of survey sites. Rapid (non-standardised counts) will be undertaken at the 12 core monitoring sites during fish and tadpole monitoring to identify incidental species.
Native vegetation	Vegetation Diversity (Cat 2)	As per standard method, four surveys per year (before, during and after flows), 3 x 30m transects (mid-Murrumbidgee oxbow lagoons), 5 x 10m quadrats (Lowbidgee floodplain wetlands).	None
Other species (frogs)	Tadpole and Turtle community (Wetland) (Cat 3) (frog and turtle data used in Diversity theme at Basin scale)	Aligned with wetland fish sampling- 2 x replicate sets of 12 mm double winged large fyke (80 cm hoops) and 2 x replicate sets of 2 mm (double wing) small fyke nets (50 cm hoops), four surveys per year.	Yes – Maintain alignment with wetland fish sampling but change net mesh size to 19 mm for large fykes to improve sampling efficiency. Replace McKennas Lagoon as a core site with Darlington Point Lagoon to increase replication of watered sites.
	Frogs (Cat 3) (Frog data used in Diversity theme at Basin scale)	Calling: 3 x 2 minute audio surveys (taken at 10 minute intervals), four surveys per year Adults: 2 x 20 minute nocturnal transect surveys, record snout-vent length of target species 20 individuals per transect), four surveys per year	Yes - Replace McKennas Lagoon as a core site with Darlington Point Lagoon to increase replication of watered sites.
Hydrology	Wetland hydrology floodplain inundation (Cat 3)	Inundation was not included in the original MEP and is not a costed component of the MER program.	Included as complementary data from OEH if it continues to be available.
	Hydrology (Cat 3) (Wetland)	Depth loggers currently installed at 12 wetlands	No intended changes to the current depth logger array but adding depth loggers at Darlington Point Lagoon and Matangry.

4.1.3 Contingency monitoring

The Murrumbidgee floodplain is a large complex system and there are a range of likely requirements under the contingency funding arrangements. During the previous LTIM program, contingency funding was utilised across a range of areas to support on ground management and inform longer-term adaptive management outcomes. These included waterbird breeding monitoring (Category 1 and Category 3), return flow management (Category 3), golden perch persistence and spawning on floodplains (Category 3), weir pool management to limit stratification and hypoxia and hypoxic black water management. Contingency funding may also be utilised to support monitoring and evaluation of high priority watering actions in areas not currently covered in the MERP. Such event based contingency funding arrangements will be developed in consultation with CEWO and other stakeholders during the water planning process each year. The team will also co-develop project briefs and budgets to meet the specific watering objectives, or to support management of specific watering actions. High risk, time-bound situations that require immediate action to collect data in which informs management will also be a priority for the contingency funding.

4.1.4 Research priorities

Research priorities have been co-developed by the project team and key stakeholders (Table 4-2). Given the available funding, we currently prioritised programs that value add to the existing monitoring program, particularly those that draw on existing data generated under the previous LTIM and other associated programs. We also aimed to include some activities that, as well as contributing to an improved understanding of the systems at the selected area scale, would also integrate into Basin wide research programs. The research program will prioritise projects that have a direct line of sight to water management, and contribute to an increased capacity to manage water to improve ecological outcomes. Field based research activities do have some dependencies on water availability and some of the proposed reach activities are designed to value add to the contingency funding (e.g. avian botulism which would link to waterbird breeding). The research plan leaves open the possibility of developing new research activities as questions arise through the life of the program. Research planning and prioritisation will be aligned with annual water planning and projects will be co-developed and prioritised by the team (CEWO and NSW OEH water managers, the MERP delivery team and other key stakeholders).

Table 4-2 Summary of research priorities for the Murrumbidgee Selected Area.

Priority knowledge gaps and key research questions	Overarching outline of proposed research	Links to management (project outcomes)
<p>Optimisation models for improved water management</p> <ul style="list-style-type: none"> - How should CEW be prioritised? - How can water be delivered to achieve maximum ecological benefit? - How do we best manage multiple assets, each with unique water requirements, in the face of uncertainties? 	<p>Develop process models that summarises the current understanding of system dynamics and the anticipated response of the system to environmental flows. The models will capture the cause-and-effect processes that drive anticipated responses, the variables for assessing those responses, and explicitly identify uncertainties in current knowledge to drive future monitoring priorities.</p>	<ul style="list-style-type: none"> - Improved understanding of the processes that drive ecological responses to flow and/or other drivers in the Selected Area; -Provide recommendations for how CEW can best be delivered to influence ecological outcomes and maximise ecological benefits; -Directly inform adaptive management.
<p>How do refugia support floodplain species?</p> <ul style="list-style-type: none"> -What are the hydrological characteristics of refugia habitats? -Identify patterns of use and habitat suitability for water dependant species with a focus on fish, turtles, frogs and fishing bats. 	<p>This project builds on previous LTIM and proposed MER monitoring data aims and is linked to a broader Basin wide research project. It broadly aims to identify refuge areas and quantify the changes in physical habitats (stratification), biogeochemical processes and foodwebs and habitat values for water dependant species in refuge environments, and how these change over time with maintenance, or disconnection, contraction and then reconnection.</p>	<ul style="list-style-type: none"> -Identify refugia dependent species and communities and the water quality and food web dynamics and flow dependencies that support them; -Recommend flow requirements to maintain and improve refuge availability, access and quality for key biota.
<p>Frog calling dynamics</p> <ul style="list-style-type: none"> -Are responses to environmental flows the same spatially for the same species across the study region? -Do different sizes or timing of environmental flows influence calling activity? - How do antecedent conditions influence calling activity? 	<p>Draws on existing dataset generated using recorder units (deployed since 2016). Determine the pattern and drivers of daily calling activity by key <i>resident frog species in the northern and southern basin</i> using remote automated audio monitoring equipment. Identify relationships between climatic and hydrological data to develop flow response curves for floodplain frog species during environmental watering actions.</p>	<ul style="list-style-type: none"> - Improved understanding of how CEW water can be delivered to maximise calling for water dependant frog species; - Improved understanding of how long-term CEW watering, including the refuge watering influence the persistence and abundance of the endangered (IUCN) southern bell frog.

Table 4-3 Continued. Summary of research priorities for the Murrumbidgee Selected Area.

Priority knowledge gaps and key research questions	Overarching outline of proposed research	Links to management (project outcomes)
<p>Bittern distribution and habitat use</p> <ul style="list-style-type: none"> -How are bittern species distributed through floodplain wetlands? -What times of year are bittern species most likely to reside in floodplain wetlands? -How do bittern species move between wetlands? 	<p>Bitterns are a highly cryptic poorly understood species. This project would draw on existing datasets generated using recorder units (deployed since 2016). Identify distribution of Bitterns across the monitoring area, and where sufficient data exists develop relationships between calling activity, wetland hydrological regime, and prevailing climatic conditions.</p>	<ul style="list-style-type: none"> -Improved understanding of how long-term CEW watering influences the occurrence of the endangered (EPBC Act) bittern species; -Identify high priority wetlands for bitterns to inform water delivery decisions; where to put water and timing.
<p>Reptile responses to flow management</p> <ul style="list-style-type: none"> -Do floodplain reptile species respond to CEW actions? -How does water management influence the abundance and persistence of the endangered grey snake (<i>Hemiapsis damelli</i>) (IUCN)? 	<p>The research program will improve our understanding of reptile community composition and diversity within floodplain environments, as well as evaluate the contribution of environmental watering actions to the conservation and management of wetland dependant species such as the endangered grey snake (IUCN).</p>	<ul style="list-style-type: none"> -Improved understanding of the relationships between water regime and occupancy and abundance of floodplain reptile species; - Improved understanding of the water requirements of the endangered grey snake (IUCN).
<p>Avian Botulism impacts on breeding success</p> <ul style="list-style-type: none"> -What are the water quality thresholds that result in avian botulism outbreaks? -How should water be managed to reduce the incidence of avian botulism? 	<p>Link with water bird breeding Contingency monitoring. Investigate the environmental conditions, including water levels, water quality, and air temperature that contribute to an increased risk of Avian botulism outbreaks at rookery sites.</p>	<ul style="list-style-type: none"> -Increased survival and recruitment into populations -Inform water delivery decisions during a breeding event to reduce risk of outbreaks and maximise breeding success and adult survival.

5 Indicators

5.1 Wetland hydrology (Category 3 Selected area)

5.1.1 Monitoring

Wetland hydrology provides a direct indication on the extent to which CEW achieved hydrological targets within wetlands and is an important covariate used in the evaluation of ecological outcomes in response to CEW actions. Methodology for wetland hydrology will continue to follow those described in Wassens *et al.* (2014) and will continue to utilise water depth loggers deployed at the twelve fixed-term monitoring wetlands established under the LTIM program. Analysis of wetland volumes will also continue to use the boundaries previously developed under the LTIM program (see Wassens *et al.* 2014). Wetland hydrology indirectly addresses the following Selected Area (Category 3) evaluation questions (Table 5-1).

Evaluation Questions (Selected area)

What did Commonwealth environmental water contribute to hydrological connectivity?

What did Commonwealth environmental water contribute to hydrological regime?

What did Commonwealth environmental water contribute to wetland depth and volume?

Table 5-1 Summary of proposed activities to monitor wetland hydrology in the Murrumbidgee Selected Area.

MER indicators	Evaluation questions	Metrics	Sites	Method
Hydrology Cat 3	What did Commonwealth environmental water contribute to hydrological connectivity? What did Commonwealth environmental water contribute to hydrological regime? What did Commonwealth environmental water contribute to wetland depth and volume?	Water depth (depth distributions) - water level loggers <i>in situ</i> accuracy 10cm Duration of connection - river inflows and outflows (start and end points in days) Daily extent of inundation (modelled) Daily wetland volume (modelled)	Permanent sites: 3 zones: mid-Murrumbidgee (n=4), Redbank (n=4), Nimmie-Caira (n=4)	Data drawn from depth loggers 1 per wetland already deployed under the previous LTIM program

Methods

River hydrology

The Murrumbidgee River is heavily regulated and has a very well developed network of gauges (Table 2-2, Figure 2-1) which are maintained by WaterNSW within the main river channel and key offtakes (Sinclair Knight Merz 2011). River zones in the Murrumbidgee Selected Area were specifically defined with a view to reducing hydrological heterogeneity and to align key monitoring activities with the existing gauge network. As a result, the current gauging network will be sufficient to provide hydrological information to support Category 1 (fish and stream metabolism) monitoring activities. This activity is not costed as part of the MERP.

Wetlands

Site monitoring of water level

Water level loggers were deployed at twelve fixed monitoring sites in 2014. Additional depth loggers may be deployed at other supplementary wetlands (e.g. Darlington Point Lagoon and Mantangery Lagoon) to compliment monitoring of ecological responses.

Determining volume

For the inundation extents, maps of water depth will be derived by subtracting water-surface elevations from the water-bottom elevations derived from digital terrain models (DTM). Using these maps of water depth, calculation of total volume of water for discrete wetlands is a simple calculation within a geographical information system (GIS) using depth at each included pixel (dp) and pixel area (A).

Temporal metrics - Changes in volume

Calculations of volume within discrete wetland areas will be calculated daily to provide a time series of hydrological inputs and outputs.

Duration of connection

In the mid-Murrumbidgee, a single depth logger in combination with the existing Murrumbidgee River gauge network will be adequate to determine the number of days of connection to the river channel. In the Lowbidgee floodplain, environmental flows are typically infrastructure-facilitated and with water delivery managed by WaterNSW. In systems with infrastructure facilitated water delivery, the duration of connection (number of days that the regulator structure is open) will be provided by WaterNSW.

While an accurate DTM and reliable depth measures will be available, along with a detailed validation process, a significant level of error cannot be discounted. The level of likely error will be estimated to accompany wetland hydrology metrics. An estimate of the level of error in the digital elevation model (DEM) is already available and will enable a fuzzy dataset to be used within any GIS based analysis of bathymetry related metrics. For example, a probability of inundation at each pixel (particularly at inundation area boundaries) can be produced rather than a simple Boolean style

map. A range of inundation areas can then be produced within a set confidence limit. Best estimates will be produced along with confidence intervals for each derived wetland hydrology metric.

The relatively large area subject to monitoring in the Murrumbidgee Selected Area is subject to change; patterns of inundation can be affected by subtle changes in geomorphology due to flow deposition and erosion, vegetation growth and infrastructure change.

5.1.2 Research

Wetland hydrology is an important covariate that informs evaluation of ecological response to CEW actions, and forms part of the research plan for vegetation diversity, frogs and tadpoles, wetland fish and waterbirds. There are no specific research questions that relate specifically to wetland hydrology. However, hydrology metrics collected during the MER program will be used as predictor variables in the analysis of wetland fish communities, frog abundance and the synthesis analyses (see integrated research section 6).

5.2 Stream Metabolism

5.2.1 Monitoring

The structure and function of river and floodplain ecosystems is driven by the supply of carbon-based energy and nutrients derived from organic matter (Young *et al.* 2008). Organic matter enters aquatic ecosystems through *in situ* aquatic primary production (algae and macrophytes) and terrestrial inputs (e.g. fallen leaves and branches). Organic matter derived from these two pathways contrasts in quality and quantity, with different consequences for the supply of basal resources to aquatic food webs (Marcarelli *et al.* 2011). Perturbations that affect this supply have the potential to alter the structure and function of aquatic ecosystems, with flow-on effects to biota at higher trophic levels such as microinvertebrates, tadpoles and fish.

Stream metabolism is an integrated measure of both primary production and respiration, providing a functional measure of ecosystem health (Young *et al.* 2008) and a means to evaluate changes to the supply of energy to aquatic food webs. Metabolism is affected by the availability of nutrients, particularly carbon, nitrogen and phosphorous, geomorphic features that enable organic matter to accumulate, water temperature, which affects the rates of biochemical reactions, and the availability of light, which affects rates of photosynthesis (Young & Huryn 1996).

Flow affects metabolism by disturbing microbial and algal communities that carry out carbon transformations, thus changing the availability of nutrients and physicochemical conditions. In undisturbed streams, metabolism is in a constant state of flux but is typically dominated by heterotrophy in upland, lowland and floodplain ecosystems with increasing dominance of primary production in medium-sized streams (Vannote *et al.* 1980). Where regulation has reduced the frequency of bankfull and overbank flows, connections between rivers and heterotrophic energy sources are severed, increasing system reliance on in-stream production (Robertson *et al.* 1999). Environmental flows have the potential to re-establish natural energy pathways, boosting overall rates of metabolism in river channels through the supply of nutrients and energy, while increasing heterotrophy relative to primary production.

Chlorophyll-*a* is the most dominant photosynthetic pigment and is used as an indicator of phytoplankton primary productivity and algal biomass (Wetzel & Likens 2000). Monitoring chlorophyll-*a* within wetland and river sites will give an indication of the level of primary productivity before, during and after the delivery of flows and will

be measured in conjunction with fish spawning to determine whether changes in primary productivity within wetland and river sites have flow on affects for higher trophic levels (Kobayashi *et al.* 2009).

5.2.2 Evaluation

Stream metabolism indirectly addresses the following Basin scale and Selected Area evaluation questions provided in Table 5-2. The key monitoring and evaluation questions are listed below.

Basin-scale evaluation questions (CAT 1)

What did Commonwealth environmental water contribute to patterns and rates of decomposition?

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

Selected Area evaluation questions

What did Commonwealth environmental water contribute to patterns and rates of decomposition?

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

Table 5-2 Summary of proposed activities to monitor stream metabolism responses to environmental water delivery in the Murrumbidgee Selected Area.

MER indicators	evaluation questions	Metrics	Sites	Method
Stream metabolism (cat 1)	<p>What did Commonwealth environmental water contribute to patterns and rates of decomposition?</p> <p>What did Commonwealth environmental water contribute to patterns and rates of primary productivity?</p>	<p>Continuous logging (10 minute intervals) of: photosynthetically active radiation (PAR), barometric pressure, dissolved oxygen (DO), temperature. Monthly water samples assayed for: dissolved organic carbon (DOC), Chlorophyll-a, Nutrients (TN, TP, NOx, NH4, FRP). Monthly spot measures of conductivity, turbidity and pH. Daily metabolism (gross primary production, community respiration, net daily metabolism)</p>	Carrathool zone Murrumbidgee River (paired with Cat 1 larval fish and river fish sample sites)	As per Cat 1 standard method

Methods

Category 1 In-stream metabolism monitoring

The sections of river being studied in the Murrumbidgee are typically larger both in magnitude and distance between sites than for other MER regions. Because the scale of sampling is dwarfed by the scale of the selected zones, a single logging station is unlikely to provide reliable results to inform the fish evaluation or Selected Area questions. There is currently no information available to inform the degree of expected spatial heterogeneity within the Murrumbidgee Selected Area zones.

To evaluate the response of Commonwealth watering actions within the Selected Area, additional replication across other zones is required. As a minimum, we propose to maintain one Category 1 stream metabolism point in the Carrathool zone (358 km) aligned with Category 1 larval fish and riverine fish community sites, as well as the

wetland monitoring sites in the mid-Murrumbidgee zone. Discharge data will be drawn from the established gauge network at Darlington Point and Carrathool. Metabolism will be monitored continuously from September until the end of March each year.

Field sampling and sample processing

Metabolism will be monitored following the Category 1 standard method, including collection of continuous dissolved oxygen, temperature, discharge, PAR and barometric pressure, and monthly duplicate water samples to be analysed for nutrients (TN, TP, FRP, NO_x, NH₄, PO₄), dissolved organic carbon (DOC) and chlorophyll-a. Each site will be approximately 150 m long, with samples collected randomly along this length from mid-stream. Each month, nutrient samples as well as spot measures of temperature, conductivity, turbidity and pH will be made at three separate locations using a calibrated multi-parameter handheld meter.

Nutrients including (TN, TP, FRP, NO_x, PO₄ as per standard method), DOC and chlorophyll-a will be analysed at a NATA accredited laboratory. Dissolved oxygen data will be downloaded and calibrated monthly. Sensors will be cleaned during the intervening two weeks. Daily metabolism (GPP, CR, NDM) will be calculated from diurnal oxygen curves following the Category 1 standard method, using the software provided by Mike Grace and associates.

Data analysis

Linear regression will be used to test the dependence of metabolism on flow, temperature, and other dependent variables (Marcarelli *et al.* 2010). Using these established relationships, the effect of environmental watering on metabolism will be inferred by the difference between observed environmental flows and the predicted hydrology and nutrient status in the absence of environmental water. Where applicable, the impacts of environmental flows will be estimated by analysing changes in metabolism and associated covariates before, during, and after discrete releases.

5.2.3 Research

Stream metabolism is a Category 1 indicator associated with evaluation of response to CEWO water at the Basin scale. There are no proposed research questions related specifically to stream metabolism at the Selected Area scale. However, weir stratification is a potential management issue that can arise in the lower reaches of the Murrumbidgee River, optional monitoring activities associated with stream metabolism includes the deployment of temperature and dissolved oxygen (DO) loggers in rafts to measure temperature and DO at different depths within the weir pool, which can then be used to evaluate responses to CEWO management interventions. Metabolism may also be included in research programs focused on floodplain refugia (see research priorities section 4).

5.3 Fish Communities (River)

5.3.1 Monitoring

Fish communities in the Murrumbidgee catchment are severely degraded, with only eight of the 21 native species historically recorded in the region recorded since 1975 (Gilligan 2005). Alien species (specifically common carp, *Cyprinus carpio*) can occupy up to 80% of the total biomass in some areas. In addition, small-bodied floodplain species such as the Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and olive perchlet (*Ambassis agassizii*) were historically abundant from Murrumbidgee River wetland habitats (Anderson 1915), but are now considered locally extinct (Gilligan 2005).

The alteration of natural flow regimes has significantly contributed to these declines. The use of CEW to restore more natural flow characteristics can benefit native fish by increasing reproduction, stimulating in-stream migration associated with triggering a spawning response (Humphries *et al.* 1999; Humphries *et al.* 2002; King *et al.* 2003) or improving food availability which can translate to improved condition. Many native fish species use wetlands and floodplains for nursery habitat and feeding, thus allowing movement into and out of connected wetlands can increase recruitment and population persistence of some species (Lyon *et al.* 2010).

Environmental water delivery is known to provide detectable changes in fish communities. For example, Wassens *et al.* (2014) examined changes to the fish community before and after a large in-channel release in the Murrumbidgee and identified significant changes in community composition, biomass and spawning of native fish species.

Many fish species are highly mobile, and fish community changes can often occur as a result of redistribution at a site scale during environmental water delivery, due to localised changes in hydraulic and structural habitat availability, and food resources (Wassens *et al.* 2014). However, changes in fish community composition at the reach and valley scale are also likely to occur in response to environmental water delivery. For example, over longer time scales (>10 years), landscape fish diversity is influenced by available habitat, connectivity and disturbance, which in turn are influenced by the interactions between flow and geomorphology (Jackson *et al.* 2001). Providing

greater access to habitat through connectivity is achievable using environmental water and will lead to a detectable change over the medium-long term. Over shorter time scales, flow can influence fish condition and biotic dispersal and also sustain populations which are currently under threat. Flow can also influence reproduction directly through cues that stimulate reproductive behaviour or by providing suitable available habitat. Likewise, fish recruitment is also influenced indirectly by:

1. Increasing riverine productivity and stimulating food,
2. Increasing available habitat such as backwaters and nest sites,
3. Promoting suitable water quality,
4. Facilitating longitudinal and lateral connectivity and dispersal.

5.3.2 Evaluation

Fish communities will directly address the following Basin scale and Selected Area evaluation questions provided in Table 5-3. The key monitoring and evaluation questions are listed below.

Basin-scale evaluation questions (CAT 1)

What did Commonwealth environmental water contribute to native fish populations?

What did Commonwealth environmental water contribute to native fish reproduction?

What did Commonwealth environmental water contribute to native fish community survival?

Selected Area evaluation questions

How does the fish community vary in the Murrumbidgee Selected Area in relation to abundance, biomass and size?

Do commonwealth environmental water delivery events result in detectable changes in the abundance, biomass and size (length) of the fish community in the Murrumbidgee Selected Area?

Table 5-3 Summary of proposed activities to monitor fish community responses to environmental water delivery in the Murrumbidgee Selected Area.

MER indicators	Evaluation questions	Metrics	Sites	Method
Fish (river) Cat 1	<p>What did Commonwealth environmental water contribute to native fish populations?</p> <p>What did Commonwealth environmental water contribute to native fish survival?</p> <p>What did Commonwealth environmental water contribute to native fish reproduction?</p>	<p>CPUE</p> <p>Length and mass of target species</p> <p>Length-age of target species</p>	<p>Murrumbidgee River (Carrathool reach) 10 sites</p>	<p>Annual sampling (Mar-May) consisting of: Electro fishing (n=16 x 2 x 90 sec shots)</p> <p>Small mesh fyke nets (n=10/site)</p>

Methods

Standard methods will be used in the Carrathool Zone (Darlington point to Carrathool) for Basin-scale reporting as per Hale *et al.* (2014). These methods will provide information on native fish responses to environmental water across multiple time scales. Note that we have provided a budget for the annual ageing of a periodic and/or equilibrium species (e.g. bony brim) in each year to generate growth curves.

1. The amount of sampling effort per 90 second electrofishing 'shot' is to be partitioned between littoral/structural and open water habitats at a ratio of 5:1 in order to maintain comparability with CPUE data generated using the standard SRA protocol. This means that within any single electrofishing operation, 75 seconds should be used to sample littoral/structural habitats and 15 seconds of sampling should be undertaken in open-water habitats < 4 m deep.

2. Length data from all species is recorded for all operations of every gear type (with sub-sampling of 20 individuals per shot/net/trap) to allow generation of SRA metrics. This includes alien and both large and small bodied species.
3. The individual weight of the first 50 individuals measured for length of each non-target species will also be recorded.
4. Ten unbaited bait traps will be set for the duration of the electrofishing operations (minimum of 1.5 hours) to maintain consistency with SRA protocol.

Data analysis

Recruitment

Fish length structure will be compared among zones for each species (where sample sizes permit) using Kolmogorov-Smirnov tests to examine changes in length distribution. Increased recruitment would be expected in years where the hydrological regime facilitated successful reproduction and provided suitable conditions conducive to growth and survival of larvae.

Native fish diversity and abundance, native fish biomass, recovery of the fish community

Fish community data will be summarised to compare results to three main SRA Indicators (these are fully explained in Robinson 2012). The SRA derived Indicators will be: (1) *expectedness* (provides a comparison of existing catch composition with historical fish distributions), (2) *nativeness* (combination of abundance and biomass describing the proportion of the community comprised of native fish), and (3) *recruitment* (provides a proportion of the entire native fish population that is recruiting within a zone). Recruitment will be further divided into recruiting taxa (proportion of native species present recruiting) and recruiting sites (proportion of sites where recruitment occurs). These Indicators produce a score that is related to reference conditions, and receive a condition rating (Extremely Poor (0-20), Very Poor (21-40), Poor (41-60), Moderate (61-80), Good (81-100). Changes to SRA condition ratings will be examined in years with and without environmental water, with an overall expectation that condition ratings will improve over time.

5.3.3 Research

Fish community is a Category 1 indicator associated with evaluation of response to CEWO water at the Basin scale. There are no proposed research questions related to riverine fish communities at the Selected Area scale. However, fish community data will be incorporated into other research projects (see Integrated Research section 6).

5.4 Larval Fish

5.4.1 Monitoring

The larvae stage is the most critical and fragile part of a fish's life history. Successful spawning of native freshwater fish requires high survival to ensure persistence of populations over the long term. Larval survival is highly dependent on environmental conditions (Rolls *et al.* 2013), which can be dramatically influenced by flows, including habitat availability (Copp 1992), water temperature (Rolls *et al.* 2013), dispersal (Gilligan & Schiller 2003), microinvertebrate abundance at first feed (King 2004) and nest site inundation (Baumgartner *et al.* 2013). Using environmental water allocations to provide positive outcomes for these factors will lead to increased reproductive opportunities, greater larval survival, and hence, recruitment to the population.

In the Murrumbidgee River, regulation of the flow regime has reduced the timing, frequency and magnitude of high flow events, the frequency of reconnections between the Murrumbidgee River and mid-Murrumbidgee wetlands, as well as caused a decline in water permanence of wetlands. Consequently, several small-bodied fish species such as the Murray hardyhead (*Craterocephalus fluviatilis*), olive perchlet (*Ambassis agassizi*), southern pygmy perch (*Nannoperca australis*) and southern purple spotted gudgeon (*Mogurdna adspersa*) that historically utilised wetland habitats as critical spawning grounds are now rare (Gilligan 2005).

Other native fish species have also declined throughout the catchment. For example, the golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*), both periodic species with flow dependent migration strategies and drifting larval stages, have declined substantially. The Murray cod (*Maccullochella peelii*) and trout cod (*Maccullochella macquariensis*) are nesting species threatened by highly variable flow regimes which can expose nests and limit larval survival (Lake 1967). Understanding the critical links between flow and early life history survival are crucial to provide more natural hydrological regimes which can support and improve populations of these species. The recovery of substantial volumes of water, for environmental use, is a major opportunity to facilitate recovery throughout the Murrumbidgee catchment.

Recent literature syntheses provide guidelines for the provision of environmental water to support the reproduction and recruitment of native fish (Baumgartner *et al.* 2013; Cameron *et al.* 2013). Collectively, these works suggest that environmental water,

using a specifically designed hydrograph, could benefit groups of species based on similar reproductive strategies. For example, environmental water releases at or above bankfull result in a re-connection of the river and wetlands, providing an opportunity to access spawning and nursery habitat during inundation. The newly inundated habitat should lead to an increase in microinvertebrate abundance, which will provide a food source for larvae spawned within wetlands thereby optimising survival.

5.4.2 Evaluation

Larval fish communities will directly address the Basin scale and Selected Area evaluation questions provided in Table 5-4. The key monitoring and evaluation questions are listed below.

Basin-scale evaluation questions (CAT 1)

What did Commonwealth environmental water contribute to native fish populations?

What did Commonwealth environmental water contribute to native fish species reproduction?

What did Commonwealth environmental water contribute to native fish survival?

Selected Area evaluation questions

What did Commonwealth environmental water contribute to native fish reproduction?

What did Commonwealth environmental water contribute to native fish survival?

Table 5-4 Summary of proposed activities to monitor larval fish community responses to environmental water delivery in the Murrumbidgee Selected Area.

MER indicators	Basin-scale evaluation questions	Metrics	Sites	Method
Fish (larvae) Cat 1 and 3	<p>Long term: What did Commonwealth environmental water contribute to native fish populations?</p> <p>Short term: What did Commonwealth environmental water contribute to native fish reproduction?</p> <p>What did Commonwealth environmental water contribute to native fish survival?</p>	Species presence/absence, CPUE	Murrumbidgee River (Carrathool reach): 3 in-channel river sites sampled over 6 events	In-channel: Light traps (10) Drift nets (8) (floating sites 100m apart)

Methods

Category 1 larval fish sampling will be conducted in the Carrathool zone at three in-channel as per the standard methods outlined by (Hale *et al.* 2014). Given the low probability of detecting the target species using the standard method alone based on previous data analysis, we propose to increase the number of drift nets from three to eight at each in-channel site given that sites will be treated as replicates for Selected Area evaluations rather than pooled. Each site will be sampled once per fortnight for six consecutive fortnights (n=6 trips per year).

Data analysis

Dependent variables for analysis include:

- Abundance of larvae, standardised to catch per unit effort (CPUE) (as required by standard methods),
- Number of larvae captured per megalitre of water in drift nets and tows, and
- Number of larvae per net night for light traps.

To examine the effect of multiple water indices on larval fish abundance, a Generalized Linear Regression modelling approach will be used. Using a model selection approach enables quantification of the magnitude and direction of change in larval fish abundance driven by key covariates including water temperature, discharge and water level.

5.4.3 Research

Do flow conditions in rivers influence food choice and condition of young fish?

The early life of fishes is a period of high natural mortality, with <1% of young surviving to recruit into the adult population. Environmental watering in our rivers is often now targeted at triggering spawning and improving survival of young fish. However there is surprisingly little information about how diet and condition of young fish varies under different flow conditions. This project is aimed at determining how food choice and condition of young fish varies under different flow conditions such as low flows, floods and with the use of environmental water. The project will use existing samples collected under LTIM and strengthen links between river flows and native fish spawning, survival and food availability. Collaborators: Alison King (La Trobe), Skye Wassens (CSU), Jason Thiem (DPI Fisheries).

Optional monitoring for periodic species (e.g. golden perch) could be considered during CEWO watering actions targeting in-channel or floodplain habitats in the Carrathool, Hay and Balranald reach. Key indicators will be eggs and larvae older than 14 days given larvae 0-14 days post-hatch are extremely fragile and may be destroyed in larval drift nets. Intensive sampling could be undertaken in floodplains or downstream reaches (Maude to Balranald) or to extend the monitoring period in the Carrathool reach to increase the likelihood of detecting early or late spawning event using a modified standard methods (n=8 larval drift nets and n=10 light traps).

5.5 Vegetation Diversity

5.5.1 Monitoring

The percent cover and composition of aquatic vegetation can determine the availability of oviposition sites for macroinvertebrates (Humphries 1996), calling and spawning locations for frogs (Wassens *et al.* 2010) and support wetland food webs and zooplankton communities (Warfe & Barmuta 2006). The response of aquatic and semi-aquatic vegetation following a flow event is important in its own right and as a critical covariate to explain the breeding and recruitment outcomes by frogs and waterbirds, as well as nutrient transfer, and composition of macroinvertebrate communities.

Prolonged drought can reduce the diversity and cover of wetland vegetation and the resilience of established seed banks (Brock *et al.* 2003; Tuckett *et al.* 2010). The recovery of aquatic vegetation communities in the mid-Murrumbidgee wetlands has been intensively monitored by CSU researchers since November 2010, and in the Lowbidgee floodplain since 2014 as part of the LTIM program (Wassens *et al.* 2014). Environmental releases targeting wetlands in the mid-Murrumbidgee region since 2011 have been successful in promoting recovery of aquatic and semi-aquatic vegetation (Wassens *et al.* 2018) and the maintenance and recovery of aquatic vegetation remains a high priority for environmental watering as part of the LTWP (Office of Environment and Heritage 2019). Vegetation diversity is a Category 2 indicator and forms part of the evaluation of Basin scale outcomes, it is therefore collected across multiple selected areas using an agreed standard method with common evaluation questions (Table 5-5).

5.5.2 Evaluation

Basin-scale and Selected area evaluation questions

What did Commonwealth environmental water contribute to vegetation species diversity over time?

What did Commonwealth environmental water contribute to vegetation community diversity over time?

Table 5-5 Summary of proposed activities to monitor vegetation diversity responses to environmental water delivery in the Murrumbidgee Selected Area.

MER indicators	evaluation questions	Metrics	Sites	Method
Vegetation diversity (Cat 2)	<p>What did Commonwealth environmental water contribute to Vegetation species diversity?</p> <p>What did Commonwealth environmental water contribute to Vegetation community diversity?</p>	<p>Understorey species richness</p> <p>Percent cover of each understorey species</p> <p>Tree recruitment</p> <p>Photo point</p>	Mid-Murrumbidgee wetlands (River red gum oxbow lagoons (4 sites, Nimmie-Caira (4 sites), Redbank south (4 sites))	<p>Four surveys per year (Sep, Nov, Jan, Mar)</p> <p>As per standard method for vegetation Diversity (Cat 2)</p> <p>9 or 10 x 1m quadrats collected along transects with variable length, 3 x 90 m, 3 x 150 or 2 x 250 m</p>

Methods

Understorey vegetation diversity (Cat 2)

Vegetation community composition, percent cover and tree recruitment will be assessed as per the standard method and will be undertaken at twelve fixed wetlands (aligned with fish wetland monitoring sites). These sites are representative of dominant vegetation communities across the mid-Murrumbidgee (n=4) (river red gum- oxbows) and Lowbidgee floodplain (n=8) (lignum (n=2), black-box (n=2), river red gum-spike rush depressions (n=2), river red gum – aquatic grasses/forbs (n=2)). Surveys will be undertaken on four occasions each year (September, November, January and March) to capture annual changes in vegetation growth and establishment and wetland draw down.

The monitoring regime will be a continuation of the LTIM program. The length of transects will be based on the size and bathymetry of the target wetland with the length of transects increasing as the size of the wetland increases. This ensures that all sites have similar level of sampling effort from the edge into the centre (deepest point) of the wetland. Standard transect lengths are 90 m (30 x 1 m quadrats spaced at 3 m intervals), 150 m (30 x 1 m quadrats spaced at 5 m intervals), and 250 m (50 x 1 m quadrats spaced at 5 m intervals). Three permanent transects (90 - 150 m) or two 250

m transects are spaced at least 100 m at each wetland and align with the previous LTIM sites. Within each quadrat, vegetation species and percent cover are estimated, leaf litter, logs > than 10 cm diameter, bare ground, open water, soil moisture, and water depth and tree size class as per standard method (Cat 2) are also recorded. Permanent photo points were established at the start of each quadrat in 2014 to provide a graphic representation of vegetation recovery over time.

Data analysis

The change in vegetation community composition before, during and after Commonwealth environmental watering actions within the Selected Area, will be analysed using PERMANOVA for multivariate community data. Vegetation diversity change will be assessed at two temporal scales – within year change in vegetation cover and diversity following environmental watering actions is evaluated within and between water years, and between zones using PERMANOVA (Anderson *et al.* 2008) in Primer (Clarke & Gorley 2006). Post-hoc testing will be used to examine where significant differences were observed among times and zones. This will allow us to evaluate whether environmental water changed the relative contribution of key functional groups.

5.5.3 Research

The primary focus of research and optional monitoring around the vegetation diversity theme is to quantify the recovery trajectories of vegetation communities following the reinstatement of suitable watering regimes using CEW. The vegetation diversity program also aligns with the Basin scale vegetation theme. Vegetation metrics collected during the MER program will be used as predictor variables in the analysis of wetland fish communities, frog abundance and in the synthesis analyses (see Integrated Research section 6). Optional monitoring activities related to vegetation that could be considered would include benchmarking of understory vegetation at wetlands in the Junction wetlands and at the start of managed pumping activities in the mid-Murrumbidgee. Benchmarking would allow for the longer-term success of CEW actions to be quantified in future years.

5.6 Wetland Fish Communities

5.6.1 Monitoring

Historically, small-bodied fish species such as the Murray hardyhead (*Craterocephalus fluviatilis*), olive perchlet (*Ambassis agassizi*), southern pygmy perch (*Nannoperca australis*) and southern purple spotted gudgeon (*Mogurdna adspersa*) utilised wetland habitats of the Murrumbidgee River (Anderson 1915). These species presumably moved into wetlands during connection (high flows and floods), taking advantage of the highly productive wetland nursery habitats to spawn and recruit, and successfully re-colonised in-channel habitats during re-connection to the main channel. The change to flow variability within the Murrumbidgee River has led to a major decline in the frequency of reconnections between the Murrumbidgee River and connected wetlands as well as a decline in water permanence, which is one of the primary causes of major declines of many native fish species (Humphries *et al.* 1999).

Prior to major regulation of the Murrumbidgee River, many native fish species utilised off-channel habitats such as wetlands and floodplains due to the increased habitat diversity and food availability that these habitats provide (Lyon *et al.* 2010). Small-bodied native fish actively moved into wetland habitats upon commencement of filling (Lyon *et al.* 2010) and used this habitat to successfully spawn and support larval development and recruitment. Environmental watering in the Murrumbidgee to fill mid-Murrumbidgee wetlands will introduce flow variability into the mid-Murrumbidgee region, allowing for native fish species to spawn and reproduce in a productive wetland environment and also disperse via the main channel.

5.6.2 Evaluation

Wetland fish communities will directly address several Selected Area evaluation questions provided in Table 5-6. The key monitoring and evaluation questions for this indicator are listed below.

Selected Area evaluation questions

What did Commonwealth environmental water contribute to native fish populations and native fish diversity over time?

What did Commonwealth environmental water contribute to native fish community resilience and native fish survival over time?

Table 5-6 Summary of proposed activities to monitor wetland fish community responses to environmental water delivery in the Murrumbidgee Selected Area.

MER indicators	evaluation questions	Metrics	Sites	Method
Wetland fish Cat 3	<p>Long term: What did Commonwealth environmental water contribute to native fish populations and native fish diversity?</p> <p>Short term: What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?</p>	<p>Species diversity and abundance of large and small-bodied fish (CPUE)</p> <p>Population structure: size frequency</p> <p>Species occupancy patterns and changes in spatial distribution</p> <p>Community composition (proportion of native species)</p>	<p>Mid-Murrumbidgee wetlands (River red gum oxbow lagoons (4 sites) Nimmie-Caira (4 sites), Redbank south (4 sites)</p>	<p>Four surveys per year (Sep, Nov, Jan, Mar)</p> <p>2 x replicate sets of 19 mm double winged large fyke (80 cm hoops) or 2 replicates 19 mm mesh double winged 50 cm hoop shallow wetlands) and 2 mm (double wing) fyke nets (50 cm hoops) optimised methods.</p>

Methods

Wetland fish monitoring is integrated with assessment of wetland recruitment (e.g. fish and other vertebrates such as frogs and turtles) as well as critical covariates, including water quality, nutrients and primary productivity.

Site selection

Monitoring will be undertaken at twelve fixed wetland monitoring locations continuing on from the LTIM program (Wassens *et al.* 2014). In the event that one of the fixed monitoring locations does not received CEW in a given year and remains dry throughout the sampling year, options for the incorporation of an alternate site within the same monitoring zone will be discussed with CEWO water managers, and where practical, data will be drawn from these alternate sites to support evaluation of CEW actions. The benefit of including fixed sites across multiple years is that it allows for evaluation of long-term changes in fish communities over successive years of environmental watering and provides a more accurate estimate of recruitment and population change, which is not possible to obtain from single year sampling. This approach also recognises that time lags can exist and that the key responses such as changing population structure may not be evident when monitored over a single year.

Field methods

Wetland fish will be sampled using large and small double winged fyke nets to ensure high detection rates for the target species and to provide robust data for assessment of community composition, population size structure, the presence of exotic species and changes of demographic structure, including identification of young-of-year following Commonwealth environmental watering actions.

As wetlands dry, it becomes difficult to place large fyke nets as water is too shallow to cover the hoops. As small (fine mesh) nets are likely to bias against a number of key native species, large fyke nets will be replaced by 5 m double winged 50 cm D-bottom fyke nets with 12 mm mesh. Recording wing width and depth of the fyke nets will allow for correction of CPUE circulations to account for smaller net size.

Data Analysis

Community composition

The change in fish community composition within (including before and after Commonwealth environmental watering actions) and between water years will be assessed using Plymouth Routines in Multivariate Ecological Research (PRIMER). Analyses will include consideration of both fish abundance (CPUE) and biomass estimates for sites sampled to determine changes. A vector analysis will be used to demonstrate how species contributed to any observed groupings. Statistical differences in Bray-Curtis transformed fish abundances and biomass data will be investigated using two-way crossed Analysis of Similarities (ANOSIM) using region, sampling period as factors.

Change in population structure

Length-frequency distributions of fish species with higher relative abundances (more than 20 individuals) will be quantified using a Kolmogorov-Smirnov goodness of fit test to determine whether there were significantly larger or smaller individuals (length) among sampling trips (as an indicator of potential recruitment).

5.6.3 Research

The current monitoring and evaluation regime within wetlands provides a very robust long-term dataset that can be utilised to test a range of hypothesis associated with native fish requirements and growth on floodplains, patterns of occurrence of native fish through floodplain wetlands and exotic fish colonisation and population. Data generated from wetland fish monitoring also informs studies of food availability for waterbirds and floodplain food web dynamics. Given the current availability of data there are no plans to undertake additional field based research on floodplain fish communities.

5.7 Frogs, tadpoles and turtles

5.7.1 Monitoring

The endangered (IUCN) and vulnerable (EPBC Act 1999) southern bell frog (*Litoria raniformis*) is an iconic wetland species in the Lowbidgee floodplain. Environmental watering is critical for the persistence of both Redbank and Nimmie-Caira southern bell frog populations (Wassens *et al.* 2018) and is therefore a priority for the Selected Area evaluation. Monitoring of recruitment of the southern bell frog and other frog species within the mid-Murrumbidgee and Lowbidgee floodplain will follow the Category 3 standard method. Tadpole monitoring is fully integrated with wetland fish surveys and therefore does not represent an additional cost to the project.

Frogs are sensitive to changes in wetland flooding regimes and respond strongly to environmental releases with large increases in breeding activity. Higher levels of tadpole abundance and recruitment are commonly recorded during managed flood events (see Bino *et al.* 2018; Wassens *et al.* 2018). In many areas, managed environmental watering is critical for the persistence of flood sensitive frog species. For example, key populations of the southern bell frog were successfully maintained using environmental watering in the Lowbidgee floodplain between 2007 and 2010 (Wassens 2010a).

Frogs exhibit three key responses to flooding: (1) calling activity, (2) tadpole abundance and development, and (3) metamorphosis. Calling activity is a useful measure of the distribution of frogs with respect to underlying hydrological regimes and wetland characteristics (Wassens 2010b; Wassens *et al.* 2010). That is, it is an indicator of whether a specific environmental watering event has created conditions suitable for *attempted* breeding by resident species. Monitoring tadpole communities and defining development stages is important when managing water levels, because it allows for estimation of how close tadpoles are to reaching metamorphosis and, as such, can provide an early indicator on the need for top-up watering. Size structure within populations has proven to be a useful indicator as it provides a measure of the number of individuals recruiting into the adult population.

While not a specific target of the monitoring program, freshwater turtles are important members of riverine and wetland communities and are frequently collected during wetland fish surveys. There are three turtle species occurring in the Murrumbidgee Catchment: the broad-shell turtle (*Chelodina expansa*) (listed as threatened in Victoria and considered to be near threatened in NSW), the eastern long-neck turtle (*Chelodina longicollis*) and the Macquarie turtle (*Emydura macquarii*). While all three species occur within the main river channel, neighbouring wetlands are particularly important as feeding and nursery habitats for turtles (Chessman 1988; Chessman 2011).

5.7.2 Evaluation

Frog diversity will directly address several Selected Area evaluation questions provided in Table 5-7. The key monitoring and evaluation questions are listed below.

Selected Area evaluation questions

What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations over time?

What did Commonwealth environmental water contribute to breeding and recruitment of other vertebrates?

What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?

What did Commonwealth environmental water contribute to the maintenance of refuge habitats for other aquatic vertebrates?

Table 5-7 Summary of proposed activities to monitor other vertebrate responses to environmental water delivery in the Murrumbidgee Selected Area.

MER indicators	Basin-scale evaluation questions	Metrics	Sites	Method
Wetland frogs, tadpoles and Turtles Cat 3	<p>What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?</p> <p>What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations?</p> <p>What did Commonwealth environmental water contribute to the maintenance of refuge habitats?</p>	<p>Tadpole abundance (CPUE)</p> <p>Tadpole development stage</p> <p>Adult size structure (selected species)</p> <p>Calling activity</p> <p>Adult abundance</p> <p>Community composition</p> <p>Turtle community composition</p> <p>Sex</p> <p>Size structure (Shell length and width and plastron length)</p>	<p>Mid-Murrumbidgee wetlands (River red gum oxbow lagoons (4 sites) Nimmie-Caira (4 sites), Redbank south (4 sites))</p>	<p>Four surveys per year (Sep, Nov, Jan, Mar)</p> <p>Tadpoles and turtles. 2 replicates sets of 19 mm double winged large fyke (80 cm hoops) (Single wing) and 2 mm (double wing) fyke nets (50 cm hoops)</p> <p>Four surveys per year</p> <p>Calling</p> <p>3 x 2 minute audio surveys (taken at 10 minute intervals)</p> <p>Four surveys per year</p> <p>Adult frogs</p> <p>40 minute nocturnal transect surveys</p> <p>Record snout-vent length of target species (20 individuals per transect)</p> <p>Turtles record species and carapace length</p>

Methods

Monitoring of tadpoles will be undertaken during wetland fish surveys (see previous section). The methodology will follow that used previously in the Lowbidgee and mid-Murrumbidgee as part of the LTIM program (Wassens *et al.* 2014). Intensive monitoring of adult frogs, size structure, tadpole development and recruitment will be undertaken in association with wetland fish (Category 3) and will include twelve fixed sites - mid-

Murrumbidgee (four sites) and Lowbidgee (Redbank (four sites) and Nimmie Caira (four sites).

Adult frogs and metamorphs will be surveyed within each wetland after dark using a 2 x 20 minute visual encounter and a 6 x 2 minute audio survey (Wassens *et al.* 2017). A 30 watt spotlight will be used to search for frogs along the wetland edge and into the surrounding terrestrial habitats. A subsample of twenty individuals of *Limnodynastes tasmaniensis* and *L. fletcheri* will be measured (snout-to-vent length) to give an indication of demographic structure and presence of recent metamorphs. Audio surveys involve listening for the distinct calls of resident frog species, general estimates of the number of calling individuals will be determined using the methodology described in (Wassens *et al.* 2017).

Tadpoles are monitored in association with wetland fish communities. A combination of sampling methods targeting different habitats within each wetland will be employed to survey for fish and tadpoles. Including two small (2 x 2 m wings, 2 mm mesh) and two large (10 m wing, 19 mm mesh). Wing width and depth (m) will be recorded at each site. Tadpoles will be identified to species and the development stage of the first 50 individuals from each net will be assessed by visual examination of limb development, with remaining individuals identified to species and then counted. Turtles will be identified to species and the length and width of the carapace will be measured to the nearest mm.

Data Analysis

Community composition

The change in frog and tadpole communities within and between water years, and between zones will be assessed using Plymouth Routines in Multivariate Ecological Research (PRIMER). Analyses will consider of both tadpole and adult abundance (CPUE) and biomass estimates for sites sampled to determine changes. A vector analysis will be used to demonstrate how species contributed to any observed groupings. Statistical differences in Bray-Curtis transformed fish abundances and biomass data will be investigated using two-way crossed Analysis of Similarities (ANOSIM) using region, sampling period as factors.

Occupancy patterns of frogs

Occupancy patterns are determined in the form of a Boolean presence–absence values for each site–season–species combination, from which detection history is derived (MacKenzie *et al.* 2006). There were two key modelling steps. (1) Single site covariate models, or simple models (2) Individual covariates of high predictive value are combined in complex models. *Akaike information criterion* AIC, model weightings are used to rank models. Goodness of Fit tests are carried out using 100 parametric bootstraps and a model considered to be a poor fit to the data if the p-value (probability of obtaining a test statistic \geq observed) \leq 0.05. A p-value approaching 1 indicates over-fitting (MacKenzie *et al.* 2006).

5.7.3 Research

Frog and tadpole community and diversity measures collected during the MER program will be used in the synthesis analysis. At each wetland automatic call recorder units were deployed in 2016 and these have the capacity to support research on the relationship between wetland hydrology and frog calling (see Research Priorities section 4). Data generated from this program and the previous LTIM program will also be included in the optimisation of flows project which will draw on current available data to test relationships between frog abundance and water management.

As a complementary method to surveying wetland frogs, arboreal cover board arrays will be deployed at a minimum of twelve fixed wetlands to monitor the presence, abundance, distribution and diversity of arboreal herpetofauna. This novel survey technique will produce additional information on suitable arboreal habitat for tree-dwelling frogs (e.g. Peron's Tree Frog *Litoria peronii*) and will be used to refine the understanding of frog responses to environmental flows.

5.8 Waterbird Diversity

5.8.1 Monitoring

Waterbirds can provide useful indicators of wetland availability at large regional and local wetland scales. The number of species, total number of individuals and breeding activity is influenced by total wetland area, the diversity of inundation habitats, the health of wetland vegetation and the abundance of food resources (e.g. fish, frogs, and aquatic vegetation). This means that wetlands with vegetation in good health and a complex of habitats with varying water depths tend to support the greatest diversity of waterbird species and highest waterbird abundance (Scott 1997; Kingsford & Norman 2002).

Previous monitoring in the Murrumbidgee Selected Area has demonstrated local increases in waterbird abundance and species richness, including waterbird species of conservation significance, in response to overbank flows (Wassens *et al.* 2018). Waterbird diversity will be monitored at a Selected Area scale using the Category 2 methods.

Biannual ground surveys will be taken in spring and early autumn at established survey sites in the Lowbidgee Floodplain and mid-Murrumbidgee wetlands. This data collection will align with complementary monitoring activities, including existing spring ground surveys undertaken by NSW OEH and annual aerial waterbird surveys coordinated by the University of New South Wales. Additional information on waterbird species richness will be collected through event-based colony surveys undertaken for the Basin scale and Selected Area scale evaluation (see optional Waterbird Breeding Section in the Appendix).

5.8.2 Evaluation

The contribution of environmental water to habitat provision for waterbird diversity will be evaluated at a Selected Area Scale (Table 5-8). Key metrics detailed in will be used to evaluate waterbird responses to environmental water delivery in the Murrumbidgee Selected Area.

Selected Area Evaluation questions (Cat 2)

What did Commonwealth environmental water contribute to waterbird species diversity over time?

What did Commonwealth environmental water contribute to waterbird abundance over time?

Table 5-8 Summary of evaluation questions and monitoring activities for the waterbird diversity theme.

MER Indicator	Evaluation questions	Metrics	Sites	Method
Waterbird Diversity (Cat 2)	<p>Did Commonwealth environmental water contribute to waterbird species diversity?</p> <p>Did Commonwealth environmental water contribute to waterbird abundance?</p>	<p>Number of waterbird species.</p> <p>Abundance of each waterbird species.</p> <p>Number of species of conservation significance.</p> <p>Number of breeding species.</p>	42 wetland sites through the Lowbidgee and mid-Murrumbidgee floodplain	<p>Biannual (October, March) waterbird ground surveys</p> <p>Event-based surveys of active colony sites (see Waterbird Breeding)</p>

Methods

Category 2 methods will be employed to survey 42 fixed wetland survey sites (30 sites in the Lower Murrumbidgee and 12 sites in the mid-Murrumbidgee region biannually (spring and autumn) in each water year (this include the 12 fixed MERP wetland monitoring sites). A range of wetland types will be surveyed including open lakes and lagoons, vegetated spike-rush and lignum wetlands, and riverine sites across the Murrumbidgee Selected Area. Undertaking ground counts for waterbirds will align with previous survey data collected by CSU and NSW OEH in the Murrumbidgee Selected Area. The survey sites will include the 12 core wetland monitoring sites previously surveyed quarterly through the LTIM program (2014-19) (Wassens *et al.* 2018) and sites included in NSW OEH spring survey program since 2008 (Spencer *et al.* 2018). These two complementary datasets will be shared for analysis purposes.

Each site has established survey points and survey areas (in ha) used by the observers to ensure site coverage is consistent between survey periods and survey teams. The preferred survey method is the Point survey method. The survey method is based on the BirdLife Australia Area Radius Method, whereby all birds observed from one or more survey points within the wetland are recorded. During the survey as much of each wetland as possible is accessed which is defined as the survey area boundary. A new survey point is generally out of sight of the previous survey points or a different habitat within the same wetland. A transect method is used for large and/or linear sites where start and end points have been used to define the survey boundary.

Waterbird species will be counted with binoculars (and/or telescope for large open waterbodies) at each site on at least two occasions (over separate days) during each survey period to estimate the maximum number of waterbird species and maximum count of each species per site. Dry sites are only surveyed once. Total number of each waterbird species are recorded along with any evidence of breeding activity, i.e. the number of broods or nests. Two observers will spend a minimum of 20 minutes and not more than one hour in each survey site.

A minimum of two counts (one in the morning and one in the late afternoon) will be undertaken per site to provide an estimate of total number of waterbird species and maximum total abundance that can be used to evaluate waterbird responses to inundation. This approach is used as some species may only use wetlands as a roosting site in the early morning or late afternoon and if the methods were limited to a single survey in each survey period this would result in low detection for some species and underestimate the number of waterbird species utilising a given wetland.

Data Analysis

Multivariate analyses will be used to investigate differences in waterbird assemblages in response to patterns of wetland inundation. Waterbird species will be separated into functional feeding groups as per (Hale *et al.* 2014) to investigate differences in waterbird assemblages among wetlands and survey periods. This approach will allow for an evaluation of the contribution of Commonwealth environmental water to waterbird species diversity in the Murrumbidgee Selected Area.

5.8.3 Research

It was identified at the Murrumbidgee Selected Area workshop that the Australasian bittern (*Botaurus poiciloptilus*) and Australian little bittern (*Ixobrychus dubius*) were priority waterbird species for environmental water managers. Yanga National Park and neighbouring wetlands in North Redbank and the Gayini Nimmie-Caira zone are likely to be important areas for the nationally endangered Australasian bittern (EPBC Act 1999). Both the Australasian bittern and Australian Little Bittern (*Ixobrychus dubius*) were confirmed breeding in the Murrumbidgee Selected Area during recent surveys in 2018-19 (Herring 2019) and the Australasian bittern has been recorded in the Lowbidgee Floodplain in every year of the Murrumbidgee LTIM surveys (Wassens *et al.* 2018). In the targeted bittern surveys in 2018-19, eight adults were recorded in Yanga National Park and it was thought that there were over 20 birds were present in total (Herring 2019). Commonwealth and NSW environmental water was delivered over 2018-19 to extend wetland inundation into summer months to support bittern breeding. However, information to guide the adaptive management of flows for this watering event was limited as reliable development data for Australasian bitterns does not exist so fledging times were estimated from data available for the Eurasian bittern (*Botaurus stellaris*).

6 Integrated research

The Murrumbidgee Selected Area covers an extensive area and receives relatively large volumes of Commonwealth environmental water each year. Consequently, it is not possible to directly monitor and evaluate ecological outcomes in all wetlands and riverine zones receiving Commonwealth environmental water. Instead, monitoring activities are focused on representative areas within key zones, with the analytical approach designed to allow the development of robust models that are able to infer the observed ecological outcomes with regard to Commonwealth environmental watering actions to unmonitored areas within the Selected Area.

Our approach to the evaluation of the available long term data generated through the LTIM (2014-19) and MER programs (2019-2022) will focus on tracking trends and states in response to both long and short term water regime and quantifying links between the major components of the systems to identify interdependencies between flow, biotic interactions and characteristics of the supporting environment.

Explicitly, we will integrate all available monitoring data, including previously collected since 2008, to quantify annual trends of indicators (e.g. abundance, number of species, breeding), and the prevalence of states by quantifying their probability density function (i.e. percentiles) to evaluate annual outcomes relative to past events. We will also integrate data on monitored indicators to evaluate relationships between water availability, function (metabolism), resources (e.g. prey) and ecological responses of indicators (see research plan) using appropriate statistical models (e.g. generalised linear mixed effect models) and up-to-date conceptual models. Developing ecological response models will provide the foundation to predict responses to water availability and quantify the added contribution of environmental flows to restoration targets as well as extrapolate predicted responses to alternative flow, climate and management scenarios.

Table 6-1 Selected indicators and metrics to be evaluated and integrated within question-focused monitoring

Habitat	Indicator	Metric
Riverine	Hydrology	Water level Water temperature Rate of rise and fall
	Fish	Abundance Occurrence of spawning Species diversity
	Metabolism	Gross Primary Production (GPP) Ecosystem Respiration (ER)
Wetland	Hydrology	Depth loggers Inundation mapping Water quality
	Vegetation	Species diversity Community structure
	Frog and tadpole	Abundance Species diversity
	Turtle	Abundance Size structure Species diversity
	Fish	Abundance Size structure Species diversity

7 Summary of monitoring, evaluation and research activities

The MER program aims to contribute to the evaluation of CEW at the Basin scale (Category 1 and 2 indicators) and Selected Area scale (Category 3 indicators) (Table 7-1). However, it is noted that the methodology for frog surveys is consistent across multiple selected areas and this may be utilised in the Basin scale evaluation for the Diversity theme (formally generic diversity). The surveys sites largely remain consistent with the previous LTIM program in order to retain the integrity of the long-term dataset.

Table 7-1 Summary of proposed monitoring and evaluation activities under the MERP

Ecological Objective	MER Indicator	method
Native Fish	Fish spawning (River) (Cat1) Carrathool reach	In-channel light traps (10) and drift nets (8) (flowing sites 100 m apart), and wetland light traps (10) and larval trawls (3 × 5 min).
	Fish community (River) (Cat1) Carrathool reach	Annual sampling (Mar-May) consisting of electro fishing (n=16 × 2 x 90 sec shots), and small mesh fyke nets (n=10/site).
	Wetland fish community (Cat 3)	Four surveys per year (Sep, Nov, Jan, Mar) 12 sites (mid-Murrumbidgee n=4), Nimmie-Caria (n=4), Redbank (n=4) Aligned with Tadpole and turtle sampling- 2 x double winged large fyke (80 cm hoops) and 2 small fyke nets (50 cm hoops), four surveys per year.
Ecosystem Function	Stream metabolism (River) (Cat1) Carrathool reach	Cat 1 standard method, including collection of continuous dissolved oxygen, temperature, discharge, PAR and barometric pressure, and monthly duplicate water samples to be analysed for nutrients (TN, TP, FRP, NO _x , NH ₄ , PO ₄), dissolved organic carbon (DOC) and Chlorophyll-a.
	Wetland water quality (spot measurements)	Spot measurements of pH, NTU, conductivity and DO.
Waterbirds	Waterbird Diversity (Cat 2)	42 wetlands surveyed twice per year (October and Feb) and will integrate data collected by NSW OEH. This will allow for increased spatial replication or survey sites. Rapid (non-standardised counts) will be undertaken at the core monitoring sites during fish and tadpole monitoring in order to identify incidental species.
Native vegetation	Vegetation Diversity (Cat 2)	As per Cat 2 standard method. Four surveys per year (Sep, Nov, Jan, Mar) 12 sites (mid-Murrumbidgee n=4), Nimmie-Caria (n=4), Redbank (n=4) 3 x 90m, 3 x 150 or 2 x 250 transects
Other species (frogs)	Tadpole and Turtle community (Wetland) (Cat 3)	Four surveys per year (Sep, Nov, Jan, Mar) 12 sites (mid-Murrumbidgee n=4), Nimmie-Caria (n=4), Redbank (n=4) Aligned with wetland fish sampling- 2 x double winged large fyke (80 cm hoops) and 2 small fyke nets (50 cm hoops), four surveys per year.
	Frogs (Cat 3)	Four surveys per year (Sep, Nov, Jan, Mar) 12 sites (mid-Murrumbidgee n=4), Nimmie-Caria (n=4), Redbank (n=4) Calling: 3 x 2 minute audio surveys (taken at 10 minute intervals), four surveys per year Adults: 2 x 20 minute nocturnal transect surveys, record snout-vent length of target species (20 individuals per transect), four surveys per year
Hydrology	Wetland hydrology floodplain inundation (Cat 3)	Included as complementary data from OEH if it continues to be available
	Hydrology (Wetland) (Cat 3)	12 sites (mid-Murrumbidgee n=4), Nimmie-Caria (n=4), Redbank (n=4). Logged depth data (10min intervals) downloaded twice per year.

7.1 Timeline

This section contains a detailed outline of the timing of key activities associated with the MER program including the collection of field data, reporting of Category 1 and 2 metrics, Selected Area evaluation and reporting, communications and engagement activities, and informing adaptive management (Table 7-2).

Table 7-2 Schedule of monitoring, evaluation and reporting activities in the Murrumbidgee.

Indicator Year 1	Activity	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Hydrology Wetland	Maintain Depth (logger) Array												
	Derive flow metrics												
	Information transfer												
Stream Metabolism Cat 1	Logging DO, monthly nutrients												
	Information transfer												
	Field sampling @larval fish sites												
Fish community (river) Cat 1	Information transfer												
	Field sampling												
Larval fish Cat 1 and (SA)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Wetland fish, frogs (SA)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Vegetation diversity (Cat 2)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Waterbird diversity (Cat 2)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Reporting	Quarterly reports												
	Evaluation report												
	Verbal (monthly) (working group)												
Communication and engagement	Annual flow planning												
	Newsletter												
	Social Media												
	Field days/workshop												

Indicator Year 2	Activity	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Hydrology Wetland	Maintain Depth (logger) Array												
	Derive flow metrics												
	Information transfer												
Stream Metabolism Cat 1	Logging DO, monthly nutrients												
	Information transfer												
	Field sampling @larval fish sites												
Fish community (river) Cat 1	Information transfer												
	Field sampling												
Larval fish Cat 1 and (SA)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Wetland fish, frogs (SA)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Vegetation diversity (Cat 2)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Waterbird diversity (Cat 2)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Reporting	Quarterly reports												
	Evaluation report												
	Verbal (monthly) (working group)												
Communication and engagement	Annual flow planning												
	Newsletter												
	Social Media												
	Field days/workshop												

Indicator Year 3	Activity	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Hydrology Wetland	Maintain Depth (logger) Array												
	Derive flow metrics												
	Information transfer												
Stream Metabolism Cat 1	Logging DO, monthly nutrients												
	Information transfer												
	Field sampling @larval fish sites												
Fish community (river) Cat 1	Information transfer												
	Field sampling												
Larval fish Cat 1 and (SA)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Wetland fish, frogs (SA)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Vegetation diversity (Cat 2)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Waterbird diversity (Cat 2)	Processing, data entry and analysis												
	Information transfer												
	Field sampling												
Reporting	Quarterly reports												
	Evaluation report												
	Verbal (monthly) (working group)												
Communication and engagement	Annual flow planning												
	Newsletter												
	Social Media												
	Field days/workshop												

Indicator Year 4	Activity	Jul	Aug	Sep	Oct	Nov	Dec
Reporting	Quarterly reports						
	Verbal (monthly) (working group)						
	Final Evaluation report						
Communication and engagement	Annual flow planning						
	Newsletter						
	Social Media						

8 Engagement and communication

8.1 Purpose

The purpose of this Communication Plan is to guide the delivery of MER communications and engagement activities in the Murrumbidgee Selected Area, and to determine how and when information will be disseminated to key stakeholders to maximise research impact and community outreach during the next phase of the MER program (2019-2022).

8.2 Communications goals

The main communication goals include raising public awareness of the MER program, influencing community attitudes on the use of environmental water for the purpose of improving the health of the Murrumbidgee River, floodplain and associated wetlands, and to build partnerships with local Aboriginal and community groups. The delivery of Commonwealth environmental water is a pivotal talking point because the entire Murray-Darling Basin river system is under stress. Utilising water in more cost-efficient ways will be a critical part of ensuring more water is available for the environment under climate uncertainty. These are important messages that need to be communicated to the broader community.

Communication objectives should be measurable and align with the main communication goals. The key communications objectives below reflect how, when and where information will be delivered to specific target audiences.

1. Build community awareness of the ecological, cultural and economic importance of the Murray-Darling river system, floodplain environments and associated wetland ecosystems.
2. Increase community capacity, knowledge and awareness of the Murrumbidgee LTIM and MER projects, river and wetland health and flow management complexity.

3. Provide key stakeholders, community groups and end users with timely feedback on the ecological outcomes of environmental watering actions in the Murrumbidgee Selected Area.
4. Influence best practice water management and attitudes towards the delivery of environmental water in Australia.
5. Develop strong partnerships with private landholders, land managers and traditional owners across the mid to lower Murrumbidgee region.

8.3 Stakeholders and tools of engagement

The types of communication activities and expected stakeholders to be engaged in the MER program are provided in Table 8-1. This table is representative only and is not intended to be an exhaustive list of activities and end users.

Table 8-1 provides a list of key stakeholders, main tools of engagement and the relationship with key communication objectives.

Target Audiences	Tools of Engagement	Objectives
E-water agencies, government organisations and corporations		
Commonwealth Environmental Water Office Office of Environment & Heritage – water managers NSW Department of Primary Industries – Fisheries Water NSW Murray-Darling Basin Authority Local Land Services (Riverina, Western, Murray) Councils (Murrumbidgee, Balranald, Hay)	Technical & summary reports Interim progress reports Newsletter Teleconferences – TAG Meetings/Workshops Social media/Podcasts Electronic direct mail Website material	To provide timely feedback on monitoring and evaluating the ecological outcomes of e-water To inform planning and improve the delivery of future e-water actions Forge strong partnerships and develop future research projects
Private companies		
Murrumbidgee Irrigation The Nature Conservancy Colleambally Irrigation Company	Social media/Podcasts Electronic direct mail Field days	Increase awareness of the ecological outcomes and benefits of e-water
Non-government organisations		
Murray-Darling Wetlands Working Group Ltd The Nature Conservancy	Quarterly newsletter Field days Social media/Podcasts Workshops	Share findings from the LTIM and MER projects Collaborate on future research projects and field days
Basin community groups		
Environmental Water Action Group	Attendance at meetings Verbal presentations Newsletter Calendar Electronic direct mail	Share findings from the LTIM and MER projects
Murrumbidgee Field Naturalists Murrumbidgee Landcare Network	1 X Field day per year Meetings (e.g. EWARG) Social media/Podcasts	Improve community capacity building Share findings from the LTIM and MER projects Collaborate on future research projects and field days
Primary school students	1 x Field day per year Website	Raise awareness and understanding of threats and solutions to wetland ecosystems
Private landholders directly involved in the project	2 x landholder presentations/year Face-face conversations Species lists provided via email Newsletter Calendar	Improve community capacity building Share findings from the LTIM and MER projects Exchange local knowledge Forge strong partnerships

	Social media/Podcasts	
Broader community not directly involved in the project	Mainstream media (e.g. ABC Riverina & National) Social media/Podcasts YouTube	Improve community capacity building Communicate ecological outcomes of e-water Influence public perception of e-water use
Traditional owners/Aboriginal groups		
Nari Nari Tribal Council Muthi Muthi Wiradjuri	Face to face conversations Newsletter Calendar 3 x Workshops over 3 years	Share findings from the LTIM and MER projects Exchange local knowledge Forge strong partnerships and future research projects
Other scientists		
Academics, research fellows, governments scientists and students	Peer reviewed journal articles	Increase awareness of the ecological outcomes and benefits of e-water Improve knowledge gaps

8.4 Communication activities

The following section outlines the proposed communication products and engagement tools that will be developed and implemented over the next phase of the MER program to achieve key communication and engagement objectives. Annual reports and quarterly newsletters are core milestone requirements and are not included in the following list of additional activities.

8.4.1 Communication products

Calendar

A financial year calendar will be produced for the project. The purpose of the calendar is: 1) provide a visually attractive product that will be distributed via the Riverina and Murray LLS, or posted by CSU team members to a broad range audiences, 2) showcase wetlands in the mid to lower sections of the Murrumbidgee River, 3) disseminate information on significant or iconic flora and fauna, and 4) increase public awareness of the ecological response of environmental watering actions. 250 copies will be printed in 2019 and will increase depending on demand and feedback.

Target audiences: Key stakeholders include: CEWO, Murray and Riverina LLS, members of the Murrumbidgee Landcare Network and private landholders directly involved in the project.

Social media

The primary purpose of establishing a Murrumbidgee Selected Area social media presence on Facebook, Instagram and Twitter is: 1) to provide background information on the project, 2) share key ecological outcomes of the project via links to other social media platforms and/or websites, 3) advertise upcoming field days and community events, and 4) share photos and relevant news articles. The Murrumbidgee LTIM project has an existing Twitter account (@BidgeeLTIM), with 190 followers (June 2019), which will

be used to share stories from the field, research highlights and real time updates on e-water outcomes.

Target audiences: Community groups (EWAG, Murrumbidgee Field Naturalist, Murrumbidgee Landcare Network), private landholders and interested members of the general public. Followers include government organisations (e.g. CEWO, OEH, LLS and water NSW).

Website

The Murrumbidgee LTIM Project currently has a webpage associated with the Institute for Land, Water and Society

<https://www.csu.edu.au/research/ilws/research/environmental-water/murrumbidgee-ltim-project#horizontalTab3>.

The page requires updating and does not allow direct engagement with end users. It is however, useful for directing interested members of the community, stakeholders and end users to background information on the project, team profiles and previous reports. Rather than produce an additional website for the Murrumbidgee Selected Area, the team will contribute a minimum of two articles each year to be published on the Flow-MER website.

Target audiences: Community groups (EWAG, Murrumbidgee Field Naturalist, Murrumbidgee Landcare Network), private landholders and interested members of the general public.

Podcasts and mainstream media (Radio, TV)

We propose to produce a minimum of 6 podcasts over three years. Podcasts are an efficient and cost effective way of disseminating information to a specific target audience. The purpose of developing a podcast series is to distil complex topics into short digestible 15 minute audio segments that are easily assessable by private landholders, irrigators and the broader farming community while they are conducting routine

agricultural activities. Topics will be presented by experts in their relevant fields and cover example subjects such as: 1) how e-water is improving water quality, 2) lessons from wetland reconnection events, 3) trends in native fish populations, 4) wetland frogs and threatened species research, 5) factors influencing bird breeding success, 6) floodplain bats, 7) floodplain reptiles 8) native vegetation conservation and management on private property. In addition, team members will be available to conduct TV and radio interviews, indirect response to watering actions or environmental issues, or to promote research findings as they arise.

Target audiences: Private landholders, irrigators and the broader farming community as well as interested members of the general public.

8.4.2 Community engagement activities

Landholder presentations

The purpose of landholder presentations is to strengthen partnerships with the Riverina LLS and local Landcare Groups across the Murrumbidgee catchment and to provide the local community with regular up-to-date information on flow management, freshwater ecology and the response of vegetation and wildlife to management interventions. A minimum of two evening 'powerpoint' presentations will be held each year and could involve 1-2 speakers on various topics such as wetland restoration, native fish management, enhancing farm dams for frogs and other wildlife, bird breeding success and floodplain reptiles. Presentations will be held in local community halls following a free BBQ. In addition, face to face conversations will be conducted in parallel with monitoring activities and species lists for private properties will be generated and provided to landholders at the end of the project.

Audiences: Community groups (EWAG, Murrumbidgee Field Naturalist, Murrumbidgee Landcare Network), private landholders and interested members of the general public.

Aboriginal community group workshops

The purpose of holding Aboriginal community group workshops is to promote knowledge exchange between researchers, interested community groups and traditional owners. The aim of the workshops is to build community capacity, identify areas for future collaboration, refine future research activities and share local knowledge. Three workshops involving Wiradjuri, Nari Nari and the Muthi Muthi community will be conducted over three years to explore future collaborative research projects and monitoring of biodiversity on Aboriginal lands, as well as provide opportunities for knowledge exchange between Indigenous groups and researchers.

Audiences: Aboriginal community groups.

Field days.

Field days provide participants with practical hands on experiences and opportunities to observe and learn about wildlife in natural settings. The purpose of the field days are to: 1) provide local school groups, 2) special interest groups, and 3) the farming community with opportunities to participate in field activities that involve engaging with local wildlife, water management issues and wetland restoration activities. A minimum of one field day each year involving school groups or local community groups is proposed. Example activities tailored towards school students could include frog call identification, water bug identification, tracks and scat identification, bird identification and reptile identification; whereas activities tailored towards Landcare members and the broader farming community could involve assessing farmland restoration efforts. The field days also provide opportunities to partner and co-host events with the Murray-Darling Wetland working group, Local Land Services and Landcare groups.

Target audiences: Primary school students from Balranald to Narrandera, special interest groups and the farming community.

8.5 Communication protocols

The Murrumbidgee Selected Area MER project involves monitoring and evaluating ecological outcomes across twelve wetlands in three wetland zones. These wetlands are located within Yanga National Park, Murrumbidgee Valley National Park and various private properties. The MER project involves surveying and monitoring a number of Commonwealth and State listed threatened species in areas that support sensitive bird breeding habitat. The purpose of these guidelines is to avoid negative impacts that media communications or community engagement activities might have on sensitive habitat, bird breeding sites, landholder privacy and threatened or iconic species of conservation concern. These guidelines will assist the team as well as Landcare groups, Local Land Services, NRM staff and university researchers to develop products, advertisements and activities which minimise any negative impacts on the environment while striving to enhance participant and end user experience.

8.5.1 Protocols around colonial breeding waterbird sites.

Colonial breeding waterbirds are dependent on wetland inundation and are extremely sensitive to disturbances (Brandis *et al.* 2018). Issues may also arise for private landholders and NPWS from making the locations public, including using site names on event maps and fliers. Colony nesting sites are also more sensitive to disturbance in the early part of the event (when setting up nests) but less so towards the end when young birds are creching or starting to do short flights. To minimise disturbance to colony sites the following guidelines are recommended.

- Locality information and wetland names are not made public on community event advertisements or social media posts.
- Field days should avoid visiting colony sites early in the breeding season.
- Participants should keep an appropriate distance from breeding colonies and should view birds with the aid of telescopes and binoculars.

- Extended observations should use a blind, bird hide or take advantage of natural cover.
- Sound recordings and other methods of attracting birds are to be avoided.
- Spotlighting for nocturnally active wildlife (e.g. frogs, snakes and arboreal marsupials) should be avoided near colony sites. Low intensity spotlights, head torches and red filter should be used when surveying nocturnal fauna at wetlands with known colonies.
- Birdlife Australia has produced ethical birding guidelines that provide practical advice on bird photography <https://www.birdlife.org.au/documents/POL-Ethical-Birding-Guidelines.pdf>

8.5.2 Culturally sensitive sites

Advice from the local Indigenous community and NPWS Indigenous engagement officers should be sought before conducting field days in areas that support culturally significant sites. A recent risk assessment for Nimmie-Caira should be consulted.

8.5.3 Social media protocols

Social media can be a powerful tool for sharing real-time information and digital images of plants and animals captured during field surveys and community events. However, unrestricted access to locality information can damage scientist, agency and landholder relationships (Lindenmayer *et al.* 2017). Furthermore, social media have become increasingly popular platforms to gather locality information and trade in illegal wildlife (Siriwat *et al.* 2018). To protect threatened species locality information and maintain ethical standards for handling wildlife the following principles are recommended.

- Disable geotagging in your phone or cameras privacy settings. This will ensure that locality data is not linked to images that are posted.
- Do not mention location or park information in social media posts.

- Wildlife should be photographed in situ or where applicable in the context of explaining ecological survey methods. Gloves should be worn when handling and photographing frogs.
- Adhering to strict hygiene protocols for handling frogs is a mandatory requirement of animal care and ethics. The Office and Environment and Heritage has developed protocols for handling frogs and controlling the spread of disease which provides further advice <https://www.environment.nsw.gov.au/research-and-publications/publications-search/hygiene-protocol-for-the-control-of-disease-in-frogs>

9 Reporting

9.1 Written reports

Reporting processes are vital to stakeholder engagement. Timely reporting of monitoring information is a key step to sharing this knowledge which, in turn, aids better water delivery through adaptive management.

Monthly progress reports

Verbal progress reports via teleconferences in conjunction with post-survey emails will be provided to CEWO throughout the entire project. During the teleconferences the team will provide summaries of field trips, including any relevant recommendations and any landholder or community concerns that the team have been made aware of.

Quarterly progress reports

A written quarterly progress report will be produced. The purpose of the progress reports are to provide CEWO with a clear indication of how the project is tracking against key milestones, summarise field activities and forms of engagement, and report on the ecological outcomes of watering actions.

Quarterly newsletter

A written quarterly newsletter will be produced. The purpose of the newsletter is to communicate MER activities (e.g. monitoring, research, engagement and extension), preliminary observations and findings, and case studies about environments and people. These will be published on the CEWO and CSU websites quarterly and will be written in plain language accompanied with visually appealing photographs and narratives that explain the use of environmental water and related outcomes.

Annual area evaluation report

The technical and summary reports are a cumulative evaluation of the outcomes of Commonwealth environmental water at each Selected Area, prepared in accordance with this Plan that is delivered annually to the CEWO (Draft 30 Aug, Final 31 October). The report will be written in plain English with easily understandable science and be suitable for publication on the CEWO and CSU websites.

9.2 Annual Forum

Four of the Murrumbidgee project team will attend each Annual Forum and contribute to the basin theme meetings as required. It is expected participation in the forums will provide opportunities to discuss and collaborate on lessons learned and so assist in continual improvement and knowledge sharing between Selected Areas. Annual forums will run for two days. A total of three annual forums over the project duration, with the first forum taking place in July 2020.

10 Project management

10.1 Governance, leadership and administration

Dr Wassens will be responsible for organising the project into one or more sub-projects, managing the day-to-day aspects of the project, resolving planning and implementation issues and communicating monitoring outcomes to inform adaptive management, as well as scheduled reporting. Nikki Scott (CSU) will be the project administrator managing budgets, contracts, workplace health and safety and project auditing. Dr Wassens (project leader) will be supported by one assistant project leader (Dr Spencer) who will assume the role of project leader as required to ensure continuity in project delivery. Team leaders will be responsible for communicating monitoring and evaluation activities (Table 10.1) and ensuring that strong links are maintained with complementary projects run within their organisations. The project leader will report to the CEWH at regular intervals and manage client, partner and stakeholder relationships.

10.2 Landholder and land manager relationships

The importance of the cooperation and collaboration offered freely by private landholders and public land managers where environmental water is being delivered cannot be understated. The value in liaising with landholders to receive local advice regarding access, constraints, monitoring, and opportunities for watering and other vital local information is significant to the success of the project. In regard to this, the project team place high importance on the MER code of conduct delivering safe, collaborative, cooperative, courteous and respectful behaviours to build these relationships. Gaye Bourke (CSU) will manage the on ground communicators with landholders creating a single point of contact for the community and other stakeholders.

Table 10-1 Core project team and responsibilities

Name	Organisation	Project Role	Responsibility- evaluation and reporting
Dr Skye Wassens	CSU	Project Leader CSU Team Leader	Project leader, Vegetation Diversity
Dr Andrew Hall	CSU	CSU team member	Hydrology and ecosystem type
Dr Damian Michael	CSU	CSU team member	Wetland frogs and fish, engagement and communications
Gaye Bourke	CSU	CSU team member	Technical and field manager, land holder liaison and communications
Dr Jennifer Spencer	NSW OEH	OEH team member	Waterbird diversity and breeding
Dr Rachael Thomas	NSW OEH	OEH team member	Hydrology and ecosystem type
Dr Yoshi Kobayashi	NSW OEH	OEH team member	Stream metabolism
Dr Jason Thiem	NSW DPI	DPI team member	Riverine Fish, larval fish and fish movement
Dr Gilad Bino	UNSW	UNSW team member	Data analysis, process modelling and synthesis
Dr Kate Brandis	UNSW	UNSW team member	Waterbird breeding

Table 10.2 Summary of primary responsibilities for each monitoring, evaluation and reporting of each activity outlined in the MERP

Indicator	Monitoring coordination - data collection	Evaluation and reporting
Hydrology	Hall/Thomas	Hall/Thomas
Stream metabolism	Kobayashi	Kobayashi
Wetland nutrients, WQ	Kobayashi	Kobayashi
Fish community (river) Cat 1	Thiem	Thiem
Larval fish Cat 1	Thiem	Thiem
Wetland Fish	Thiem	Thiem
Tadpoles Cat 3	Michael	Michael
Wetland frogs	Michael	Michael
Vegetation diversity	Wassens	Wassens
Waterbird diversity	Spencer/Michael	Spencer
Waterbird breeding (Cat 1 and 3) (optional)	Spencer/Brandis	Spencer/Brandis
Project management		Wassens
Synthesis and evaluation		Bino
Reporting		Wassens/Michael
Progress reports		Bourke/Michael
Communication and engagement		Bourke/Michael/Wassens
Auditing/administration		CSU Research

10.3 Data management

Charles Sturt University will be principally responsible for data management as part of this project. The management of data arising from this project will form part of the teams Research Data Management plan developed in line with the Australian Code for Responsible Conduct of Research. To ensure CSU researchers follow good RDM practice, CSU has established an RDM policy. This policy requires all active research projects (whether funded externally or not) to have a RDM Plan. CSU staff are also required to undertake research data management training and pass skills test as a terms of their employment.

Field data on wetland fish, frogs, tadpoles, turtles and waterbirds are collected on paper field proformas before being entered into a master Access database. Weather stations, depth loggers and call recorders are downloaded to a laptop computer four times a year during scheduled field surveys. Gaye Bourke (CSU) is responsible for entering, curating and uploading all field data. All field data is entered into a databases managed by ach responsive organisation- DPI Fisheries database for riverine fish and larvae, NSW OEH Waterbird database for waterbird diversity and breeding and CSU project database for riverine nutrients and wetland water quality, fish, frogs and tadpoles, turtles and vegetation. Very large continuous datasets (for water depth loggers, weather station, and dissolved oxygen logger data) are stored in CSU dedicated research data servers, where they are backed up to tape. MS Teams is the preferred method of sharing active documents, datasets and reports with collaborators and CEWO staff. At the end of each field season all data is uploaded to the CEWO Monitoring Data Management System.

11 References

- Anderson, H.K. (1915) Rescue Operations on the Murrumbidgee River. *The Australian Zoologist* **1**, 157-160.
- Anderson, M., Gorley, R.N., and Clarke, K.R. (2008) 'Permanova+ for Primer: Guide to Software and Statistical Methods.' (PRIMER-E Plymouth.)
- Baumgartner, L.J., Conallin, J., Wooden, I., Campbell, B., Gee, R., Robinson, W.A., and Mallen-Cooper, M. (2013) Using flow guilds of freshwater fish in an adaptive management framework to simplify environmental flow delivery for semi-arid riverine systems. *Fish and Fisheries*, n/a-n/a.
- Bino, G., Wassens, S., Kingsford, R.T., Thomas, R.F., and Spencer, J. (2018) Floodplain ecosystem dynamics under extreme dry and wet phases in semi-arid Australia. *Freshwater Biology* **63**(2), 224-241.
- Brandis, K., Bino, G., Spencer, J., Ramp, D., and Kingsford, R. (2018) Decline in colonial waterbird breeding highlights loss of Ramsar wetland function. *Biological Conservation* **225**, 22-30.
- Brandis, K.J., Kingsford, R.T., Ren, S., and Ramp, D. (2011) Crisis water management and ibis breeding at Narran Lakes in arid Australia. *Environmental Management* **48**(3), 489-498.
- Brock, M.A., Nielsen, D.L., Shiel, R.J., Green, J.D., and Langley, J.D. (2003) Drought and aquatic community resilience: the role of eggs and seeds in sediments of temporary wetlands. *Freshwater Biology* **48**(7), 1207-1218.
- Cameron, L.M., Baumgartner, L.J., and Maguire, J. (2013) Management plan to use environmental water to enhance the Murrumbidgee River system for native fish. . NSW Department of Primary Industries, Cronulla.
- Chessman, B. (1988) Habitat Preferences of Fresh-Water Turtles in the Murray Valley, Victoria and New-South-Wales. *Wildlife Research* **15**(5), 485-491.
- Chessman, B. (2003) 'Integrated monitoring of environmental flows: state summary report 1998-2000.' (NSW Department of Infrastructure, Planning and Natural Resources: NSW)
- Chessman, B.C. (2011) Declines of freshwater turtles associated with climatic drying in Australia's Murray-Darling Basin. *Wildlife Research* **38**(8), 664-671.

Childs, P., Webster, R., Spencer, J., and Maguire, J. (2010) Yanga National Park - 2009-10 Environmental Watering: Waterbird Surveys Final Report. Western Region, Griffith.

Clarke, K.R., and Gorley, R.N. (2006) 'PRIMER v6: User Manual/Tutorial.' (PRIMER-E: Plymouth)

Commonwealth Environmental Water (2013) 'The Environmental Water Outcomes Framework.' (Commonwealth Environmental Water Holder for the Australian Government.: Canberra)

Copp, G.H. (1992) Comparative microhabitat use of cyprinid larvae and juveniles in a lotic floodplain channel. *Environmental Biology of Fishes* **33**(1-2), 181-193.

CSIRO (2008a) Water availability in the Murrumbidgee. CSIRO: Canberra.

CSIRO (2008b) 'Water Availability in the Murrumbidgee:A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project.' (CSIRO: Canberra)

Dijk, A.I., Beck, H.E., Crosbie, R.S., Jeu, R.A., Liu, Y.Y., Podger, G.M., Timbal, B., and Viney, N.R. (2013) The Millennium Drought in southeast Australia (2001–2009): Natural and human causes and implications for water resources, ecosystems, economy, and society. *Water Resources Research* **49**(2), 1040-1057.

Frazier, P., and Page, K. (2006) The effect of river regulation on floodplain wetland inundation, Murrumbidgee River, Australia. *Marine and Freshwater Research* **57**(2), 133-141.

Frazier, P., Page, K., and Read, A. (2005) Effects of flow regulation in flow regime on the Murrumbidgee River, South Eastern Australia: an assessment using a daily estimation hydrological model. *Australian Geographer* **36**(3), 301-314.

Gawne, B., Brooks, S., Butcher, R., Cottingham, P., Everingham, P., and Hale, J. (2013a) Long term intervention monitoring project monitoring and evaluation requirements Murrumbidgee River system for Commonwealth environmental water. Final report prepared for the Commonwealth Environmental Water Office. Wodonga.

Gawne, B., Brooks, S., Butcher, R., Cottingham, P., Everingham, P., Hale, J., Nielsen, D.L., Stewardson, M., and Stoffels, R. (2013b) 'Long Term Intervention Monitoring Project: Logic and Rationale Document ' (Final report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre.: Wodonga)

Gilligan, D. (2005) Fish communities of the Murrumbidgee catchment: status and trends. *NSW Department of Primary Industries. Fisheries final report series*(75), 138.

Gilligan, D.M., and Schiller, C. (2003) 'Downstream transport of larval and juvenile fish in the Murray River.' (NSW Fisheries Office of Conservation.)

Gosner, K.L. (1960) A simplified table for staging anuran embryos and larvae with notes on identification *Herpetologica* **16**, 183-189.

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S., and Gawne, B. (2014) Commonwealth Environmental Water Office Long Term Intervention Monitoring Project - Standard Methods.

Hardwick, L., and Maquire, J. (2012) 'Environmental water needs of the Lower Murrumbidgee (Lowbidgee) floodplain: Discussion Paper 1 - Approach and ecological considerations.' (NSW Office of Water)

Humphries, P. (1996) Aquatic macrophytes, macroinvertebrate associations and water levels in a lowland Tasmanian river. *Hydrobiologia* **321**(3), 219-233.

Humphries, P., King, A.J., and Koehn, J.D. (1999) Fish, flows and floodplains: links between freshwater fishes and their environment in the Murray-Darling River System, Australia. *Environmental Biology of Fishes* **56**(1), 129-151.

Humphries, P., Serafinia, L., and King, A.J. (2002) River regulation and fish larvae: variation through space and time. *Freshwater Biology* **47**, 1307-1331.

Jackson, D.A., Peres-Neto, P.R., and Olden, J.D. (2001) What controls who is where in freshwater fish communities the roles of biotic, abiotic, and spatial factors. *Canadian Journal of Fisheries and Aquatic Sciences* **58**(1), 157-170.

Herring, M. (2019). Bittern surveys in the Lowbidgee Wetlands: December 2018-January 2019. Summary report for the NSW Office of Environment and Heritage. Murray Wildlife.

King, A.J. (2004) Density and distribution of potential prey for larval fish in the main channel of a floodplain river: pelagic versus epibenthic meiofauna. *River Research and Applications* **20**(8), 883-897.

King, A.J., Humphries, P., and Lake, P.S. (2003) Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences* **60**(7), 773-786.

Kingsford, R.T., and Norman, F.I. (2002) Australian waterbirds - products of the continent's ecology. *Emu* **102**, 47-69.

Kingsford, R.T., and Thomas, R.F. (2001) 'Changing water regimes and wetland habitat on the Lower Murrumbidgee floodplain of the Murrumbidgee River in Arid Australia.' (NSW National Parks and Wildlife Service: Sydney)

Kobayashi, T., Ryder, D., Gordon, G., Shannon, I., Ingleton, T., Carpenter, M., and Jacobs, S. (2009) Short-term response of nutrients, carbon and planktonic microbial communities to floodplain wetland inundation. *Aquatic Ecology* **43**(4), 843-858.

Lake, J. (1967) Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning. *Marine and Freshwater Research* **18**(2), 137-154.

Lindenmayer, D., and Scheele, B. (2017) Do not publish. *Science* **356**(6340), 800-801.

Lyon, J., Stuart, I., Ramsey, D., and O'Mahony, J. (2010) The effect of water level on lateral movements of fish between river and off-channel habitats and implications for management. *Marine and Freshwater Research* **61**(3), 271-278.

MacKenzie, D.I. (2006) 'Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence.' (Academic Press)

MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L.L., and Hines, J.E. (2006) 'Occupancy estimation and modeling.' (Academic Press: Burlington, MA)

Marcarelli, A.M., Baxter, C.V., Mineau, M.M., and Hall, R.O. (2011) Quantity and quality: unifying food web and ecosystem perspectives on the role of resource subsidies in freshwaters. *Ecology* **92**(6), 1215-1225.

MDFRC (2013) Long-term Intervention Monitoring - Generic Cause and Effect Diagrams Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre., MDFRC Publication

Murray-Darling Basin Authority (2012a) 'Assessment of environmental water requirements for the proposed Basin Plan: Lower Murrumbidgee River (in-channel flows).' (Murray-Darling Basin Authority for and on behalf of the Commonwealth of Australia: Canberra)

Murray-Darling Basin Authority (2012b) 'Assessment of environmental water requirements for the proposed Basin Plan: Mid-Murrumbidgee River Wetlands.' (Murray-Darling Basin Authority for and on behalf of the Commonwealth of Australia Canberra)

Murray-Darling Basin Authority (2012c) 'Assessment of water requirements for the proposed Basin Plan: Lower Murrumbidgee River Floodplain.' (Murray-Darling Basin Authority for and on behalf of the Commonwealth of Australia: Canberra)

Murray-Darling Basin Authority (2014) Preliminary Overview of Constraints to Environmental Water Delivery in the Murray-Darling Basin. Vol. 2014. (Murray-Darling Basin Authority)

Murray, P. (2008) 'Murrumbidgee wetlands resource book.' (Murrumbidgee Catchment Management Authority: New South Wales)

Murrumbidgee Catchment Management Authority (2009) 'Lower Murrumbidgee Floodplain: Natural resource management plan.' (Murrumbidgee Catchment Management Authority

Wagga Wagga)

NSW Commissioner for Water (2013) Adaptive Environmental Water Use Plan for the Murrumbidgee Water Management Area. *NSW Office of Environment and Heritage*.

Office of Environment and Heritage (2019) Murrumbidgee Long Term Water Plan. Part A: Murrumbidgee catchment. Draft. Sydney.

Robinson, W. (2012). Calculating statistics, metrics, sub-indicators and the SRA Fish theme index. *A Sustainable Rivers Audit Technical Report*. Murray-Darling Basin Authority, Canberra.

Robertson, A.I., Bunn, S.E., Boon, P.I., and Walker, K.F. (1999) Sources, sinks and transformations of organic carbon in Australian floodplain rivers. *Marine and Freshwater Research* **50**(8), 813-829.

Rolls, R.J., Growns, I.O., Khan, T.A., Wilson, G.G., Ellison, T.L., Prior, A., and Waring, C.C. (2013) Fish recruitment in rivers with modified discharge depends on the interacting effects of flow and thermal regimes. *Freshwater Biology*.

Scott, A. (1997) Relationships between waterbird ecology and river flows in the Murray-Darling Basin. CSIRO Land and Water: Canberra.

Sinclair Knight Merz (2011) 'Environmental Water Delivery: Murrumbidgee Valley.' (Prepared for Commonwealth Environmental Water, Department of Sustainability, Environment, Water, Population and Communities: Canberra.)

Siriwat, P., and Nijman, V. (2018) Illegal pet trade on social media as an emerging impediment to the conservation of Asian otters species. *Journal of Asia-Pacific Biodiversity* **11**(4), 469-475.

Spencer, J., Ocock, J., Amos, C., Borrell, A., Suter, S., Preston, D., Hosking, T., Humphries, J., Hutton, K., Berney, P., Lenon, E., Brookhouse, N., Keyte, P., Dyer, J., and Lenehan, J. (2018). *Monitoring Waterbird Outcomes in NSW: Summary Report 2016-17*. Unpublished report. NSW Office of Environment and Heritage, Sydney.

Spencer, J., Thomas, R., Wassens, S., Lu, Y., Wen, L., Iles, J., Kobayashi, Y., Hunter, S., Ling, J., and Saintilan, N. (2011) 'Environmental flow monitoring in the Lowbidgee wetlands and Macquarie Marshes in 2009-10. Testing wetland resilience: monitoring the response of iconic wetlands to re-flooding following historic drought project.' (NSW Department of Environment, Climate Change and Water: Sydney)

Spencer, J.A., and Wassens, S. (2010) 'Monitoring the responses of waterbirds, fish and frogs to environmental flows in the Lowbidgee wetlands from 2008–10. Final report for the NSW Rivers Environmental Restoration Program. Rivers and Wetland Unit.' (NSW Department of Environment, Climate Change and Water and Institute for Land, Water and Society, Charles Sturt University: Sydney and Wagga Wagga.)

Spencer, J.A., Wassens, S., Maguire, J., Hardwick, L., Webster, R., and Maher, M. (2012) 'Draft Management Plan for the Southern bell frog in the Murrumbidgee Catchment.' (NSW Office of Environment and Heritage: Sydney)

Tuckett, R.E., Merritt, D.J., Hay, F.R., Hopper, S.D., and Dixon, K.W. (2010) Dormancy, germination and seed bank storage: a study in support of ex situ conservation of macrophytes of southwest Australian temporary pools. *Freshwater Biology* **55**(5), 1118-1129.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and Cushing, C.E. (1980) The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* **37**(1), 130-137.

Warfe, D., and Barmuta, L. (2006) Habitat structural complexity mediates food web dynamics in a freshwater macrophyte community. *Oecologia* **150**(1), 141-154.

Wassens, S. (2010a) Flooding regimes for frogs in lowland rivers of the Murray-Darling Basin In Ecosystem Response Modelling in the Murray-Darling Basin. (Eds. N Saintilann and IC Overton) pp. 213-228. (CSIRO Publishing Canberra)

Wassens, S. (2010b) Frogs. In Floodplain wetland biota in the Murray-Darling Basin: Water and habitat requirements. . (Eds. K Rogers and TJ Ralph) pp. 253-274. (CSIRO Publishing: Canberra)

Wassens, S., Bindokas, J., Jenkins, K., Lenon, E., Spencer, J., Watts, R.J., Kobayashi, T., Iles, J., Baumgartner, L., Thomas, R., and Hall, A. (2013) 'Monitoring the ecosystem responses to Commonwealth environmental water delivered to the Murrumbidgee River and connected wetlands, 2012-13. Report 1. Prepared for Commonwealth Environmental Water.' (Institute for Land, Water and Society, Charles Sturt University: Albury)

Wassens, S., Hall, A., Osborne, W., and Watts, R.J. (2010) Habitat characteristics predict occupancy patterns of the endangered amphibian *Litoria raniformis* in flow-regulated flood plain wetlands. *Austral Ecology* **35**(8), 944-955.

Wassens, S., Hall, A., and Spencer, J. (2017) The effect of survey method on the detection probabilities of frogs and tadpoles in large wetland complexes. *Marine and Freshwater Research* **68**(4), 686-696.

Wassens, S., Jenkins, K., Spencer, J., Thiem, J., Kobayashi, T., Bino, G., Lenon, E., Thomas, R., Baumgartner, L., Brandis, K., Wolfenden, B., and Hall, A. (2014) 'Murrumbidgee Monitoring and Evaluation Plan ' (Commonwealth of Australia Canberra)

Wassens, S., Spencer, J., Wolfenden, B., Thiem, J., Thomas, R., Jenkins, K., Brandis, K., Hall, A., Ocock, J., Kobayashi, Y., Bino, G., Heath, J., and Callaghan, D. (2018) Commonwealth Environmental Water Office Long-Term Intervention Monitoring project Murrumbidgee River system Selected Area evaluation report, 2014-17. . Canberra.

Wassens, S., and Spencer, J.A. (2012) 'Monitoring of ecosystem responses to a major natural flood in Autumn 2012 ' (Institute for Land, Water and Society, Charles Sturt University for Department of Sustainability, Environment, Water, Population and Communities Albury)

Wassens, S., Watts, R., Howitt, J., Spencer, J., Zander, A., and Hall, A. (2011) 'Monitoring of ecosystem responses to the delivery of environmental water in the Murrumbidgee system. Report to DSEWPaC.'. In (Institute of land, Water and Society. Report 1. : Albury)

Wen, L., Ling, J., Saintilan, N., and Rogers, K. (2009) An investigation of the hydrological requirements of River Red Gum (*Eucalyptus camaldulensis*) Forest, using Classification and Regression Tree modelling. *Ecohydrology* **2**(2), 143-155.

Wetzel, R.G., and Likens, G.E. (2000) Composition and Biomass of Phytoplankton. In *Limnological Analyses*. pp. 147-174. (Springer New York)

Young, R.G., and Huryn, A.D. (1996) Interannual variation in discharge controls ecosystem metabolism along a grassland river continuum. *Canadian Journal of Fisheries and Aquatic Sciences* **53**(10), 2199-2211.

Young, R.G., Matthaei, C.D., and Townsend, C.R. (2008) Organic matter breakdown and ecosystem metabolism: functional indicators for assessing river ecosystem health. *Journal of the North American Benthological Society* **27**(3), 605-625.

12 Budget

Commercial-in-Confidence

13 Appendices

Appendix 1 - Workplace Health & Safety Plan

See standalone WHS document.

Appendix 2 - Risk Assessment

See standalone risk assessment document.

Appendix 3 - Standard operating procedures for indicators monitored

Standard operating procedures (SOPs) for all indicators will follow the protocols established for CAT 1 indicators. The revised SOP for frogs and tadpoles is provided below.

Standard Operating Procedure Frogs and tadpoles

Frogs are sensitive to changes in wetland flooding regimes and respond strongly to environmental releases with large increases in breeding activity. Higher levels of tadpole abundance and recruitment are commonly recorded during managed flood events e.g. (Spencer *et al.* 2010; Spencer *et al.* 2011; Wassens *et al.* 2011; Wassens *et al.* 2012; Spencer & Wassens 2010; Spencer *et al.* 2011; Wassens *et al.* 2013). In many areas managed environmental watering is critical for the persistence of flood sensitive frog species. For example, key populations of the vulnerable (EPBC Act 1999) Southern bell frog were successfully maintained using environmental watering in the Lowbidgee floodplain between 2007 and 2010 (Wassens 2010a).

Frogs exhibit three key responses to flooding: (1) calling activity, (2) tadpole abundance and development, and (3) metamorphosis. Calling activity is a useful measure of the distribution of frogs with respect to underlying hydrological regimes and wetland characteristics (Wassens 2010b; Wassens *et al.* 2010). That is, it is an indicator of whether a specific environmental watering event has created conditions suitable for *attempted* breeding by resident species. Monitoring tadpole communities and defining development stages is important when managing water levels, because it allows for estimation of how close tadpoles are to reaching metamorphosis and, as such, can provide an early indicator on the need for top-up watering. Size structure within populations has proven to be a useful indicator as it provides a measure of the number of individuals recruiting into the adult population.

Evaluation questions

What did Commonwealth environmental water contribute to other vertebrate: 1) community resilience, 2) species diversity, 3) body condition, and 4) reproduction?

Relevant ecosystems

Rivers, wetlands and floodplains

Relevant flow types

All

Overview and context

Frog community responses can be assessed at two spatial and temporal scales: (1) broad scale assessment of occupancy patterns within connected wetlands addressing long-term (five year) objectives) and (2) intensive monitoring of tadpole development and recruitment (can be carried out in association with wetland fish monitoring) at a subset of connected wetlands or in areas where there are known populations of threatened or locally significant species. Note that small and large fyke nets have the highest probability of detecting tadpoles in large wetland systems so tadpole surveys can be run concurrently with fish surveys with tadpoles being identified in the field at the same time as fish. However as tadpoles can be extremely difficult to identify it is recommended that an experienced observer is present for initial surveys to ensure that staff are properly trained.

Establishing assessment sites

Equipment

GPS

Map of floodplain wetlands in area or zone

Selected Area

Zone

Site

Minimum of three surveys per year (Autumn, Spring, Summer) timing may need to be modified to suit climatic characteristics of the region. Aim to include a minimum of 10 sites per year for adult frog surveys and at least 5 sites for tadpole surveys if being undertaken.

Monitoring protocol

Equipment (adult frogs)

- Torch or spotlight with a minimum of 300 Lumens
- Notebook- Pocket notebooks are far easier to manage than A4 datasheets for general surveys
- Callipers (for size measurement)
- Disposable gloves
- GPS
- Watch (record start and finish times)
- Disinfectant hand wash
- Optional (handheld temperature/ weather station)

Other considerations

All surveyors must adhere to the NSW OEH hygiene protocol for frogs, or other state approved hygiene protocol.

<http://www.environment.nsw.gov.au/animals/HygieneProtocolForFrogs.htm>

Gloves must be worn when handling frogs as contact with sunscreens and insect repellents can cause irritation.

Protocol

Broad scale

Broad scale assessment of frog communities can be undertaken every two months from late winter (August-April). Generally timed surveys are easier than set transects because variable water levels over time can make the use of fixed transects impractical. But it is recommended that repeat surveys broadly have the same starting point and surveys are carried out within 20 meters of the waterline.

Adult frogs and metamorphs are surveyed within each wetland after dark using a 2 x 20 minute visual encounter (person minutes) and a 6x1 minute audio survey (Wassens *et al.* 2011; Wassens *et al.* 2013). However 15 minute transects (person minutes) would be sufficient in small systems and in rivers/creek lines if you were not measuring size structures and still achieves greater than 80% detection probability for most species. Use longer transects if the study area contains rare, or difficult to detect species such as *L. raniformis*.

Recording start and finish times allows for frog abundance to be standardised as frogs/minute.

A 15-30 watt spotlight or torch can be used to search for frogs along the wetland edge and into the surrounding terrestrial habitats. All individuals observed are identified to species and the number recorded (it is possible to identify individuals without capture). Recording data for 4 x 10 minute sets rather than a single 30 minute surveys allows for estimation of detection probabilities and more accurate statistical analyse of occupancy patterns.

Optional

An estimate of breeding activity from common species can be obtained by measuring the snout-vent length of a subset of 20 individuals (in mm) as size structure can give an indication of the number of recently metamorphosed individuals. In the southern basin, *Limnodynastes tasmaniensis* and *L. Fletcheri* and in the northern basin, *L. fletcheri* and *Litoria latopalmata* could be measured (snout-to-vent length) to give an indication of demographic structure and presence of recent metamorphs. This methodology was trialled in the Mid-Murrumbidgee between October 2011 and April 2012 with success.

Audio surveys involve listening for the distinct calls of resident frog species. General estimates of the number of calling individuals will be determined using the methodology described in (Wassens *et al.* 2011).

Tadpole surveys

Tadpoles are most effectively surveyed as part of wetland fish assessments. Tadpoles should be identified to species when possible and the development (Gosner stage recorded for the first 50 individuals of each species)(Gosner 1960).

Data analysis and reporting

- Site name
- Lat/long
- Time start- time finished
- Surveyor name
- Number observed (each species) per minute

- Number calling (each species) mean of replicate counts
- Size structure- Length (mm) of target species (if undertaken)
- Presence/absence for each timed replicate (allows estimation of detection probability)

Tadpoles

- Site name
- Lat/long
- Net type and replicate
- Number of individuals of each species
- Development stage subset of 30 individuals per net

Covariates

- Wetland type
- Hydrology
- Vegetation percent cover and diversity (we use a rapid assessment of the percent cover of plant functional groups within 10m sections) (e.g amphibious emergent, amphibian submerged etc)
- Fish

Water quality (point measurements if not returning to the site).

Zone	Site name	Estimated Status (March)	Water Quality	Microinvertebrates Chlorophyll A	Carbon Nutrients	Ecosystem metabolism	Larval fish	Riverine fish	Tadpoles, fish and turtles	Frogs	Waterbirds	Vegetation			
mid-Murrumbidgee	Gooragool	Dry	J	J	J				J	J	J/M	J/M			
	Mckennas	Dry	J									J	J/M	J/M	
	Sunshower	Dry											J/M	J/M	
	Yarradda	½ full	J/M	J/M	J/M				J/M	J/M	J/M	J/M	J/M	J/M	
South Redbank	Mercedes	Dry	J	J	J							J	J	J/M	J/M
	Two Bridges	Dry											J	J/M	J/M
	Piggery Lake	Dry												J/M	J/M
	Waugorah Lagoon	Channel only (low)	J/M	J/M	J/M				J/M	J/M	J/M	J/M	J/M	J/M	J/M
Nimmie-Caira	Nap Nap	Dry											J	J/M	J/M
	Avalon	Dam-only	J/M	J/M	J/M				J/M	J/M	J/M	J/M	J/M	J/M	J/M
	Telephone	¼ full	J/M	J/M	J/M				J/M	J/M	J/M	J/M	J/M	J/M	J/M
	Eulimbah	Dry										✓	✓	J/M	J/M
River sites	Mckennas (Carrathool zone)								Compl. (Apr18)	Complete: October-December 2017	Mar/Apr				
	Bringagee (Carrathool zone)														
	Yarradda (Carrathool zone)														
	Narrandera (Narrandera zone)					Compl. (Dec17)									
	Euroley (Narrandera zone)														
	Dairy (Narrandera zone)														

Appendix 5 - Waterbird Breeding

(Cat 1) (Optional event based Monitoring)

The links between colonial waterbird breeding success and hydrological conditions have been well established (Kingsford 1995, Kingsford and Johnson 1998, Brandis *et al.* 2010, Brandis *et al.* 2011). Colony monitoring provides a critical link between water delivery and measurable outcomes. The collection of quantitative data on the breeding success of colonial waterbirds is essential for future understanding, real-time monitoring and predictions of conditions for management.

Detailed methods are outlined in the Standard Operating Procedure: Murrumbidgee Selected Area waterbird breeding.

Breeding surveys

For the duration of breeding by Straw-necked ibis, Glossy ibis, Australian White ibis, or Royal Spoonbills a subset of marked nests will be visited fortnightly to measure reproductive success for these species. These species typically nest in colonies within the channelized lignum. These species have been shown to be sensitive to changes in water levels (Brandis *et al.* 2011), therefore regular monitoring at each stage of chick development (fortnightly visits) is crucial for assessing the contribution of Commonwealth Water contributed to waterbird breeding.

Monitoring will occur every two weeks to obtain a measure of overall breeding success. Surveys will be undertaken by canoe. Surveys of lignum nesting species (Ibis, Spoonbills) will continue fortnightly until chicks have fledged and it is no longer possible to associate chicks with specific nests (Brandis *et al.* 2011). A total of six colony surveys will be conducted.

To minimise disturbance to the colony all ground surveys of the colonies will be limited to two periods, either in early morning (6-11am) or late afternoon (3-8 pm) to avoid causing heat stress to nesting birds and their offspring. This approach has worked effectively in previous studies of large waterbird colonies in the Lowbidgee which recorded high levels of nesting success (Brandis *et al.* 2011b).

As straw-necked ibis are particularly sensitive to sudden changes in water level real-time information on the status of nesting birds and water levels is needed during breeding events to support adaptive management of environmental water (Brandis *et al.* 2011a; Brandis *et al.* 2011b).

The breeding period for straw-necked ibis, from laying to chicks leaving their nests and taking short flights (flapper stage), is around 45-53 days (Brandis *et al.* 2011a). If monitoring is scheduled monthly and the first survey is at egg stage, the second survey a month later will be at a development stage where chicks are off the nests and success rates for individual nests cannot be measured. To ensure that basin and selected area objectives can be evaluated, we plan to undertake ground surveys at fortnightly intervals, with the

first survey taking place after eggs are laid, thus ensuring accurate estimates of the number of nests successfully fledged and mean number of chicks per nest for a subsample of nests. The three-month breeding period is assumed to be a large enough window to cover the period from birds pairing up, laying and incubating eggs, rearing chicks and cover the period of post-fledging dependency in the three ibis species (Brandis & Bino 2016).

Colony mapping

During the first colony survey, as close as possible to colony establishment, the boundary of the colony will be mapped using a differential GPS mounted on a boat to provide a framework for random sampling of a subset of nesting sites. Where a nesting site is defined as a group of nests on a clump of lignum separated from another clump of lignum by open water or non-flattened vegetation. A representative sub-set of nests will be monitored for the three-month breeding period. All nests will be recorded with GPS and marked using coloured tape and given a unique identifier as per methods developed by Brandis *et al.* (2011a). Selected nests will be monitored throughout the breeding period from egg to fledgling development stages through repeat field surveys by trained observers.

Hydrology and Water Quality

In addition to reproductive success data hydrological indicators relevant to waterbird breeding will be measured. These include measurement of water depth and replicate spot measurements of water quality (dissolved oxygen, turbidity, conductivity, and temperature) at each nesting site.

Predators and Reasons for Nest Desertion/Failure

Known predators at colonies are humans, dingos (wild dogs), foxes, cats, Australian raven, and raptors. Any evidence or observation of nest contents or adult bird predation by these or other species should be recorded. Also, mass nest desertion can occur if water levels drop suddenly around the nests or if the ground below the nest dries out (or if islands become connected to the main shore, for ground-nesting species), and these events and the likely triggers for desertion/nesting abandonment should be recorded.

Waterbird Breeding (Cat 3) Monitoring

Category 3 colony sites in the Redbank, Nimmie-Caira and mid Murrumbidgee zones include sites that have historically supported nesting egrets, cormorants, spoonbills, herons and pelicans. Initial colony assessments will be carried out alongside spring surveys undertaken in October each year as part of biannual waterbird diversity monitoring of fixed wetland sites (see Waterbird Diversity section). UNSW's annual aerial surveys will also inform the colony ground surveys.

Subsequent follow up surveys will be undertaken monthly (Nov-Mar) at active sites to the end of the breeding period. Ground surveys are conducted on foot or using a large canoe or small boat. During each survey detailed assessment of the colony will be made to include estimates of colony boundary, total number of nests of each species and stage of nesting and water depths. This information will be used to inform the need for delivery of environmental water to maintain active sites.

For most colony sites, a complete assessment of total number of nests per species is possible by two observers systemically moving from one nesting tree to the next. An evaluation of breeding success for each site is based on observations made during the monthly surveys where the number of birds in each development stage is recorded. It is assessed at the end of the breeding events using a count of total number of fledged birds, number of predators (i.e. feral predators and raptors) observed and number of dead birds (if present) recorded in each colony. Observations of non-colonial waterbird species and their breeding activity will also be recorded to contribute to the waterbird diversity monitoring.

Theme	Scale of Monitoring	of Evaluation questions	Metrics	Critical covariates	Survey methods
Waterbird Breeding	Eulimbah and Telephone Bank colonies (Cat 1)	What did Commonwealth water contribute to waterbird breeding	Number of species breeding Number of birds breeding	Number of nests, eggs, chicks. Number of birds fledged. Water depth	Fortnightly monitoring of nests and water depth measurements.
	Redbank, Nimmie-Caira and Mid-Murrumbidgee (Cat 3)	What did Commonwealth water contribute to waterbird breeding	Number of species breeding Number of birds breeding	Number of nests	Monthly surveys over 5 month period (Nov – March)

Evaluation

The monitoring of colonial waterbird breeding in the Murrumbidgee Selected Area uses Category 1 methods to address selected area evaluation questions.

- What did Commonwealth environmental water contribute to waterbird populations?
- What contribution did the Murrumbidgee selected area make to Basin wide colonial waterbird breeding?

Short and long-term selected area evaluation questions.

- What did Commonwealth environmental water contribute to colonial waterbird breeding in the Murrumbidgee selected area?
- How did Commonwealth environmental water contribute to colonial waterbird breeding the Murrumbidgee selected area?
- What contribution did the Murrumbidgee selected area make to Basin wide colonial waterbird breeding?

- What did Commonwealth environmental water contribute to colonial waterbird breeding in the Murrumbidgee selected area?
- How did Commonwealth environmental water contribute to colonial waterbird breeding the Murrumbidgee selected area?
- What were the colonial waterbird responses to Commonwealth environmental watering?

Evaluation of results

Evaluation of watering actions will occur on an event-based schedule rather than annually. Colonial waterbird breeding does not occur annually and relies upon relatively large volumes of water often as a result of natural flooding. During the period 2015-2019 breeding occurred in one year (2016/17). If more than one colonial waterbird breeding event occurs during LTIM2 then they can also be evaluated cumulatively.

During a waterbird breeding event researchers communicate with water managers following/during each survey time to provide information on the colony and water conditions within the colony. This allows water managers to make real time decisions regarding water delivery to support colonial waterbird breeding.

Research

See Research proposed in Waterbird Diversity.

References

Brandis, K. (2010) Colonial Waterbird Breeding in Australia: wetlands, water requirements and environmental flows. University of New South Wales, Sydney

Brandis, K., Kingsford, R.T., Ren, S., Ramp, D. (2011a) Crisis water management and ibis breeding at Narran Lakes in arid Australia. *Environmental Management* 48(3), 489-498.

Brandis, K., Ryall, S., Kingsford, R. (2011b) Lowbidgee 2010/2011 Colonial Waterbird Breeding. Australian Wetlands and Rivers Centre, UNSW.

Brandis, K., and Bino, G. (2016) A review of the relationships between flow and waterbird ecology in the Condamine-Balonne and Barwon-Darling River Systems. Murray-Darling Basin Authority.

Kingsford, R.T. (1995) Occurrence of high concentrations of waterbirds in arid Australia. *Journal of Arid Environments* 29, 421-425.

Kingsford, R.T., and Johnson, W. (1998) Impact of water diversions on colonially-nesting waterbirds in the Macquarie Marshes of Arid Australia. *Colonial Waterbirds* 21 (2), 159-170.