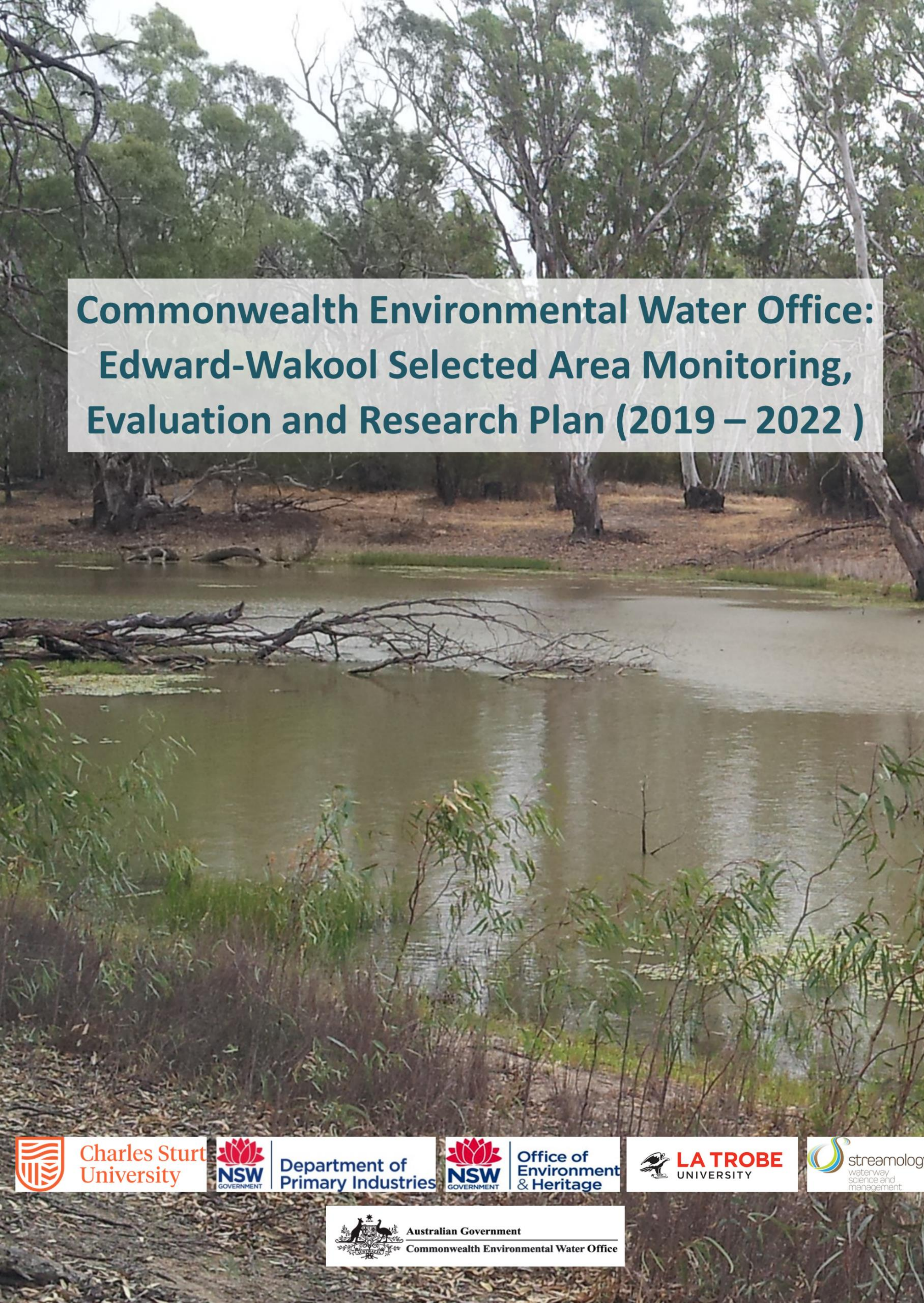

Commonwealth Environmental Water Office: Edward-Wakool Selected Area Monitoring, Evaluation and Research Plan (2019 – 2022)

Charles Sturt University

NSW Government Department of Primary Industries

NSW Government Office of Environment & Heritage

La Trobe University

streamology waterway science and management

Australian Government Commonwealth Environmental Water Office

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Contents

1. Introduction

1.1 Background

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, evaluation and research are critical for supporting effective and efficient use of Commonwealth environmental water. Monitoring, evaluation and research will also provide important information to support the CEWH meet their reporting obligations.

In June 2014, the CEWO commenced the Long Term Intervention Monitoring Project (LTIM Project, https://www.environment.gov.au/water/cewo/monitoring/ltim-project), which facilitated the monitoring and evaluation of the contribution of Commonwealth environmental water delivery in the Murray-Darling Basin over five years from July 2014 to June 2019. Over the period from 2014 to 2019 the CEWO also funded the Murray-Darling Basin Environmental Water Knowledge and Research Project (EWKR Project, https://www.environment.gov.au/water/cewo/monitoring/ewkr) that aimed to improve the science available to support environmental water management in the Murray-Darling Basin. The EWKR project implemented research aimed to better understand the links between ecological responses to environmental flows and changes in condition, and the impact of threats such as pests, grazing or poor water quality on ecological improvements through environmental flows. The CEWO-MER Program (2019 to 2022, see https://www.environment.gov.au/water/cewo/monitoring/mer-program) is an extension of the LTIM and EWKR projects, with monitoring, evaluation and research activities undertaken within a single integrated program.

1.2 Monitoring, Evaluation and Research approach for the Edward-Wakool Selected Area

This MER Plan describes the monitoring, evaluation and research activities that will be undertaken as part of the CEWO MER Program from July 2019 to December 2022. This project will be undertaken as a collaboration between Charles Sturt University, NSW DPI (Fisheries), NSW Office of Environment and Heritage, La Trobe University and Streamology.

The overarching principle that underpins this MER Plan for the Edward-Wakool Selected Area is that we are taking an ecosystem approach to evaluate the responses to Commonwealth environmental watering. A set of questions and indicators have been selected that each have clear linkages to other components of the MER project (see Figure 1). The plan has a strong focus on fish (including movement, reproduction, recruitment and adult populations) and water quality. The Edward-Wakool system is recognised as a priority area for fish diversity in the Murray-Darling Basin, including threatened and endangered fish, and it is part of the 'aquatic ecological community in the natural drainage system of the lower Murray River catchment' in New South Wales (*NSW Fisheries Management Act 1994*). Outcomes for fish and water quality have been the main focus of environmental watering actions in the Edward-Wakool system since 2010. Some of the other indicators (e.g. stream metabolism and aquatic vegetation) strongly influence the health of the ecosystem, and thus a key goal of this MER Plan is to improve our understanding and interpretation of these interdependencies.

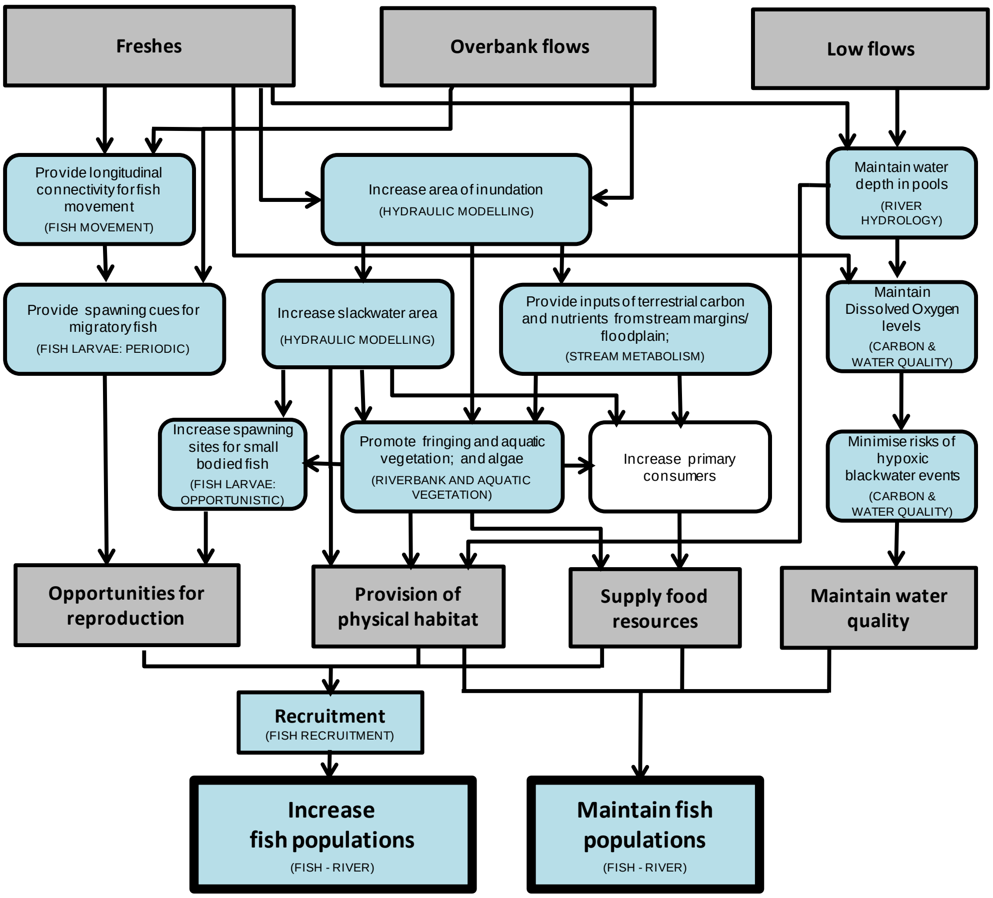

Figure 1 Conceptual diagram illustrating three main flow types (low flows, freshes, overbank flows) and their influence on ecosystem components and processes that, in turn, influence fish population dynamics. Indicators included in the Edward-Wakool MER Plan are shown in brackets in boxes shaded blue.

Ecosystem responses to Commonwealth environmental water will be evaluated in two ways:

i) Indicators that respond quickly to flow (e.g. hydrology, water quality and carbon, stream metabolism) will be evaluated for their responses to specific watering actions. These indicators will be evaluated with respect to the discharge data with and without the environmental water.

ii) Indicators that respond over longer time frames (e.g. riverbank and aquatic vegetation, fish recruitment, fish populations) will be evaluated for their response to the longer-term environmental watering regimes. This will be undertaken by comparing responses over multiple years in reaches that have received environmental water (e.g. LTIM Project zones 1, 3 and 4) compared to zones (e.g. LTIM Project zone 2) that have received none or minimal environmental water.

This Edward-Wakool MER Plan (2019 to 2022) is an extension of the monitoring and evaluation that was undertaken in the Edward-Wakool system for the Long-Term Intervention Monitoring (LTIM) project (2014-2019). The LTIM project developed conceptual models and generic cause and effect diagrams (MDFRC 2013) to describe the relationship between flow and ecological responses in freshwater systems. These were used to describe the potential role of Commonwealth environmental water in achieving the environmental objectives. The LTIM project also developed standard methods for each of the key indicators (Hale et al. 2014) that will continue to be used as part of the MER project, noting that a few minor changes to these methods have been during the LTIM project.

The MER Plan for the Edward-Wakool Selected Area includes this introduction followed by a description of the Edward-Wakool Selected Area (section 2), Commonwealth environmental water use, objectives and watering actions in this system (section 3), and an overview of the monitoring and research priorities and process for prioritisation (section 4). Details of the monitoring and evaluation for each indicator is presented in section 5 and research projects descriptions in section 6. Monitoring and research activities is in section 7. Sections 8 and 9 outline the engagement, communications and reporting for the project. Sections 10 and 11 outline the project management and data management.

2. Edward-Wakool Selected Area description

The Edward-Wakool system is a large anabranch system of the Murray River in the southern MDB, Australia. The system begins in the Millewa Forest and travels north and then northwest before discharging back into the Murray River (Figure 2). It is a complex network of interconnected streams, ephemeral creeks, flood-runners and wetlands including the Edward River, Wakool River, Yallakool Creek, Colligen-Niemur Creek and Merran Creek.

Under regulated conditions flows in the Edward River and tributaries remain within the channel, whereas during high flows there is connectivity between the river channels, floodplains and several large forests including the Barmah-Millewa Forest, Koondrook-Perricoota Forest and Werai Forest (Figure 2). These three forests make up the NSW Central Murray Forests Ramsar site, which was gazetted as State Forest under the management of Forests NSW (Harrington and Hale 2011; NSW Office of Environment and Heritage 2018), being one of the matters of national environmental significance listed under the *Environment Protection and Biodiversity Conservation Act, 1999 (Commonwealth)* (EPBC Act) applies. The NSW Central Murray Forests Ramsar site is located in the south-east of NSW, within the Murray-Darling Drainage Division (bioregion). At the time of listing, the site covered approximately 84 000 hectares and was within the Shires of Conargo, Murray, Jerilderie and Berrigan (Harrington and Hale 2011). Threatened species of the site include the trout cod, Murray hardyhead, Murray cod, silver perch, Australasian bittern, Australian painted snipe, superb parrot, and swamp wallaby grass (Department of Environment and Energy 2019).

The Edward-Wakool Selected Area can be broadly divided into three aquatic ecosystem types: 1) The main semi-permanent flowing rivers including Yallakool and Colligen creeks and the Wakool, Niemur and Edward rivers, 2) The floodplain forests and woodlands including the Niemur and Werai Forests, and 3) Several small intermittent and ephemeral creeks of ecological significance including Tuppal, Jimaringle, Cockran and Gwynne's Creeks.

Edward River, Colligen- Niemur, Yallakool Creek and Wakool River

- These rivers and creeks support high regional biodiversity values and have significant value as drought refugia for native fish and other biota. The dominant vegetation is river red gum (*Eucalyptus camaldulensis*) with areas providing habitat for a number of threatened species.

Floodplain – Werai and Niemur Forest

- Werai Forest is of special significance to the Aboriginal community. The Werai Forest is a culturally significant area of land identified as a potential future Indigenous Protected Area, the first in the Murray region of NSW. The higher floodplain areas are dominated by river red gum with lower lying areas typically dominated by giant rush. The low lying areas, floodrunners and backwaters in Werai Forest may be important habitat for larval and juvenile fish and is a potential source of carbon to feed the lower Edward River and Niemur River systems. The Werai Forest supports significant breeding colonies of several species of cormorants, whilst the Niemur Forest supports egrets and nankeen knight heron breeding colonies. Both forests support a number of listed species and migratory species. Werai Forest is part of the Ramsar listed NSW Central Murray State Forests (NSW OEH 2018) and Niemur Forest is located in a National Park (CEWO 2012c).

Ephemeral and intermittent creeks - Tuppal, Jimaringle, Cockran and Gwynnes

- Tuppal Creek is an intermittent flood runner connecting the Murray River to the Edward River and has a largely continuous riparian corridor which provides habitat connectivity for over 120 terrestrial native species and supports a number of state listed threatened and vulnerable species (Brownbill and Warne 2010; CEWO 2012c). Jimaringle, Cockran and Gwynnes Creeks are all ephemeral creeks and considered a biodiversity hotspot of significant regional value.

The Edward-Wakool system is considered to be important for its high native species richness and diversity including threatened and endangered fish, frogs, mammals, and riparian plants. It is listed as an endangered ecosystem, as part of the 'aquatic ecological community in the natural drainage system of the lower Murray River catchment' in New South Wales (*NSW Fisheries Management Act 1994*). This system has abundant areas of fish habitat, and historically had diverse fish communities which supported both commercial and recreational fisheries.

The area supports a productive agricultural community, has a rich and diverse Indigenous history, and supports both active and passive recreational uses such as fishing, bird-watching and bush-walking. Many Aboriginal nations maintain strong connections to the country (including the Yorta Yorta, Wiradjuri, Barapa Barapa, Wemba Wemba and Wari Wari), with the Werai Forest in the process of conversion to an Indigenous Protected Area.

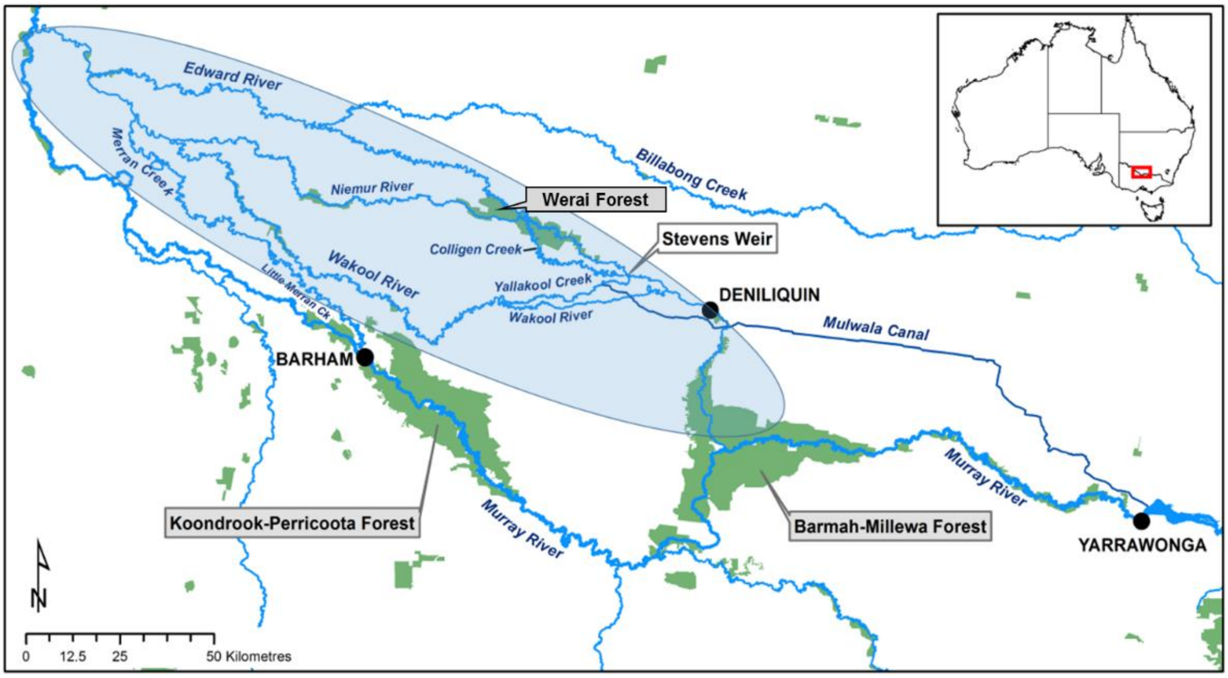

Figure 2 Map showing the location of the Edward-Wakool system.

The Edward-Wakool system also plays an important ecological role in connecting upstream and downstream ecosystems in the mid-Murray River. The multiple streams and creeks in this system provide important refuge and nursery areas for fish and other aquatic organisms, and adult fish regularly move between this system and other parts of the Murray River. As some of the rivers in the Edward-Wakool system have low discharge (compared to the Murray River) there is a risk of poor water quality developing in this system, particularly during warm periods or from floodplain return flows. Maintaining good water quality in the Edward-Wakool system is crucial for both the river ecosystem, the communities and landholders that rely on the water from this system, and downstream communities along the Murray River that are influenced by the water quality in this system.

Like many rivers of the MDB, the flow regimes of rivers in the Edward-Wakool system have been significantly altered by river regulation (Green 2001; Hale and SKM 2011). Natural flows in this system are strongly seasonal, with high flows typically occurring from July to November. Analysis of long-term modelled flow data show that flow regulation has resulted in a marked reduction in winter high flows, including extreme high flow events and average daily flows during the winter period (Watts et al. 2015). There is also an elevated frequency of low to median flows and reduced frequency of moderate high flows. These flow changes reflect the typical effects of flow-regime reversal observed in systems used to deliver dry-season irrigation flows (Maheshwari et al. 1995).

The Edward-Wakool system has experienced a wide range of flow conditions over the past 15 years, and these antecedent conditions will influence the way in which the ecosystem responds to Commonwealth environmental watering. From 1998 to 2010 south-eastern Australia experienced a prolonged drought (referred to as the Millennium drought) and flows in the MDB were at record low levels (van Dijk 2013; Chiew et al. 2014). During this period the regulators controlling flows from the Edward River into tributary rivers such as Yallakool Creek and the Wakool River were closed for periods of time. Between February 2006 and September 2010 there were periods of minimal or no flow in the Wakool River and localised fish deaths were recorded on a number of occasions including in 2006 and 2009. At the break of the drought after many years without overbank flows, a sequence of unregulated flow events between September 2010 and April 2011 triggered a widespread hypoxic (low oxygen) blackwater event in the mid-Murray (MDBA 2011; Whitworth et al. 2012). In late 2016 there was a widespread flood in the southern-MDB associated with record-breaking rainfall in the catchment. Some areas of the floodplain were inundated that had not been flooded for more than 20 years. In the Murray catchment, Murray River flows at Yarrawonga in October were the highest since 1993 (MDBA River Murray Weekly Report, 7th Dec 2017). The unregulated flows from the Murray River inundated the floodplain including Barmah Forest and Koondrook–Perricoota Forests and agricultural land, resulting in a very large flood event in the Edward-Wakool system (BOM 2017). In association with the floods there was a hypoxic blackwater event that extended throughout the Murray River system, including the Edward-Wakool system.

At the commencement of the LTIM program daily discharge data from 14 hydrological stations in the Edward-Wakool system were analysed along with information on geomorphology and location of major distributaries to classify the system into distinct hydrological zones (Watts et al. 2014). Fifteen distinct zones were identified (Figure 3, Table 1). Transitions between these zones occur where there are major inflows or outflows to a river or at locations where there are significant changes in geomorphology. The zones range from ephemeral watercourses (e.g. Jimaringle, Cockran and Gwynne's Creeks), to smaller creeks and rivers (Wakool River, Yallakool Creek, Colligen-Niemur system, and Merran Creek) to the larger Edward River system.

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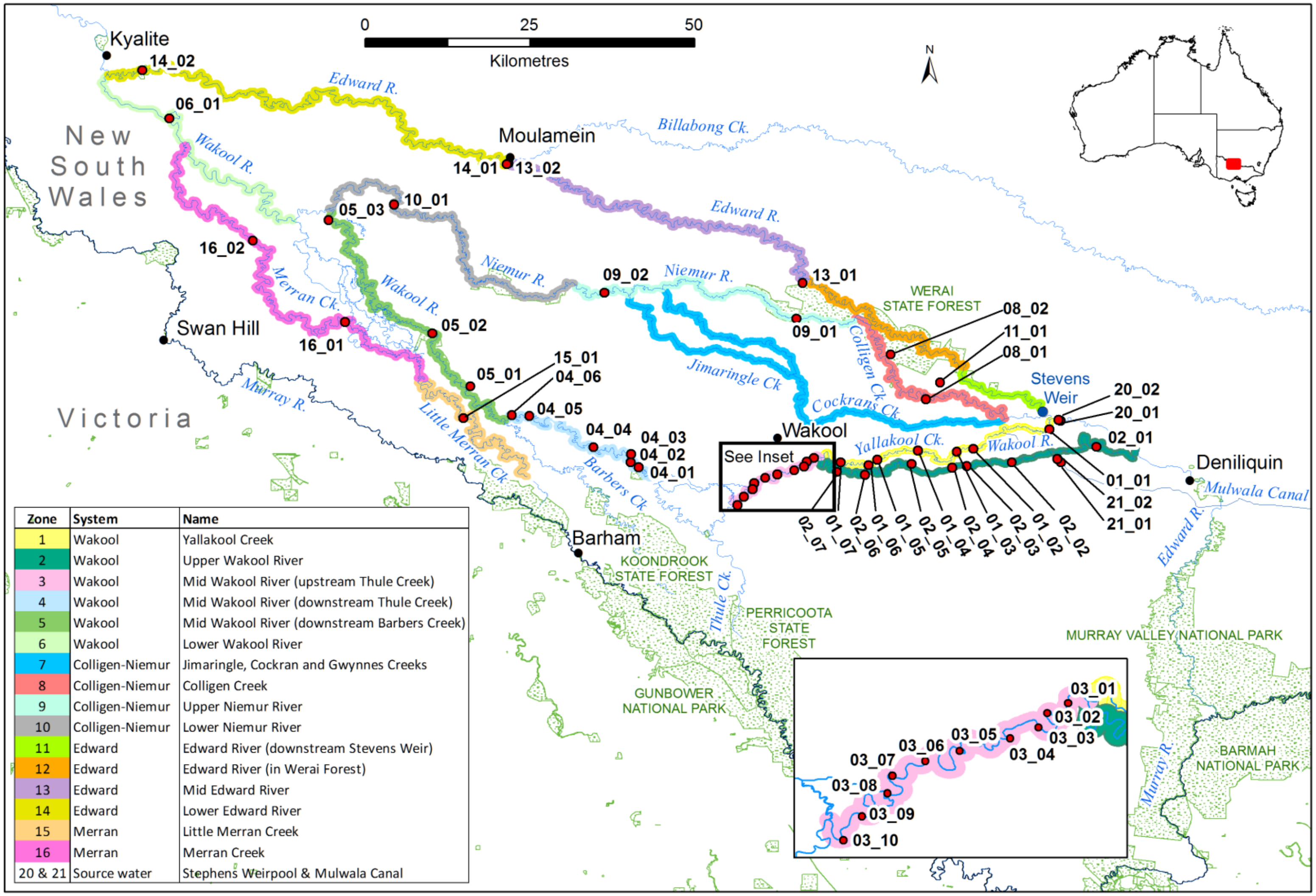

Created by Spatial Data Analysis Network, Charles Sturt University, May, 2015

Data Source: NSW "Place Point" & "Hydroline" spatial data: Digital Cadastral Database [CD-ROM]. LPMA, 2008, New South Wales; Australian Reserves GEODATA TOPO 250K Series 3, 2006, OEH NSW National Parks 2012

Figure 3. Map showing 16 hydrological zones within the Edward-Wakool system. Site names are listed in Table 1**.**

Table 1 List of site codes and site names for the CEWO MER Project in the Edward-Wakool Selected Area.

Zone Name	Zone	Site Code	Site Name
Yallakool Creek	01	EDWK01_01	Yallakool/Back Ck Junction
Yallakool Creek	01	EDWK01_02	Hopwood
Yallakool Creek	01	EDWK01_03	Cumnock
Yallakool Creek	01	EDWK01_04	Cumnock Park
Yallakool Creek	01	EDWK01_05	Mascott
Yallakool Creek	01	EDWK01_06	Widgee, Yallakool Ck
Yallakool Creek	01	EDWK01_07	Windra Vale
Upper Wakool River	02	EDWK02_00	Brassi Bridge
Upper Wakool River	02	EDWK02_01	Fallonville
Upper Wakool River	02	EDWK02_02	Yaloke
Upper Wakool River	02	EDWK02_03	Carmathon Reserve
Upper Wakool River	02	EDWK02_04	Emu Park
Upper Wakool River	02	EDWK02_05	Homeleigh
Upper Wakool River	02	EDWK02_06	Widgee, Wakool River1
Upper Wakool River	02	EDWK02_07	Widgee, Wakool River2
Mid Wakool River (upstream Thule Creek)	03	EDWK03_01	Talkook
Mid Wakool River (upstream Thule Creek)	03	EDWK03_02	Tralee1
Mid Wakool River (upstream Thule Creek)	03	EDWK03_03	Tralee2
Mid Wakool River (upstream Thule Creek)	03	EDWK03_04	Rail Bridge DS
Mid Wakool River (upstream Thule Creek)	03	EDWK03_05	Cummins
Mid Wakool River (upstream Thule Creek)	03	EDWK03_06	Ramley1
Mid Wakool River (upstream Thule Creek)	03	EDWK03_07	Ramley2
Mid Wakool River (upstream Thule Creek)	03	EDWK03_08	Yancoola
Mid Wakool River (upstream Thule Creek)	03	EDWK03_09	Llanos Park1
Mid Wakool River (upstream Thule Creek)	03	EDWK03_10	Llanos Park2
Mid Wakool River (downstream Thule Creek)	04	EDWK04_01	Barham Bridge
Mid Wakool River (downstream Thule Creek)	04	EDWK04_02	Possum Reserve
Mid Wakool River (downstream Thule Creek)	04	EDWK04_03	Whymoul National Park
Mid Wakool River (downstream Thule Creek)	04	EDWK04_04	Yarranvale
Mid Wakool River (downstream Thule Creek)	04	EDWK04_05	Noorong1
Mid Wakool River (downstream Thule Creek)	04	EDWK04_06	Noorong2
Mid Wakool River (downstream Barbers Creek)	05	EDWK05_01	La Rosa
Mid Wakool River (downstream Barbers Creek)	05	EDWK05_02	Gee Gee Bridge
Mid Wakool River (downstream Barbers Creek)	05	EDWK05_03	Glenbar
Lower Wakool River	06	EDWK06_01	Stoney Creek Crossing
Colligen Creek	08	EDWK08_01	Calimo
Colligen Creek	08	EDWK08_02	Werrai Station
Upper Neimur River	09	EDWK09_01	Burswood Park
Upper Neimur River	09	EDWK09_02	Ventura
Lower Niemur River	10	EDWK10_01	Niemur Valley
Edward River (downstream Stephens Weir)	11	EDWK11_01	Elimdale
Mid Edward River	13	EDWK13_01	Balpool
Mid Edward River	13	EDWK13_02	Moulamien US Billabong Ck
Lower Edward River	14	EDWK14_01	Moulamien DS Billabong Ck
Lower Edward River	14	EDWK14_02	Kyalite State Forest
Little Merran Creek	15	EDWK15_01	Merran Downs
Merran Creek	16	EDWK16_01	Erinundra
Merran Creek	16	EDWK16_02	Merran Creek Bridge
Tuppal Creek	17	EDWK17_01	Tuppal Creek
Edward River, Stevens weir	20	EDWK20_01	Weir1
Edward River, Stevens weir	20	EDWK20_02	Weir2
Mulwala canal	21	EDWK21_01	Canal1
Mulwala canal	21	EDWK21_02	Canal2

3. Commonwealth environmental watering

3.1 Commonwealth environmental watering actions 2009-2019

Commonwealth environmental watering actions have occurred in the Edward-Wakool system since 2009 (Table 2). Between July 2009 and June 2019 Commonwealth environmental watering actions delivered base flows and freshes, contributed to the recession of flow events, delivered water from irrigation canal escapes to create local refuges during hypoxic blackwater events, and contributed to flows in ephemeral watercourses (Table 2). Many of the watering actions in ephemeral creeks were undertaken jointly with NSW OEH. One Commonwealth watering action in 2009-10 for Werai State Forest (DEE 2017) was undertaken to deliver environmental water to Edward-Wakool forests (Table 2). In the winter of 2017 an environmental watering action was undertaken to maintain winter base flows during the period when the regulators to some of the smaller streams are usually shutdown in winter (Table 2). To date it has not been possible to deliver large within channel freshes (> half bankful) or overbank flows due to the current operational constraints of 600 ML/d at confluence of the Wakool River and Yallakool Creek. However, in spring 2018 a flow trial was undertaken to deliver 800 ML/d at the confluence of Wakool River and Yallakool Creek.

Table 2 Summary of Commonwealth environmental watering actions and unregulated overbank flows in the Edward-Wakool system from July 2010 to June 2019. More detailed information about environmental watering in the mid-Murray catchment is available from the CEWO website (Department of the Environment and Energy 2017)

	In-channel environmental watering actions				Environmental watering actions using irrigation infrastructure			Unregulated overbank flows
Water Year	Base flows and small freshes	Contribute to flow recession	Maintain winter base flows	Larger within channel freshes[1]	Flows from canal escapes during hypoxic events	Flows in ephemeral streams[2]	Watering forests	Flooding forests and/or floodplains
2009-10							✓	
2010-11					✓	✓		✓
2011-12	✓					✓		
2012-13	✓				✓	✓		
2013-14	✓	✓				✓		
2014-15	✓	✓				✓		
2015-16	✓	✓				✓		
2016-17	✓	✓			✓	✓		✓
2017-18	✓	✓	✓			✓		
2018-19	✓							

[1] Delivery of larger within channel freshes to the Wakool River and Yallakool Creek is not possible under current operational constraints (e.g. constrained to 600 ML/d at the confluence of the Wakool River and Yallakool Creek). Some of the watering actions in ephemeral creeks done jointly with NSW Office of Environment and Heritage

Environmental water in the Edward-Wakool system may be delivered to contribute to the slower recession of freshes, delivered during low flow periods to provide refuge habitat, or delivered to manage water quality issues, such as hypoxic events (Gawne et al. 2013; Watts et al. 2017a).

In addition to watering actions specifically targeted for the Edward-Wakool system, water from upstream Commonwealth environmental watering actions and actions that are targeted for downstream watering actions transit through the Edward-Wakool system in some years. For example, in 2015-16 environmental water returning from Barmah-Millewa Forest influenced the hydrograph in the Edward-Wakool system (Watts et al. 2016).

In some years operational flows limit the ability to deliver the planned use of Commonwealth environmental water in the Edward Wakool system. For example, in 2018-19 the planned environmental watering actions were suspended to enable operational flows to be delivered, reflecting CEWO's good neighbour policy related to channel sharing.

3.2 Expected outcomes relevant to the Mid-Murray Region

Expected outcomes from the Basin-wide Environmental Watering Strategy (MDBA 2014) that are relevant to the Mid Murray Region are listed below and in Tables 3 and 4.

River flows and connectivity

- Base flows are at least 60 per cent of the natural level
- Contributing to a 30 per cent overall increase in flows in the River Murray
- A 30–60 per cent increase in the frequency of freshes, bankfull and lowland floodplain flows

Vegetation

- Maintain the current extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain
- Improve condition of black box, river red gum and lignum shrublands
- Improve recruitment of trees within black box and river red gum communities
- Increased periods of growth for non-woody vegetation communities that closely fringe or occur within the river and creek channels, and those that form extensive stands within wetlands and low-lying floodplains including Moira grasslands in Barmah–Millewa Forest

Fish

- No loss of native species
- Improved population structure of key species through regular recruitment, including:
  - Short-lived species with distribution and abundance at pre-2007 levels. Breeding success every 1–2 years
  - Moderate to long-lived with a spread of age classes and annual recruitment in at least 80% of years
- Increased movements of key species
- Expanded distribution of key species and populations

Table 3 Important Basin environmental assets for native fish in the Mid Murray (from MDBA 2014)

Environmental asset	Key movement corridors	High Biodiversity	Site of other Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge	In-scope for Cwealth water
Koondrook–Perricoota	*	*	*	*	*		Yes
Gunbower	*	*	*	*	*		Yes
Barmah–Millewa	*	*	*	*	*	*	Yes
Edward–Wakool system	*		*	*	*	*	Yes
Werai Forest			*	*			Yes
Billabong–Yanco–Columbo Creeks		*	*	*	*	*	Yes
Lake Mulwala	*		*	*	*	*	Yes

Table 4 Key species for the Mid Murray (Source: MDBA 2014)

Species	Specific outcomes	In-scope for C'th water ?
Flathead galaxias (*Galaxias rostratus*)	Expand the core range in the wetlands of the River Murray	Yes
Freshwater catfish (*Tandanus tandanus*)	Expand the core range in Columbo-Billabong Creek and Wakool system	Yes
Golden perch (*Macquaria ambigua*)	A 10–15% increase of mature fish (of legal take size) in key populations	Yes
Murray cod (*Maccullochella peelii peelii*)	A 10–15% increase of mature fish (of legal take size) in key populations	Yes
Murray hardyhead (*Craterocephalus fluviatilis*)	Expand the range of at least two current populations. Establish 3–4 additional populations, with at least one in the Mid Murray conservation unit.	Yes
Olive perchlet (*Ambassis agassizii*)	Olive perchlet are considered extinct in the southern Basin. Reintroduction using northern populations is the main option for recovery. Candidate sites may result from improved flow that reinstates suitable habitat in the River Murray.	Restoration of flow to Murray R could support future reintroduction of the species
River blackfish (*Gadopsis marmoratus*)	Expand the range of current populations from the Mulwala canal	Yes
Silver perch (*Bidyanus bidyanus*)	Expand the core range within the River Murray (Yarrawonga–Euston)	Yes
Southern purple-spotted gudgeon (*Mogurnda adspersa*)		Yes
Southern pygmy perch (*Nannoperca australis*)	Expand the range of current populations at Barmah-Millewa and other Mid Murray wetlands	Yes
Trout cod (*Maccullochella macquariensis*)	Expand the range of trout cod up the Murray upstream of Lake Mulwala and into the Kiewa River. For the connected population of the Murrumbidgee–Murray–Edward: continue downstream expansion.	Yes
Two-spined blackfish (*Gadopsis bispinosus*)	Establish additional populations (no specific locations identified)	Yes

Waterbirds

The expected outcomes for waterbirds are increased abundance and the maintenance of current species diversity. The MDBA (2014) Basin-Wide Environmental Watering Strategy identifies Gunbower-Koondrook-Perricoota as an important asset for colonial waterbird breeding. The environmental watering strategy states that from 2014, the expected outcomes are:

- That the number and type of waterbird species present will not fall below current observations
- A significant improvement in waterbird populations in the order of 20 to 25% over the baseline scenario, with increases in all waterbird functional groups
- Breeding events of colonial nesting waterbirds to increase by up to 50% compared to the baseline scenario
- Breeding abundance (nests and broods) for all other functional groups to increase by 30–40% compared to the baseline scenario, especially in locations where the Basin Plan improves over-bank flows.

Water Quality targets

The water quality targets of the Basin Plan (2012) are outlined in Chapter 9, Part 4, sub-section 9.14(5) of the Basin Plan. The targets for recreational water quality in Section 9.18 of the Basin Plan contains Guidelines for Managing Risks in Recreational Water. The target for dissolved oxygen in the Plan is to maintain dissolved oxygen at a value of at least 50% saturation and suggests this be determined at 25°C and 1 atmosphere of pressure (sea level). This equates to a dissolved oxygen concentration of approximately 4 mg/L. The CEWO has used a trigger of 4.0 mg/L for the potential provision of refuge flows into catchments like the Edward-Wakool River system. The Guidelines for Managing Risks in Recreational Water also guide the green, amber and red alert levels issued by relevant state management agencies (e.g. in NSW – the Regional Algal Coordinating Committees) who are responsible for the catchment scale management of algal blooms. The CEWO has access to the alert advice issued by these state agencies and can adjust the use of Commonwealth environmental water accordingly.

3.3 Commonwealth environmental water holdings

The Commonwealth environmental water holding in the Murray catchment as at February 2019 is shown in Table 5.

Table 5 Commonwealth environmental water holdings in the Murray catchment as at 28 February 2019 (Source: CEWO 2019)

Location	Security	Registered entitlements (ML)	Long Term Average Annual Yield (ML)
NSW	High[1]	20,933	17,847
	General[2]	391,193	278,447
	Conveyance	20,214	18,556
	Unregulated	184	184
	Supplementary[3]	211	148
	Groundwater	1,522	1,522
VIC	High	324,116	308,342
	Low	25,489	10,125
SA	High	161,417	145,276
Total		**945,280**	**780,448**

1 Includes 3075 ML of High security entitlement in the Lower Darling

2 Includes 21,564 ML of General security entitlement in the Lower Darling

3 For supplementary entitlements, no 'carryover' or 'water account balance' is reported. 'New allocations' and 'available water transferred for delivery or delivered directly' are accounted at the time of take.

3.4 Practicalities of environmental watering in the Edward-Wakool system

The main source of Commonwealth environmental water for the Edward-Wakool system is from the Murray River through the Edward River and Gulpa Creek. During high flow events in the Murray River, water can also flow from the Murray River through Koondrook-Perricoota Forest and into the Wakool River via Thule and Barber Creeks. The main flow regulating structure within the Edward-Wakool system is Stevens Weir, located on the Edward River downstream of Colligen Creek (Figure 3). This structure creates a weir pool that allows Commonwealth environmental water to be delivered to Colligen Creek-Niemur River system, Yallakool Creek, the Wakool River, the Edward River and Werai Forest.

Water diverted into the Mulwala Canal from Lake Mulwala can also be delivered into the Edward-Wakool system through numerous 'escapes' or outfalls managed by the irrigator-owned company Murray Irrigation Limited (MIL). These escapes can be used to deliver flows to the river system. During a hypoxic blackwater event in 2010, environmental water was released from Mulwala Canal escapes to lessen the impact of hypoxia and create localised refugia with higher DO and lower DOC (Watts et al. 2017a). The Wakool escape was also used to deliver environmental water as refuge flows in response to the 2016 hypoxic blackwater event (Watts et al. 2017c) and in the 800 ML/d flow trial in spring 2018 to avoid third party impacts that would have occurred due to a lack of demand in the canal network and corresponding management of the weir pool.

The ability to deliver environmental water to the Edward-Wakool system depends on water availability and circumstances in the river at any given time. Environmental water delivery in this system involves various considerations as outlined by Gawne et al. (2013), including:

- the capacity of the off takes / regulators and irrigation escapes
- channel constraints (e.g. to avoid third party impacts)
- the availability of third party infrastructure to assist in delivering water into the system
- existing flows and other demands on the system.

Delivery of instream flows to the Edward River, Wakool River, Yallakool Creek, Colligen Creek, Niemur River and Merran River system are managed within regular operating ranges as advised by river operators to avoid third party impacts, such as inundation of low lying private bridges. For example, in the Wakool-Yallakool system the operational constraint is 600 ML d^{-1} at the confluence of the Wakool River and Yallakool Creek. Thus, the types of flow components that can be achieved under current operating ranges are in-channel baseflows and freshes (Gawne et al. 2013). Environmental watering may also be constrained due to the limitations on how much water can be delivered under regulated conditions. At times of high irrigation demand channel capacity will be shared with other water users. The Edward-Wakool system plays a key role in the operations and ecosystem function of the Murray River and the southern MDB. Some of the water released from Hume Dam is diverted from the Murray River through the Edward-Wakool system to avoid breaching operational constraints in the mid-Murray River. Given the prolonged below average inflows to the River Murray System over the past 2 years, there is a high likelihood that there will be a need for system transfers to recommence in 2019 and this may limit the options for the delivery of environmental water in this system (as per 2018-19). Similarly, if the system is receiving higher unregulated flows, there may not be enough capacity to deliver environmental water (Gawne et al. 2013).

4. Monitoring and research priorities

4.1 Principles to underpin the development of the MER Plan

The following principles were used to guide the development of the Edward-Wakool MER project Plan:

1. The project team will be inclusive, consultative and respectful during the development of the MER Plan for the Edward-Wakool system. We recognise that local community members have important knowledge that can make a significant contribution to the development of the MER Plan. As such we will consult with the following stakeholders:
    - Commonwealth Environmental Water Office
    - Local stakeholders in the Edward-Wakool area, including the Edward-Wakool Environmental Water Reference Group, Murray Local Land Services, Wakool River Association, Edward-Wakool Angling Association, Yarkuwa Indigenous Knowledge Centre Aboriginal Corporation, Murray Irrigation Limited, Ricegrowers' Association of Australia Inc., and landholders and individual community members
    - NSW Office of Environment and Heritage
    - NSW Department of Primary Industries (Fisheries)
    - WaterNSW
    - CEWO-MER project Basin Evaluation Team
    - CEWO-MER project Selected Area teams
2. Meetings with stakeholders will be organised to ensure as wide participation in the planning process as possible
3. Where possible, the MER Plan will maintain monitoring and evaluation methods from the LTIM project to ensure continuity of data over time.
4. The MER Plan will include outputs and engagement activities that will enable the findings to be shared regularly and with a range of audiences, including managers and community.
5. The MER Plan will focus on reaches in the Edward-Wakool Selected Area where we can best assess responses to Commonwealth environmental watering.
6. The MER Plan will include a suite of indicators that will enable linkages between different indicators to be explored to ensure clear interpretation of the findings
7. The approach to evaluation developed for the Edward-Wakool MER Plan will be consistent with the MER Basin Evaluation Plan. We will collaborate with other Selected Area teams and the Basin Evaluation team to align methods, and coordinate evaluation and research to enable selected area results to be incorporated in the basin evaluation and findings to be extrapolated to other areas of the basin.
8. Where possible we will aim to value-add to any proposed monitoring, evaluation and research activities. For example, we will seek opportunities to undertake complementary research in the Selected Area. Honours or PhD students enrolled at Charles Sturt University or La Trobe will be supported to undertake projects that complement the contracted monitoring and research.

4.2 Process for prioritisation of hydrological zones

Due to funding constraints it is not possible to undertake monitoring and evaluation in all sixteen of the hydrological zones identified in the Edward-Wakool system (Figure 3). The following factors were considered when prioritising the zones to include in the MER Plan:

- Likelihood of hydrological zones receiving Commonwealth environmental water or serving as a comparison zone (i.e. not receive Commonwealth environmental water)
- Location of hydrological gauging stations
- Availability of historical monitoring data in each zone and existing arrangements for access, including maintaining continuity of monitoring established during the LTIM project
- Ease of access for undertaking fieldwork under a range of weather conditions
- Need for a number of zones that experience a range of flows to facilitate predictive ecosystem response modelling and Selected Area gradient analysis
- Capacity to inform on specific objectives aligned with values and needs of local community, including Aboriginal people

Taking all of these factors into account, the proposed MER project in the Edward-Wakool system will include monitoring in the following hydrological zones:

- Monitoring sites established during the LTIM project that focus on the upper and mid reaches of the Wakool-Yallakool system (zones 1, 2, 3 and 4) will be maintained for the MER project. During the LTIM project these four hydrological zones have been referred to as the Focal Area.
- Twenty sites that were established for fish community surveys in 2010 and were monitored in year one (2015) and year five (2019) of the LTIM project will be maintained and will be surveyed for fish community indices in year three of MER (2022).
- Additional sites will be added to the existing network of water quality monitoring sites established during LTIM project. For the MER project there will be a total of 17 water quality monitoring sites throughout the whole system, including ongoing sites in Yallakool Creek, Wakool River zones 2 to 4, and source water sites in the Mulwala Canal and the Edward River at Stephens Weir. New sites expand the water quality monitoring to further downstream in the Wakool River as well as in Tuppal Creek, the Edward River and the Colligen-Niemur system to enable an evaluation of environmental water across the broader system.
- Additional monitoring sites will be established in the Edward River downstream of Stevens Weir to inform the adaptive management of environmental water in the Edward River. This river system was not monitored as part of LTIM.

Hydrological zones not included in the MER Plan

The Milewa Forest and Koondrook-Perricoota forest are not included in the MER Plan because they are currently monitored by other programs such as the MDBA Living Murray Program. The ephemeral creeks in zone 15, Jimaringle, Cockran and Gwynnes Creek, have not been included in the MER Plan to avoid duplication of monitoring, as environmental watering actions in these ephemeral creeks have previously been monitored by the NSW Office of Environment and Heritage (OEH). We will seek to integrate outcomes of environmental watering in these systems in a qualitative evaluation of the outcomes of Commonwealth environmental water in the Edward-Wakool system.

4.3 Priorities identified by stakeholders

During the development of the Edward-Wakool MER Plan the following activities were undertaken to seek a wide range of stakeholder input to the plan:

- In January 2019 the Edward-Wakool MER team meeting met to review the LTIM project, identify knowledge gaps and discuss and scope potential complementary research projects
- A presentation on the MER project was given to the Edward-Wakool Environmental Water Reference Group meeting on 26 March 2019 in Deniliquin. At that meeting feedback from stakeholders was sought on the LTIM monitoring and evaluation and attendees were invited to contribute ideas for the MER Plan. In particular, we sought ideas for engagement, communications and citizen science.
- Members of the Edward-Wakool MER team attended an inception workshop organised by Basin MER team. This workshop included several sessions on basin themes (fish, vegetation and stream metabolism, hydrology, biodiversity) in which the standard methods were reviewed.
- Several Selected Area team meetings were held both face-to-face and by teleconference to progress ideas for the plan
- CEWO staff were regularly updated and were given opportunities to provide input to the plan as it was being developed
- A second planning workshop for local stakeholders was held on 6th May in Deniliquin to provide stakeholders with an update on the plan and seek further input to the engagement and communications strategy. Stakeholders from the Edward-Wakool Environmental Water Reference Group, Wakool River Association, Murray Local Land services, Edward-Wakool Angling Association, Yarkuwa Indigenous Knowledge Centre Aboriginal Corporation, Ricegrowers' Association of Australia Inc., landholders and other community members were invited to this meeting. Staff from the Commonwealth Environmental Water Office, NSW Office of Environment and Heritage and the Murray-Darling Basin Authority also attended this meeting and contributed to the discussion.
- A meeting was held at the Yarkuwa Indigenous Knowledge Centre to develop opportunities for indigenous involvement in the monitoring, evaluation and research.

Through these meetings, themes identified as being of high priority by stakeholders included:

- Understanding the links between environmental watering and fish spawning, recruitment and survival
- The role of environmental water in maintaining water quality
- Understanding responses to environmental water during winter flows and refuge flows
- Increasing knowledge of flows downstream of Stevens Weir and in relation to Werai Forest
- The engagement of local community, including involvement in monitoring where possible
- Good communication of outcomes of the MER Project, with outputs targeted to local audiences.

Aspects of the MER Plan identified as being of lower priority by stakeholders was:

- Undertaking continued studies of fine scale fish movements. Stakeholders were very interested in gaining a better understanding of fish movement into and out of the Edward-Wakool system and understanding the role of the system in the southern connected Basin. However, this was regarded to be at a larger landscape scale than the Edward-Wakool MER project, and would be better funded by another program

5. Indicators for Monitoring and Evaluation

Section five of this MER Plan outlines the methods for each of the indicators for monitoring and evaluation of Commonwealth environmental water in the Edward-Wakool system. The detailed methods for each indicator are presented in sections 5.1 to 5.10.

Table 6 provides a summary of the monitoring and evaluation activities for this MER Plan and provides a summary of the changes or additions relative to the Edward-Wakool LTIM project (2014-2019). One of the main changes is that carbon and water quality monitoring has been extended so that evaluation can be undertaken across the entire Edward-Wakool system (Table 6). A summary of the long-term and short-term evaluation questions is provided in Table 7. Category 1 monitoring and evaluation questions follow those outlined in the CEWO LTIM Standard methods (Hale et al. 2014).

Table 6 Summary of monitoring and evaluation to be undertaken in the Edward-Wakool system for the CEWO Monitoring, Evaluation and Research (MER) Project from 2019 to 2022. Changes and additions relative to the Edward-Wakool LTIM project (2014-2019) are described. Zones and sites are described in section 2. Category 1 and 2 indicators are monitored using standard operating protocols to inform Basin-scale evaluation and may be used to answer Selected Area questions. Category 3 indicators are those monitored to answer Selected Area questions.

Theme	Cat	Zones	Changes or additions compared to the LTIM project (2014-19)
Monitoring and Evaluation			
River hydrology	1	system	No changes to monitoring or evaluation from LTIM project
Hydraulic modelling			Hydraulic modelling was undertaken in zones 1,2,3,4 and 8 as part of the LTIM project. These models will continue to be used as part of MER evaluations but no new hydraulic modelling will be undertaken in these zones. Reaches in zones 11 and 12 will modelled as part of the integrated Edward River research project (see section 6)
Carbon and water quality	3	system	No changes in methods from LTIM. New sites have been added for the MER project so that the evaluation of this indicator will be undertaken across the whole Edward-Wakool system.
Stream metabolism	1	1,2,3,4,8	No changes in methods from LTIM. Additional dissolved oxygen logger site established in Colligen Creek
Riverbank and aquatic vegetation	3	1,2,3,4,8	No changes in methods from LTIM. Four reaches added in Colligen Creek for the MER project were previously monitored 2014-2019 through a project funded by Murray Local Land Services
Fish movement	2	system	Golden perch movement will be monitored from June-Sept 2019 to evaluate the 2019 winter environmental watering action. No fish movement will be monitored as part of the MER project after September 2019.
Fish reproduction	1	3	No changes to monitoring or evaluation from LTIM project
Fish reproduction	3	1,2,3,4,	No changes in methods from LTIM. Research on fish spawning will be undertaken in the Edward River as part of the integrated research project (see section 6)
Fish recruitment	3	1,2,3,4	Minor changes to monitoring methods from LTIM project. No changes to monitoring sites
Fish river (Cat 1)	1	3	No changes to monitoring or evaluation from LTIM project
Fish community survey	3	system	No changes from LTIM project. This monitoring and evaluation will be undertaken in 2022 only (year 3 of the MER project)

Table 7 Summary of the long-term and short-term evaluation questions for the Edward-Wakool MER project

Indicator	Evaluation questions
Hydrology	*Short and long-term questions* • What was the effect of CEW (Commonwealth environmental water) on the hydrology of the rivers in the Edward-Wakool system? • What did CEW contribute to longitudinal connectivity?
Carbon and water quality	*Short and long-term questions* • What did CEW contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected in-channel habitat? • What did CEW contribute to dissolved oxygen concentrations? • What did CEW contribute to nutrient concentrations? *Question for contingency monitoring* • What did CEW contribute to reducing the impact of hypoxic blackwater or other adverse water quality events in the system?
Stream metabolism (Cat 1)	*Short and long-term questions* • What was the effect of CEW on rates of GPP, ER and NPP • What did CEW contribute to total GPP, ER and NPP? • Which aspect of CEW delivery contributed most to productivity outcomes?
Riverbank and aquatic vegetation	*Long-term questions* • What has CEW contributed to the recovery (measured through species richness, plant cover and recruitment) of riverbank and aquatic vegetation that have been impacted by operational flows and drought and how do those responses vary over time? • How do vegetation responses to CEW delivery vary among hydrological zones? *Short-term questions* • What did CEW contribute to the percent cover of riverbank and aquatic vegetation? • What did CEW contribute to the diversity of riverbank and aquatic vegetation taxa?
Fish movement	*Short term questions* • Does CEW facilitate longitudinal connectivity for periodic species during winter?
Fish reproduction (Cat 1)	*Long term questions* • What did CEW contribute to native fish populations? • What did CEW contribute to native fish species diversity? *Short term questions* • What did CEW contribute to native fish reproduction? • What did CEW contribute to native fish survival
Fish reproduction	*Short and Long-term questions* • What did CEW contribute to the spawning of 'Opportunistic' (e.g. small bodied fish) species? • What did CEW contribute to spawning in 'flow-dependent' spawning species (e.g. golden and silver perch)?
Fish recruitment	*Short and Long-term questions* • What did CEW contribute to native fish recruitment to the first year of life? • What did CEW contribute to native fish growth rate during the first year of life?
Fish river (Cat 1)	*Long term questions* • What did CEW contribute to native fish populations? *Short term questions* • What did CEW contribute to native fish reproduction? • What did CEW contribute to native fish survival?
Fish community	*Long-term question* • How does the fish community in the Edward-Wakool system vary over 3-5 years, and does this link with sequential flow characteristics?

5.1 Hydrology (Category 1)

5.1.1 Monitoring

Overview and context

Monitoring of river hydrology will be used to describe the flow regime of rivers in the Edward-Wakool system and evaluate the contribution of Commonwealth environmental water to the flows in this system. Hydrological data will be used to underpin the evaluation of water quality, stream metabolism, aquatic and riverbank vegetation, and native fish in this system.

Hydrological data will be obtained from:

- Downloading data from WaterNSW automated hydrological gauges
- Obtaining discharge data for irrigation escapes from Murray irrigation Limited
- Field readings of gauge boards

The key elements of river hydrology used for the Selected Area monitoring and evaluation are shown in Figure 4.

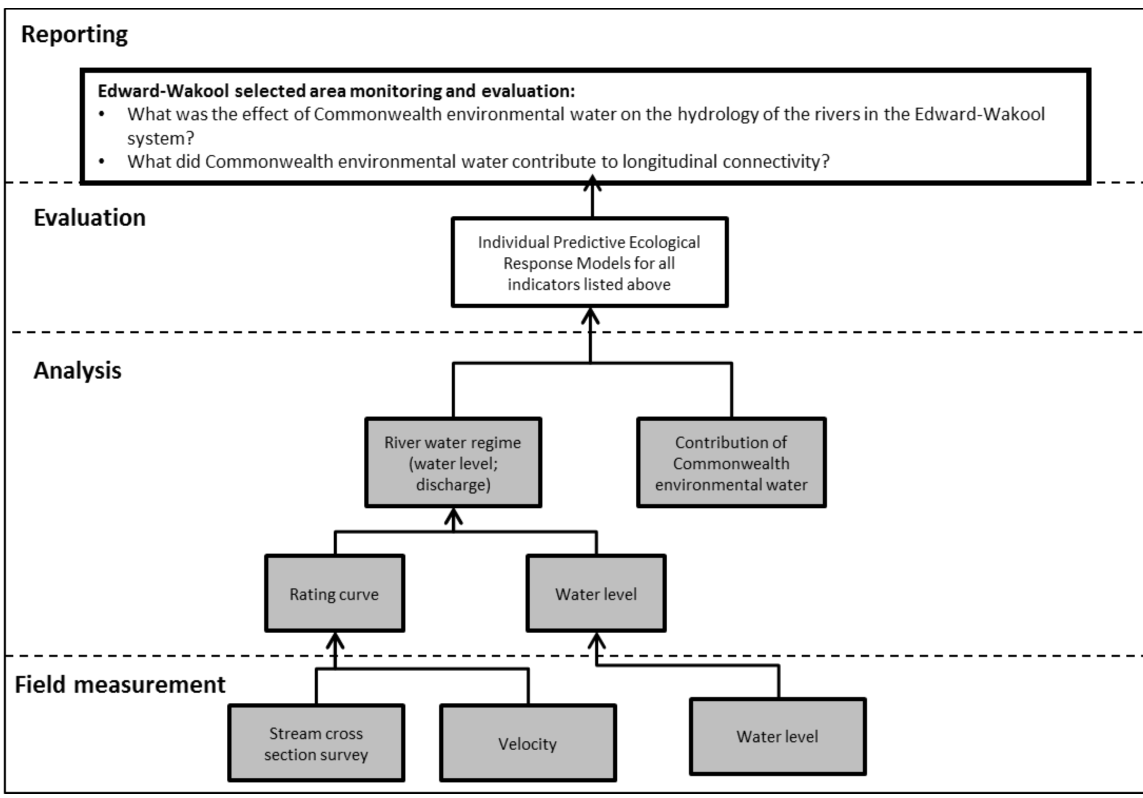

Figure 4 Schematic of key elements of River Hydrology used for the Selected Area monitoring and evaluation. Components covered by this protocol are highlighted in grey.

Indicators

- Daily discharge (ML/d)
- Minimum, maximum, mean, median and coefficient of variation (SD/mean) of the daily discharge

Location for monitoring

Hydrological data is available at sites listed in table 8 from ten established automated hydrological gauges in this system. For a small number of study reaches where there is no automated gauge, the daily discharge will be determined by numerical estimation from the nearest upstream gauge, taking into account losses.

An array of gauge boards have been installed throughout the river system and data from these will complement the existing network of automated gauges.

Table 8 Details of Water NSW hydrometric gauges used to obtain discharge data. Zone codes are as described in Figure 3 and Table 2.

River	Hydrological zone	Gauge number	Name of gauge
Yallakool Creek	1	409020	Yallakool Creek @ Offtake
Wakool River	2	409019	Wakool River Offtake regulator
Wakool River	4	409045	Wakool @ Wakool-Barham Road
Wakool River	5	409062	Wakool River Gee Gee Bridge 2
Wakool River	6	409013	Wakool @ Stoney Crossing
Colligen Creek	8	409024	Colligen Creek B/L regulator
Niemur River	9	409048	Niemur R Barham-Moulamein Road
Niemur River	9	409086	Niemur @Mallan School
Edward River	11	409023	Edward R D/S Stevens
Edward River	14	409014	Edward R @ Moulamein

Timing and frequency

Water NSW automated gauging stations record discharge continuously. Field readings of gauge boards in hydrological zones 1 to 4 will be undertaken fortnightly between September and March and monthly between April and August. Staff gauges elsewhere in the system will be monitored monthly.

Responsibilities

- CSU staff will download discharge data from water NSW website and obtain discharge data from Murray Irrigation Limited.
- Field readings of gauge boards will be undertaken by CSU, DPI and OEH staff.
- Data analysis and reporting will be undertaken by Robyn Watts (CSU)

Methods

Daily discharge data for automated hydrometric gauges will be obtained from the New South Wales Office of Water website (https://realtimedata.waternsw.com.au/water.stm). Daily discharge data for non-automated sites, such as the Wakool escape from Mulwala Canal, and daily usage of Commonwealth environmental water will be obtained from WaterNSW and the Commonwealth Environmental Water Office staff.

Some of the study reaches do not have hydrometric gauging stations. The daily discharge data for sites in the Wakool River zone 2 will be estimated by adding the discharge from gauge 409019 Wakool River offtake regulator to the discharge data from the Wakool escape from Mulwala canal. The daily discharge data for Wakool River zone 3 will be estimated by adding daily discharge data from Yallakool Creek offtake (gauge 409020), the Wakool offtake regulator (gauge 409019) and the Wakool Escape from Mulwala Canal with an adjustment during regulated flows to account for travel time (4 days) and estimated 20% losses (V. Kelly, WaterNSW pers. comm.) between the offtakes and the confluence of Yallakool Creek and the Wakool River.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.1.2 Evaluation

River hydrology monitoring will address the Selected Area evaluation questions in table 9.

Table 9 River Hydrology evaluation questions

Evaluation questions
Short and Long-term questions • What was the effect of Commonwealth environmental water on the hydrology of the rivers in the Edward-Wakool system? • What did Commonwealth environmental water contribute to longitudinal connectivity?

In addition to the questions listed above, this protocol is important for informing the Selected Area evaluation for the following indicators: Carbon and Water Quality, Metabolism, Fish (Larvae), Fish recruitment, and Fish (River).

Data analysis and reporting

The following river water regime parameters will be reported:

- Daily mean river ‘stage’ water height (cm)
- Daily mean river discharge (ML/day)

Daily discharge data will be used to produce hydrographs showing the overall daily discharge and the proportion of that flow that is Commonwealth environmental water for reaches where usage of Commonwealth environmental water is available.

The minimum, maximum, mean, median and coefficient of variation (SD/mean) of the daily discharge will be calculated with and without Commonwealth environmental water.

All data provided for this indicator will conform to the data structure defined in the LTIM Project Data Standard (Brooks and Wealands 2014). The data standard provides a means of collating consistent data that can be managed within the LTIM Project Monitoring Data Management System (MDMS).

5.1.3 Research

No new research on hydrological indicators will be undertaken as part of the MER project.

5.2 Carbon and water quality (Category 3)

5.2.1 Monitoring

Overview and context

Dissolved organic carbon characterisation by ultra-violet/visible spectroscopy and fluorescence excitation-emission spectroscopy is a category 3 indicator for the Edward-Wakool River System, to be interpreted in conjunction with other water quality parameters, collected as described in the stream metabolism protocol (section 5.3). These methods have been applied to studies in this system since 2010 and have proved to be valuable tools for tracking the progress of hypoxic blackwater events and as rapid-response indicators for evaluating the releases of Commonwealth environmental water from the Mulwala Canal to mitigate the effects of hypoxic blackwater in the river system (Watts et al 2013, Watts et al 2017). During the 2012-13 sampling season the fluorescence technique also proved invaluable as a marker of connectivity and assisted with interpretation of a number of other key response variables as a result. During the 2016 algal bloom event these indicators were also valuable for identifying a substantial shift in the composition of the DOC in the system during the bloom (Watts et al 2016). This indicator is complementary to DOC, nutrient and DO indicators used as part of the metabolism analysis.

The Edward-Wakool River system has a history of hypoxic blackwater events (Baldwin et al*.* 2001; Howitt et al. 2007; Hladyz et al. 2011; Whitworth et al. 2012). In recent years the area has been impacted by blackwater generated upstream, (especially from the Barmah Forest) (Howitt et al*.* 2007; Watts et al. 2013), but has also seen blackwater generated within the system during re-wetting of non-flowing rivers (Hladyz et al. 2011) and a broader flooding event bringing organic matter from both upstream and within the system (Watts et al 2017). Understanding the processes controlling hypoxic blackwater events and alternatively, flow conditions that result in the input of valuable organic matter resources to the river channel without creating hypoxic conditions is essential for the long-term management of this system. In addition, it is important to fully understand the role of Commonwealth environmental water in the provision of temporary refuges within the river channel during severe hypoxic blackwater events.

As noted in the Cause and Effect diagrams (CED) from the LTIM Project standard methods manual for decomposition, dissolved oxygen and dissolved organic carbon (Figs. 21, 35, and 37, Hale et al. 2014) all of these parameters/processes are inter-related and have a flow dependence. A modified CED highlighting the linkages between key parameters involved in the development of hypoxic blackwater is given below (Figure 5).

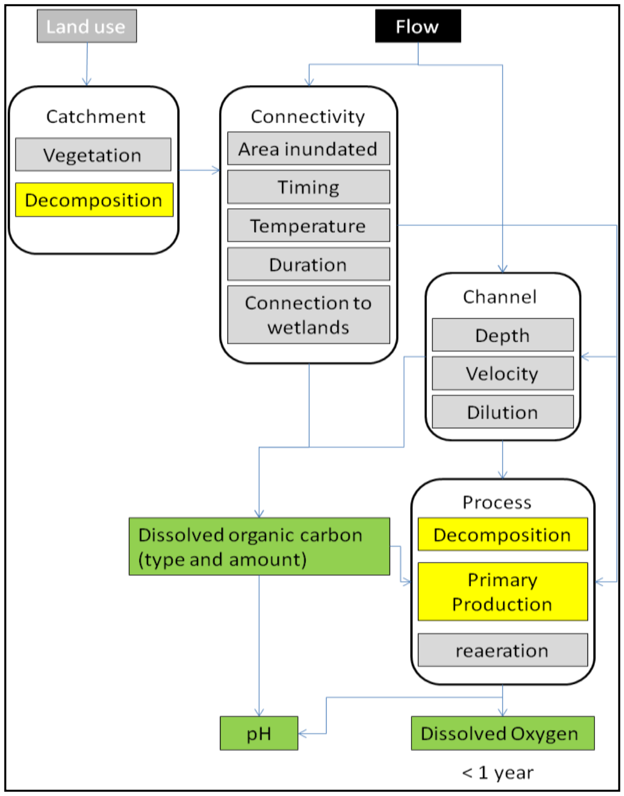

Figure 5 Modified Cause and Effect Diagram illustrating the effect of flow on key parameters associated with hypoxic blackwater events.

The process for evaluating the evaluation questions is illustrated in Figure 6, with components covered by the protocol highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model.

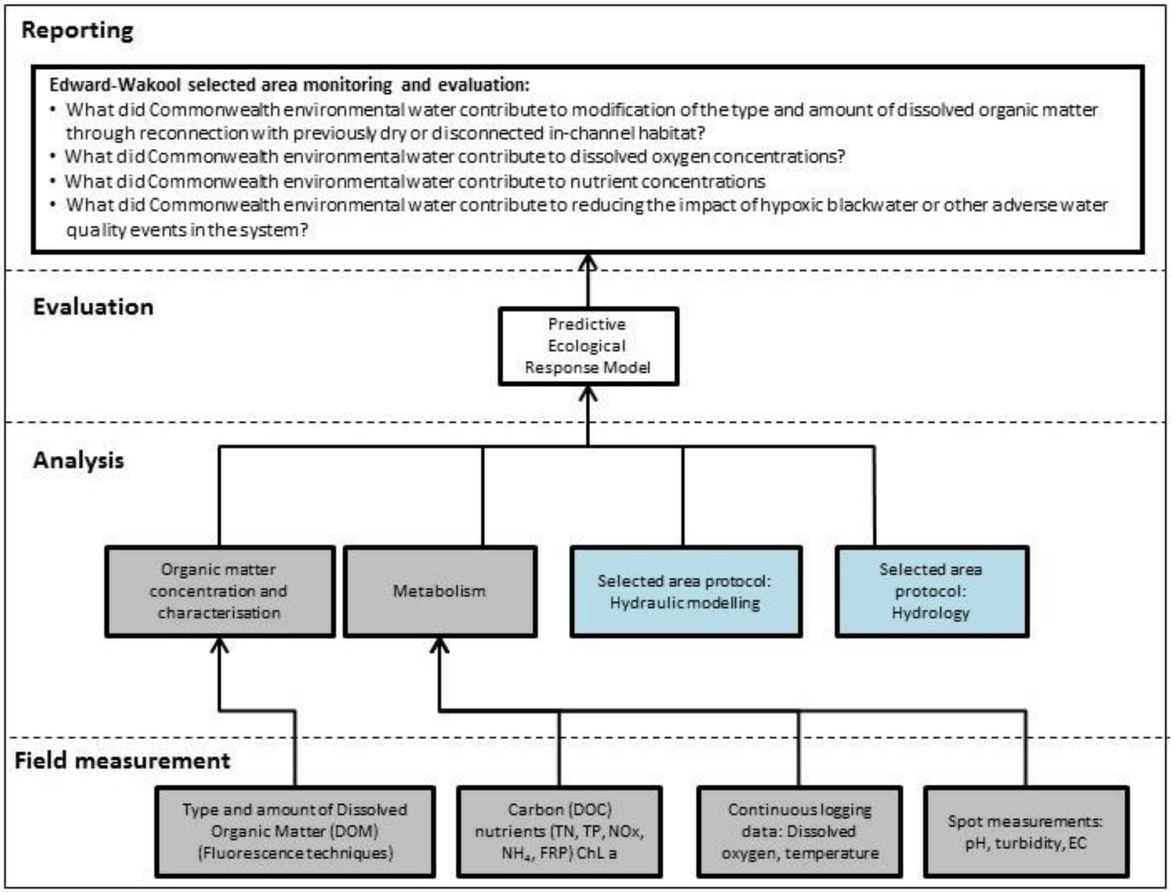

Figure 6 Schematic of key elements in Selected Area Monitoring and Evaluation – Water Quality. Components covered by this protocol are highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model.

Indicators

DOC, nutrients (TN, TP, FRP/NOx), dissolved oxygen, pH, temperature. These parameters will be collected as described for the Stream Metabolism indicator (Section 5.3), including at core monitoring sites for water quality that are not included in the metabolism study sites.

UV-vis and fluorescence organic matter profiles

Carbon fluorescence techniques can be used as rapid-response indicators of the progress of a blackwater event through the tracking of complex organic matter and serve as a sensitive marker of connectivity with previously dry habitat (Watts et al. 2013) During the natural flooding event in 2012 these techniques provided the only strong indicators that the blackwater event in the Edward Wakool system had originated upstream of the study sites and had not developed within the study rivers themselves. They also provided a rapid indication that the environmental water releases from the Mulwala canal would be less effective than during the previous event (but still useful) due to floodwater impacts on the DOC concentrations in the canal(Watts et al. 2013).

The combination of fluorescence spectroscopy as an indicator of floodplain connectivity and the use of inundation models is valuable for the interpretation of other ecological indicators measured to assess the impacts of environmental water uses.

Critical covariates

Area of inundation

Locations for monitoring

This work has two components- an annual core monitoring component at standard sites and an expanded contingency component with more frequent sampling and a broader range of sites which will come into effect if hypoxic blackwater or other poor water quality occurs in the system.

The core carbon fluorescence and water quality data will be collected at sites listed in Table 10 and includes ongoing monitoring at established sites in Yallakool Creek, Wakool River zones 2 to 4, and source water for these sites from the Mulwala Canal and the Edward River at Stephens Weir (Nutrients not sampled at source sites). New sites expand the water quality monitoring further downstream in the Wakool River and to Tuppal Creek, the Edward River channel, and the Colligen-Niemur River system to better capture the impact of environmental water in the broader system. Sites 5 and 6 (Edward River) together with 8, 9 and 10 (Colligen-Niemur) (Table 10) may be used in combination to assess carbon and nutrient exchange between the river systems and the Werai Forest should an appropriate overbank flow occur.

Should the contingency component be triggered due to blackwater or other adverse water quality in the system, additional downstream sites will be selected to monitor the progress and severity of the blackwater in the broader system. The sites will be determined on an event basis in collaboration with the CEWO but may include sites with existing dissolved oxygen loggers as marked in figure 7.

Table 10 Sites for Water Quality and Organic carbon routine monitoring.

No.	Site name	River system	Coordinates	Gauging number	LTIM existing DO logger	WaterNSW DO logger	New MER DO logger to be installed
1	Tuppal Creek	Tuppal Creek	35°37'41.2"S 145°03'18.7"E	409056			
2	Mulwala Canal		35°30'08.3"S 144°46'55.0"E				
3	Toonalook	Edward River	35°38'34.1"S 144°57'34.6"E	409047			
4	Stevens Weirpool	Edward River	35°26'21.8"S 144°45'48.2"E	409101			
5	Downstream Stevens Weir	Edward River	35°25'53.3"S 144°45'29.1"E	409023			
6	Downstream Werai Forest	Edward River	35°16'23.7"S 144°27'54.7"E				
7	Moulamein	Edward River	35°05'23.6"S 144°01'59.2"E	409014			
8	Colligen	Colligen-Niemur River	35°26'48.8"S 144°42'39.6"E	409024			
9	Niemur Barham Road	Colligen-Niemur River	35°16'26.0"S 144°09'34.2"E	409048			
10	Niemur Mallan School	Colligen-Niemur River	35°08'06.4"S 143°48'00.4"E	409086			
11	Zone 1 site 5	Yallakool Creek	35°30'21.6"S 144°29'08.2"E				
12	Zone 2 site 4	Wakool River	35°31'22.1"S 144°31'09.1"E				
13	Zone 3 site 5	Wakool River	35°33'50.8"S 144°20'41.6"E				
14	Wakool Barham Road	Wakool River	35°30'37.8"S 144°12'35.6"E	409045			
15	Zone 4 site 5	Wakool River	35°26'29.0"S 144°02'11.0"E				
16	Gee Gee Bridge	Wakool River	35°19'44.4"S 143°55'55.9"E	409062			
17	Stony Crossing	Wakool River	35°02'15.4"S 143°34'12.7"E	409013			

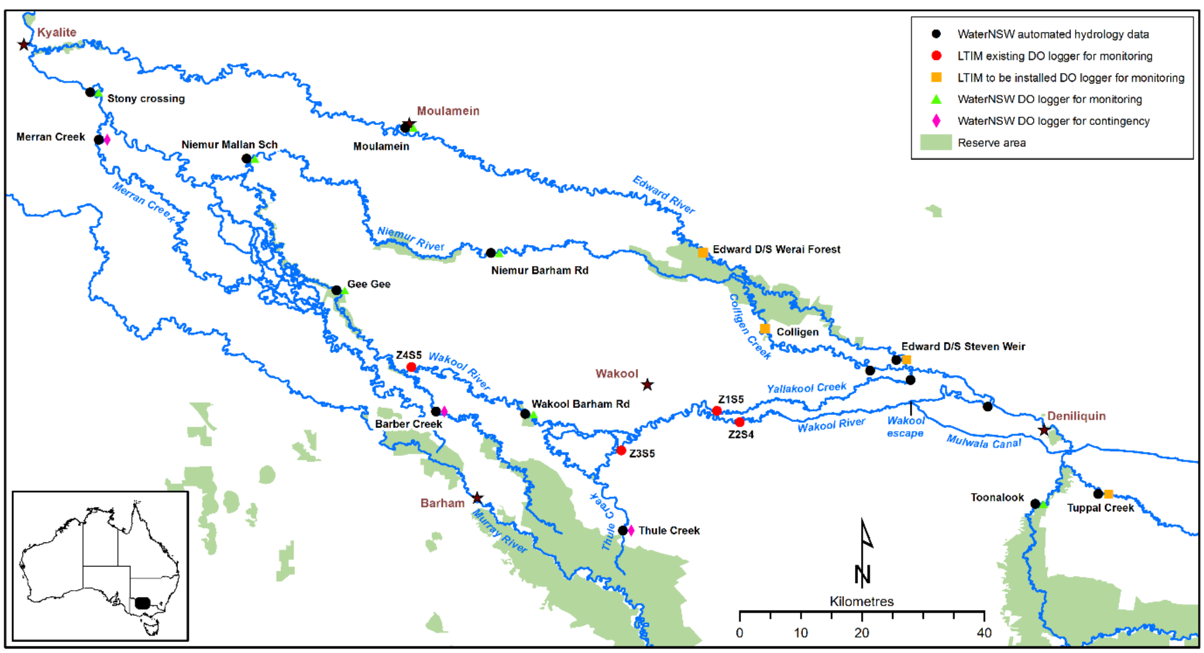

Figure 7 Map of the Edward Wakool Selected Area showing existing LTIM sites that will be continued (red), sites where water quality sampling will be supplemented with data from WaterNSW loggers (green), sites where new loggers will be installed (yellow). Sites with existing DO loggers that will not be routinely sampled but may be considered for contingency sampling events (pink).

Timing and frequency

Core monitoring

The focus of the annual monitoring is the assessment of organic matter inputs and water quality changes during in-stream flows. Sampling will consist of water samples collected from each site in table 10 on a monthly basis throughout the year (expanded from 8 months monitoring during LTIM program to include monitoring of winter flows during the MER program). Where possible, sites will be aligned with dissolved oxygen loggers established for the assessment of metabolism.

Targeted monitoring

Large flow events, water quality crises and releases of environmental water for hypoxic blackwater mitigation require more intensive sampling than the core monthly monitoring. The sampling design for contingency monitoring will be developed depending on the event.

Responsibilities

- Field work: Dr Xiaoying Liu (CSU) will lead the field program with assistance from Robyn Watts (CSU), John Trethewie (CSU) and casual staff (CSU)
- Laboratory analysis for organic matter characterisation will be undertaken by Dr Xiaoying Liu (CSU) under the supervision of Dr Julia Howitt (CSU). Nutrient and DOC analysis will be subcontracted as fee for service (CSIRO NATA certified lab)
- Data analysis and data management: Dr Julia Howitt (CSU), Xiaoying Liu (CSU), Dr Nicole McCasker (CSU), Prof Nick Bond (La Trobe)
- Data analysis and reporting: Dr Julia Howitt (CSU), Dr Xiaoying Liu (CSU)

Field Methods

Water samples for organic matter characterisation (approx 30 mL) will be filtered in the field using 0.2 μm syringe filters. Samples will be stored on ice, in the dark (not frozen) and brought to the CSU laboratories in Wagga Wagga at the end of each field trip. Spot water quality, nutrients, DOC and Chlorophyll-a will be collected and analysed as described in section 5.3 (stream metabolism).

Laboratory methods

Water samples will be analysed by UV-Vis and fluorescence spectroscopy within 1 day of receipt by the laboratory (48 hours may be necessary during a blackwater event due to the larger number of samples). Absorbance scans will be collected using a Varian Cary 4000 instrument across a wavelength range of 550 nm to 200 nm (green through to ultraviolet) with a 1 nm step size. Fluorescence scans will be collected using a Varian Eclipse spectrofluorometer scanning both emission and excitation wavelengths to give an excitation-emission matrix.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.2.2 Evaluation

This component of the monitoring is composed of two parts: annual core sampling and targetted studies of adverse water quality events. The monitoring consistes of a combination of the water quality sampling described in the Cat 1 Stream Metabolism Methodology (See Section 5.3) expanded to a greater range of sites, and Cat 3 methods for organic matter characterisation. This monitoring protocol addresses the Selected Area evaluation questions listed in Table 11.

Table 11 Carbon and water quality evaluation questions

Evaluation questions
Selected Area questions for core monitoring
Short and Long-term questions • What did Commonwealth environmental water contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected in-channel habitat? • What did Commonwealth environmental water contribute to dissolved oxygen concentrations? • What did Commonwealth environmental water contribute to nutrient concentrations?
Selected Area questions for targeted contingency monitoring
• What did Commonwealth environmental water contribute to reducing the impact of hypoxic blackwater or other adverse water quality events in the system?

Data analysis and reporting

Spectroscopic analyses will be plotted using Sigma Plot or R for comparison between sampling sites and sampling dates. UV-Vis scans will be plotted as line graphs and fluorescence results will be corrected for sample absorption and plotted as contour plots (Howitt et al. 2008). Spectroscopic analyses will be reported annually for the core monitoring component. Spectroscopic analyses during targeted contingency water quality monitoring can serve as rapid-response indicators with the UV-Vis results available on the day of analysis (same day as receipt if urgent) and the fluorescence results available within 2-3 days (due to the greater data processing requirements). Combined with spot water quality measurements, this data will provide a critical guide to the progress of a blackwater event and the impact of any releases from channel escapes.

5.2.3 Research

New research on carbon and water quality indicators will be undertaken as part of the integrated research project on the Edward River (see section 6).

5.3 Stream metabolism (Category 1)

5.3.1 Monitoring

Overview and context

The key objective of the stream metabolism monitoring program is to enable determination of the effects of environmental watering actions on the rates of Gross Primary Production (GPP) and Ecosystem Respiration (ER) within the Edward-Wakool system. These processes support and sustain aquatic food webs, and hence are directly related to ecosystem health and viable fish populations. Important drivers for these processes, notably nutrient and organic carbon concentrations and light are collected concurrently to allow flow effects to be distinguished from nutrient variations and daily weather fluctuations.

Flow variability is a key factor influencing rates of GPP and ER in river systems. For example, flow pulses that inundate benches and areas of low lying floodplain increase terrestrial carbon inputs, as well as increasing the area of shallow water where benthic and planktonic algae can grow. In turn this primary production help provide food and fuels food webs. These links have been clearly identified as important processes supporting native fish and waterbird outcomes under the Basin Plan.

The aim of the stream metabolism component of the LTIM monitoring, is thus to assess how delivery of Commonwealth Environmental Water contributes to rates of primary productivity, and overall ecosystem production and respiration in the Edward Wakool River System. This component of work forms an important contribution to predicting broader ecosystem outcomes (Figure 8).

Indicators

- Rates of Gross Primary Productivity (GPP), Ecosystem Respiration (ER) and Net Primary Productivity (NPP) reported in mg Carbon / Litre / day.
- Total GPP, ER, and NPP, taking into account not just rates but also the total daily flow
- Estimated contribution of Commonwealth environmental water to total GPP, ER and NPP, based on counterfactual modelling.

Location for monitoring

Measurements of dissolved oxygen concentrations to support stream metabolism modelling will be undertaken in four hydrological zones in the Edward-Wakool system: zone 1 (Yallakool Creek), zone 2 (Upper Wakool River), zone 3 (Mid Wakool River, upstream Thule Creek), zone 4 (Mid Wakool River, downstream Thule Creek). Each logger integrates between 2 and 10 km of stream reach depending on water velocity and re-aeration rate. One logger will be deployed at the bottom end of each zone. In addition, one logger will be deployed in zone 11 in the Edward River downstream of Stevens Weir and one in zone 12 in the Edward River downstream of Werai Forest as part of the integrated Edward River research project (see section 6).

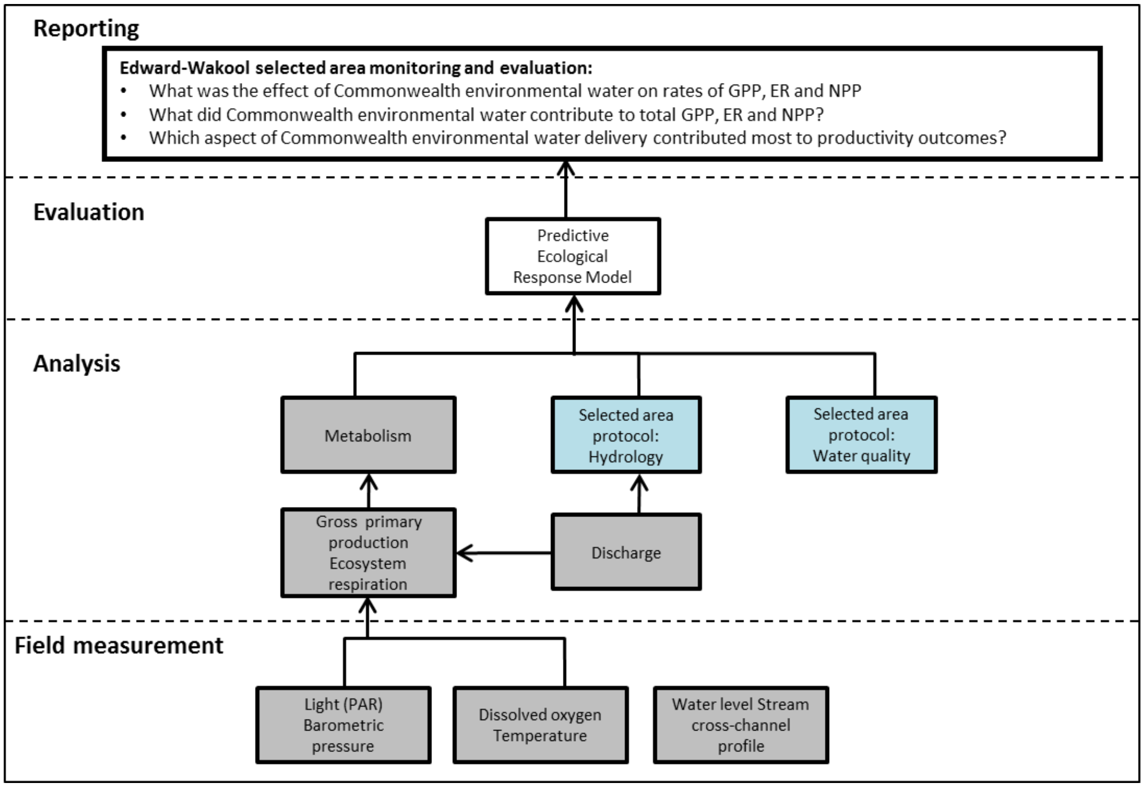

Figure 8 Schematic of key elements in Selected Area Monitoring and Evaluation – Stream metabolism. Components covered by this protocol are highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model.

Timing and frequency

Stream metabolism will be calculated for each site over the three year period, thus providing daily estimates of the metabolic parameters. Monitoring will be continuous all year round to capture the diversity of timing in unregulated flows and Commonwealth environmental water as well as seasonal responses.

Measurement of dissolved oxygen, temperature, surface light (PAR) and barometric pressure will be recorded every 10 minutes. The need for a strict maintenance, calibration check and possible recalibration means that one day's data is lost per month as the probe is removed from the stream for these activities. Water samples for nutrient analysis (FRP, NOx, ammonia, chlorophyll-a, TP, TN and DOC) will be collected once per month.

Responsibilities

- Collaboration: This is a collaboration involving Charles Sturt University and La Trobe University
- Field sampling: Field Technicians from CSU
- Data management and preparation: Nicole McCasker and John Trethewie(CSU)
- Data analysis and reporting : Nick Bond and Paul McInerney (LTU)

Methods

Stream metabolism measures for temperature, dissolved oxygen, light (PAR) and barometric pressure will be logged at ten-minute intervals.

Equipment

- Dissolved oxygen and temperature sensors with an integrated logger (e.g. ZebraTech DOpto) using optical (fluorescence) DO measurement.
- PAR sensor and logger (e.g. DataFlow Odyssey). The sensor will be calibrated against a laboratory-based sensor reading in $\mu Es/m^2/s$ across the full range of PAR expected throughout a bright summer's day.
- Barometric pressure sensor and logger (weather station).
- Tool kit and spare parts for the multi-parameter probe; including spare batteries
- Metal star pickets and star picket driver or mallet
- Anodized chain with padlock, plus cable ties to attach probe to a star picket or permanent structure
- GPS
- Probe calibration log
- Field sheets
- Laptop and data cables for connecting to probes / logger
- Air bubbler with battery (e.g. one suitable for a large fish tank) and a large bucket (e.g. 20 L), for probe calibration.

Protocol

1. Prior to deployment in the field, the probe(s) will be calibrated, using a two point (100% & 0% DO saturation) according to manufacturer's instructions and results of calibration entered into a calibration log.
2. Before leaving the office / laboratory the following will be checked for all electronic equipment (probes, loggers, GPS):
   - Batteries are charged and properly inserted
   - Previous data downloaded and memory cleared
   - Check cable and cable connections
   - Check for any obvious/minor faults on sensors including growth or dirt on the probes or tubing
   - Check contents and condition of probe toolkit
   - All equipment listed above is present and in functional order
3. A suitable location, above the area likely to be inundated and in a clear open (unshaded) area will be identified. This could be a nearby paddock. Note that on private property locations a fence post near gate access may be suitable.
4. Secure PAR logger to existing structure or if necessary, a newly placed star picket.
5. Set loggers to read at 10 minute intervals.
6. The following information will be recorded on field sheets:

- River name and ANAE Streamid
- Date and time
- GPS coordinates (latitude and longitude; GDA94)
- Name(s) of survey team

7. Record site characteristics:
   - Substrate type
   - Width of channel
   - Presence of any geomorphic features
   - Percent canopy cover
   - Land use immediate adjacent to site
8. Collect water quality samples and spot measures as described above.
9. Calibrate dissolved oxygen sensor on site:
   - Calibrate according to manufacturer's instructions for both oxygen free water (e.g. 1% sodium sulfite Na_2SO_3 solution) and 100% saturation (air saturated water). The easiest way to obtain a reliable on-site calibration of 100% saturation is to place the probe in a bucket of stream water which itself is sitting in the stream to ensure thermal control. Air is bubbled through the water in the bucket for at least 45-60 minutes. This should result in a stable reading from the probe. It is important that the probe is not in the direct line of air bubbles.
10. Set the dissolved oxygen, temperature, PAR and barometric pressure loggers to record at ten minute intervals. Synchronise loggers so as to obtain corresponding readings.
11. Select appropriate place for deployment of sensors and loggers noting:
    - Dissolved oxygen and temperature sensors must be placed in open water, mid stream and at a depth that will not expose sensors for entire deployment period. Sensors should not be placed in eddies, stratified zones, backwaters or where flow is influenced by structures.
    - Sensors can be deployed on suitable existing structures or on star pickets securing embedded mid-stream.
12. Deploy loggers.
13. Leave loggers deployed for between four and six weeks. Experience over the LTIM program in these streams indicated that more frequent cleaning was required, hence loggers will be maintained every 2 weeks during the warmer months when necessary.
14. Perform servicing, cleaning and calibration of loggers at each repeat visit.
15. Repeat water quality samples and spot measures at each repeat visit.
16. Repeat 100% saturation value check (water saturated air) and note the value of any drift.
17. Record any relevant information, such as changes in site characteristics since deployment.
18. Upload data onto laptop following manufacturer's instructions.
19. Calibrate all sensors and loggers and perform routine maintenance / cleaning as necessary.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.3.2 Evaluation

Metabolism monitoring will address the Selected Area evaluation questions in table 12.

Table 12 Stream metabolism evaluation questions

Evaluation questions
Short and Long-term questions • What was the effect of Commonwealth environmental water on rates of GPP, ER and NPP • What did Commonwealth environmental water contribute to total GPP, ER and NPP? • Which aspect of Commonwealth environmental water delivery contributed most to productivity outcomes?

Data analysis and reporting

This method adopts the approach of determining GPP, ER and reaeration rate (K_{O2}) from the diel dissolved oxygen curves using the daytime regression model reviewed by Kosinski (1984). A program to evaluate these parameters for the diel dissolved oxygen curve, 'BASE', has been developed by Mike Grace, Darren Giling and Ralph MacNally at Monash University.

The model requires data for dissolved oxygen in mg O_2/L, temperature, PAR and barometric pressure (in atmospheres) at 10 minute intervals. The salinity also needs to be entered. This will be approximated as 0 unless the electrical conductivity increases above 500 µS/cm, in which case salinity = 6 x 10^{-4} x EC (Based on conversion factor of 1 µS/cm = 0.6 mg/L TDS). The 'BASE' program provides estimates of GPP and ER in mg O_2 /L/Day with uncertainties for each and goodness of fit parameters.

The current version of BASE (BASEmetab; https://github.com/dgiling/BASEmetab) includes a number of changes made following Song et al. (2016). Results published by Song et al. (2016) showed that BASE underestimated metabolic rates in some cases due to two differences in the model formulation compared to other aquatic metabolic models (e.g. Hall and Tank 2005; Hanson et al. 2008; Holtgrieve et al. 2010; Van de Bogert et al. 2007):

1. BASE used a 'stepwise' approach to model changes in DO concentration (Δ[DO]) between successive measurements rather than DO concentration ([DO]) directly.
2. BASE also used the measured DO concentration ([DO]measured) to estimate oxygen deficiency for reaeration rates instead of the modelled DO concentration ([DO]measured).

Given the findings of Song et al. (2016), these inconsistencies in the BASE model were rectified:

BASE: $\Delta[DO]t\Delta t/{=}AItp{-}R(\theta(Tt{-}\bar{T})){+}KDO.(1.0241(Tt{-}\bar{T})).([DO]sat,t{-}\ [DO]meas,t)$

BASEv2: $[DO]t{+}1{=}[DO]t{+}AItp{-}R(\theta(Tt{-}\bar{T})){+}KDO.(1.0241(Tt{-}\bar{T})).([DO]sat,t{-}\ [DO]modelled,t)$

Here, t indicates the timestep, A is a constant, p is an exponent describing incident light use, Θ describes temperature dependence of respiration, T is water temperature and sat, meas and mod indicate [DO] at saturation, observed concentration and modelled concentration. The updated model of BASEv2 improved fit (visual and R2) of modelled DO to observed values and reduced uncertainty in parameter estimates of the validation dataset of Grace et al. (2015). There was greater agreement between the estimates from BASEv2, BaMM (Holtgrieve et al. 2010) and the 'accurate' method of Song et al. (2016), for a wide range of stream characteristics and range of metabolic rates.

As part of the update of the BASE model, there was also a change in software for the MCMC (Markov Chain Monte Carlo) algorithm from OpenBUGS (Lunn et al. 2000) to JAGS (Plummer 2003) for platform-independence and to allow for parallel core processing of the three chains, greatly increasing computational speed.

Subsequent data analysis will involve using the daily estimates for the two metabolic parameters with the collected explanatory variables (nutrients, DOC, chlorophyll-a, light) as well as daily discharge and season to determine the influence of flow on rates of GPP, ER and NPP, and also total GPP, ER, and NPP. By undertaking counterfactual modelling estimates of the contribution of Commonwealth environmental water to GPP, ER and NPP will be determined and reported.

5.3.3 Research

New research on stream metabolism and productivity is planned for the MER program as part of the integrated research project on the Edward River (see section 6).

5.4 Riverbank and aquatic vegetation (Category 3)

5.4.1 Monitoring

Overview and context

Riverbank vegetation and aquatic vegetation play an important role in the functioning of aquatic ecosystems, supporting riverine productivity and food webs and providing habitat for fish, invertebrates, frogs and birds (Roberts and Marston 2011). The cover and composition of aquatic vegetation can determine the availability of oviposition sites for macro invertebrates and calling and spawning locations for frogs (Wassens et al. 2010) and support wetland food webs and zooplankton communities (Warfe and Barmuta 2006). Furthermore, the response of aquatic and riverbank vegetation following a flow event can assist understanding the response of other biological indicators.

Riverbank plant survival and growth is affected by the frequency and duration of inundation (Toner and Keddy 1997; Johansson and Nilsson 2002; Lowe et al. 2010). Frequent inundation can delay reproduction (Blom and Voesenek 1996), whilst long duration of inundation can reduce growth or survival (Blom et al. 1994; Johansson and Nilsson 2002; Lowe et al. 2010). Favourable soil moisture and nutrient conditions created by a receding flood can encourage rapid recovery and root and shoot development and many plants, including emergent macrophytes and riparian understorey herbs, often germinate on flood recession (Nicol 2004; Roberts and Marston 2011). Differences in seasonal patterns of inundation within a single year can result in different survival, growth and reproduction responses of riverbank and aquatic plant species (Lowe 2002).

The process for evaluating the questions is illustrated in Figure 9, with components covered by the protocol highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model.

Indicators

- Percent cover of aquatic vegetation
- Percent cover and maximum height of riverbank vegetation
- Diversity of aquatic vegetation
- Diversity of riverbank vegetation

Locations for monitoring

Monitoring sites established as part of the LTIM program will continue to be surveyed as part of the MER program. Monitoring will occur in zone 1 (Yallakool Creek), zone 2 (upper Wakool River), zone 3 (mid Wakool River, upstream Thule Creek), zone 4 (mid Wakool River, downstream Thule Creek), and Colligen Creek. Four sample sites will be monitored in each zone.

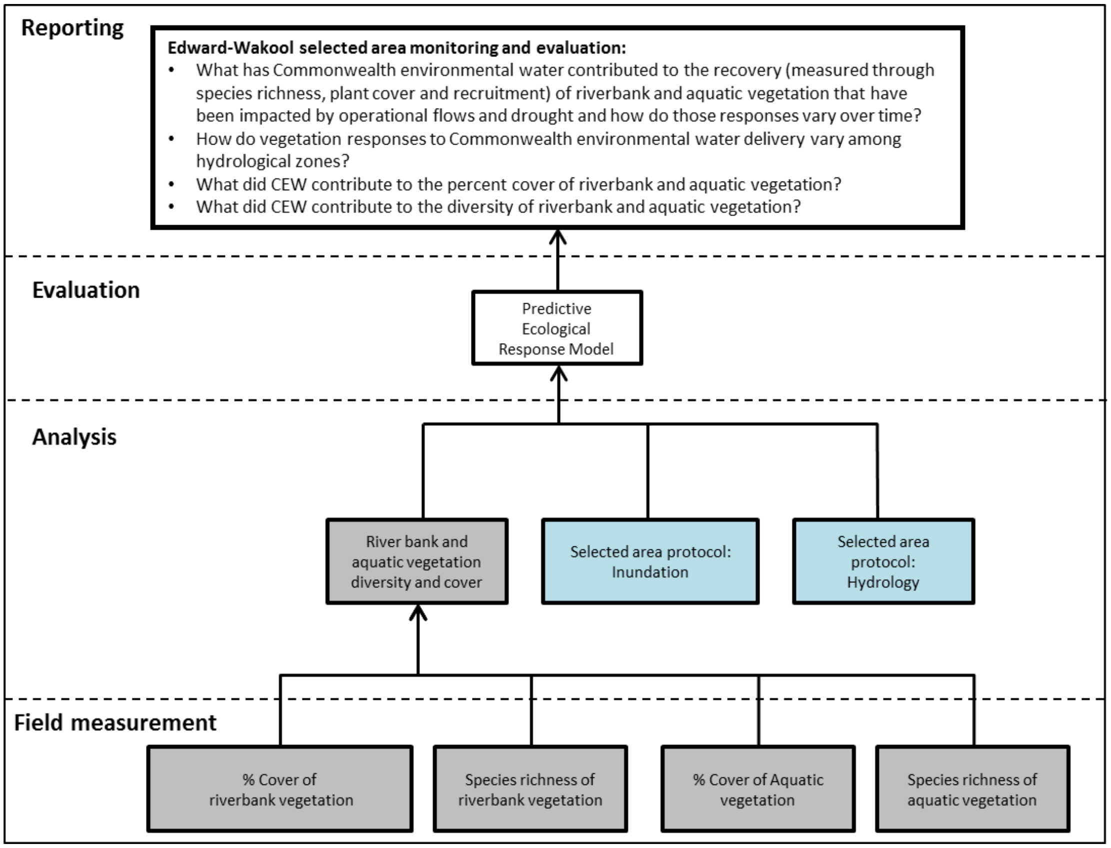

Figure 9. Schematic of key elements in Selected Area Monitoring and Evaluation – Riverbank and aquatic vegetation. Components covered by this protocol are highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model.

Timing and frequency

Monitoring of riverbank and aquatic vegetation in zones 1 to 4 and Colligen Creek will be undertaken monthly.

Responsibilities and collaboration

- Collaboration: This is a collaboration involving NSW Office of Environment and Heritage, Charles Sturt University
- Field sampling: Sascha Healy (OEH), Robyn Watts (CSU), casual staff (CSU).
- Data entry and management: Xiaoying Liu (CSU), Nicole McCasker (CSU)
- Data analysis and reporting: Robyn Watts (CSU), Sascha Healy (OEH)

Methods

Monitoring will be undertaken once per month at each site. In 2014 six permanent 20 m long transects were established parallel with the river channel. Star pickets were installed at each end of the permanent transect. The lowest transect on the riverbank was labelled as transect 0 and the other five transects labelled consecutively up to transect 5 highest on the river bank. The transects were surveyed so they were 25 cm apart in vertical height, with the five transects thus covering 1.25 m of vertical height of the bank. Transects zero and one were in the water at base operational flows, and the other four transects further up the riverbank have the potential to be inundated during Commonwealth environmental watering or during unregulated flows.

Vegetation will be assessed using the line point intercept method along transects. At each of the transects on each sampling date a 20 m tape measure will be laid out running horizontally along the riverbank between two star pickets installed at a known height of riverbank. The taxa at each 50 cm point quadrat along the 20 m transect (40 points on each transect) will be recorded. Plants will be identified to species level where possible, but if the plants are very small and without seeds or flowers to enable correct identification they will be identified to genus. If no vegetation is present at a point, then that point will be recorded as bare ground, leaf litter or log/tree trunk. For transects in the water the tape measure will be laid at the water's edge and a flexible fibreglass pole held from the tape out to the water surface to locate the point on the transect for recording data. Photopoints were established at each site in 2014 as part of the LTIM program. Photos will be taken at these sites on each sample event.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.4.2 Evaluation

Riverbank vegetation and aquatic vegetation monitoring will address the Selected Area evaluation questions in table 13.

Table13. Riverbank and aquatic vegetation evaluation questions

Evaluation questions
Long-term questions • What has Commonwealth environmental water contributed to the recovery (measured through species richness, plant cover and recruitment) of riverbank and aquatic vegetation that have been impacted by operational flows and drought and how do those responses vary over time? • How do vegetation responses to Commonwealth environmental water delivery vary among hydrological zones? *Short-term questions* • What did Commonwealth environmental water contribute to the percent cover of riverbank and aquatic vegetation? • What did Commonwealth environmental water contribute to the diversity of riverbank and aquatic vegetation taxa?

Data analysis and reporting

Each taxa will be classified into three broad functional categories using a range of sources including Brock and Casanova (1997), Casanova (2011) and Roberts and Marston (2011). Although there are some limitations of using water plant functional groups to classify taxa, the approach of using three functional categories is sound for common taxa that can be reliably distinguished and can be related to hydrological information on wetting and drying regimes.

The three functional categories are:

- Submerged taxa, being those that have special adaptations for living submerged in water. These plants grow to, but do not emerge from, the surface of the water.
- Amphibious taxa, including those that tolerate wetting and drying, and those that respond to water level fluctuations, and
- Terrestrial taxa, being those that typically occur in damp or dry habitats.

Total species richness will be calculated for each site in each zone for each month. The percent cover will be calculated for each transect for each sample date. To compare cover of vegetation across the years of the LTIM program and CEWO MER program, the month when the maximum cover occurred will be identified for each taxa.

To test if the percent cover of vegetation is significantly different among the hydrological zones across years, the total percent cover of all taxa will be transformed and analysed using a one way ANOVA with zone as the treatment factor. Analysis of the percent cover for the eight most common taxa will be analysed individually using Kruskal-Wakllis nonparametric test because the data are usually not normally distributed. Statistical analyses will be undertaken using the freeware R and the R package MASS (R Development Core Team 2013) and IBM SPSS Statistics v20. When significant differences are indicated, post hoc pairwise comparisons will be undertaken to determine differences between hydrological zones.

5.4.3 Research

Research on riverbank and aquatic vegetation will be undertaken as part of the integrated research project on the Edward River and Werai Forest (see section 6).

5.4.4 Links to other monitoring and research themes

The riverbank and aquatic vegetation theme links with the hydrology (section 5.1), larval fish (section 5.6, 5.7) and fish recruitment (section 5.8) themes and with several aspects of the integrated research project (e.g. hydraulic modelling and turtle research, section 6).

5.5 Fish movement (Category 2)

5.5.1 Monitoring

Overview and context

Freshwater fish make reproduction, dispersal and feeding movements in response to biotic and abiotic stimuli (Lucas et al. 2001) (Figure 10). The delivery of Commonwealth environmental water will affect the scale of fish responses to these stimuli, as the frequency, timing and magnitude of fish movements are strongly related to flow (Taylor and Cooke 2012). It is important that any fish movements are able to be quantified and related back to discharge (whether it is delivered by the Commonwealth or otherwise), to enable adaptive management of future flow events. For example, elevated flows increase longitudinal and lateral habitat connections, enabling fish to seek refuge to avoid disturbances such as hypoxic blackwater events or to recolonise following disturbances. Commonwealth environmental water objectives have, in the past, had ecological objectives which required monitoring of fish movements to determine outcomes. For instance, if fish reproduction (and thus changes in landscape fish diversity) is an objective, then tracking the movements of fish to breeding locations, or documenting behaviour consistent with reproduction, provides direct evidence that the delivery was successful. In addition, movement data can demonstrate whether fish survived during poor water quality events, or whether fish successfully moved into refuge habitat during periods of low flow. The strategic placement of acoustic receivers in the Edward-Wakool Selected Area will provide information on the timing, frequency and magnitude of movements related to Commonwealth environmental watering events. Importantly, data is logged on average every 90 seconds. With this level of precision, movement events can be linked to particular aspects of the hydrograph. Such information is important to determine whether the fish movement aspects of Commonwealth environmental water delivery are successfully achieved.

Given the climatic variability in Australia and the associated unpredictable hydrology, numerous species rely on in-channel flows, rather than off-channel connections, to complete their life cycle (Humphries et al. 1999). For example, golden perch reproduction can occur from early November to March (Roberts et al. 2008; King et al. 2009). In-channel reproduction has occurred in non-flood years for golden and silver perch, and rapid responses of reproduction to rising water levels and temperatures have been documented, often in conjunction with long-distance migrations (Reynolds 1983, Mallen-Cooper and Stuart 2003, O’Connor et al. 2005). This suggests that both species are in a state of ‘reproductive readiness’ over a specified season and are awaiting suitable environmental conditions to spawn. If these conditions are not achieved minimal reproduction may occur or the species will simply resorb gonads.

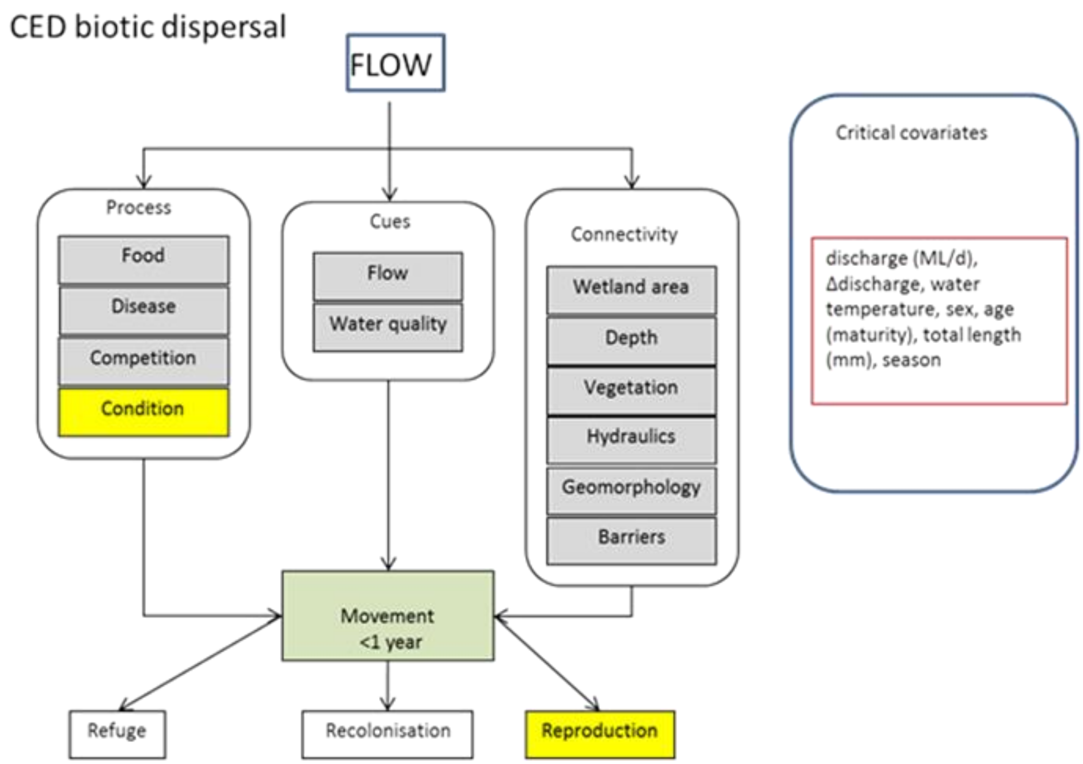

Figure 10. Modified biotic dispersal cause and effect diagram reflecting the biotic and abiotic influences on fish movement. Yellow boxes indicate other cause and effect diagrams. The critical reason biotic dispersal is important for fish is that it may be reproduction related in response to flow. (Modified from MDFRC 2013).

Telemetry is a useful method for obtaining detailed movement information on fish, as it enables quantification of the magnitude, timing and frequency of individual responses to abiotic stimuli such as flows (Taylor and Cooke 2012). In Australia, telemetry has been used to identify the reproduction related movements of golden perch in response to flow events (O'Connor et al. 2005). Leigh and Zampatti (2013) used telemetry to quantify the lateral movements of Murray cod during high discharge events. Using telemetry, Simpson and Mapleston (2002) identified a positive correlation between the distance moved by Mary River cod and discharge. Telemetry can also be used to quantify large scale dispersal, including movements to and from refuge habitats, and serves as a useful additional line of evidence to infer successful reproduction (e.g. Thiem et al. 2013, Walsh et al. 2013).

Acoustic tracking is a useful telemetry method for obtaining information on fish movements. The process involves implanting a transmitter into a fish, which is then detected by a series of stationary readers installed in a target stream. Acoustic monitoring can provide high resolution spatial information on fish location, and data can be graphically presented to identify specific movement patterns (Barnett et al. 2010). In the case of environmental water delivery, the strategic placement of acoustic receivers will provide information on timing of movements, distances travelled, residency, correlation of movements with flow delivery and evidence of reproduction behaviour. Such information is important to determine the delivery success of a particular Commonwealth environmental water volume, to provide additional evidence to support existing monitoring activities such as larval fish monitoring, and to inform the planning of future events.

These standard methods describe monitoring required for the Basin-scale evaluation and Selected Area evaluation of the response of river fish to Commonwealth environmental water. The methods describe the sampling design and protocol for large-bodied fishes in river channels for the LTIM Project.

This protocol describes equipment specifications and implantation procedures to measure dispersal rates and directions of target periodic life-history fishes

The process for evaluating Basin-scale questions is illustrated in Figure 11, with components covered by this protocol highlighted in grey.

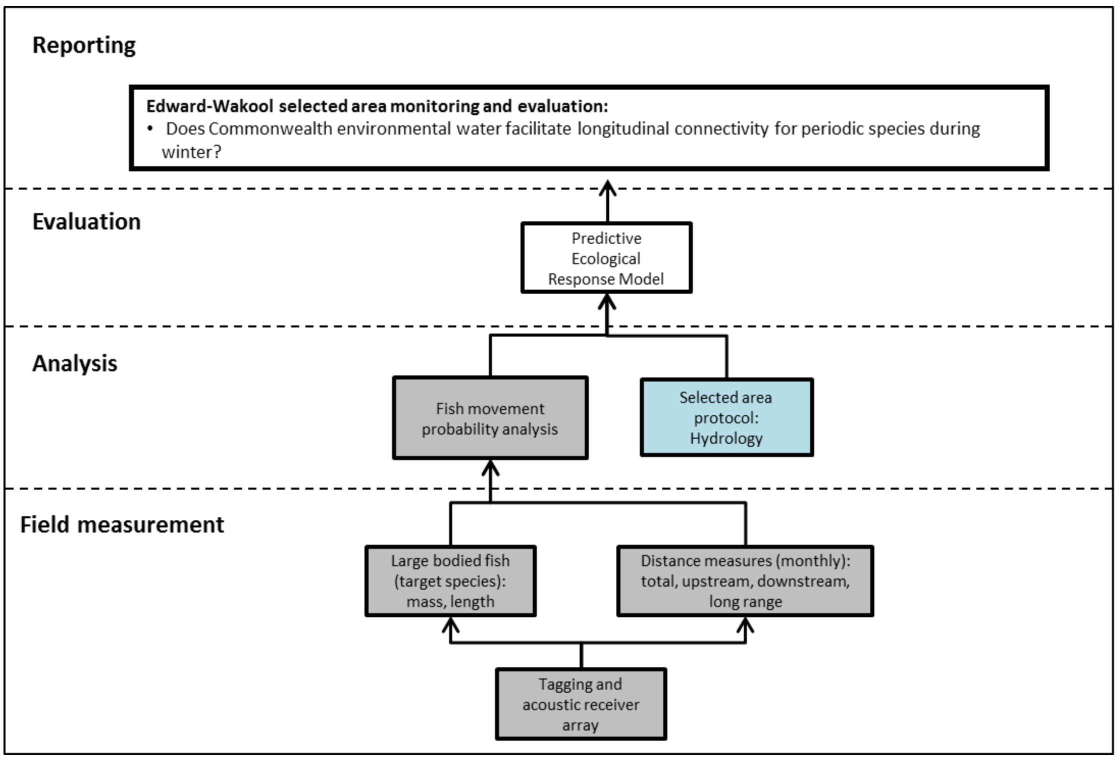

Figure 11 Schematic of key elements in LTIM Project Standard Protocol: Fish (Movement). Components covered by this protocol are highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model

Establishing sites

Protocol

LTIM Project for Basin-scale evaluation adopted a hierarchical approach to sample design. The spatial hierarchy for fish (movement) monitoring is as follows:

- Selected Area
    - Zone
        - Site

Zone placement within Selected Areas

A 'zone' is a subset of a Selected Area that represents a spatially, geomorphological and/or hydrological distinct unit at a broad landscape scale. For example, separate river systems, sub-catchments or large groups of wetlands.

For Basin-scale evaluation, we selected four zones for monitoring of fish movement in river channels based on the following recommendations of Hale et al. (2014):

- Different zones within Selected Areas represent spatially-, geomorphologically- and/or hydrologically-distinct units;
- Zones must be likely to receive Commonwealth environmental water at least once in the next five years;
- Zones must have an expected outcome related to the indicator in question (in this instance fish movement);
- The zones selected for monitoring fish movement responses to flows are to be the same as selected for monitoring fish population and community structure for Basin-scale modelling data (see LTIM Project Standard Protocol: Fish (River)). In this way we may achieve synergies amongst different forms of fish data collected.

Receiver design / placement within zones

The array and design of the telemetry study in the Edward-Wakool Selected Area (Figure 12) was established with respect to the following general requirements outlined in Hale et al. (2014):

- Receivers will span the length of channel defined by the ten sites established as part of the population/community monitoring; these are placed within Zone 3 (see LTIM Project Standard Protocol: Fish (River));
- Consistent spacing of acoustic receivers will occur within monitoring zones.
- Additional receivers will be deployed at major waterway junctions to determine the direction of movement into and out of these waterways.
- GPS coordinates of receiver locations will be recorded to facilitate calculation of distances moved by individual fish.

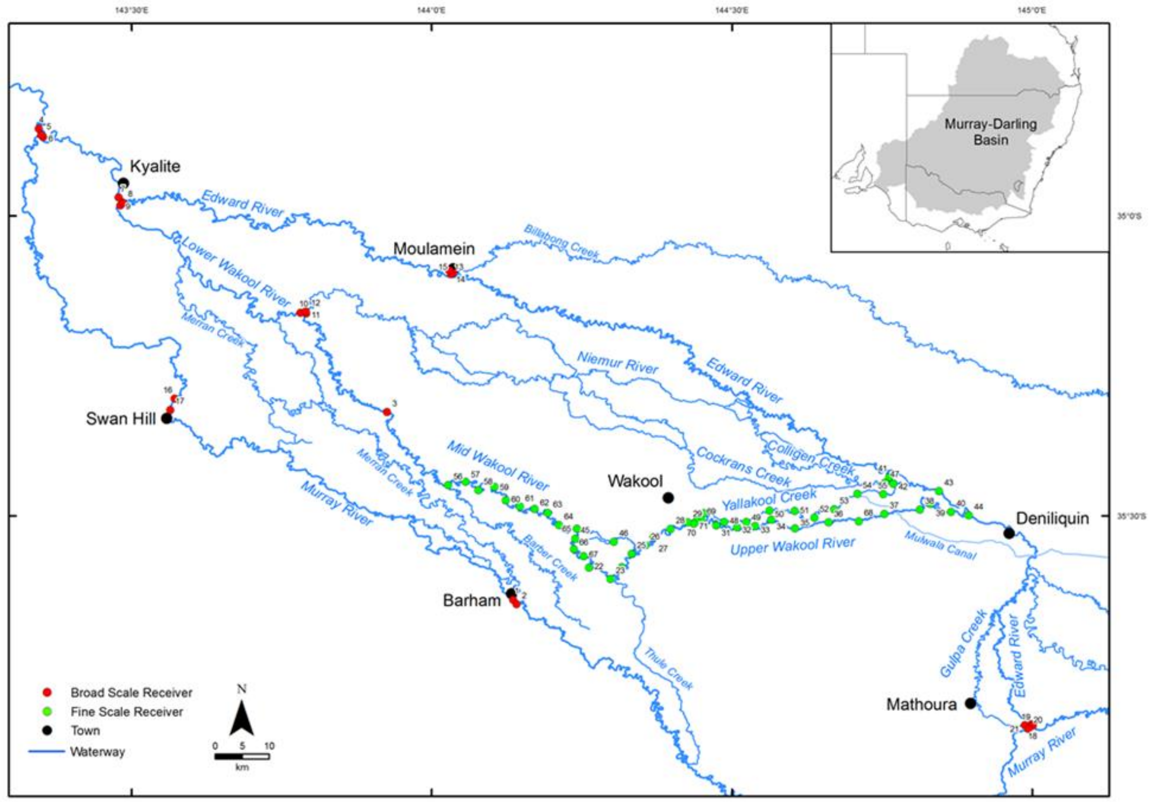

Figure 12 Locations of acoustic receivers in the Edward-Wakool system.

Indicators

Fish movement metrics and location data will be calculated including: linear range (the maximum upstream minus the maximum downstream location), mobility (the sum of all distances moved) and residency (the proportion of the tagged sample within any given location). These metrics will be relation to season and discharge for periodic species and will be queried on time-scales of days to months depending upon the question of interest.

Location for monitoring

Fish (movement) Cat 2 will be monitored in zones 1 (Yallakool Creek), 2 (Upper Wakool River), 3 (mid Wakool River, upstream of Thule Creek) and 4 (mid Wakool River, downstream of Thule Creek). Additional acoustic receivers will be placed at major junctions within the broader Edward-Wakool river system to quantify emigration and routes of travel.

Knowledge of the dispersal paths in the system will enhance management of future Commonwealth environmental watering actions targeting native fish colonisation and dispersal. The scale of movement exhibited by fish will likely vary depending upon the magnitude of Commonwealth environmental water that is delivered, and will be of the greatest magnitude during high flow events. Dispersal of tagged fish from the study area into the catchment will provide insight into resilience, emigration, immigration and blackwater related movements, informing Selected Area reporting. Movements by fish throughout the Selected Area result in increased population resilience, through dispersal into new habitats, by enabling greater access to breeding habitat, through colonisation of new or previously impacted habitat (e.g. drought or hypoxic blackwater affected areas) and avoidance of poor quality habitat (e.g. water quality). Large bodied fish communities in the mid and lower Wakool river system were significantly impacted by drought (2000 – 2010) and large scale fish kills caused by hypoxic blackwater following system wide flooding in 2010. The monitoring of flow related fish movement into and out of these zones from less affected 'refuge' areas will assist in interpretation of the role of Commonwealth environmental water in facilitating system-wide recovery. The data collected from the fish movement component will also be used to compliment fish community monitoring that will occur annually in these zones

Timing and frequency

Submerged Vemco autonomous receivers will record the time, date and identity of acoustic tagged fish swimming within detection range of the receiver units (~ 500 m). Logged receiver data will be downloaded quarterly, although there is potential to incorporate strategic downloads to inform adaptive management. Individually coded acoustic transmitters will be inserted into the peritoneal cavity of each fish and tags will have a programming-dependent battery life of up to 900 days depending upon fish size.

Responsibilities

Fisheries NSW project staff based at Narrandera Fisheries Centre will perform receiver deployment, acoustic tagging, receiver downloads, data management, analysis and reporting. Fisheries NSW staff involved in the project (Thiem, Wooden and Smith have extensive experience with all aspects of telemetry – including tagging, data management, analysis and reporting).

Methods

This fish movement indicator will build upon 4 years of monitoring fish movement under LTIM. This methodology is according to Hale et al. (2014), and includes adjustments (where relevant) to incorporate Edward-Wakool selected area methods and evaluation questions, with inclusions of Health and Safety Plan, Location for monitoring, and Responsibilities.

Representative species from life-history guilds

Overview

Fishes belonging to different life history guilds may respond in different ways to managed and natural flows. Periodic species including golden and silver perch are considered to be flow dependent spawners and are expected to provide detectable responses to Commonwealth environmental water.

Protocol

The monitoring of fish movement in the Edward-Wakool Selected Area will be undertaken with respect to the guidelines from Hale et al. (2014).

Target species for the Edward-Wakool Selected Area

Tagging of golden perch (n=79) and silver perch (n=43) was undertaken in LTIM (2014-19). From December 2018 until May 2019 n=14/27 golden perch and n=8/32 silver perch tagged in 2017 were detected on acoustic receivers in the Edward-Wakool. Eighteen of the golden perch tagged in 2017 will have active transmitters during the winter 2019 watering action and are available to be detected (i.e. battery life extends past this point). No silver perch tagged in 2017 will have active transmitters during the 2019 winter watering action. Subsequently, the movement responses of golden perch already fitted with active acoustic transmitters will be monitored from May 2019-September 2019 in response to a winter watering event.

Sampling protocol

Equipment

- For reliability as well as consistency with current projects (Murrumbidgee, Gwydir and Goulburn) we will use Vemco (http://vemco.com/) VR2W acoustic monitoring receivers operating on 69 kHz; VR2Ws are a submerged, single channel, omni-directional receiver that record time, date and identity of fish fitted with acoustic transmitters. VR2W receivers are powered by a single "D" sized 3.6 Volt lithium battery, with a projected battery life of 15 months. Range testing of receivers in other Australian installations indicated 100% detection efficiency to 300 m which declines to 60% at 400 m. Receiver locations will be placed where channel widths are less than reliable detection ranges (< 600 m) and possess clear open substrate to eliminate detection shadows.
- Vemco tags will be used. Other 'compatible' tags are available on the market but cannot guarantee unique tag numbers. Duplicate tag numbers will be avoided;
- Tag size may vary with target species body size within the Edward-Wakool Selected Area. We will ensure that tag burden does not exceed 2% of the body weight of fish. Tag battery life will be maximised while considering transmission delays to reduce code collision, taking into account the following points raised by Hale et al. (2014):
    - Tag size is governed by battery size; larger tags = larger battery = longer tag life;
    - Tags with a 3 year life can be purchased but only implanted into large fish;
    - Tags transmit on a random delay. The delay is determined at the time of purchase and influences two things:
        - The chances of code collision. More tags in a location at any given time requires a longer transmission delay to reduce the risk of tags transmitting at the same time and collision of transmission codes (i.e. 2 tags transmitting at the same time in the same location will usually result in no detections)
        - Tag life. Longer delays = longer tag life. BUT increase the chance a fish can swim past a receiver and not be detected as receivers are passive and only detect tags when tags transmit.
    - Previous Edward-Wakool projects used Vemco model V9 tags (http://vemco.com/products/v7-to-v16-69khz/) on an average 90 second delay (i.e.

transmission occurs randomly between 50 and 130 seconds) for small fish (tag weight 3.6 g, battery life ~225 days) and V13 tags on an average 90 second delay for larger fish (tag weight 11g, battery life ~885 days). It is expected that these tags will continue to be used

Implantation

- Telemetry tagging will be conducted between March and August to avoid high water temperatures and reproductive events. Fish with advanced gonad development have little room in the coelomic cavity to accommodate a tag.
- Fish will be immediately tagged on-site following recovery from capture.
- All telemetry tags will be surgically implanted into the coelomic cavity whilst fish are under anaesthesia. Dose rates of anaesthesia will comply with animal ethics approval.
- Anaesthesia will be achieved through submersion of fish in an induction bath of either benzocaine or Aqui-S (http://www.aqui-s.com/).
- Stage 4 anaesthesia, characterised by total loss of equilibrium and no reaction to handling, is typically the stage required for surgical procedures on fish (Summerfelt & Smith 1990).
- Relevant total length (TL: mm) and fork length (FL: mm) as well as mass (g) will be recorded
- Fish exhibiting visible signs of disease, injuries and deformities will be excluded from tagging.
- Surgery will take place in a V-shaped cradle and fish are to have water continually pumped over the gills (containing a reduced concentration of anaesthetic where necessary).
- Mid-ventral incisions of 20–30 mm will be made through the body wall of the fish posterior to the pelvic girdle and anterior of the anal vent.
- Every possible effort will be made to determine the sex of fish by examining the gonads through the incision prior to transmitter insertion or by collecting a fin clip to retrospectively assign sex. It will be important for later interpretation of data and identifying possible reproductive behaviour during flow events.
- Incisions will be closed using 2–3 interrupted monofilament absorbable sutures (Ethicon PDS II sutures: http://www.ecatalog.ethicon.com/sutures-absorbable/view/pds-ii-suture) using multiple surgeons knots.
- A single surgeon will be used for all tag implantation where possible, or record kept if multiple surgeons are used.
- All tagged fish will be fitted with external, individually numbered dart tags in the dorsal musculature to aid angler identification and facilitate tag returns which is important to understand the fate of the fish if it is not detected in the future.

  Post-surgery fish will be recovered on-site and released within 24 hours of capture/surgery at the point of capture.

Quality Assurance/Quality Control

Quality control and quality assurance protocols are documented in the Quality Plan developed as part of the Monitoring and Evaluation Plan for the Edward-Wakool Selected Area. QA/QC activities specific to this protocol include:

- Electrofishers will be experienced operators of units. They will be supervised by Senior Operators on-site, and have obtained their electrofishing certificates through a reputable course.
- Monitoring and Evaluation Providers will have relevant boat licenses.
- Monitoring and Evaluation Providers will have specific fisheries and ethics permits with them while sampling.
- Monitoring and Evaluation Providers will have appropriate experience in the surgical implantation of telemetry tags.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.5.2 Evaluation

Fish movement monitoring will address the Selected Area evaluation question in table 14.

Table 14 Fish movement evaluation questions

Evaluation question
Short term questions • Does Commonwealth environmental water facilitate longitudinal connectivity for periodic species during winter?

Selected area hypothesis:

H_1 Delivery maintains ecological connectivity for periodic species during winter watering

Data analysis and reporting

Receiver download schedule

- Acoustic receivers will be downloaded quarterly to reduce the possible risk of lost/stolen receivers
- Data will be filtered to remove single detections (Clements et al. 2005), false detections and orphan tags.
- Data files will be stored and managed appropriately.

Data outputs

Downloaded acoustic receiver data will be uploaded into a custom built SQL database. This database will comprise a distance matrix of receiver locations that account for river sinuosity so that movement paths of individual fish can be recreated and distances moved quantified. Single detections will be removed and false detections and orphan tags filtered by the database prior to any analysis.

An interactive fish movement visualisation will be provided to CEWO to be linked to their website that will include all detection data for the life of LTIM/MER in a format mutually agreed upon between DPI and CEWO.

Data management
All data provided for this indicator will conform to the data structure defined in the LTIM Project Data Standard (Brooks and Wealands 2014). The data standard provides a means of collating consistent data that can be managed within the LTIM Project Monitoring Data Management System (MDMS).

The spatial unit for which data is reported for this indicator is known as an 'assessment unit'. The assessment unit for this indicator is the site (river section).

Each row of data provided for this indicator will identify the assessment unit, the temporal extent of the data and a number of additional variables (as guided by this standard method). The exact data structure for this indicator is maintained and communicated in the LTIM Project Data Standard and will be enforced by the MDMS when data is submitted.

5.5.3 Research

No new research on fish movement indicators will be undertaken as part of the MER project.

5.6 Fish Reproduction (Larvae) (Category 1)

5.6.1 Monitoring

Overview and context

This methodology follows the methods developed for the Long-Term Intervention Monitoring Program (2014-2019), as set out in Hale et al. (2014) with inclusions of location for monitoring, responsibilities and Health and Safety Plan subsections. Fish (Larvae) – Cat 1 methods will be used by the Basin-team to address Basin-scale evaluation questions. Some of the Cat 1 data will also be used to address Selected Area questions along with data collected through the Fish Reproduction – Cat 3 methods (section 5.7).

The process for which the Basin-matter team will evaluate Basin-scale evaluation questions for Fish (larvae) is illustrated in Figure 13, with components covered by this protocol highlighted in blue. Note that the boxes marked in red for otolith examination and daily age and growth will not be monitored for Basin-Scale evaluation in the Edward-Wakool Selected Area.

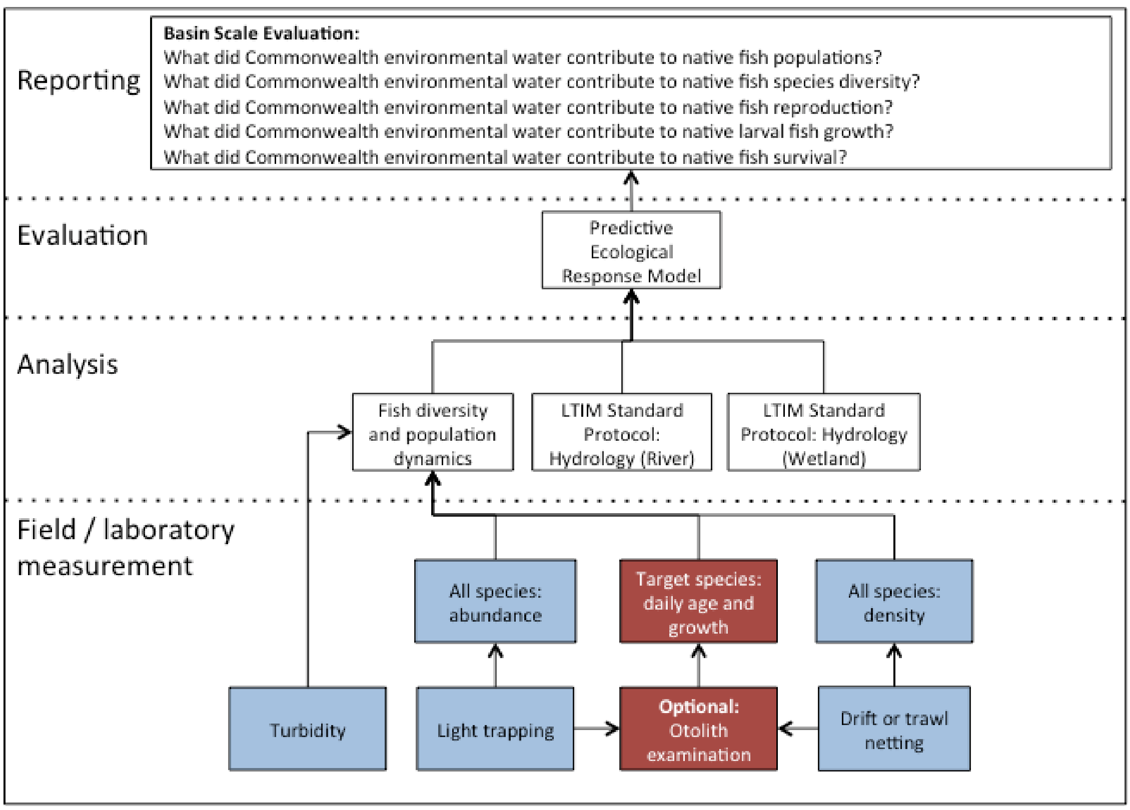

Figure 13 Schematic of key elements in MER Project Standard Protocol: Fish (larvae) – Cat 1. Boxes marked in red for otolith examination and daily age and growth are optional (category 2) and will not be monitored in the Edward-Wakool Selected Area.

Indicators

This protocol describes sampling over five years, each year to measure:

- Catch-Per-Unit-Effort (CPUE) of each larval fish species in rivers using fixed position drift nets
- And the *in situ* measurement of turbidity.

Note: In 2016 an amendment to the Cat 1 larval fish survey methods was agreed upon by the CEWO, Basin-matter fish leads and the Edward Wakool selected area team, which saw the replacement of light trap sampling with the addition of two extra drift net sampling trips (from 5 survey trips to 7) (See Watts et 2018 for details on LTIM Plan addendum).

Location for monitoring

Larval fish monitoring for Basin-scale analysis will take place in Zone 3 (Mid Wakool River, upstream of Thule Creek). Three of the ten sampling sites specified for the monitoring of adult fish in Zone 3 will be used, Cummins (EDWK03_05,) Llanos Park1 (EDWK03_09), and Llanos Park2 (EDWK03_10). The rationale underlying this is to seek as much synergy as possible among the three different monitoring components for fishes.

Timing and frequency

Larval sampling will occur fortnightly, with 7 trips in total taking place between September and December every year, inclusive.

Responsibilities and Collaboration

- Collaboration: This is a collaboration involving Charles Sturt University and NSW DPI Fisheries. Cat 1 fish larvae will be evaluated by the Basin-scale MER team led by CSIRO.
- Field sampling: Field Technicians from CSU and NSW DPI Fisheries
- Larval identification and sample processing: Nicole McCasker and John Trethewie(CSU)
- Data analysis and reporting : Nicole McCasker (CSU)

Methods

The standard methods outlined here describe the monitoring required for the Basin-scale evaluation of fish spawning in response to Commonwealth environmental water for the MER Project.

Larval density will be measured using stationary drift nets for higher current areas. Three drift nets per site (total of nine per zone, per sampling event) will be positioned in water with a moderate velocity, preferably where the discharge is concentrated through a narrow section of the river (a funnel effect). Ideally, drift nets will not be closer than 100 m to each other.

At each site on each sampling event, turbidity will be measured *in situ* via an appropriately calibrated meter and recorded.

Drift nets will be constructed from 500 µm mesh, have an opening diameter of 50 cm, tapering over 1.5 m to an opening of 9 cm, to which a reducing bottle is fitted. Positioning of drift nets is explained earlier. Volume through the net will be estimated so that larval abundances in drift nets can be expressed as a density: number of individuals per m^3. Volume sampled by the net is estimated as $\pi r^2 \cdot v \cdot t$, where *r* is radius in metres, *v* is mean velocity in m s^{-1}, and *t* is time set in seconds.

Entire samples will be preserved individually in 90% ethanol and returned to the laboratory for larval identification and enumeration.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.6.2 Evaluation

Evaluation of Cat 1 fish larvae data will be undertaken by Basin-scale evaluation team led by CSIRO. Fish larvae (Cat 1) monitoring will address the Basin-scale evaluation questions in table 15.

Table 15 Fish larvae (Cat 1) Basin-scale evaluation questions

Evaluation questions
Long term questions
• What did Commonwealth environmental water contribute to native fish populations? • What did Commonwealth environmental water contribute to native fish species diversity?
Short term questions • What did Commonwealth environmental water contribute to native fish reproduction? • What did Commonwealth environmental water contribute to native fish survival?

Data analysis and reporting

All data provided for this indicator will conform to the data structure defined in the LTIM Project Data Standard (Brooks and Wealands 2014). The data standard provides a means of collating consistent data that can be managed within the LTIM & MER Project Monitoring Data Management System (MDMS).

The spatial unit for which data is reported for this indicator is known as an 'assessment unit'. The assessment unit for this indicator is: the site (river section or wetland). Each row of data provided for this indicator will identify the assessment unit, the temporal extent of the data and a number of additional variables (as guided by this standard method). The exact data structure for this indicator is maintained and communicated in the LTIM & MER Project Data Standard and will be enforced by the MDMS when data is submitted.

Turbidity measures will be recorded as mean turbidity per site per sampling event and matched to Light trap abundance data.

Drift net abundances will be expressed as densities; number of individuals per cubic metre of water filtered.

CPUE data at the level of the site (species by site abundance matrices) will be recorded.

Abundance data will be reported for each species as the mean CPUE for the site.

Quality Assurance/Quality Control

Quality control and quality assurance protocols are documented in the Quality Plan developed as part of the Monitoring and Evaluation Plan for all Selected Areas. QA/QC activities specific to this protocol include that the specific fisheries, national park and ethics permits are carried with the monitoring team while sampling.

5.6.3 Research

No additional research on fish larvae (Cat 1) will be undertaken as part of the MER project.

5.7 Fish Reproduction (larvae) (Category 3)

5.7.1 Monitoring

Overview and context

The delivery of environmental water is seen as a key way of enhancing the spawning and recruitment of native fish species (Murray-Darling Basin Commission 2004). The environmental and hydraulic conditions under which the spawning and recruitment of Murray-Darling fish takes varies across species (Humphries et al. 1999). These methods describe the monitoring approach for the Selected Area evaluation of fish breeding in response to Commonwealth environmental water, focussing on two broad groups of fish; small-boded 'opportunistic' fish, and large-bodied 'perodic' flow-dependent species (Humphries et al. 1999).

For small-bodied 'opportunistic' fish, the prevalence of slackwater environments characterized by low flows, warm temperatures, high food resources and microhabitat such as aquatic vegetation are considered key environmental factors amenable for spawning and recruitment (Humphries et al. 2006)(see Figure14). Monitoring the larval abundance and diversity of 'opportunistic' fish species will be undertaken across a gradient of rivers with differing hydrological variability, in order to assess the effect of CEWO delivered water on fish spawning. We hypothesize that environmental water delivery that seeks to increase the inundation of slackwater areas will increase the spawning and recruitment of native small bodied, opportunistic fish species.

For large-bodied 'periodic' flow-dependent species, high spring flows are considered to be key spawning cue (Figure 14). Monitoring of the eggs and larvae of silver and golden perch will be undertaken to detect the occurrence and magnitude of spawning in response to commonwealth environmental water. By monitoring the presence/absence and abundance of silver and golden perch eggs and larvae under a range of different hydraulic conditions, across rivers and across seasons, we aim to develop a predictive model that will look at what environmental factors trigger spawning in golden and silver perch in the Edward-Wakool Selected Area. These models will help to provide predictive capabilities for spawning success for these species under different environmental watering actions.

The process for evaluating Fish (Larvae) Selected Area questions is illustrated in Figure 14, with components covered by the protocol highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model.

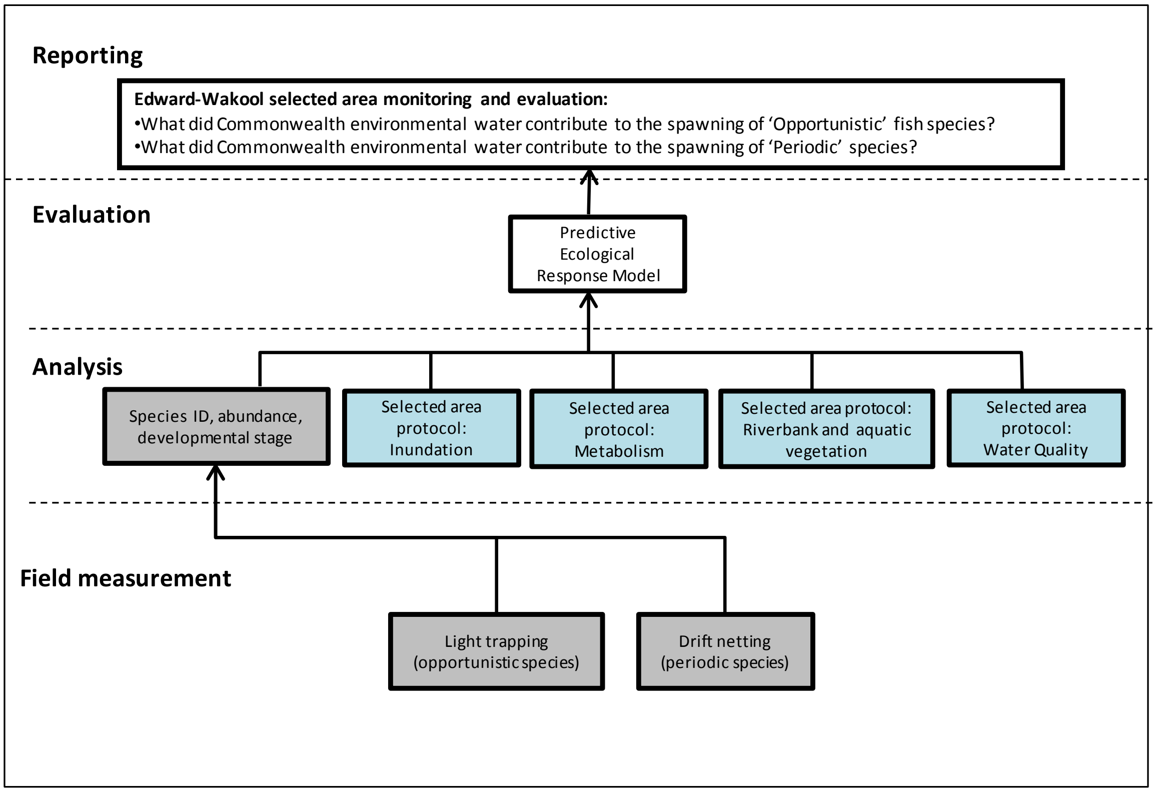

Figure 14. Schematic of key elements in Selected Area Monitoring and Evaluation - Fish larvae (Cat 3). Components covered by this protocol are highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model.

Indicators

- Abundance of small bodied 'opportunistic' larval fish
- Abundance of eggs and larvae of large bodied 'periodic' flow dependent fish

Location for monitoring

Opportunistic fish species

Sampling for the fish larvae of opportunistic fish species will take place at 5 sites in 4 hydrological zones: zone 1 (Yallakool Creek), zone 2 (upper Wakool River), zone 3 (Mid Wakool River, upstream of Thule Creek), and zone 4 (Mid Wakool River, downstream of Thule Creek). Note: Only 2 sites in zone 3 will need to be sampled as per the Fish (Larvae) standard methods (Cat 3). This is because a subset of the data collected from the three sites used in Fish (Larvae) Basin-level-evaluation will be used to make up the full complement of data required from Zone 3.

Periodic fish species
Drift nets will be set at 1 site in each of the following hydrological zones: zone 1 (Yallakool Creek), zone 2 (upper Wakool River) and zone 4 (mid Wakool River, downstream of Thule Creek). Data collected for Fish (Larvae) Basin Level evaluation (drift nets) from Zone 3 will be also used for Selected Area evaluation.

In addition to the drift net sampling taking place in zone 1 – 4 as described above, additional drift netting will take place in the Edward River downstream of Steven's Weir, near Deniliquin, as part of the integrated research project in the Edward River (see section 6). The location of these sites will be determined following consultation with CEWO and other stakeholders at the same time as reaches are selected for hydraulic modelling and vegetation (see section 6).

Timing and frequency

Opportunistic fish species

Light trap sampling for larvae of Opportunistic fish species will occur fortnightly, from September to February inclusive in zone 1, zone 2, zone 3 and zone 4. Each zone will be sampled for 1 night on each sampling event. This type of sampling will also capture other species, including more 'Equilibrium' fish species (e.g Murray Cod, sensu Humphries et al. 1999), that spawn every year independently of flow conditions.

Periodic fish species

To compliment the sampling of Periodic larval fish species for the Basin-Scale evaluation, drift net sampling for the Edward-Wakool Selected Area evaluation will also be undertaken on a fortnightly basis, between September and December of each year in zones 1, zone 2, zone 3 and zone 4

Responsibilities and collaboration

- Collaboration: This is a collaboration involving Charles Sturt University and NSW DPI Fisheries
- Field sampling: Field Technicians from CSU and NSW Fisheries will undertake the monitoring in the Wakool River and Yallakool Creek.
- Larval identification and sample processing: Nicole McCasker and John Trethewie(CSU)
- Data analysis: Nicole McCasker (CSU)
- Report writing: Nicole McCasker (CSU)

Field methods

Opportunistic fish species

In alignment with the gear used in Fish (Larvae) standard methods (Cat 1) for light trapping (Hale et al. 2014), modified quatrefoil light traps with 5 mm entrances and 3mm knot-to-know mesh will be used to sample fish larvae (as described in Humphries et al. 2002). Light traps will be deployed fortnightly at five sites in zones 1, 2, 3 and 4. Three light traps will be randomly allocated within each site, whereby 3 random GPS waypoints are used to locate the closest slackwater to each waypoint for the positioning of light traps. If no slackwater is available within 20 m either side of the waypoint, another random waypoint will be selected.

Light traps will be deployed late afternoon, and retrieved the following morning. Set and retrieval times will be recorded, so that relative abundance can be expressed as catch-per-unit-effort (CPUE). Each light trap will be baited with a yellow Cyalume 12 h light stick.

Upon retrieval, light traps will be rinsed down and entire samples will be preserved individually in 90% ethanol, and returned to the laboratory for processing.

Periodic fish species

In alignment with the gear used in Fish (Larvae) standard methods for Basin-Scale evaluation, drift nets constructed of 500 μm mesh, with an opening of 50 cm and tapering over 1.5 m to an opening of 9 cm will be used to collect eggs/larvae of golden and silver perch. On each sampling trip, Three, fixed station drift nets will be deployed at 1 site within each zone (zone 1, 2 and 4). Because the Edward River is much larger compared to the Wakool and Yallakool Rivers, a greater effort of drift net sampling will take place, with three drift nets to be deployed at 4 sites.

Drift nets will be positioned in the water with a moderate velocity, at locations within each zone where the discharge is concentrated through a narrow section of the river (a funnel effect). Each drift net will be fitted with an Oceanic Flow Meter to estimate the volume of water that has passed through the drift net during its deployment. Volume through the net will be estimated so that larval abundances in drift nets can be expressed as a density: number of individuals per m^3. Volume sampled by the net is estimated as $\pi r^2 \cdot v \ \cdot t$, where *r* is radius in metres, *v* is mean velocity in m s^{-1}, and *t* is time set in seconds.

Drift nets will be deployed late afternoon, and retrieved the following morning. Set and retrieval times will be recorded, so that relative abundance can be expressed as catch-per-unit- effort (CPUE). Upon retrieval, drift nets will be rinsed down and entire samples will be preserved individually in 70% ethanol, and returned to the laboratory for processing.

Laboratory methods

All eggs/larvae collected in the light trap and drift net samples will be identified to species, and enumerated. The developmental stage of each individual will also be recorded according to classifications of Serafini and Humphries (2004). Here, ontogeny is classified into seven key developmental stages: egg, yolksac protolarvae, protolarvae, flexion, post-flexion, metalarvae and juvenile/adult.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.7.2 Evaluation

Fish larvae (Cat 3) monitoring will address the Selected Area evaluation questions in table 16.

Table 16 Fish larvae (Cat 3) evaluation questions

Evaluation questions
Short and Long-term questions • What did Commonwealth environmental water contribute to the spawning of 'Opportunistic' (e.g. small bodied fish) species? • What did Commonwealth environmental water contribute to spawning in 'flow-dependent' spawning species (e.g. golden and silver perch)?

Selected Area question hypotheses

H_1 Spawning of opportunistic fish species, as measured by abundance of larvae, will increase either during or immediately following environmental water delivery, compared to nearby rivers not receiving environmental water (<1 year reporting).

H_2 Successful spawning of flow-dependent spawners such as golden and silver perch will occur either during or immediately following the delivery of CEWO environmental water that is delivered as high spring flows, compared to nearby rivers not receiving environmental water (<1 year reporting).

H_3 Total production of fish larvae during spawning season will be significantly greater in the rivers that received environmental freshes compared to those that did not (1-5 years reporting).

H_4 The magnitude of spawning in opportunistic fish species will be significantly influenced by key hydrological and physical chemical parameters including the amount and duration of slackwater habitat, water depth, instream aquatic vegetation (1-5 years reporting).

H_5 The successful spawning of flow-dependent spawners will be significantly influenced by key hydrological and physical chemical parameters including magnitude of discharge change, rate of discharge change, extent and duration of overbank flow, and temperature (1-5 years reporting).

Critical covariates

- For opportunistic fish species: temperature, area of slackwater inundated, velocity, depth and discharge, and whether the zone received environmental water
- For periodic fish species: temperature, rate and magnitude of discharge change, extent of overbank flow and duration, whether the zone received environmental water.

Data analysis and reporting

Spawning in opportunistic fish species

Light trap abundance will be expressed abundance of larvae collected at the site level. To do this, data from the three light traps per site will be pooled.

For event-based analysis, data will be analysed with a BACI style approach comparing larval abundance in zones that received environmental water to zones that did not receive environmental water; before, during and after environmental water releases.

For short (<1 year analysis), data will be analysed using a traditional ANOVA approach, to answer the question: Was the magnitude of fish spawning over the spawning season greater in hydrological zones that received environmental water compared to those that did not. Here the total number of larvae collected in light traps across the entire season will be used as the dependent variable, and hydrological zone used as the treatment factor.

For longer term (1-5 year analysis) trends: a hierarchical model (continuous modelling) will be used to look at what environmental factors drive spawning magnitude in the Edward-Wakool area. Independent variables that will be assessed in this model include a <u>mix of continuous variables</u> including temperature, season, and hydrological variables such area of slackwater within sites, velocity, depth and discharge, and <u>categorical variables</u> such as (e.g. hydrological zone, and whether zone received environmental water). This model will be important for understanding the mechanisms behind observed trends in spawning magnitude of small bodied fish, and thus help to provide predictive capabilities under different environmental watering actions.

The magnitude of spawning in fish is an important variable influencing the amount of recruitment taking place in native fish populations. Therefore, the data gathered in this cat 3 component will be important data that is used in a larger fish recruitment model (see Cat 3: Fish recruitment, section 5.9).

Spawning in periodic fish species

Eggs and larvae collected from drift nets will be expressed as 'catch-per-unit-effort' (CPUE), where the units are density of eggs/larvae (number of individuals collected per drift net per volume of water passed through the net). Density data will be analysed at the site level, meaning that data from the three drift nets per site will be pooled.

For short (1 year) analysis, data will be analysed using a more traditional ANOVA approach, to answer the question: Was the spawning magnitude of golden and silver perch over the entire spawning season greater in hydrological zones receiving environmental water compared to those that did not. Here the total density of eggs/larvae collected in drift nets across the entire season is used as the dependent variable, and hydrological zone used as the treatment factor.

For longer term (1-5 year) analysis trends, a hierarchical model (continuous modelling) will be used to look at what environmental factors influence the successful spawning of golden and silver perch spawning in the Edward-Wakool area. Independent variables that will be assessed in this model include a <u>mix of continuous variables</u> including temperature, season, and hydrological variables such as rate of discharge change, magnitude of discharge change, extent of overbank flow and duration, as well as categorical variables such as hydrological zone, and whether the zone received environmental water. These models will be important for understanding the mechanisms behind both the success and magnitude of spawning in flow-dependent spawners like golden and silver perch, and help to provide predictive capabilities of spawning for these species under different environmental watering actions in the Edward-Wakool Selected Area.

The magnitude of spawning in fish is an important variable influencing the amount of recruitment taking place in native fish populations. Therefore, the data gathered in this cat 3 component will be important data that is used in a larger fish recruitment model for golden and silver perch (see Cat 3: YOY Fish recruitment methods, section 5.9).

5.7.3 Research

New research on fish reproduction will be undertaken as part of the integrated research project in the Edward River (see section 6).

5.8 Fish recruitment (Category 3)

5.8.1 Monitoring

Overview and context

The early stage of the life of a fish is when the highest mortality occurs. Recruitment, or survival of eggs/larvae to young-of-year life-history stage, is a fundamental process required to sustain fish populations. Previous data from the Edward-Wakool system (Watts et al. 2012; 2013) demonstrate that recruit stages of large-bodied fish will not be sampled effectively under proposed Cat 1 boat electrofishing and larval fish sampling methodologies. The proposed monitoring aims to develop an annual index of recruitment for young-of-year (YOY) juveniles and age-class 1 (1+) fish, specifically targeting Murray cod, golden perch and silver perch. Daily and annual age-length curves developed from recruit stage fish will fill gaps contributing to Cat 1 otolith age requirements.

This component aims to develop a recruitment index for young-of-year (YOY) and age-class 1 (1+) fish across a range of species and will develop age-length growth models for target species including Murray cod, golden perch and silver perch. The age-length data will contribute to Cat 1 age and growth requirements by providing aged samples of fish less than 2 years old and will provide an annual index of fish recruitment for large bodied species that will not otherwise be available as part of the proposed standard methodology.

A gap in the current proposed Cat 1 methodology is a targeted monitoring programme to understand changes in fish recruitment in response to Commonwealth Environmental Watering actions. The standard methodology for sampling larvae, an indicator of adult reproduction, does not target or effectively sample young-of-year fish of large-bodied species including Murray cod, golden perch and silver perch. Furthermore, annual Category 1 Fish River monitoring is targeted only in zone 3 of the Edward-Wakool system. This Category 3 method addresses the spatial limitations of the Category 1 approach, and specifically addresses questions regarding fish recruitment.

The process for evaluating YOY Fish Recruitment questions is illustrated in Figure 15, with components covered by the protocol highlighted in grey. Components highlighted in blue are required for the predictive ecological response model.

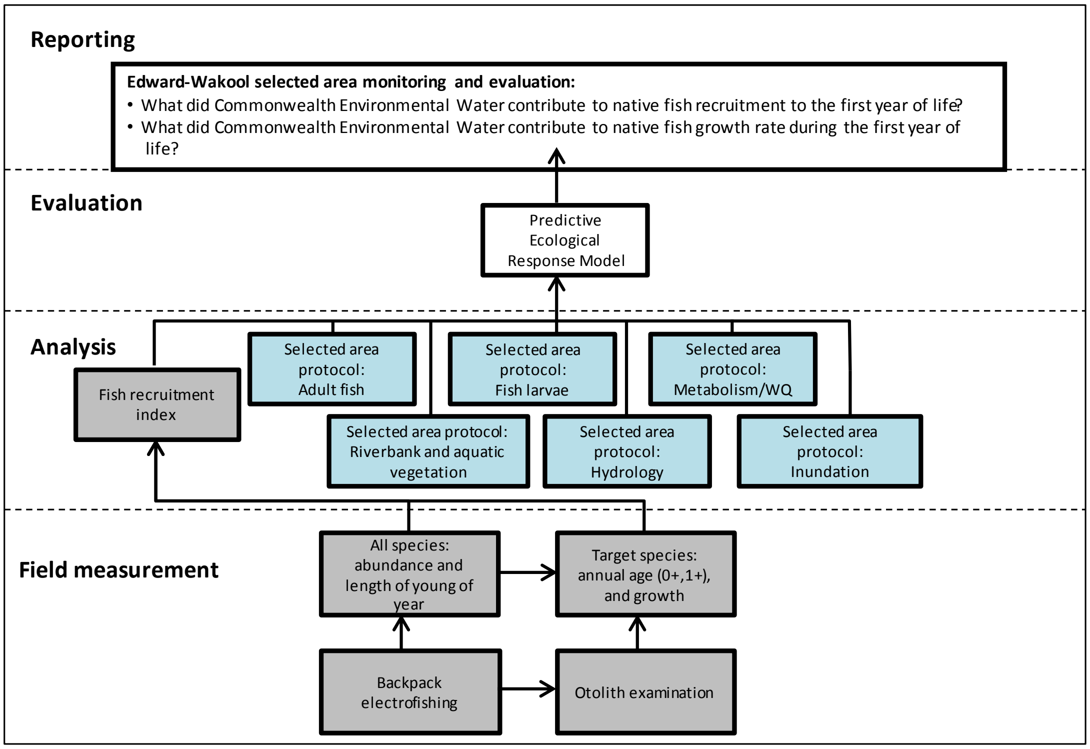

Figure 15 Schematic of key elements in Selected Area Monitoring and Evaluation – Fish recruitment. Components covered by this protocol are highlighted in grey. Components highlighted in blue are required for the predictive ecological response model**.**

Indicators

Two annual recruitment indices and one index of annual recruit growth will be developed for Murray cod, golden perch and silver perch in each zone:

- Recruitment index 1: Annual relative abundance of YOY juveniles:
- Recruitment index 2: Annual relative abundance of 1+ fish
- Recruit growth: Annual variation in length of recruits (YOY and 1+)

Critical covariates

Species, area of inundation, year, zone, temperature, adult CPUE, ecosystem metabolism, invertebrate biomass and annual flow parameters.

Location for monitoring

Monitoring of YOY fish recruitment will be undertaken in zone 1 (Yallakool Creek), zone 2 (upper Wakool River), zone 3 (mid Wakool River upstream Thule Creek) and zone 4 (mid Wakool River downstream Thule Creek.) with four sites per zone.

Timing and frequency

Targeted sampling for recruits will occur between January and April at which point fish hatched in October-December that year (YOY) and the previous year (1+) will be targeted.

Responsibilities

- Collaboration: This is a collaboration involving Charles Sturt University and NSW DPI Fisheries.
- Planning and organizing field trips, maintaining equipment, conducting fish sampling using boat electrofishing, backpack electrofishing fishing, setlines and standardised angling: John Trethewie (CSU) and Field Technicians (NSW DPI)
- Extracting and mounting otoliths: Fish Aging Services, Queenscliff
- Lab processing of otoliths: Fish Aging Services, Queenscliff
- Otolith age estimates, analysis and reporting: John Trethewie (CSU)

Field methods

Four sites will be sampled in each zone between January and April. Sites will be sampled in random order among zones. Sampling will be targeted in and around coarse woody debris, overhanging vegetation and other physical structure that may provide cover for young fish.

Each sampling occasion and site will consist of boat or backpack electrofishing depending on depth, ten setlines with two baited hooks per line and standardised angling to sample young individuals of large-bodied species.

Juveniles of all species will be identified enumerated and measured in the field. Otoliths from estimated young-of-year, 1+ and 2+ fish of each species including Murray cod, golden perch and silver perch will be retained for annual aging.

Laboratory methods

Annual aged otoliths will be extracted and embedded in a polyester resin, sectioned to approximately 100 µm thick, mounted on a microscope slide and polished with lapidary film. Each sample will be aged once by an internal reader (John Trethewie) and twice by the Fish Ageing Services. Digitized photographs of each otolith and each annulus reading will be recorded. The final age estimate will be determined by using the matching readings and samples with low reading precision will be discarded (Campana 2001).

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.8.2 Evaluation

Fish recruitment monitoring will address the Selected Area evaluation questions in table 17.

Table 17 Fish recruitment evaluation questions

Evaluation questions
Short and Long-term questions • What did Commonwealth environmental water contribute to native fish recruitment to the first year of life? • What did Commonwealth environmental water contribute to native fish growth rate during the first year of life?

Selected Area Hypotheses

We will test two hypotheses:

- H_1: Annual recruitment of YOY and 1+ Murray cod, golden perch and silver perch will be highest in years with increasing area and duration of inundation.
- H_2: Growth rate of YOY and 1+ Murray cod, golden perch and silver perch will highest in years with increasing area and duration of inundation.

Data analysis and reporting

Recruitment indices of YOY and 1+ juvenile Murray cod, golden perch and silver perch will be calculated from catch per unit effort of samples collected from boat and backpack electrofishing, setlines and standardised angling.

Raw catch per unit effort for recruitment indices will be examined using a Generalized Linear Mixed Effects Model (GLMM) incorporating temporal, spatial and abiotic factors including flow related parameters and inundation area model estimates for each zone and year over the five year project duration. Factors influencing variation in recruit length after removing the effects of age will also be examined using a GLMM incorporating the same factors.

Estimates of recruit age will be derived from age-length models in individuals where otoliths were not extracted. The trajectory of change (positive, neutral, negative) in recruit growth will be estimated from GLMMs to evaluate effect of Commonwealth environmental water.

Reporting will include the three annual indicators (two annual recruitment indices and one index of annual recruit growth) for Murray cod, golden perch and silver perch within each zone.

- Recruitment index 1: Annual relative abundance of YOY juveniles
- Recruitment index 2: Annual relative abundance of 1+ fish
- Recruit growth: Annual variation in length of recruits (YOY and 1+)

Discussion will focus on whether annual recruitment and growth indices were affected by changes in flow conditions and to what extent Commonwealth environmental water contributed these changes.

5.8.3 Research

No additional research on fish recruitment will be undertaken as part of the MER project.

5.9 Fish River (Category 1)

5.9.1 Monitoring

Overview and context

These standard methods describe monitoring required for the Basin-scale evaluation of the response of river fish to Commonwealth environmental water. The methods describe the sampling design and protocol for small- and large-bodied fishes in river channels for the LTIM Project. The process for evaluating these questions is illustrated in Figure 16, with components covered by this protocol highlighted in blue.

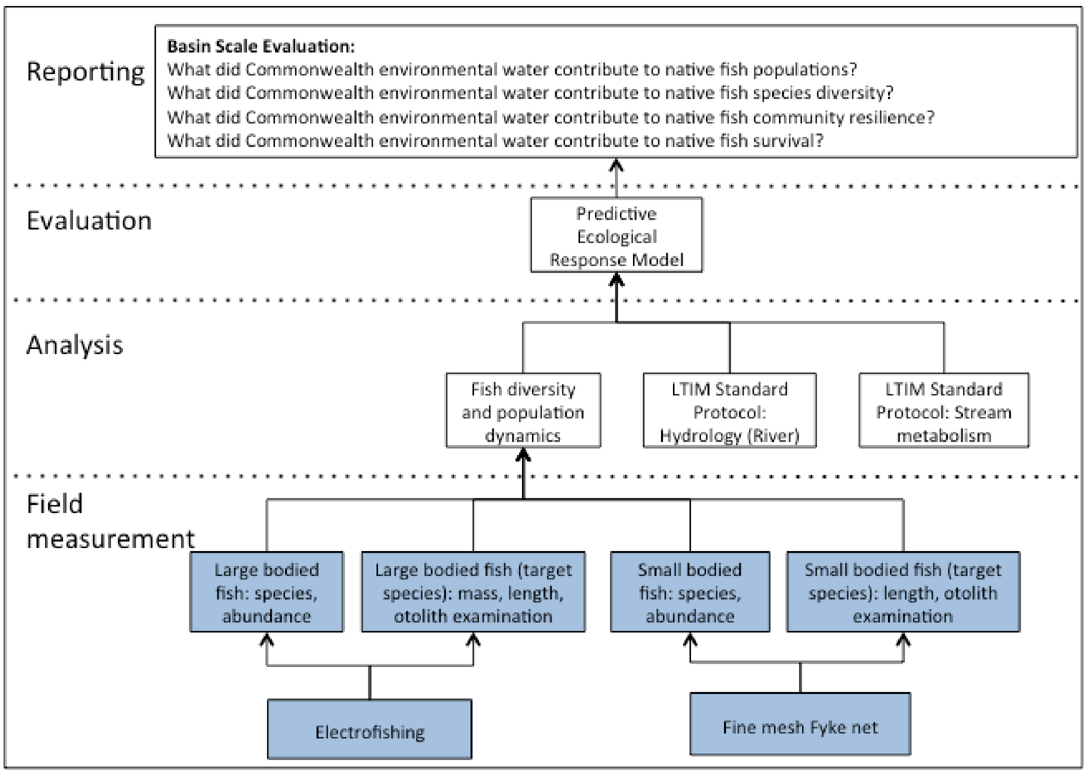

Figure 16 Schematic of key elements in LTIM Project Standard Protocol: Fish (River) – Cat 1. Components covered by the Fish (river) Cat 1 methods are highlighted in blue.

Indicators

This protocol describes sampling once each year during autumn to measure:

- Catch-Per-Unit-Effort (CPUE) of each fish species for:
  - Electrofishing
  - Small-meshed fyke nets
- Population structure data for target species:
  - Length
  - Weight
  - Approximate age structure (from otolith examination)

Location for monitoring

Monitoring for Fish (River – Cat 1) will take place in Zone 3 (Mid Wakool River, upstream of Thule Creek).

Timing and frequency

The channel sites of each Selected Area will be sampled once each autumn (March-May inclusive).

Responsibilities

- Collaboration: This is a collaboration involving NSW DPI Fisheries and Charles Sturt University.
- Field sampling: NSW DPI Fisheries staff and CSU Technical Officer
- Data entry and management, Data analysis and reporting: Fisheries NSW project staff based at Narrandera Fisheries Centre (Thiem, Wright, Smith, Rehwinkel) will coordinate and schedule the sampling, data management, analysis and reporting for this component; with assistance from other team members as required.

Methods

The following sections outline the methodology for fish (river) Cat 1 according to Hale et al. (2014) and also fish (river) Cat 3, with inclusions of Location for monitoring, Responsibilities and Health and Safety Plan subsections. The fish (river) – Cat 1 methodology will be used for Basin-scale evaluations, however part of the data obtained will also be used to address Selected Area questions as part of the Fish (River) – Cat 3 methodology.

Protocol for establishing sites

LTIM Project for Basin-scale evaluation adopted a hierarchical approach to sample design (Figure 17). The spatial hierarchy for fish (river) monitoring is as follows:

- Selected Area
    - Zone
        - Site

Zone placement within Selected Areas

A ‘zone’ is a subset of a Selected Area that represents a spatially, geomorphological and/or hydrological distinct unit at a broad landscape scale. For example, separate river systems, sub-catchments or large groups of wetlands.

For Basin-scale evaluation, Zone 3 will be used. Following the recommendations of Hale et al. (2014):

- Different zones within Selected Areas represent spatially-, geomorphologically- and/or hydrologically-distinct units;

- Zones must be likely to receive Commonwealth environmental water at least once in the next five years;
- Zones must have an expected outcome related to the indicator in question (in this instance fish);

For Basin-scale analysis one zone (Zone 3) will be monitored within the Edward-Wakool Selected Area. The zone selected for Basin-scale data will have the following characteristics:

- The zone will be situated on a single river channel within a Selected Area, and the zone should contain channel habitat that is generally representative of the Selected Area as a whole;
- Within the channel of this zone there will ideally be a flow gauging station measuring height and discharge (otherwise a manual gauging station must be established (see LTIM Project Standard Protocol: Hydrology (River);
- The zone will contain relatively high abundances of the target species to maximise potential to obtain powerful age- or stage-structure data.
- This zone will be among the zones of an Selected Area most likely to receive Commonwealth environmental water, towards some significant change in river hydrology during that Commonwealth environmental water delivery event;
- The zone will contain channel habitat that can be readily accessed—either by boat or car—for sampling using the full suite of active and passive gears detailed below;

Site placement within zones

A 'site' is defined as follows:

- An 800 m reach of channel within a zone
- Site location for channel sampling will be fixed throughout the project.
- Each site will be accessible and be representative of the zone.
- Ideally, each site will coincide with a pre-existing discharge and river height gauging station. In the event a site does not contain a gauging station, new gauging stations (and associated rating curves etc.) may have to be established.
- Each site will not be within 1 km of a significant tributary and/or distributary.

The below specifications for site number and distribution will be applied:

- Ten channel sites will be located within the zone targeted for Basin-scale monitoring/analysis.
- All ten sites for Basin-scale data will be located on a single channel.
- These sites will be distributed randomly throughout the zone selected for Basin-scale data collection, such that the samples collected are representative of that zone. However, they will not be spread over a distance farther than 100 km.

Sample placement within sites

A sampling grid will be established within each site to ensure individual samples can be randomly sampled from that site, and are therefore representative of that site as a whole. Sampling will be random with respect to the environment to avoid temporal and spatial biases.

Hale et al. (2014) propose that a totally random sampling design is most appropriate for detecting flow-induced temporal trends within zones and Selected Areas, and spatiotemporal trends among zones and Selected Areas. Each 800 m site is subdivided by fixed transects spaced 50 m apart. Points of intersection between transects and the river bank define the sampling grid (Figure 17).

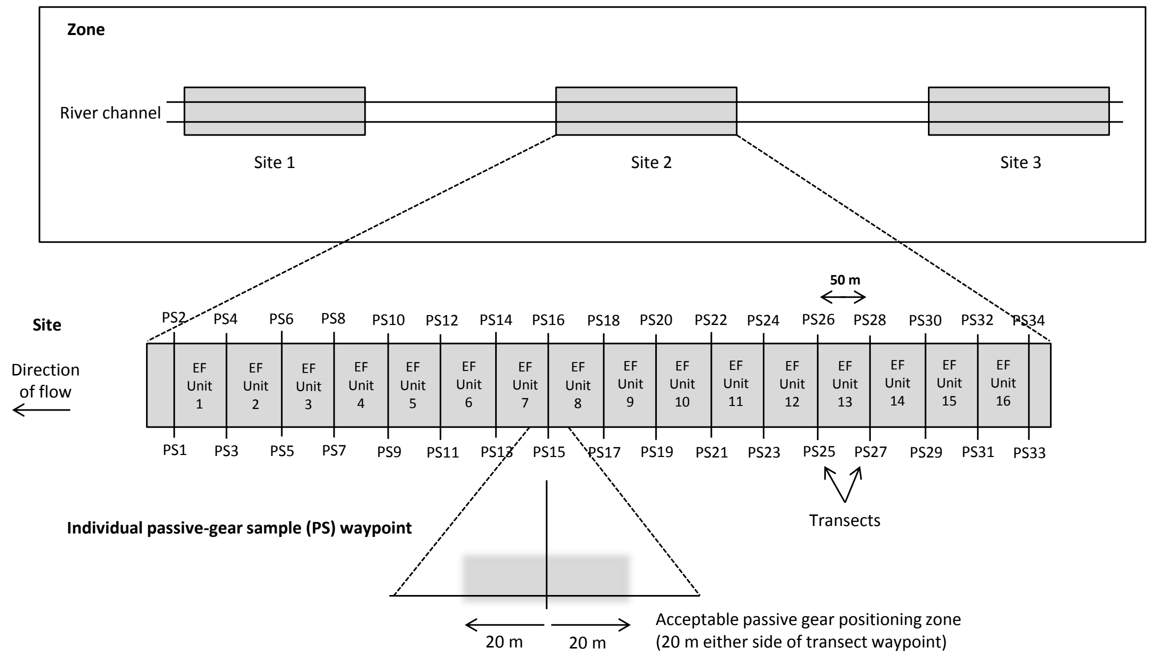

Figure 17 Diagram of hierarchical sample design illustrating zones, sites and sample locations.

The sample design defines two key sampling locations: electrofishing (EF) units (16 in total), and passive-gear sample (PS) waypoints (34 in total). Use of these EF units and PS waypoints will be explained below.

To establish the PS grid, each PS waypoint will be saved in a GPS, so that the GPS can be used to locate each PS waypoint over the monitoring period. That is, it is not necessary to establish visible transects and physically label each PS waypoint (e.g. a stake, floats or flagging tape).

Representative species from life-history guilds

Fishes belonging to different life history guilds may respond in different ways to managed and natural flows. Towards a more complete knowledge of fish population response to flows, monitoring will target representatives of the three primary life history guilds: equilibrium, periodic and opportunistic. Additional data will be collected from these target species.

Protocol

The following protocol from Hale et al. (2014) will be followed:

- Within the Selected Area we will identify six target species, two from each guild. Within each guild, one of the two species will be fixed, and common to all Selected Areas (as much as practicable), while the identity of the other species will be flexible across Selected Areas.
- The equilibrium life history species targeted for detailed data collection will be Murray cod.
- Across all Selected Areas the periodic life-history species targeted will be golden perch. Across all Selected Areas the opportunistic life-history species targeted will be carp gudgeon, *Hypseleotris* spp.

Sampling protocol

Equipment

- Backpack or boat electrofisher, including nets, storage and processing equipment;
- Ethics and fisheries permits from relevant institutions;
- GPS;
- GPS coordinates of site structure (PS waypoints and EF units)
- PS waypoints determined using random number generator (sample locations within sites);
- 12 fine-mesh fyke nets (10 for use; 2 spare) per site;
- Anchoring devices for fyke nets (stakes, chains, etc.);
- Large (1000 mm) and small (300 mm) measuring boards;
- Scales, either quality hanging scales with bag or bench scales with bucket/tray for fish;
- Data sheets

Large-bodied species

Sampling

Large-bodied species will be sampled using either boat or backpack electrofishing, depending on the river height.

Sustainable Rivers Audit (SRA) electrofishing protocol will be a subset of what is described here, so that data collected as part of the CEWO MER Project can be compared and contrasted with SRA large-bodied fish data. We will not collect small-bodied species for processing using electrofishing, but collect all stages (including juveniles) of large-bodied species for processing.

Herein, 'small-bodied' species are those belonging to the following families:

- Galaxiidae;
- Retropinnidae;
- Atherinidae;
- Melanotaeniidae;
- Ambassidae;

- Nannopercidae;
- Eleotridae;
- Gobiidae;
- Poecilidae;

All other fish families of the Basin are considered ‘large-bodied’.

The following methods are suggested by Hale et al. (2014) and will be followed, with some adjustments to standard protocol (as described in a section below).

- The entire 800 m site will be electrofished. Within each electrofishing unit of a site (EF unit; Figure 17) two ‘shots’ of 90 s ‘on-time’ should be carried out. This results in a total of 2880 s (48 min on-time) for each site. No more than 180 s of shocking will be allocated to each EF unit, such that electrofishing effort is spread out across the entire site, thus giving a more random sample with respect to the (site’s) environment. Note that, *within* EF units the location of shots is left to the discretion of the service provider.
- If boat electrofishing alone results in a sample biased towards larger and/or older individuals, then effort may be split in half, across both boat and backpack methods. For example, 50% of the EF units might be shallow enough to be intensively fished (still 180 s) with backpack electrofishing, thus enabling fishers to target the shallower (< 40 cm deep), more structurally complex habitats where 0+ and 1+ individuals might reside. Alternatively a certain proportion of the 16 (EF units) x 2 (90 s shots per EF unit) = 32 shots may be allocated to backpack electrofishing the shallow margins.
- It is difficult to standardise electrofishing across areas towards meeting the objective of a robust sample that is representative of the population present. Once a certain ‘balance’ or partitioning of boat and backpack electrofishing is devised—within the constraints of the general ‘shot structure’ laid out above—the design will be maintained over the entire five years.

Processing - electrofishing

For every individual belonging to a target large-bodied species, the following will be obtained or implemented:

1. Identified to species;
2. Total (TL; round or square caudal fin species) OR fork (FL; fork-tailed species) lengths, in millimetres (mm);
3. Mass in grams (g) (use scales that have been recently calibrated);

If > 20 individuals are obtained within a 90 s shot, the above information will be recorded on a random sub-sample of 20 individuals only. The random sub-sample will be the first 20 individuals sampled during a 90 s shot. That is, if 20 individuals from a target species are obtained in less than 90 s, sampling will cease until the above statistics are obtained, or we will separate the first 20 individuals from those caught subsequently during that 90 s shot.

Non-target species will be identified and enumerated; lengths and masses of these non-target species will not be measured. All individuals (including alien species) will be returned to the water.

Small-bodied species

Sampling

Small-bodied species will be sampled using a passive technique only; fine-mesh fyke nets. The fine-mesh fyke nets (2 mm mesh) should be double wing (each wing: 2.5 m × 1.2 m), with a first supporting hoop covered by a plastic grid (5 cm x 5 cm) to keep large aquatic vertebrates out of the trap.

A random number generator will be used to randomly select a subset of 10 PS waypoints from the total of 34. A waypoint encompasses a total of 40 m of bank (20 m either side of specific waypoint), so we will endeavour to find the point on the bank as close to the exact waypoint as possible. The purpose of this system is to ensure sampling is random with respect to the environment. If it is impossible (in the strict sense, not just inconvenient) to set a fyke net at a certain waypoint (current is too fast; bank is far too steep; water too deep; too many emergent macrophytes to be an effective fish sample), then an adjacent, unoccupied waypoint will be used.

Fine-mesh fyke nets will be set in the afternoon and retrieved the following morning. Set and retrieval times will be recorded for each individual net/trap, so that abundances can be expressed as rates.

Past monitoring programs have not used fine-mesh fyke nets in the channel. In many cases, however, fine-mesh fyke nets can be set in certain locations within river channels. Fine-mesh fyke nets sample a much broader subset of the overall fish community than minnow traps, and are effective for estimating relative abundances of active, pelagic species such as smelt and hardyhead. Furthermore, use of fyke nets in the river channel and in wetlands may allow comparisons of community and population structure among these two major habitat types.

Fine-mesh fyke nets will be set with the cod end facing the current, so that water velocity is deflected around the net and wings (Figure 18). For the net to be effective both wings and the cod end need to be anchored to the bottom very well using steel stakes. So that sampling effort is held constant across nets, the wings will have an aperture of 1 m.

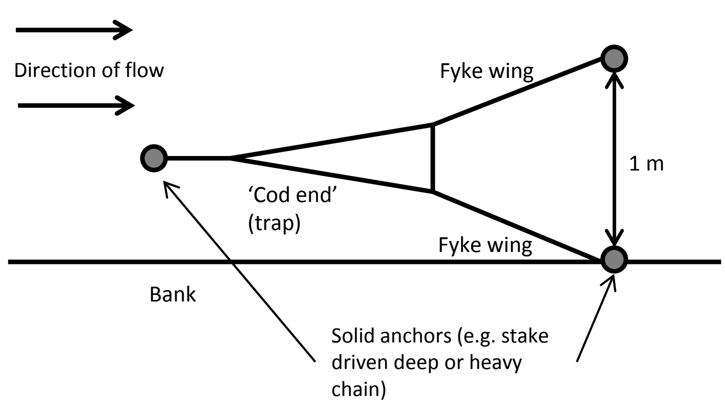

Figure 18 Diagram indicating the positioning of fine-mesh fyke nets in river channels, relative to the bank and direction of water flow. Cod-end should face upstream so as to not collect debris and act as a water velocity 'parachute'**.**

Processing

The following measurements will be made for non-target, small-bodied species:

1. Identify (to species) and enumerate all individuals. Random sub-samples will be used if nets capture too many fish for complete processing, as long as proportion of total sample sub-sample represents is recorded;

Further measurements are required for those small-bodied species targeted as part of the opportunistic guild:

2. Obtain total (TL; round or square caudal fin species) OR fork (FL; fork-tailed species) lengths, in millimetres (mm), of up to the first 10 individuals from both target species, from each net. We will ensure the first ten are randomly selected from the overall sample. This may be achieved, for example, by using an aquarium net to 'blindly' sub-sample from a bucket until 10 individuals have been measured.

Adjustments to standard protocol

Annual sampling for Basin-scale analysis within zone 3 will follow the standard methods for riverine fish as specified by Hale et al. (2014). However, in order to improve comparability with historical data (SRA, NSW DPI) and increase sampling effectiveness for target species the following additional protocols and augmentations at each site have been proposed;

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.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.9.2 Evaluation

Fish River monitoring will address the Basin scale and Selected Area evaluation questions in table 18.

Table 18 Fish river evaluation questions that are relevant to the Edward-Wakool Selected Area

Evaluation questions
Basin scale evaluation questions
Long term questions • What did Commonwealth environmental water contribute to native fish populations? *Short term questions* • What did Commonwealth environmental water contribute to native fish reproduction? • What did Commonwealth environmental water contribute to native fish survival?

Selected Area Hypothesis

H_1 The Edward-Wakool fish community responds to large-scale hydrological changes (floods and drought), and Commonwealth environmental water can contribute to the protection, maintenance and enhacement of the native fish community through strategic water delivery.

Data analysis and reporting

Relative abundance estimation

Abundances will be recorded as 'catch-per-unit-effort' (CPUE). Data will be structured in spreadsheets by individual 'samples', which are individual net hauls, or abundances within discrete electrofishing shots. Units will depend on sampling method—electrofishing versus trapping. Electrofishing CPUE will have units number of individuals per unit on-time for each shot. Passive trap CPUE units will be number of individuals per net per hour.

Population structure data for target species

Additional data will be collected for target species:

- Total length or fork length (mm), depending on species.
- Mass (gm).

Community data

The Basin Team (CSIRO) will also be conducting Basin-scale analyses of community response to Commonwealth environmental water. For these analyses they require CPUE data at the level of the site (species by site matrices) corresponding to each sampling method.

Data management

All data provided for this indicator will conform to the data structure defined in the LTIM Project Data Standard (Brooks and Wealands 2014). The data standard provides a means of collating consistent data that can be managed within the LTIM Project Monitoring Data Management System (MDMS).

The spatial unit for which data is reported for this indicator is known as an 'assessment unit'. The assessment unit for this indicator is: the site (river section).

Each row of data provided for this indicator will identify the assessment unit, the temporal extent of the data and a number of additional variables (as guided by this standard method). The exact data structure for this indicator is maintained and communicated in the LTIM Project Data Standard and will be enforced by the MDMS when data is submitted.

Quality Assurance/Quality Control

Quality control and quality assurance protocols are documented in the Quality Plan developed as part of the Monitoring and Evaluation Plan for all Selected Areas. QA/QC activities specific to this protocol include:

- Electrofishers will be experienced operators of units. They will be supervised by Senior Operators on-site, and have obtained their electrofishing certificates through a reputable course.
- Monitoring and Evaluation Providers will have relevant boat licenses.
- Monitoring and Evaluation Providers will have specific fisheries and ethics permits with them while sampling.
- Fyke nets will be checked for holes in either wing- or cod-ends prior to every field trip. Any net with a hole will be repaired or replaced.

5.9.3 Research

No new research on Fish River (Cat 1) indicator will be undertaken as part of the MER program.

5.10 Fish River (Category 3)

5.10.1 Monitoring

Overview and context

Detecting valley-scale native fish changes in response to hydrological regimes

River regulation reduces habitat complexity, alters the timing and magnitude of flows necessary for critical life stages for fish, reduces in- and off-channel connectivity and promotes invasion of generalist alien species (Bunn and Arthington 2002). The use of Commonwealth environmental water to restore more natural flow characteristics can benefit native fish by increasing reproduction opportunities, stimulating in-stream migration to trigger a reproduction response or improving food availability which can translate to improved condition and larval survival (Humphries et al. 1999, Humphries et al. 2002, King et al. 2003). Further, many native fish species have been known to opportunistically use wetlands and floodplains for nursery habitat and to benefit from increased food availability (Lyon et al. 2010), and the delivery of Commonwealth environmental water can promote connectivity with these off-channel habitats.

The Edward-Wakool Selected Area presents an opportunity to understand flow-related outcomes because delivery options are flexible and controlled. We have designed a monitoring program that will enable 1) in-channel long-term broad scale trends in fish community composition in relation to sequential hydrological events and the long-term hydrological regime. A broad scale fish community monitoring program will be undertaken in years 3 that will report on changes in native and alien species abundance and biomass using Sustainable Rivers Audit health indices. The design will be strengthened by having access to long term data collected (at some sites up to 20 years of data) and will extend the existing datasets at each of these sites.

Background

Dryland rivers in Australia are characterised by unique ecological communities that have adapted to extreme hydrological regimes, such as extensive flooding interrupted by long periods of low flow and drought (Humphries et al. 1999, Thoms and Sheldon 2000). Following European settlement, the majority of fish communities within these systems have undergone severe declines, and the alteration of natural flow regimes has contributed significantly. Flow regulation reduces habitat complexity, alters the timing and magnitude of flows necessary for critical life stages for fish, reduces in- and off-channel connectivity and promotes invasion of generalist alien species (Bunn and Arthington 2002). The use of Commonwealth environmental water to restore more natural flow characteristics can benefit native fish by increasing reproduction opportunities, by stimulating in-stream migration to trigger a reproduction response (Humphries et al. 1999, Humphries et al. 2002, King et al. 2003) or improving food availability which can translate to improved condition and larval survival. Further, many native fish species have been known to opportunistically use wetlands and floodplains for nursery habitat and to benefit from increased food availability (Lyon et al. 2010), and the delivery of Commonwealth environmental water can promote connectivity with these off-channel habitats.

Environmental water delivery has previously provided detectable short-term changes in fish communities in the Edward-Wakool system. For example, Gilligan et al. (2009) examined changes to the fish community before, during and after a 30 GL environmental flow. The objective of the flow was to sustain existing populations by improving water quality in deteriorating conditions during an extreme drought. Reproduction was triggered in Murray-Darling rainbowfish (*Melanotaenia fluviatilis*) and un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*), although there was no change detected in the abundances of Murray cod or silver perch (*Bidyanus bidyanus*) (Gilligan et al. 2009). Following the environmental water release, the abundance of golden perch and carp gudgeon (*Hypseleotris* spp) was found to decline (Gilligan et al. 2009). These outcomes were all based on a short-term before and after comparison. Whether these benefits contributed to overall long term changes was not determined.

It is likely that short term changes in fish community redistribution during environmental water delivery are driven by movement, localised changes in hydraulic and structural habitat availability and food resources. However, changes in fish community composition at the reach and valley scale are also likely to occur in response to environmental water delivery as indicated in the landscape fish diversity CED (MDFRC 2013). These landscape-scale changes are manifested by increasing biomass across the system, overall improvements to fish condition, the presence of recruitment, positive changes in native fish abundance and increased species richness. For example, landscape fish diversity over longer time scales (>10 years) is influenced by available habitat, connectivity and disturbance, which are mainly influenced by the interactions between flow and geomorphology. Providing greater access to habitat through connectivity is achievable using environmental water and will lead to a detectable change, at the valley scale, over the medium-long term. These are expected and measurable changes. The ability to detect change is often influenced by the overall objective of water delivery. Changes in landscape-scale fish condition are generally only applicable if environmental water delivery occurs to drive these impacts, and that only occurs when water holdings are high.

During periods when holdings are low, Commonwealth environmental water can be used to prevent deterioration of fish condition, to encourage dispersal to refuge sites and to sustain populations already present within refuge areas. For instance, a previous Commonwealth environmental water allocation in the Edward-Wakool river system successfully prevented a hypoxic blackwater event and protected many fish when water was released from irrigation escapes into the upper Wakool River and Yallakool Creek. Many fish survived in the area where water delivery took place, whilst many thousands of fish perished elsewhere.

The delivery of Commonwealth environmental water can also influence native fish reproduction directly by providing cues that stimulate reproductive behaviour or provide access to suitable available habitat. Likewise, the delivery of Commonwealth environmental water to drive fish recruitment outcomes can therefore be influenced indirectly by:

1. The provision of food,
2. Increasing available habitat,
3. Promoting suitable water quality,
4. Facilitating connectivity and dispersal

We have designed a monitoring protocol capable of detecting the changes likely to occur to the fish community structure in the Selected Area. The design enables the evaluation of fish community changes over:

- Medium term (1-5 years; recruitment and young of year abundance, fish condition, redistribution); and
- Long-term (5+ years; species richness, abundance and biomass).

The design will also enable comparison of the community structure with long term trends by including existing long term sites.

Basin plan objective and outcome

- Biodiversity (Fish species diversity)
- Resilience (Individual survival and condition)

The process for evaluating these questions is illustrated in Figure 19, with components covered by the protocol highlighted in grey. A modified CED is presented in Figure 20 and 21.

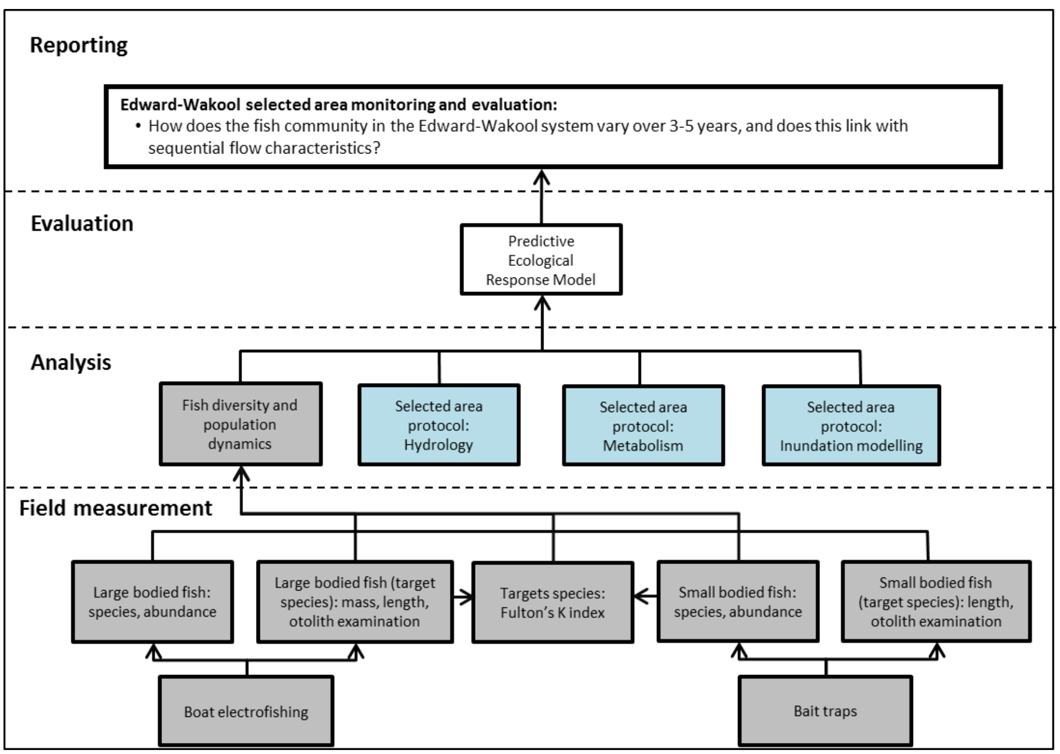

Figure 19. Schematic of key elements in Selected Area Monitoring and Evaluation – Fish (river) – Cat 3. Components covered by this protocol are highlighted in grey. Components highlighted in blue are also required for the predictive ecological response model.

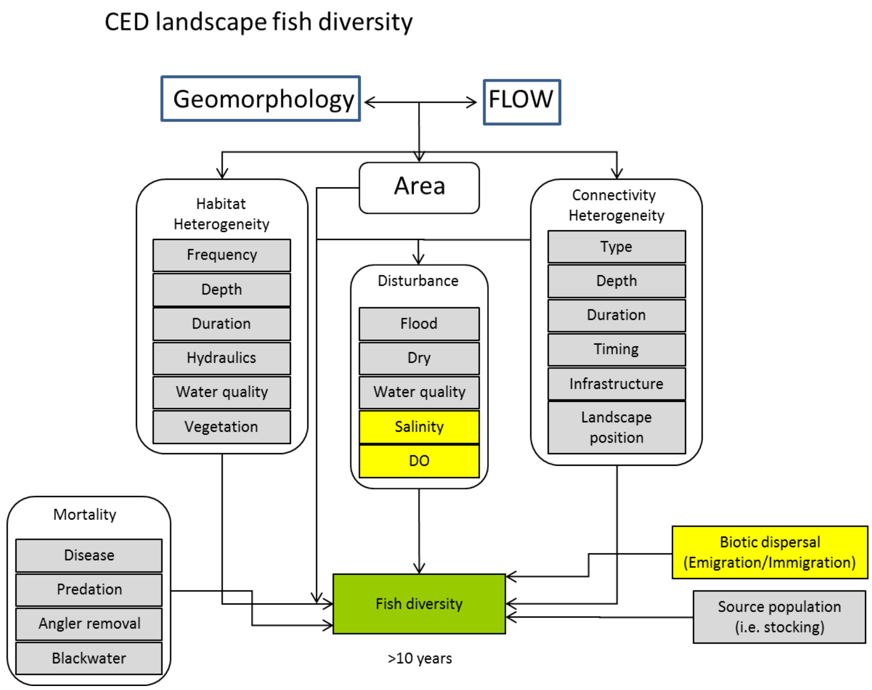

Figure 20. Modified landscape fish diversity cause and effect diagram. Yellow boxes indicate other CED's.

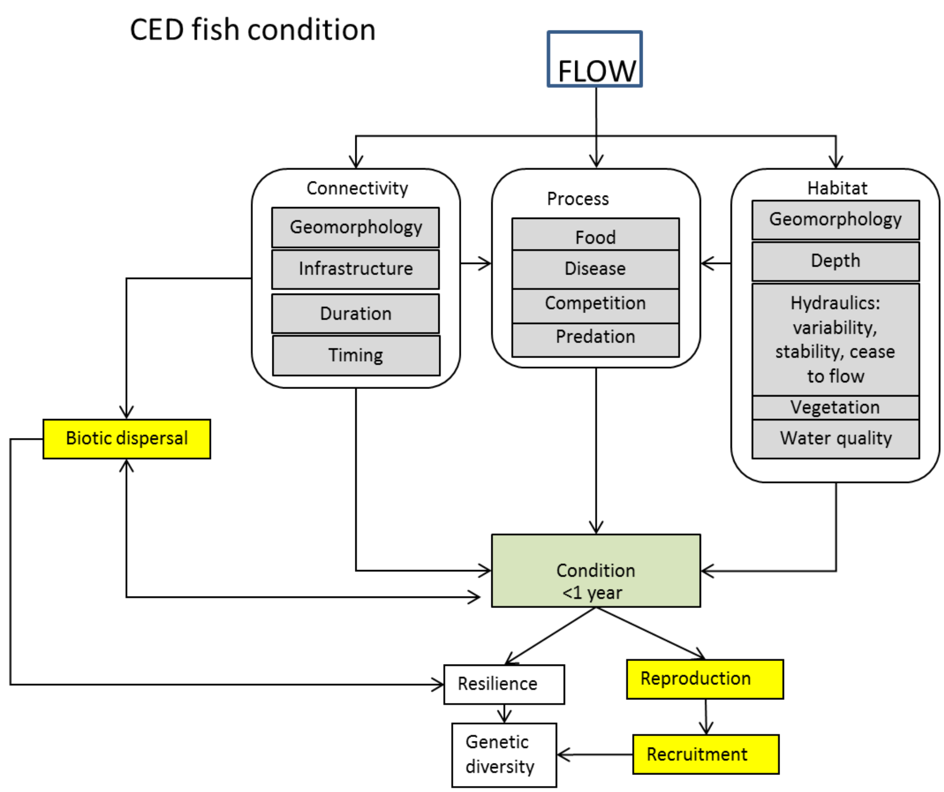

Figure 21. Modified Fish condition cause and effect diagram depicting the influences of flow. Yellow boxes indicate other CED's.

Indicators

- CPUE of fish, length of fish, weight of fish, spatial distribution
- *Covariates:* Hydrology: (discharge, Δdischarge, height/level, wetted area, connectivity); water quality: temp, DO

Locations for monitoring

Sampling of an additional 20 sites distributed throughout the Edward-Wakool system will occur in year 3 (2022) of the MER project. These will all be in-channel sites, and will be located outside the Focal Area. Use of data from these additional sites coupled with data collected from a subsample of sites in the Fish (River) Cat 1 will enable long-term change trajectories of the native fish population to be determined using SRA health indices.

Timing and frequency

Cat 3 Fish River monitoring will be undertaken in 2022 (year 3 of MER program) between March and May following flow recession.

Responsibilities

- Collaboration: This is a collaboration involving NSW DPI Fisheries and Charles Sturt University.
- Field sampling: NSW DPI Fisheries staff and CSU Technical Officer
- Data entry and management, Data analysis and reporting: Fisheries NSW project staff based at Narrandera Fisheries Centre (Thiem, Wright, Smith, Rehwinkel) will coordinate and schedule the sampling, data management, analysis and reporting for this component; with assistance from other team members as required.

Methods

Existing long term fish community data exists at numerous sites within the Edward-Wakool Selected Area and was collected as part of other projects including short-term intervention monitoring, Edward-Wakool Fish and Flows, SRA, and NSW rivers survey. Where possible, sites with long term data sets will be retained.

Sampling will be conducted in year three of the MER program from March-May. In the interests of cost-efficiency and comparability with data generated by previous projects within the study area, the area scale assessment of the status of fish populations and assemblages will be conducted using Sustainable Rivers Audit (SRA) protocol (Davies et al. 2010). Fish will be sampled using a combination of boat or backpack electrofishing (12 x 90 second shots) and unbaited bait traps (n = 10). Additional augmentations to the standard SRA protocol will be:

1. The LTIM Project subsampling procedure of measuring the first 20 individuals per shot/net/trap will be utilised in place of the SRA's subsampling procedure.
2. The individual weight of the first 50 individuals measured for length of each species will be recorded.

Important points of difference to LTIM Project Fish (river) Cat 1 sampling methods are that:

- Small-meshed fyke nets will not be used
- Only 18 to 20 minutes of electrofishing sampling effort will be used per site (depending on electrofishing equipment used).
- No otolith samples will be retained.

All fish community data will be entered onto the Fisheries NSW database.

Health and Safety

The Edward-Wakool Selected Area Health and Safety Plan (HSP) includes an assessment of all identified potential risks and a plan on how these risks will be managed.

5.10.2 Evaluation

Fish River (Cat 3) monitoring will address the Selected Area evaluation question in table 19.

Table 19 Fish River (Cat 3) evaluation questions

Evaluation questions
Long-term question • How does the fish community in the Edward-Wakool system vary over 3-5 years, and does this link with sequential flow characteristics?

Data analysis and reporting

Raw catch and effort data for each sampling operation (electrofishing shot or net/trap set) will be recorded. Processed data for fish abundances will be reported as standardised catch-per-unit-effort (CPUE) per site.

Recruitment: Fish length structure will be evaluated 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 four main SRA Indicators (see 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), 3) Recruitment (provides a proportion of the entire native fish population that is recruiting within a zone) and 4) Native and alien Biomass. Recruitment will be further divided; 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 2014, 2019 and 2022, with an overall expectation that condition ratings will improve over time as a result of Commonwealth environmental water. In addition, fish community structure (species specific abundance and biomass at each site) will be analysed using permutational multivariate analysis of variance (PERMANOVA), with year as a fixed factor.

5.10.3 Research

No new research on Fish River (Cat 3) indicators will be undertaken as part of the MER Program.

5.10.4 Links to other monitoring themes and research

The fish river (Cat 3) indicator links with the hydrology (section 5.1), larval fish (section 5.7), fish recruitment (section 5.8) and eDNA research (section 6).

6. Integrated Research

This section outlines an integrated research project that will specifically target gaps in knowledge that are necessary to improve the delivery, monitoring and evaluation of environmental water in the Edward-Wakool system. It will improve our understanding of the processes that drive physical and ecological responses to flow, and will inform adaptive management by providing recommendations for how Commonwealth environmental water can best be managed to achieve desired responses in the Edward-Wakool Selected Area.

This integrated research project focusses on the Edward River. This part of the Edward-Wakool river system was not monitored as part of the LTIM project, so there is a considerable knowledge gap that needs to be addressed to inform the future delivery of Commonwealth environmental water to the Edward River and the management of environmental water in relation to the Werai Forest, which is part of the NSW Central Murray Forests Ramsar site (NSW Office of Environment and Heritage 2018).

This integrated research project includes physical, ecological, and social research (Table 20) that will examine how managed flows in the Edward River, and the operation of Stevens Weir, influence physical aspects (e.g. lateral connectivity and physical form) and ecological processes, such as river productivity, wetland plant emergence and survival, turtle movement and condition, and fish spawning. In addition, an e-DNA approach will be used to determine the presence and spatial distribution of threatened, uncommon and iconic species of crustacean, frog, turtles, fish and aquatic mammals in the Edward-Wakool system that have not been the target of the LTIM and MER monitoring and evaluation. Integrated with these biophysical research themes, social research will be undertaken to examine stakeholder attitudes to, and acceptance of, the concept and use of Commonwealth environmental water. This will help identify what institutional, social and/or cultural interventions could improve the acceptance and impact of environmental water in the Edward-Wakool system.

A particularly innovative aspect of this research project is that several stakeholder groups will participate in the research. Members of the Edward-Wakool Angler Association will participate in research on fish spawning. Members of the indigenous community will participate in the riverbank and aquatic vegetation research in and near Werai Forest, which is in the process of being transferred to the Werai Land and Water Aboriginal Corporation as an Indigenous Protected Area. Members of the community will also participate in the research on turtle distribution and movement.

The integration of physical, ecological and social research within a research project is extremely rare, and the engagement and participation of community groups in this type of project is very uncommon. Thus, this project provides an opportunity to explore interrelationships and responses to flow, as well as examine other influences on the system. The results of this integrated research will inform the future adaptive management of environmental water and the approach to future monitoring in the Edward-Wakool system. The integrated nature of the research will also have broader relevance and will inform the adaptive management of environmental water in other areas of the Murray-Darling Basin.

Table 20 Summary of components that are part of the integrated research project to be undertaken in the Edward-Wakool system for the CEWO Monitoring, Evaluation and Research (MER) Project from 2019 to 2022. For information on hydrological zones see Figure 3 and Table 1 in section 2 of this MER Plan.

Theme	Zone	Overview
Hydraulic modelling	11,12	Hydraulic models will be developed for reaches in zones 11 and 12. This will be undertaken using a similar approach to the hydraulic models developed for Yallakool Creek, Wakool River and Colligen Creek as part of the LTIM project
Physical habitat	4, 8,11,12	Physical habitat evaluation will be undertaken in 2019-20 using an Unmanned Aerial Vehicle to assess riverbank condition and link with the evaluation of vegetation cover in response to flow
Riverbank and aquatic vegetation	11,12	Research on vegetation will be undertaken on riverbanks and in low lying parts of Werai Forest in collaboration with Yarkuwa Indigenous Knowledge Centre
Stream metabolism	11,12	The effect of flows and lateral connectivity on river productivity will be assessed comparing sites upstream and downstream of Werai Forest in the Edward River
Turtles	11,12	Research on turtle populations in the Edward River and adjacent wetlands is planned for 2019-21 to assess how connectivity of wetlands, affects turtle distribution, movement, and body condition.
Fish reproduction	11	Research on perch spawning will be undertaken in the Edward River downstream of Stevens Weir in 2019-20 in collaboration with the Edward-Wakool Angler Association
Biodiversity (e-DNA)	system	A biodiversity assessment will be undertaken 2019-20 to assess the presence of a range of rare and threatened taxa, including fish, frogs, mammals and crayfish.
Social science	system	Social science research is planned for 2020-21 to examine stakeholder attitudes to, and acceptance of, the concept and use of Commonwealth environmental water. This follows on from a project undertaken to assessment stakeholder responses to flow trials in the Edward-Wakool system in 2017 and 2018.

Some of the components of this research program will initially be undertaken for a period of 1 year (2019-20) under current budget allocations. This will limit the number of flow conditions that can be assessed. The opportunities for continuing this research beyond the first year will be assessed following the evaluation of the first year of results.

6.1 Two-dimensional hydraulic modelling

6.1.1 Background

Understanding the extent of riverbank inundation under different discharge scenarios is essential to describe changes in wetted benthic surface area, shallow water habitat and water velocity during environmental watering actions. Hydraulic modelling can also assist the interpretation of other indicators.

The use of digital elevation models to create a floodplain surface that can be inundated under different discharge scenarios may not give the best representation of floodplain inundation, because even small impediments on a predominantly flat floodplain can affect the models. However, in the Edward-Wakool system where much of the environmental watering is contained within the channel, the use of digital elevation models to create flow path assessments below bankfull is an appropriate approach to compare the extent of riverbank inundation and the area of slow flowing slackwater under different discharge scenarios. The inundation models can also serve as a tool to help predict the likely outcome of different flow management options on patterns of riverbank inundation.

The key objective of the hydraulic modelling is to estimate the extent of in-channel inundation and the area of different categories of velocities and depths that are created during flow events of different magnitude from base flows up to bankful flows. Inundation of riverbanks is important for river productivity. The creation of low flow shallow areas is important for the survival and growth of some riverbank plants and the survival of organisms such as larval fish. Similarly, the creation of higher velocity zones is important for spawning of some fish species.

The 2-D hydraulic modelling undertaken here will contribute to the Edward River integrated research project by informing the extent of inundation of low lying geomorphological features (e.g. benches, flood runners) and wetlands along the Edward River. It will also assist the communication of likely outcomes of planned watering events with stakeholders.

6.1.2 Research Question

- What is the relationship between flows and lateral connectivity, as measured by the in-channel wetted benthic area?
- What is the relationship between flows and the area of slackwater and slow flowing water?
- How does the management of Stevens Weir influence connectivity of wetlands and low lying features upstream and downstream of the weir?

6.1.3 Responsibilities and Collaboration

- Inundation modelling will be undertaken by a consultant in collaboration with the Project Manager. The Consultant will provide GIS layers and files to the Project team
- The mapping of inundated benthic area and velocity zones will be undertaken by the Charles Sturt University Spatial Analysis Unit (SPAN)
- Data analysis and reporting will be undertaken by Robyn Watts (CSU) and Nick Bond (La Trobe)

6.1.4 Research Proposal

2D hydraulic models will be created for study reaches in the Edward River both upstream and downstream of Stevens Weir, to complement the monitoring and research in that system. The location of reaches in the Edward River will be determined following consultation with CEWO and other stakeholders.

Each reach will be represented within the hydraulic model using a digital elevation model (DEM) supplied by the Murray LLS. It is fortunate that LIDAR was flown in the Edward-Wakool system during the drought when the majority of the river channels in this system were dry, so the DEMs are appropriate for modelling inundation within the river channel. Six discharge scenarios will be modelled for each zone or reach ranging from low flow to estimated bank-full flows including discharges at which Commonwealth environmental water is to be delivered.

Each scenario will be modelled assuming an initial dry starting condition with no residual water in the system. All scenarios will be run until stable state flow is achieved whereby the instantaneous flow rate at the downstream boundary condition stabilised and matched the upstream inflow value. Discharge scenarios will be modelled using the 2D grid implementation of Eonfusion Flood (Myriax Software) with model outputs post-processed using the GIS functionality of Eonfusion (Myriax Software).

Upon reaching stable state flow, an extent output from the model will be captured representing the spatial coverage of the water surface. Within each cell of the extent the water depth and surface elevation will be captured allowing a 3D surface of the stream bed underlying the water surface to be constructed. The wetted benthic surface area covered by the water surface will then be calculated using the derived 3D surface. Post-processing, including surface area calculations, will be undertaken achieved using Eonfusion (Myriax Software), Quantum GIS and made distributable using Google Earth.

Post processing of model outputs will be undertaken to quantify the spatial configuration into three velocity categories: Group 1: 0 – 0.02 $m.sec^{-1}$ (still water/slackwater), Group 2: 0.02 – 0.3 $m.sec^{-1}$ (slow water); Group 3: >0.3 $m.sec^{-1}$ (fast water). Post-processing, including surface area and depth calculations, will be achieved using Eonfusion Quantum GIS, Excel and made distributable using Google Earth. The results will be ground truthed by comparison with depth logger data at each site and through engagement with local landholders, especially for modelling of large flow events.

Several data sets will be constructed to quantify and represent the spatial distribution of each velocity zone including:

- Water velocity frames exported as a multiband raster in GeoTiff format suitable for viewing in ArcGIS or a similar GIS platform (GDA_MGA_1994_Zone_55),
- Water surface extent for each velocity zone for each scenario exported as bounding contours and polygons suitable for viewing in ArcGIS or a similar GIS platform (GDA_MGA_1994_Zone_55),

- Water surface extent for each velocity zone exported in a KMZ vector format which can be loaded directly into Google Earth for viewing against satellite imagery (WGS84).
- 3D surface area calculations for each velocity zone provided in spread sheet (.xlsx)

Data will be mapped for visual representation, and outputs will be analysed for comparison among discharge scenarios. 2D hydraulic models will be used to estimate a) the extent of lateral connectivity (as measured by benthic wetted area) under different flows, b) Area of water in different categories of velocities under different discharge scenarios, c) Area of water in different categories of depth under different discharge scenarios.

6.1.5 Timing and frequency

The modelling will be undertaken in the first year of the project. We have also budgeted for additional flow scenarios to be undertaken in the final year of the MER project year, to facilitate assessment of additional discharge scenarios that may be required to reflect delivery conditions of Commonwealth environmental water. Data analysis and reporting of the initial modelling will be included in the 2020 annual report.

6.1.6 Links to other monitoring and research themes

This research links with all of the other components of the integrated research project.

6.2 Physical habitat research

6.2.1 Background

Bank condition is explicitly linked to Commonwealth Environmental Water (CEW) and other variable flows. The risk to biota from changes in bank morphology and sediment liberated from erosion make bank condition an important, and explanatory, variable for assessing the value of these water delivery patterns for achieving ecosystem objectives.

River banks influence the velocity of flow, depth of water, and provide the sediment conditions for biota including flora and fauna. River bank condition can alter conditions for biota, and this is often related to the extent of bank activity and river flow. For example, appropriate levels of erosion provide niches for vegetation establishment, yet, excessive erosion can lead to sediment smothering of bed habitat (as well as concerns for riparian infrastructure such as bridges and property).

Riverbank vegetation richness and diversity are also impacted by flows, including due to flow characteristics such as prolonged inundation, high velocities, and smothering (see section 5.4). These vegetation changes can be independent of bank condition, or extricable linked. There are considerable advantages to monitoring bank condition in concert with riverbank vegetation condition.

Quantifying the relationship between CEW and bank condition can assist with understanding flows that enhance the ecological objectives sought (i.e. bank vegetation establishment) and reduce any potential unintended consequences. The Cause and Effect Diagrams (CEDs) developed as part of the original LTIM illustrate some of the linkages between bank condition and a range of ecological and ecosystem values, Figure 22.

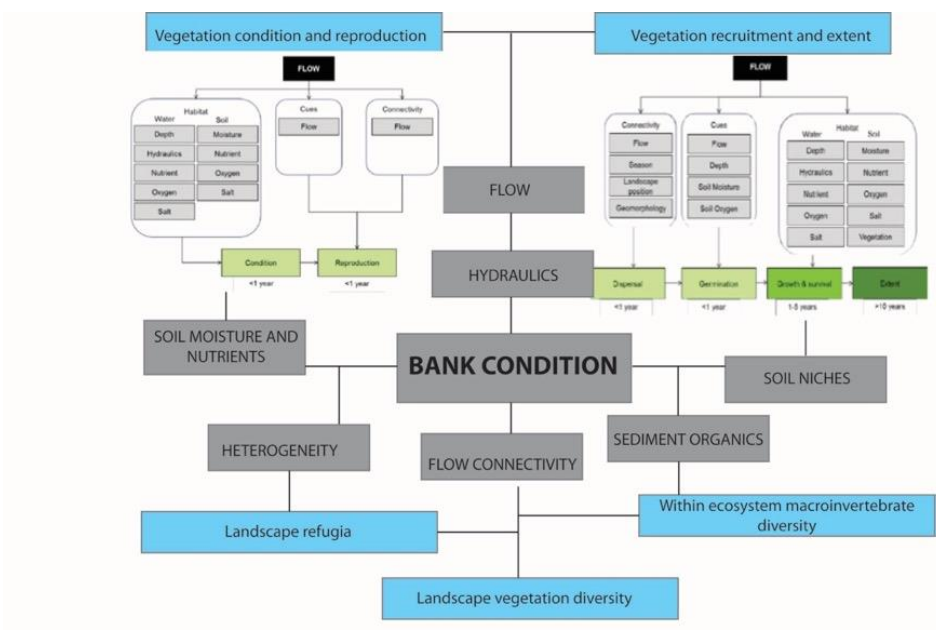

Figure 22 Contribution of bank condition monitoring to example CEDs developed for the CEW monitoring program.

Streamology has been undertaking physical habitat monitoring, including hydraulic habitat (hydraulic modelling) and bank condition monitoring (including erosion pins) for more than five years. Unmanned Aerial Vehicle (UAV) technology and photogrammetry methods have been used to generate spatial and temporal data investigating the impacts of environmental flows. UAVs were used to capture high resolution aerial imagery to process with photogrammetry methods to produce;

1) Detailed digital elevation models (DEMs), DEMs of Difference (DoDs) and quantifying bank condition changes.
2) Classified riparian vegetation maps displaying spatial and temporal differences associated with flow events, quantification of the percentage loss of riparian vegetation, and locating areas of most/least impact.

This approach has been successfully applied in the Goulburn River system. Similar techniques will be undertaken the Edward-Wakool MER project to gain accurate insights into the impacts of flow operations on riverbank habitat and riverbank condition. The Edward-Wakool system is a much smaller system than the Goulburn River. One of the aims of this research is to test this method during the 'low flow delivery' periods of the Edward Wakool.

6.2.2 Research Questions

The broad research questions are:

1) What are the characteristics of the flow regime and river operations that drive erosion and deposition?
2) What are the characteristics of flow regime and river operations that affect riverbank vegetation and aquatic vegetation cover?

Questions related to Commonwealth environmental watering actions in the Edward-Wakool system are:

3) How does Commonwealth environmental watering in the Edward-Wakool system contribute to sustaining bank condition?
4) How does the timing and delivery of Commonwealth environmental watering actions affect bank condition of rivers in the Edward-Wakool system?
5) How do vegetation responses to Commonwealth environmental watering actions vary between sites with different channel features and different bank conditions?
6) Is the use of Commonwealth environmental water adversely impacting the banks of the creeks and rivers?

The main outcomes of the riverbank vegetation and riverbank condition protocol using drones is:

- determining links between flow operations and bank erosion or deposition;
- determining links between flow operations and vegetation changes;
- identifying how bank erosion/deposition and/or vegetation changes might be linked;
- explaining how bank erosion/deposition and/or vegetation changes might explain other ecological responses (e.g. for fish or macroinvertebrates); and
- better informing management of the pattern and timing of delivery of environmental flows to reduce bank instability, maintain/improve vegetation, and achieve ecological objectives.

6.2.3 Responsibilities and Collaboration

- Collaboration: This is a collaborative project involving Streamology and Charles Sturt University
- Field monitoring: UAV data collection will be undertaken by Streamology, vegetation ground truthing will be undertaken by Sascha Healy (OEH) and Robyn Watts (CSU)
- Data management: Desktop processing of UAV data to generate DEMs of difference and classified vegetation maps (Streamology)
- Data analysis and reporting: Geoff Vietz and Mick Donges (Streamology)

6.2.4 Research Proposal

Background

During 2018-2019, Streamology employed a new technique to improve the monitoring of bank condition and riparian vegetation for investigating the impacts of environmental flows. The previous best practice methodology involved the use of erosion pins to measure and assess geomorphic condition and vegetation transect surveying to assess changes in riparian vegetation. The erosion pin approaches were able to gather insights for environmental flow management but were not spatially encompassing, not well suited to assessing some of the specific mechanisms associated with environmental flows (i.e. bank notching) and were time consuming. Compared to vegetation transects (one line of vegetation) the broad-scale assessment of vegetation has considerable advantages for assessing variability in vegetation changes and proportional change. The use of UAVs for riverbank vegetation and riverbank condition can be at the expense of detail, but is focused on providing a robust, repeatable measure of changes resulting from flowing conditions that can be used to monitor and inform flow operations.

Site selection

Sites have not yet been finalised for this project, but will be based on the following criteria:

1) Sites must be directly influenced by environmental flow deliveries.
2) Site characteristics of interest should be considered those sensitive to flow changes
3) Sites should be preferably in close proximity to gauging stations.
4) Sites must have appropriate access, but limited public access.
5) If possible, sites will be preferentially considered if they have a history of ongoing geomorphic or vegetative surveying, as this will provide greater context for the changes occurring as a result of environmental flows.
6) Sites must have sufficient vegetation to monitor, but must not have significant overhanging tree canopies which interfere with UAV image capture.

Timing of field visits

The timing of field visits will be coordinated to coincide with periods of low mean daily discharge, to gain as much insight possible into the condition of submerged banks associated with heightened environmental flows. As an example from the Goulburn River, Figure 23 illustrates the timing of past site visits measuring bank. Site visits were coordinated with low flow deliveries.

UAV bank and vegetation assessments will be undertaken four times during the first year of the MER to enable capture a minimum of change in two flow periods. Timing of UAV image collection will be scheduled to coordinate with low flow deliveries, so as to gain as much insight into the condition of the otherwise submerged banks.

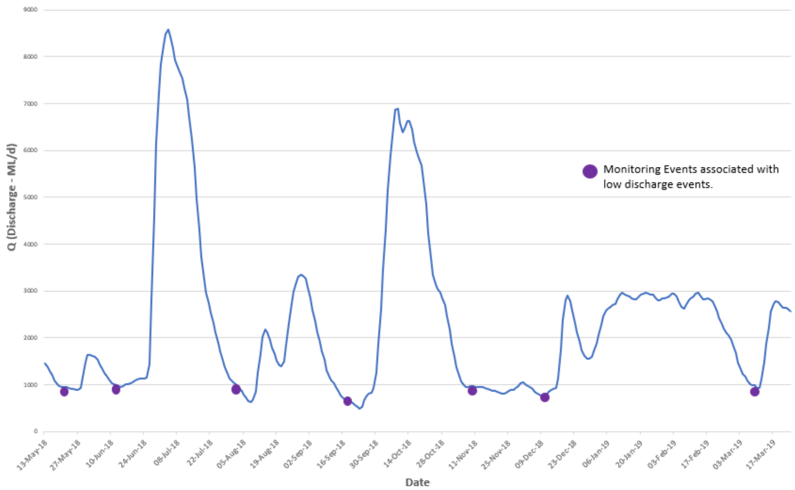

Figure 23 Hydrograph illustrating flow and the timing of past monitoring project at McCoy's Bridge (Goulburn River) between 2018 and 2019.

Field monitoring protocol

The following section details an abridged summary of the suggested field monitoring protocol as developed by Streamology.

1) Ground control points (GCPS) are distributed

   GCPs used in for this project will be bright objects such as orange traffic cones and bright yellow disks with large black ‘x’s in the centre. Approximately 10 GCPs will be distributed along riverbanks, with an even spread present on both banks. The GCPs will be placed in areas not constrained by canopy cover or hidden obstructions so they can be clearly identified and marked in both nadir and oblique imagery.

2) UAV data collection

   A DJI Phantom 4 with real-time kinetic (RTK) capability will be deployed to capture survey quality imagery. This is paired with a RTK base station providing real time corrections to the UAV. The DJI Phantom 4 is a sub-2kg class drone, and can be flown without a commercial license, in accordance with CASA restrictions. The Streamology team will notify CASA approximately 5 days before each flight.

   A combination of nadir, oblique and terrestrial imagery will be captured using the DJI Phantom 4 (Figure 24). Nadir imagery will be collected using an ‘aerial grid flight’ and will be flown at an altitude of 60m above water level. The oblique imagery will be collected in a ‘freestyle’ flight, obtained at a lesser altitude (approx. 5-25m above water level).

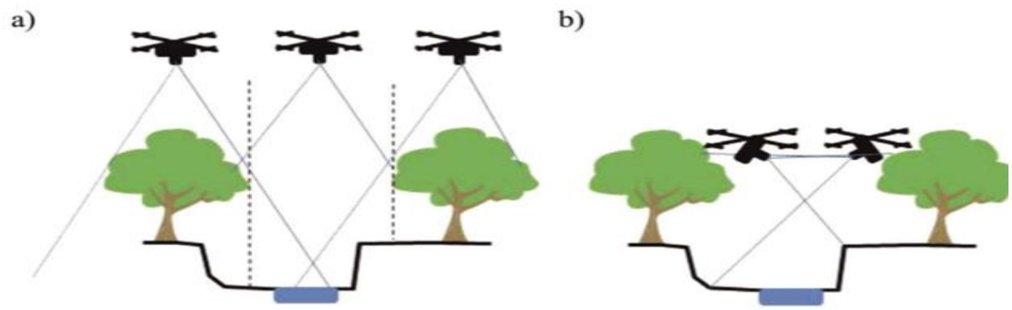

Figure 24 Imagery is captured through a combination of elevations and angles to create a detailed 3D model. Three methods include (a) nadir, (b) oblique, or (c) terrestrial or boat captured imagery (not shown)

3) Ecological Input

   Ecologists will be approached to provide expert opinion to assist Streamology by 'ground truthing' the data obtained by the UAV with observations made in the field. The input by these ecologists will involve species identification and map annotation, to provide 'ground truthed' training data for the subsequent classification of riparian vegetation.

Desktop monitoring protocol

The following section details an abridged summary of the proposed desktop monitoring protocol developed by Streamology.

1) Generation of Densified Point Cloud

   A densified point cloud is a series of 3D points which are used to generate a reconstructed model of a scene captured using UAV. The position of colour information will be stored as X, Y and Z coordinates, and these coordinates will be depicted in 3D space to generate an interactive and explorable model of the scene (riverbank). The nadir and oblique imagery collected by UAV will be input into a photogrammetry software (Pix4D Mapper). Each site visit will be separated into a new project file, and the GCPs will be used to resolve spatial differences between the nadir and oblique imagery, tying both sets of imagery into one geo-rectified densified point cloud. The densified point clouds will be necessary to generate a digital elevation model of difference.

2) Generation of Orthomosaic

   An orthomosaic is a 2D map, stitched together by correcting camera perspective from nadir imagery to display a map of uniform scale. Only nadir imagery will be used to generate the orthomosaics for each site visit. The orthomosaics will be necessary to perform the supervised image classification.

3) Generation of digital elevation model of difference (DoD)

   Densified point clouds will be exported into a spatial mapping program, to generate digital elevation models of difference which consider the minimum elevation points located for each coordinate. This will provide a more realistic picture of surface elevation changes as a result of environmental flows, with negative elevation changes represent erosion, and increased elevation indicates deposition has occurred. This will be represented spatially, with a large map per site, illustrating bank condition change, and will be accompanied by a series of smaller maps illustrating change at key areas, at high magnification and in high resolution.

4) Generation of classified maps illustrating vegetation change

   Orthomosaics will be imported into an image classification software to perform a supervised image classification to distinguish between vegetation classes (i.e. bare ground, woody debris, shrubs, high vegetation etc.). The classified images are then compared over consecutive site visits and are incorporated into a final interactive map which displays the spatial and temporal changes in riparian vegetation as a result of an environmental watering action (Figure 25). This data can also be displayed in a tabulated form, indicating the percentage change of different vegetation classes.

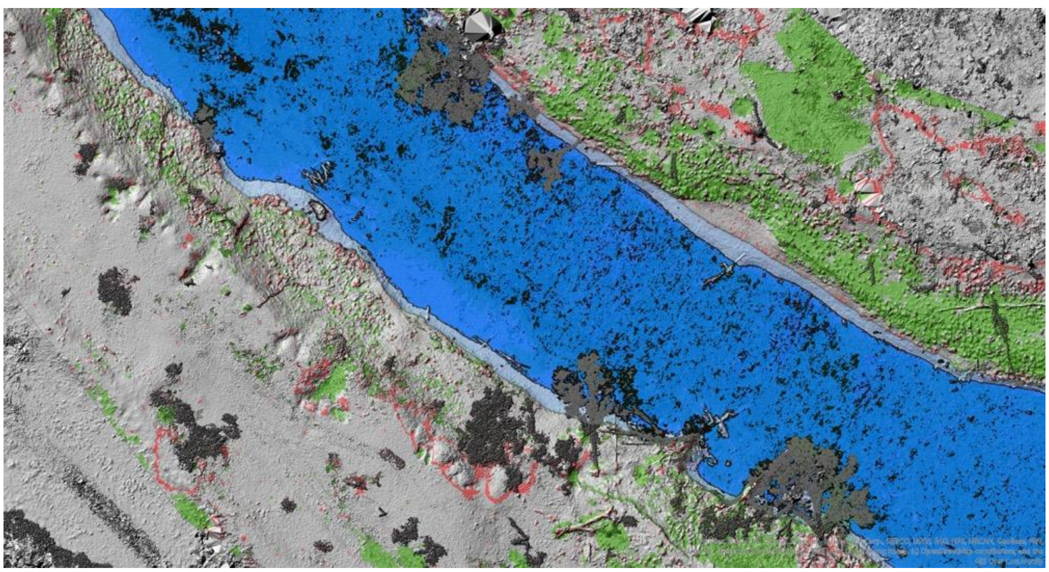

Figure 25 DOD layer overlaid upon a hillshade model produced from the UAV. Blue layer is current water level, light blue is maximum extent of IVT Flows with green represented deposition and vegetation increase and red representing erosion or vegetation mass lost.

Interpretation and outputs

Final interpretations will be performed by Streamology linking the results of riverbank vegetation changes and riverbank physical form changes (Figure 26) to hydrologic data. This will be placed in the context of ecological and ecosystem considerations to explain the influence of environmental flows on both bank condition and riparian vegetation. The data and outputs will be of great value providing insightful data for other MER activities. These results will be used to synthesise recommendations for the Commonwealth Environmental Water Holder and will greatly contribute to the growing understanding of environmental flow impact assessments in these systems.

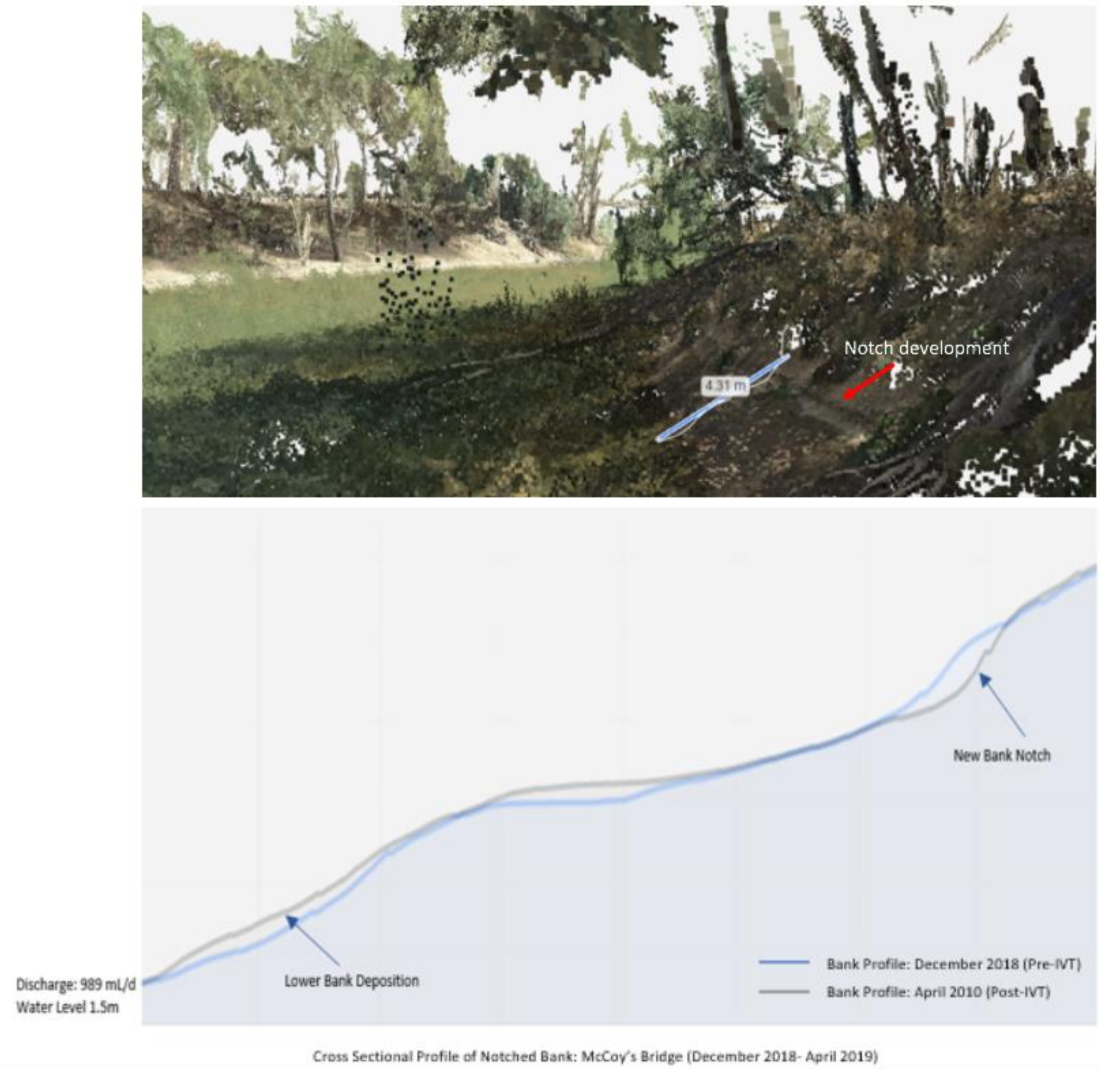

Figure 26 Example of outputs from digital models (above) and the extraction of changes in bank profiles between flows (below). Example from McCoy's Bridge on the Goulburn River from December 2018 to April 2019. Note that high flows (at notch level) often create mid-bank notching and deposit material on the lower bank.

6.2.5 Links to other monitoring and research themes

This research links with the hydrology, hydraulic modelling, primary productivity, riverbank and aquatic vegetation, and social science components of the integrated research project.

6.3 Riverbank and aquatic vegetation

6.3.1 Background

As described in section 5.4, riverbank and aquatic plant survival and growth is affected by the frequency and duration of inundation, influencing germination, root and shoot development, growth, survival and reproduction. Riverbank vegetation and aquatic vegetation play an important role in the functioning of aquatic ecosystems, supporting riverine productivity and food webs and providing habitat for fish, invertebrates, frogs and birds. Riverbank and aquatic vegetation are also important natural resources to the Indigenous people of the Riverine Plains. The Wamba Wamba, Wiradjuri, Yorta Yorta, Perrapa Perrapa, Nari Nari, Muthi Muthi and Wadi Wadi people use natural resources for food, herbs and medicines, shelter, tool and implement making and trading (Yarkuwa Indigenous Knowledge Centre, n.d.).

The Edward-Wakool MER team are working in partnership with the Yarkuwa Indigenous Knowledge Centre to assess riverbank and aquatic vegetation responses to flow regimes on the riverbanks of the Edward River and in the low lying parts of Werai Forest as part of the integrated research project in the Edward River.

6.3.2 Research Question

The specific research questions are in the process of being developed for this project. The questions and location of the study sites for the research will be informed by the results of the hydraulic modelling (section 6.1) that will identify low lying areas inundated by managed flows in the Edward River. The research will also be informed by preliminary on-ground assessment of low lying areas in Werai Forest and through collaborative discussion and consultation with CEWO and other stakeholders.

The reporting on this research will include an evaluation of the research findings from both a scientific and an Indigenous cultural perspective.

6.3.3 Responsibilities and Collaboration

- This is a collaborative project between Charles Sturt University, the Yarkuwa Indigenous Knowledge Centre and the NSW Office of Environment and Heritage.
- Vegetation modelling will be undertaken through a collaboration of CSU staff, NSW OEH staff and staff from the Yarkuwa Indigenous Knowledge Centre. Indigenous people from Deniliquin and surrounds will be employed as CSU casual staff to participate in the monitoring (see section 8).
- Data analysis and reporting will be undertaken by Robyn Watts (CSU), Yarkuwa Indigenous Knowledge Centre, Nicole McCasker (CSU) and Nick Bond (La Trobe).

6.3.4 Links to other monitoring and research themes

This research links with other components of the integrated research project including the hydrology and hydraulic modelling, physical habitat, turtle, biodiversity, and social science research.

6.4 Primary productivity and ecosystem respiration

6.4.1 Background

Stream metabolism has been a core component of the LTIM project in the Edward-Wakool system (2014-2019) and will continue to be monitored as part of the MER program (section 5.3). Stream metabolism monitoring is undertaken to estimate Gross Primary Production (GPP) and Ecosystem Respiration (ER) under different flow conditions. These processes support and sustain aquatic food webs and are directly related to ecosystem health. Flow variability is a key factor influencing rates of GPP and ER in river systems. The aim of the stream metabolism component of the LTIM monitoring is to assess how delivery of Commonwealth Environmental Water contributes to rates of primary productivity, and overall ecosystem production and respiration in the Edward Wakool River System.

As described in section 5.3, flow pulses that inundate benches and areas of low lying floodplain increase terrestrial carbon inputs, as well as increasing the area of shallow water where benthic and planktonic algae can grow. In turn this primary production help provide food for food webs.

The stream metabolism monitoring in the Edward-Wakool system for the LTIM and MER projects has been undertaken at sites on Yallakool Creek and the upper and mid-Wakool River. However, the constraints on flows in Yallakool Creek and the Wakool River (section 3.4) limits the extent to which benches and low lying floodplain can be inundated in these reaches. There are more opportunities to evaluate the influence of lateral connectivity in the Edward River, due to the occurrence of wetlands and low lying features in Werai Forest along this reach. Thus, this component of the integrated research in the Edward River will focus on understanding the influence of lateral connectivity of low lying areas in Werai Forest influence Gross Primary Production and Ecosystem Respiration.

6.4.2 Research Question

- Which aspects of the flow regime downstream of Stevens Weir contribute most to GPP, ER and NPP outcomes?

6.4.3 Responsibilities and Collaboration

- This is a collaboration between Charles Sturt University and La Trobe University
- Field sampling: CSU Staff
- Data management and preparation: Nicole McCasker
- Data analysis and reporting : Nick Bond and Paul McInerney (LTU)

6.4.4 Research Proposal

The research will be undertaken using the same methods as described in section 5.3. However, for this study one logger will be installed upstream of Werai Forest and one logger downstream of the forest to specifically evaluate the contribution of Werai Forest to river productivity under different flows. The results of the 2D hydraulics models (section 6.1) determining the relationship between flows and lateral connectivity (as measured by the in-channel wetted benthic area) will be used to examine the relationship between inundation and rates of ecosystem production and respiration in the Edward River System.

6.5 Turtle research

6.5.1 Background

About half of all Australian turtles, and 60% of all turtles worldwide, are currently listed as vulnerable, threatened, or endangered (Van Dyke et al. 2018). Within the Murray River catchment, 2 of the 3 endemic turtle species have declined by more than 70% since the 1970s: the common long-necked turtle, *Chelodina longicollis* and the Murray River Turtle, *Emydura macquarii* (Chessman 2011). The third species, *C. expansa*, has not apparently declined, but is listed as Endangered in Victoria because of its historically low abundance (Chessman 2011). Similar trends are currently being found throughout the Murray catchment (Van Dyke et al. 2019). In southern Australia, turtle declines are usually blamed on high rates of nest destruction by foxes (Spencer and Thompson 2005), which exceeds 95% throughout the catchment and has been predicted to cause demographic collapse in many populations (Thompson 1983; Thompson 1993). Other factors, including drought and road mortality, have also recently been blamed (Santori et al. 2018). These factors are typically thought of as “death from a thousand cuts”, and are likely to drive slow declines in turtle populations (Van Dyke et al. 2019).

Disruption of natural flow regimes has potential to impact turtles much more rapidly, especially at sites that are forced to dry during the winter due to current operational flow regimes. As aquatic ectotherms (ie, cold-blooded), freshwater turtles substantially reduce their activity rates during the cold of winter. If they overwinter at a site that dries completely, they are likely to be exposed to both the elements and predators (including invasive foxes). Because of their ectothermic physiology, they will not be able to escape either the cold or the predators. Thus, turtle populations in sites that dry over winter are at risk of total extirpation in a single year. In comparison, environmental water flows that help maintain wetlands over winter are likely to protect turtles from this potentially major source of mortality.

Almost all of the rivers in the Murray River catchment are now heavily regulated to provide water for irrigation and humans. The Edward-Wakool River system is an example. Long-term modelling indicates that the Edward-Wakool experienced high flows from July-November in most years, and reduced flows in the summer (Watts et al. 2015). It now experiences much-reduced flows in July-November, and some sites dry completely (Watts et al. 2015). Environmental flows that protect sites from winter drying are likely to be highly beneficial to turtles in this system. The current altered flow regime thus makes the Edward-Wakool an excellent model system for testing the impacts of altered flow regimes, and environmental flows on freshwater turtles.

Losses of turtles has cultural ramifications. Turtles are culturally important to many Indigenous Australians, and in the Deniliquin area are important to both the Barapa Barapa and Wemba Wemba Peoples as well as the nearby Yorta Yorta People (Deniliquin Local Aboriginal Land Council, 2016). Turtles are traditional food species for some Indigenous People. The broad-shelled turtle (*Chelodina expansa*), or “Bayadherra” is a totemic species for the Yorta Yorta People and is important as a protector, provider, and guide associated with creation stories

(Moama Local Aboriginal Land Council, 2016). Turtle surveys by the Yorta Yorta People have contributed to our knowledge of their decline (Moama Local Aboriginal Land Council, 2016).

6.5.2 Research Question

- How does connectivity of wetlands, driven by environmental water, affect turtle distribution, movement, and body condition?

6.5.3 Responsibilities and Collaboration

- Collaboration: This is a collaborative project involving La Trobe University, Charles Sturt University, NSW DPI Fisheries and the Yarkuwa Indigenous Knowledge Centre.
- Field monitoring: James Van Dyke (LTU), Robyn Watts (CSU), casual staff (CSU). Indigenous people from Deniliquin and surrounds will be employed as CSU casual staff to participate in this research (see section 8).
- Data management: James Van Dyke (LTU), Robyn Watts (CSU)
- Data analysis and reporting: James Van Dyke (LTU), Robyn Watts (CSU)

6.5.4 Research Proposal

The research question will be addressed by identifying at least 2 replicates of each of three wetland types (these sites have not yet been identified on-ground):

i. Permanent: Wetlands that remain permanently connected to the Edward River through winter
ii. Disconnected: Wetlands that are disconnected from the Edward River for long periods during winter, but re-connect during environmental and/or operation flows
iii. Sporadic: Wetlands that disconnect from the Edward River temporarily , but are re-connected sporadically even without environmental flows

At each site (6 total), we will determine turtle distributions through up to four trapping sessions, in October 2019, December 2019, February 2020, and April 2020. In each trapping session, we will set turtle traps both within the wetland and in the adjacent Edward River (5 traps each). Trap arrays will include cathedral traps, fyke nets, and commercially-available crab pots, all baited with offal. We will trap each site for up to four days. Every turtle captured will be identified to species and sex, measured, weighed, uniquely marked via shell notching, and released. This design will allow us to determine how turtle distributions differ in each wetland, and the associated river, at multiple time-points through the year. Thus, we will be able to compare which species occurs in each wetland type at each time point. Common long-necked turtles, *Chelodina longicollis*, are most likely to remain even in disconnected wetlands throughout the year, because they prefer wetlands that dry occasionally. In comparison, short-necked (*Emydura macquarii*) and broad-shelled turtles (*C. expansa*) prefer permanent water, so are more likely to remain in permanent and/or sporadic wetlands, and may avoid disconnected wetlands. However, as disconnected wetlands are re-flooded by environmental flows or operational flows, both species may arrive later in the year. Alternatively, if turtles do not survive the winter in disconnected wetlands, then we may expect to not catch any turtles early in the season, and individuals may move into wetlands later after re-flooding. In comparison, all three species should remain in permanent, and possibly sporadic, wetlands throughout the year. Population sizes will be determined via mark-recapture and catch-per-unit-effort. Presence/absence of a given species will be compared using logistic regression, and turtle demographics will be compared with general linear models.

Turtle movements into and out of each wetland type will be evaluated through a study of *E. macquarii*. *Emydura macquarii* do not usually move overland between wetlands, and so are most likely to enter disconnected wetlands following re-flooding via swimming. In the October 2019 trapping session, we will attach acoustic transmitters to the shells of 3-5 turtles per site (18-30 total), spread across the wetland (if turtles are present) and the adjacent river. Two acoustic receiver stations will be established in each wetland: one at the connection to the river, and one in the deepest section of the wetland. A third acoustic station will be established in the adjacent river close to its connection to the wetland. We will use this array to record movement of turtles from inside the wetland out to the river, or from the river into the wetland. We will monitor turtle movements for 12 months, from October, 2019, to October, 2020.

In combination with our ongoing trapping, the movement data will allow us to determine 1) whether and how turtles access disconnected wetlands in comparison to permanent and sporadic wetlands, and 2) how environmental flows facilitate turtle access into disconnected (and possibly sporadic) wetlands in comparison to permanent wetlands. In winter, 2020, the data will also allow us to determine whether turtles leave disconnected wetlands before they become disconnected, or whether turtles are likely to be at risk of mortality due to winter drying. Turtle movements will be compared across wetland types using generalized linear mixed models, and GIS analysis.

We will compare turtle body condition among wetland types using weight and length data collected in our trapping surveys. We will compare Scaled Mass Indices (Peig and Green 2009) of male and female turtles of each species across each wetland type, and each trapping time point. This comparison will show us how wetland type influences changes in body condition over the course of the year. We will combine this analysis with data on the aquatic vegetation at each site (from Riverbank and Aquatic Vegetation Research Theme) to make predictions about water flows not only allow turtles to access wetlands, but also may influence wetland habitat suitability by driving growth and diversity of vegetation. Turtle foraging ecology is heavily impacted by aquatic vegetation, to the point that low vegetation abundance is associated with high rates of empty stomachs in *E. macquarii*, which is omnivorous and eats large amounts of filamentous green algae (Petrov et al. 2018). Thus, sites with low vegetation abundance/diversity may have low turtle body condition, even if environmental flows make them available to turtles. Body condition (calculated via Scaled Mass Index) will be compared across wetland type using general linear models. Associations between body condition and vegetation will be compared using multivariate statistical models including principal component analysis and analysis of similarity (Petrov et al. 2018).

6.5.5 Timing and frequency

Turtle population surveys will occur approximately bimonthly from October 2019 to April 2020. We will attach acoustic tags on turtles in October-December 2019 and will monitor turtle movements continuously for one year, until December 2020 at the latest. Data analysis and report writing will occur from January 2021, with report submission for the 2020-21 Edward-Wakool MER annual report in August 2021.

The reporting on this research include an evaluation of the research findings from both a scientific and an Indigenous cultural perspective.

6.5.6 Links to other monitoring and research themes

This research links with other components of the integrated research project including the hydrology and hydraulic modelling, physical habitat, riverbank and aquatic vegetation, eDNA biodiversity research and social science research.

6.6 Fish spawning in the Edward River

6.6.1 Background

Fish reproduction has been a core component of the LTIM project in the Edward-Wakool system (2014-2019) and will continue to be monitored as part of the MER program (section 5.6, 5.7). Throughout the LTIM project (2014-2019) there has been limited evidence of perch spawning occurring in the Wakool River and Yallakool Creek. A very small number of silver perch eggs were collected in Yallakool Creek in late spring/early summer 2017 (Watts et al. 2018) and again at several sites in Yallakool Creek and the Wakool River in late spring early summer 2018. There has been the question of whether flow-dependent spawning species (e.g. golden and silver perch) may be spawning in other parts of the Edward-Wakool system, such as the Edward River, where there are possibly higher velocities and also connected wetlands that can serve as nursery areas. Local fishers have observed fish, including golden perch, congregating downstream of Stevens Weir during late spring, that suggests the Edward River may be a spawning area for this species.

This component of the integrated research in the Edward River will focus on understanding the influence of flow regime on spawning of flow dependent species.

6.6.2 Research Question

Which aspects of the flow regime in the Edward River and operation of Stevens Weir contribute to spawning in 'flow-dependent' spawning species (e.g. golden and silver perch)?

6.6.3 Responsibilities and Collaboration

- Collaboration: This is a collaboration involving Charles Sturt University, NSW DPI Fisheries and the Edward-Wakool Angling Association.
- Field sampling: The field sampling will be led by CSU staff and undertaken by members of the Edward-Wakool Angling Association, who will be employed as casual CSU staff and undergo training as part of this project
- Larval identification and sample processing: Nicole McCasker and John Trethewie(CSU)
- Data analysis: Nicole McCasker (CSU)
- Report writing: Nicole McCasker (CSU) in collaboration with Edward-Wakool Angling Association

6.6.4 Research Proposal

The research will be undertaken using the same drift net methods as described in section 5.7. For this Edward River research project, sets of drift nets will be set weekly from September to December in 2019 at four sites downstream from Stevens Weir.

The Edward River drift net monitoring will be undertaken by CSU staff and members of the Edward-Wakool Angling Association, who will be employed as casual CSU staff and will undertake training and comply with CSU WHS and other policies when undertaking the field work. Hydrology and 2D hydraulic modelling results (section 6.1) will be used to analyse the flow velocities in relation to observations of spawning.

The drift net design will also catch larvae of other species of interest in the Edward River, including Murray crayfish. Other taxa collected during this work will be included in the reporting.

The reporting on this research will include an evaluation of the research findings from both a scientific and a community engagement perspective. In collaboration with the social science research (see section 6.8), we will report on the learnings and perspectives of the community members involved in the research.

6.6.5 Links to other monitoring and research themes

This research links with other components of the integrated research project including the hydrology and hydraulic modelling, physical habitat, eDNA biodiversity research and social science research.

6.7 Biodiversity research (Environmental DNA)

6.7.1 Background

Monitoring aquatic species such as fish using traditional methods can ineffectively sample rare or cryptic species. It is critical that the distribution of these species be accurately understood given that their continued survival will depend on appropriate water management. Environmental DNA (eDNA) provides an indirect approach to detecting the presence or absence of a species. eDNA includes any DNA found in a wide range of substrates, including water, soil, ice or air. In the aquatic environment, eDNA is continuously shed by organisms when they defecate and shed cells, including gametes. This eDNA can be captured by filtering the water, extracting the eDNA and using targeted PCR to identify if the species is present or absent.

eDNA has some benefits over traditional techniques given that it does not require the species to be physically sampled, it is less labour intensive, economical and it can potentially detect species that are not targeted or not efficiently sampled as part of the Cat 1 and 3 components due to their low abundance and/or cryptic nature. The added benefit of collecting eDNA is that the extracted DNA sample contains a snap shot of the species present at that location and time. Therefore, these samples can be stored and used to identify other species of interest at a later date, which can allow for range expansions/contractions to be tracked.

The current project is focusing on identifying individual species (species-specific analysis) rather than whole communities of organisms (metabarcoding). While metabarcoding is valuable for identifying whole communities (such as fish), species in low abundance can be overlooked due to the low concentration of their eDNA in the water. For the purpose of this study, species-specific analysis will give the most accurate information of the presence/absence of species in low abundance. However, the eDNA samples collected for species-specific analysis can be stored for metabarcoding analysis should it be required in the future. For example, an evaluation of the performance of metabarcoding compared to traditional techniques in estimating species richness could be made at a later date. In addition, temporal changes in the whole aquatic community could be assessed and related to environmental conditions to determine what factors are driving fish community composition changes.

6.7.2 Research Question

- What is the presence and spatial distribution of threatened, uncommon and iconic species of crustacean, frog, turtles, fish and aquatic mammals in the Edward-Wakool system?

This question is a priority given the presence of any of the species listed under the research proposal may result in changes to the way environmental water is managed. For example, if southern pygmy perch (a wetland specialist) were detected, environmental watering actions could be planned to allow for regular watering of wetland habitat to ensure the species is able to spawn and recruit at during its short lifespan (3 to 5 years).

The main outcomes from the development and use of the e-DNA protocol/method are:

- provide additional data on the presence of cryptic fish species and other aquatic species that are not likely to be captured using the current LTIM/MER methods
- make an assessment of the ability for e-DNA methods to contribute to answering the relevant fish evaluation questions in the Edward-Wakool MER Plan
- make suggestions on the design of future monitoring and evaluation activities in the Edward-Wakool River system (provided as input into the review of LTIM to be undertaken by the CEWO)
- enable linkages with findings of other e-DNA related projects, including the Lachlan LTIM e-DNA project being undertaken during 2018-19.

6.7.3 Responsibilities and Collaboration

- Collaboration: This is a collaborative project involving NSW DPI Fisheries and Charles Sturt University.
- Field monitoring: Xiaoying Liu (CSU) and casual staff (CSU)
- Laboratory analysis: Meaghan Duncan (NSW DPI)
- Data management: Meaghan Duncan (NSW DPI), Fisheries Technician (NSW DPI)
- Data analysis and reporting: Meaghan Duncan (NSW DPI), Fisheries Technician (NSW DPI)

6.7.4 Research Proposal

Water sampling will be carried out during the spring months (September to November) given this is when most species in the Edward-Wakool system are becoming more active and thus the concentration of eDNA is likely to be higher in the water (de Souza, Godwin, Renshaw, & Larson, 2016; Hinlo, Gleeson, Lintermans, & Furlan, 2017). A total of ten sites will be selected from existing sampling locations used for Cat 1 and Cat 3 fish river methods (section 5.9 and 5.10), and will include at least two sites in the Edward River (Sites 5 and 6, Table 10, section 5.2) to ensure integration with other components of the Edward River integrated research project.

eDNA will be filtered from 8 replicate sites per sampling location using the ANDe Sampling Backpack System (Smith Root). A new filter housing (5 µM filter size) will be used at each replicate site and a maximum of 10 L of water will be filtered. The final volume of water filtered will depend on the particulate load at the time of sampling. At each sampling location an equipment control will be taken by filtering 2 L of UV sterilised water. This will be treated as an additional replicate that is processed in the laboratory in exactly the same way as the other replicates in order to check for contamination of equipment. Following collection of the equipment control, 8 replicate sites will be sampled covering a distance of approximately 150 to 200 m. Sampling will be conducted along the left bank, right bank and mid-river targeting areas where eDNA is likely to accumulate such as eddies (area of a circular current), areas of low flow and shaded areas (as UV light breaks down eDNA). To avoid sediment disturbance that could release older eDNA trapped in the sediment, mid-river samples will be taken after the left and right bank samples using a boat if necessary. Once the water is filtered, the filter housing will be removed and the filter paper stored in a 1.5 mL tube containing 100% ethanol for later eDNA extraction. Following completion of a day of sampling, a 1% bleach solution will be run through the ANDe System to decontaminate it, followed by thoroughly flushing with freshwater.

Species-specific eDNA primers will be designed for a maximum of 13 species (to be selected from Table 21) for a fragment of 12S rRNA or other appropriate sequence depending on what is available on NCBI's GenBank. Sequences from all Murray-Darling Basin fish (including introduced species) will be imported into BioEdit where they will be aligned and primers will be designed to ensure they have the maximum number of mismatches to non-target species. The selected primer pair for each species will be tested on closely related species that occur anywhere in Australia by performing real-time PCR (qPCR) to identify any amplification of non-target species.

Table 21 Potential species that could be detected for biodiversity assessment using eDNA.

Common name	Taxonomic name
Crayfish	*Euastacus armatus*
River blackfish	*Gadopsis marmoratus*
Southern pygmy perch	*Nannoperca australis*
Flat-headed galaxias	*Galaxias rostratus*
Mountain galaxias	*Galaxias olidus*
Silver perch	*Bidyanus bidyanus*
Trout cod	*Maccullochella macquariensis*
Freshwater catfish	*Tandanus tandanus*
Southern bell frog	*Litoria raniformis*
Platypus	*Ornithorhynchus anatinus*
Eastern long-necked turtle	*Chelodina longicollis*
Broad shelled river turtle	*Chelodina expansa*
Short necked turtle	*Emydura Macquarii*
Billabong mussel	*Velesunio ambiguous*
River mussel	*Alathyria jacksoni*
Water rat	*Hydromys chrysogaster*

Following sample collection the filter papers will be transported to the Narrandera Fisheries Centre for processing in a purpose-built eDNA facility. This facility is equipped with its own heating and cooling system (to avoid transfer of eDNA from other laboratories) has a room dedicated to eDNA extraction, qPCR plate preparation (DNA-free room) and a room to add eDNA to the qPCR plate. Each room has overnight UV irradiation to decontaminate surfaces of DNA prior to starting the day's work. In addition, each room is fitted with a UV hood where laboratory work can be carried out to minimise contamination. eDNA will be extracted using a DNeasy PowerWater Kit (Qiagen). qPCR composition and conditions have yet to be optimised but will contain a mixture of TaqMan Environmental MasterMix (ThermoFisher), target primers and an internal positive control (IPC) (Furlan and Gleeson 2017) that detects any species of fish present in the Murray-Darling Basin. The IPC ensures that a negative detection of the target species is not due to the failure of the qPCR. Two species will be multiplexed in each qPCR to cut down on the number of PCRs that need to be run. A positive detection will be confirmed if the amplification of the eDNA from the target species is above the threshold set in the qPCR, and if the IPC is also positive. Negative detection will be confirmed if the amplification of the target species fails to cross the threshold combined with the successful detection of the IPC.

6.7.5 Timing and frequency

The eDNA sampling will be carried out in the spring/early summer of 2019-20. The laboratory work and data analysis will be carried out over the next 3-6 months and the findings will be reported in the Edward-Wakool MER annual report in 2019-20.

6.7.6 Links to other monitoring and research themes

This research links with other monitoring in the Edward-Wakool MER Project; hydrology (section 5.1), carbon and water quality (section 5.2), fish reproduction Cat 3 (section 5.7) and fish river (section 5.10) themes.

This research is one component of the Edward River Integrated research project and links with the turtle research and fish spawning research.

This research also links with eDNA work in the Lachlan selected area. After finalising the Edward-Wakool research, we will collaborate with the Lachlan River Selected Area lead (Fiona Dyer) to develop broad recommendations/guidelines describing species-specific eDNA methodology to collect baseline species distribution data. This will include a discussion of the importance of managing contamination risks, the importance of positive controls and of adequate replication (number of water samples collected at each site and number of PCR replicates) to ensure accuracy of results.

6.8 Social science research

6.8.1 Background

There is global recognition that governing water is 'wicked' as it encompasses social and biophysical complexities and uncertainties (Freeman, 2000). The rapidly altering biogeochemical and hydrological cycles of the Anthropocene (Waters et al., 2016) increase the imperative to work with, rather than deny, the complexities of social ecological systems (Ison, Alexandra, & Wallis, 2018). Robust biophysical knowledge is necessary, but not sufficient if water is to be managed well in the future; social and institutional arrangements that facilitate new ways of understanding and operating are also required (Foster, Ison, Blackmore, & Collins, 2019; Pahl-Wostl et al., 2013). Understanding how learning and knowledge interact with individual and community values and norms can shape the use of research outputs such that actions transform at socially and ecologically meaningful scales (Steyaert & Jiggins, 2007).

This proposed social research builds on recent (Allan & Watts, 2017; Webb, Watts, Allan, & Conallin, 2018) and current social research in the Edward-Wakool River System that highlights a variety of understandings of river water, environmental water and adaptive management. This work is also highlighting a range of expectations about what the monitoring is for, what can be known and what can be achieved, as well as a range of understandings of the institutional arrangements around water management.

6.8.2 Research Question

1. How are knowledge, information and learning (i.e. acting, adapting and accepting) understood and experienced by stakeholders in the Edward-Wakool River System?
2. What are the current Edward-Wakool River system stakeholder attitudes to, and acceptance of, the concept and use of Commonwealth environmental water?
3. What institutional, social and/or cultural interventions could improve the acceptance and impact of Commonwealth environmental water for this and other sites?

6.8.3 Responsibilities and Collaboration

- Collaboration: Participatory data creation will ensure that stakeholders are, to varying extents, collaborators in the research, rather than simply sources of data.
- Data collection: Catherine Allan (CSU), casual staff (CSU)
- Data management: Catherine Allan (CSU).
- Data analysis and reporting: Catherine Allan, Robyn Watts (CSU)

6.8.4 Research Proposal

A definition of 'knowledge' can include aspects of knowing (truth and truths) information (sources, trust), wisdom and learning (acting, adapting, accepting) and learning (acting, adapting, accepting). This research will explore the interaction of these aspects of knowledge with relation to the values, attitudes and social norms of the broad 'stakeholder' community of the Edward-Wakool River System.

The research will build on a current social research project being undertaken in the Edward-Wakool Selected Area by Charles Sturt University. The findings of that research suggest that while stakeholders expect that environmental water should be managed such that it leads to obvious beneficial outcomes, there is much divergence of understanding of the concepts of 'environmental water', 'managed' 'outcomes' and even 'benefit'. Developing a clear understanding of the expectations of, and attitudes towards, environmental water and its management will inform both operational practice and the outreach and engagement around that practice.

Because knowledge and acceptance and values are complex features of society mediated through language and norms it is not effective or accurate to ask simple questions about acceptance or otherwise of environmental water. This project will take a two stage approach that first develops an appropriate tool for seeking wide community opinion, before administering that tool and analysing the results. A mixed method approach will combine participatory research design sessions (Mackay, Allan, Colliver, & Howard, 2014), supported by individual interviews (Denzin & Lincoln, 2003; Wengraf, 2001) if required, and a broad survey instrument, possibly a web based questionnaire. The latter is subject to the outcomes of the participatory design phase, and it is possible that an alternative to a web based questionnaire will be proposed and designed. This lack of certainty is a strength of this phased, participatory research design.

The 'stakeholder community' for this project is necessarily a broad term, and research participant recruitment will be from communities of use, place and interest. It is anticipated that the research will involve 15-30 participants in the qualitative phase, and up to 600 participants for the quantitative survey phase.

The apparent conflict of interest, with staff from the funding body necessarily being part of the recruitment pool, will be managed by full transparency, and by careful data management. The research proposal will be reviewed by the Charles Sturt University Human Research Ethics Committee, who will give approval once they are satisfied that it meets the guidelines of the National Statement on Ethical Conduct in Human Research.

The proposed research steps and timeline (Table 22) will include:

- Community sampling design
- Gaining approval from the Charles Sturt Human Research Ethics Committee
- Recruitment for qualitative phase
- Individual interviews and participatory design workshops
- Design of broad survey instrument (questionnaire or other approach as agreed through the qualitative phase)
- Design of recruitment sampling strategy for second phase
- Administration of broad survey instrument.
- Data collation and analysis, including analysis with the participants of the qualitative phase
- Recommendations for framing of monitoring and other information about environmental water in the Edward-Wakool.

Table 22. Timeline for social science research

Activity	Completed by	Comments
Recruit and employ research assistant	June 15 2020	Recruitment will ideally start in May 2020 for a June start
Brief, focused literature review draft completed	July 15 2020	
Community sampling design complete	July 1 2020	
Approval from the Charles Sturt Human Research Ethics Committee	August 15 2020	
Recruitment for qualitative phase	August 30 2020	
Participatory design workshops and any necessary individual interviews completed	December 2020	Exact timing will be dependent on local events and weather
Design of recruitment sampling strategy for second phase completed	December 2020	
Design of broad survey instrument (questionnaire or other approach as agreed through the qualitative phase)	February 15 2021	
Administration of broad survey instrument	April 30 2021	
Data collation and analysis, including analysis with the participants of the qualitative phase	July 1, 2021	Exact timing will be dependent on local events and weather
Draft report, including recommendations for framing of monitoring and other information about environmental water in the Edward-Wakool.	July 15, 2021	
Inclusion of findings in Annual report	August 30, 2021	

6.8.5 Links to other monitoring and research themes

This research links with all of the monitoring and research themes as it informs the framing of the use of the monitoring and evaluation, and is a bridge to the communication and engagement activities of the project.

A research project currently being undertaken by Charles Sturt University is narrowly focused on two environmental watering trials, with fewer than 15 key stakeholders interviewed. While the research questions proposed in the MER Plan are informed by the insights from the current research, the approach proposed in the MER Plan is more participatory in its design and wider reaching in its execution. Whatever method is selected through the participatory design, it will be recruiting from a large population of stakeholders. Some people who were interviewed as part of the current research project may be invited to be part of the MER project, but they will be invited to be part of developing a process for capturing a much wider view of Commonwealth and other environmental water.

7. Summary of monitoring, evaluation and research activities

This section describes the monitoring and research schedule for the Edward-Wakool Selected Area. The location of zones and indicators in the Edward-Wakool Selected Area was described in Section 4. The timing of reporting is summarised in Section 9. Details on the timing of the monitoring and research activities were described in Section 5 and 6.

The monitoring schedule was developed to ensure it is in line with the expected environmental watering in this system (Section 3). As watering actions are likely to occur throughout the year, including winter watering actions, many of the indicators will be monitored continuously throughout the year. In addition, there are contingency funds in the budget (Section 13) to allow for event based monitoring of water quality associated with blackwater events or monitoring during other events.

The Edward-Wakool Project Team designed the field monitoring schedule to utilise staff time efficiently and to ensure value for money. Field costs were kept to a minimum by incorporating several indicators into the same field trip where possible. At the same time, the schedule allows for field work to be completed on a Monday to Friday basis to ensure staff are able to spend weekends at home and thus be rested for subsequent field trips and laboratory work.

Table 23 provides an overall summary of the field and reporting activities for this MER Plan. Some activities will vary from year to year. Examples of variation in activities between years include:

- In 2019-20 fish movement will be monitored only from June-September, and this activity will not be used in subsequent years.
- Physical habitat research is currently schedule to be undertaken only in 2019-20. Depending on the outcome of that research we may seek funding for follow up research or monitoring.
- The turtle research will be undertaken from 2019-21. Depending on the outcome of that research we may seek funding for follow up research or monitoring.
- The eDNA biodiversity research is currently schedule to be undertaken only in 2019-20. Depending on the outcome of that research we may seek funding for follow up research or monitoring.
- The social science research is currently schedule to be undertaken only in 2020-21. Depending on the outcome of that research we may seek funding for follow up research or monitoring.
- The hydraulic modelling component of the integrated research project will be largely undertaken in 2019-20, with some budget allocated for additional scenarios to be modelled in 2021-22.
- No field monitoring will be undertaken after June 2022, as this will be the period in which the final evaluation report is prepared.

Table 23 Summary and schedule of monitoring and research undertaken in the Edward-Wakool system for the CEWO Monitoring, Evaluation and Research project from 2019 to 2022.

Theme	Cat	Zones	Schedule of activities											
			Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Monitoring and evaluation														
River hydrology	1	system	Continuous data from gauging stations											
Carbon and water quality	3	system	Monthly											
Stream metabolism	1	1,2,3,4,8,11,12	Continuous data from DO loggers											
Riverbank and aquatic veg	3	1,2,3,4,8,11,12	Monthly											
Fish movement	2	system	2019 only											
Fish reproduction (larvae)	1	3			Fortnightly									
Fish reproduction (larvae)	3	1,2,3,4,11			Fortnightly									
Fish recruitment	3	1,2,3,4												
Fish community (Cat 1)	1	3												
Fish community survey*	3	system											*	
Research														
Hydraulic modelling	NA	11,12	Modelling to be undertaken in 2019-20											
Physical habitat	NA	4, 8,11,12		2019-20										
Riverbank and aquatic veg		11,12	Timing to be confirmed											
Primary productivity			2019-22											
Turtles	NA	11	2019-21											
Fish spawning					2019									
Biodiversity (e-DNA)	NA	system			2019-20									
Social science	NA	system	2020-21											

* Fish community survey (Cat 3) will be undertaken in 2022 only

8. Engagement and communication

Introduction

The Engagement and Communication approach for the Edward-Wakool MER project will build on the communications and stakeholder engagement undertaken as part of the LTIM project in the Edward-Wakool system. To develop this plan we participated in two meetings with the Edward-Wakool Environmental Water Reference Group, a meeting with staff of the Yarkuwa Indigenous Knowledge Centre, and several follow up phone meetings and emails with representatives of community groups. The aim of these meetings were to review the communications activities undertaken during the LTIM project, develop activities that involve and engage local stakeholders in the monitoring, and develop a communications and engagement plan that delivers communication and engagement activities associated with CEWO environmental water in the Edward-Wakool system in a format that is meaningful to a diversity of stakeholders.

The key lessons from the review of past engagement and communication were:

- A broad range of activities and outputs is required to target different audiences
- The detailed scientific reports were not a good communication tool for local communities
- Communication through social media (e.g. twitter, Youtube) reached only some members of the local community
- Activities that involved hands-on opportunities, such as the information booth with microscopes at the Deniliquin Fishing Classic, were well received by the community and reached a wide range of the community from children through to adults
- Communication products that focussed on individual stories were well received by the local community. For example, articles in local newspapers on the first observation of catfish larvae in the system and the increased distribution of river blackfish.
- There is a strong interest of indigenous people to be more engaged in the MER project

Objectives and intended outcomes of communications and engagement activities

- Help to communicate the role and benefits of environmental water to key stakeholders and the broader community, including:
  - Local Edward-Wakool community
  - The Commonwealth Environmental Water Holder and CEWO
  - Other government agencies and policy makers
  - The broader Australian and international community
  - The science community
- Produce user friendly products for target audiences that make monitoring and research observations and outcomes accessible and useful to a wide range of stakeholders.
- Develop means by which a wide range of local stakeholders can be involved and engaged in the project

- Ensure there is meaningful aboriginal engagement in the project and in environmental water management
- Work with the Flow-MER team (Basin-scale, Selected Area and CEWO) to integrate communication outputs and outcomes of environmental watering actions and promote knowledge exchange and collaboration opportunities

Key stakeholder groups

Communications and engagement will target the following stakeholders:

- Commonwealth Environmental Water Office
- Local stakeholders in the Edward-Wakool area including: the Edward-Wakool Environmental Water Reference Group, Murray Local Land Services, Wakool River Association, Edward-Wakool Angling Association, Yarkuwa Indigenous Knowledge Centre Aboriginal Corporation, Deniliquin Local Aboriginal Land Council, Murray Irrigation Limited, Ricegrowers' Association of Australia Inc., landholders and the broader community
- Relevant government agencies including: NSW Office of Environment and Heritage, NSW Department of Primary Industries (Fisheries), WaterNSW, DPI Water, Murray-Darling Basin Authority
- Basin MER Team and other Selected Area MER Teams
- Broader Australian and International community
- Science community

Communication and engagement activities for MER project

Presentations/workshops to targeted groups:

- Edward-Wakool Environmental Water Reference Group meetings (2 per year)
- Annual MER project Forum
- Annual MER project Practitioner Forum
- Presentation to other relevant local groups, such as the Murray-Lower Darling Environmental Water Advisory Group Wakool River Association, Edward-Wakool Angler Association
- Presentations at scientific conferences

Activities that bring stakeholders, community, scientists together to foster relationships and engagement of local knowledge and expertise:

- Members of the Edward-Wakool Angling Association will be engaged to participate in the Edward River larval fish surveys (see section 6.6)
- Staff of the Yarkuwa Indigenous Knowledge Centre plus other local Aboriginal people will participate in riverbank and aquatic vegetation research in Werai Forest (see section 6.3)
- The Western Murray Land Improvement Group (Landcare) will coordinate four workshops (Barham, Moulamein, Kyalite and Wakool) to engage local community members in workshops focussing on water quality monitoring with opportunities to more broadly discuss outcomes of LTIM and the MER project
- Local Aboriginal people will participate in the turtle research component of the integrated research project (see section 6.5)

Written outputs

- Information sheets will be distributed at meetings and field days and posted to the website
- Media releases will be produced on interesting monitoring results that make good stories of interest to the local and broader community
- Annual Selected Area Evaluation report
- Quarterly progress report
- Quarterly Outcomes Newsletter
- Reporting on the integrated research project will include outputs from a community engagement perspective, including an Indigenous cultural perspective. These outputs, written in collaboration with members of the community groups, will share the learnings and perspectives of the community members involved in the research.

Individual communication with landholders on whose properties we have established monitoring sites and with community groups participating in research

- Regular email/text/ring to inform of our monitoring schedule
- Face to face catch-up with landholders and community groups while we are in the field

Participation in committees

- Edward-Wakool Environmental Water Reference Group Committee (EWEWRG) (meet 2 times each year)
- Edward-Wakool Operations Advisory Group (regular teleconferences)
- Murray and Districts Dissolved Oxygen Group (Active during poor water quality events)

Engagement with scientific community

- papers, conference presentations, collaboration on complementary projects
- supervision of research students

Online – general access

- An Edward-Wakool Environmental Water webpage will continue to be hosted by CSU. All annual reports, progress reports, info sheets, media releases are posted to this site. It serves as a single location where recent and past outputs can be accessed
- The Edward-Wakool team will contribute to Flow-MER team products and engage with Flow-MER team by providing input to the new website, calendar of events, and contributing a minimum of two stories per year. Many of the written materials will be directly transferable to the Flow-MER team requirements.

9. Reporting

A summary of the reporting for the Edward-Wakool MER project is outlined in table 24 and this is summarised as a timeline in table 25.

Table 24 Summary of the annual reporting requirements for the Edward-Wakool CEWO Monitoring, Evaluation and Research project from 2019 to 2022.

Item	Reporting activity	Activity	Date
1.	Selected Area Working Group	CSU will initiate, organise, facilitate and provide secretariat duties for Selected Area Working Group meetings consisting of CSU representatives and any subcontractors involved in the development of the Edward-Wakool MER Project.	At least two Selected Area Working Group meetings held annually
2.	Thematic Working Groups	Team members will attend at least two thematic working group meetings organised by the Basin Matter Leads for each of the following themes: fish, vegetation and stream metabolism.	Meeting dates organised by the Basin Matter Leads.
3.	Steering Committee participation	Edward-Wakool team members will attend at least two Steering Committee meetings (teleconferences) organised by the CEWO annually.	Meeting dates organised by CEWO
4.	Annual Forum	At least 4 members of the Edward-Wakool team will attend the Annual Forum each July quarter	In the July quarter
5.	Progress Reports	Progress reports will be submitted in accordance with a standard format and template. The reports will outline progress against MER Plan requirements including core monitoring and research activities. It will identify issues that have affected the delivery of services and measures taken to address this. It will include a summary of external communications.	Last Business Day of September, December, March and June
6.	Quarterly Outcomes Newsletter	Newsletters will be written in plain English for a public audience and will communicate MER activities, preliminary observations and findings relevant to environmental watering, and case studies about environments and people. It will contain opportunistic photos of outcomes from environmental watering and other visual aids relevant to demonstrating outcomes to the public. It will also include a description of the monitoring and research activities undertaken in this quarter.	Due on last Business Day of September, December, March and June
7.	Annual Selected Area Evaluation Report	The annual Selected Area Evaluation report will be submitted each year, in accordance with the requirements set out in the contract. This will include information in Monitoring, Evaluation and Research, and will include recommendations that will inform adaptive management of Commonwealth environmental water.	Draft due 30 September and final due 30 November

Table 25 Timeline of the annual reporting undertaken in the Edward-Wakool system for the CEWO Monitoring, Evaluation and Research project from 2019 to 2022.

#	Activity	Schedule of activities											
		July to Sep			Oct to Dec			Jan to March			April to June		
1	Selected Area Working Group	At least 2 per year organized by the Project Leader											
2	Thematic working Groups	2 per year organized by Basin team											
3	CEWO MER Steering Committee	2 per year organized by CEWO											
4	Annual MER Forum												
5	Progress Reports												
6	Quarterly Outcomes newsletters												
7	Annual report												
7	Final Annual Selected Area Evaluation report												
8	Data uploaded to MDMS												

10. Project management

10.1 Project governance

The project will operate under the following governance structure:

- *Corporate Client* – The government body that is funding the project – in this case, the Australian Government through the Department of Environment and Energy. The corporate client is the champion of the project with final authority; promotes the benefits of the project to the community and may be viewed as the 'public face' of the project (involvement in most high profile media activity); lends support by advocacy at senior level and ensure that necessary resources are available for the project.
- *Project Leader* – Professor Robyn Watts is the Project Leader. She will be the key person around which the project evolves and who will follow the strategic direction set by the funding body and consult with the theme leaders and project team.

  The Project Leader is responsible for all the operational aspects of the project. The Project Leader is responsible for organizing the project into one or more sub-projects, managing the day-to-day aspects of the project, maintain the project schedule, resolving planning and implementation issues and monitoring progress towards budget. The Project Leader will: manage and monitor the project activities through detailed plan and schedules; report to the Corporate Clients at regular intervals; and manage (client/partners/stakeholder) expectations through formal specification and agreement of goals, objectives, scope, outputs, resources required, budget, schedule, project structure, role and responsibilities.
- *Assistant Project Leader* - Dr Nicole McCasker is the Assistant Project Leader. The Assistant Project Leader will support the Project Leader and represent the team in the absence of the Project Leader. The Assistant Project Leader will assume the role of Project Leader as required to ensure continuity in project delivery.
- *Theme Leaders* – The theme leaders coordinate specific elements of the project. Theme Leaders will work closely with the Project Leader and Assistant Project Leader to deliver on project outcomes. The Theme Leaders are Prof Robyn Watts (hydrology), Dr Julia Howitt (water quality and carbon), Prof Nick Bond (stream metabolism), Prof Robyn Watts (riverbank and aquatic vegetation), Dr Jason Thiem (fish movement and fish adult populations), Dr Nicole McCasker (fish spawning), Mr John Trethewie (fish recruitment), and Prof Nick Bond (data analysis and modelling).

  The Theme Leaders will be coordinated by the Project Leader and are responsible for completing tasks and activities required for delivering project outputs.
- *Research Project Leaders* – The research project leaders coordinate specific elements of the project. Theme Leaders will work closely with the Project Leader and Assistant Project Leader to deliver on project outcomes. The Theme Leaders are Dr Geoff Vietz (physical habitat research), Dr James Van Dyke (turtle research), Dr Meaghan Duncan (eDNA biodiversity research), and A/Prof Catherine

Allan (social science research). The research project leaders will be coordinated by the Project Leader and are responsible for completing tasks and activities required for delivering project outputs.

- *Team members* – All team members have specific roles and will contribute to the success of the project. Team members undertake fieldwork, laboratory work, data management and analysis, evaluation, reporting and project administration. All team members will contribute to reporting, stakeholder engagement and participate in team meetings when required. The composition of the team may change as the project moves through its various phases, as the assessment and selection of people with the requisite skills required for each phase of the project is critical to its overall success.

- *Selected Area Reference Group* – This group will consist of all Team members including any subcontractors involved in the Edward-Wakool MER Project. This group is an internal governance group for the MER project and is chaired by the Project Leader. This group will ensure that the Edward-Wakool MER team regularly catches up with each other to plan monitoring evaluation and research and prepare reports and other outputs.

10.2 Risk assessment

The MER project will adhere to the Risk Management Plan for the Edward-Wakool Selected Area (Watts et al. 2014b) that was prepared in accordance with:

- CSU Risk Management framework
- CSU Risk Management Policy
- CSU guidelines on How to complete a CSU Risk Assessment
- Australian Standard AS/NZS 4360:2004 Risk Management and revised AS/NZs ISO 31000:2009 Risk Management – Principles and Guidelines.

The Project Risk Management Plan follows the CSU Risk Management framework, including policies, guidelines and procedures, identifies major risks that are considered to have potential adverse effects or provide potential opportunities to meet the project objectives, risks to the environment and individuals and records the outcomes of the risk management process undertaken with the use of the Project Risk Register.

10.3 Key personnel

This section outlines the personnel who will perform the services for this tender, including the skills, experience and qualifications of those personnel. A summary of the project team members is provided in Table 26.

Table 26 List of personnel who will perform the services for this tender, including a summary of their roles.

Name	Organisation	Roles
Prof Robyn Watts	CSU	Project Leader. Project planning, manage CSU staff, coordinate reporting, represent team on stakeholder reference group and environmental water groups, and liaise with CEWO. Lead hydrology theme and riverbank and aquatic vegetation theme. Contribute to field work, data analysis and reporting for hydrology and riverbank vegetation themes
Dr Nicole McCasker	CSU	Assistant Project Leader. Lead fish spawning theme - undertake field work, laboratory processing of fish larval samples, analysis and reporting of fish larval data. Lead Data Management and assist with analysis of data and modelling. Processing data from DO loggers for stream metabolism analysis. Assist coordination of CSU staff.
Dr Julia Howitt	CSU	Leader for water quality and carbon theme. Analysis and reporting of carbon and water quality data. Contribute to project planning and reporting.
Dr Xiaoying Liu	CSU	Leader of fieldwork for carbon and water quality theme. Undertake processing of carbon fluorescence samples, chlorophyll-a samples, vegetation monitoring and data entry. Contribute to project planning and reporting.
Mr John Trethewie	CSU	Leader of fish recruitment theme. Undertake fieldwork, manage field equipment, laboratory processing of fish larval samples. Undertake laboratory work, data analysis & reporting for fish recruitment theme. Contribute to project planning and reporting.
Casual assistants	CSU	Assistance with field work or laboratory work
A/Prof Catherine Allan	CSU	Develop and undertake social research. Contribute to project planning and reporting.
Dr James Van Dyke	CSU	Develop and undertake turtle research. Contribute to project planning and reporting.
Mr Inam Ahmed	CSU	Assist with hydrological and hydraulic data analysis. Contribute to project planning and reporting.
Dr Jason Thiem	DPI NSW	Leader of fish movement and fish population theme. Analysis and reporting activities for fish movement and fish population indicators. Supervision of DPI, budgeting and project management. Contribute to project planning and reporting.
Dr Meaghan Duncan	DPI NSW	Develop and undertake e-DNA biodiversity research. Contribute to project planning and reporting.
Mr Rohan Rehwinkel	DPI NSW	Contributing to annual fish survey, fish recruitment field work, coordination of fisheries field staff.
Mr Chris Smith	DPI NSW	Undertake fieldwork associated with fish movement, fish population surveys, fish larvae. Assist with data entry.

Casual assistants	DPI NSW	Assist with fieldwork in stage 2
Prof Nick Bond	La Trobe	Leader of stream metabolism theme. Contribute to project planning and reporting. Contribute to statistical analysis and ecosystem modelling. Contribute to hydrology analysis.
Ms Sascha Healey	OEH	Contribute to fieldwork for vegetation assessment, assist with data analysis and reporting of river bank vegetation indicators. Contribute to project planning and reporting.
Dr Geoff Vietz	Streamology	Develop and undertake physical habitat research or monitoring. Contribute to project planning and reporting.
Mr Mick Donges	Streamology	Undertake physical habitat research. Contribute to project planning and reporting.
Mrs Nikki Scott	CSU	Administration, budgets and contract management
Mrs Kris Gibbs	CSU	Administrative support for travel, meetings and purchases

The NATA-certified laboratory within the CSIRO Laboratory based at the Charles Sturt University Albury campus will undertake the nutrient and organic carbon analyses for the water quality monitoring component of the project.

10.4 Quality assurance

The Quality Management Plan for the Edward-Wakool Selected Area (Watts et al. 2014a) documents quality control and quality assurance procedures for all activities undertaken for the Edward-Wakool system under this MER Plan. The plan is in accordance with relevant standards such as AS/NZ ISO 10005:2006 Quality management systems – Guidelines for quality plans as well as ANZECC and ARMCANZ (2000) Australian Guidelines for Water Quality Monitoring and Reporting.

The Quality Assurance Plan features the three following components:

- Quality assurance – to ensure quality management processes;
- Quality control - to establish standards for acceptance of outputs, monitoring against the criteria to determine if quality has been achieved
- Quality improvement - review points to assess and improve quality where possible.

10.5 Health, Safety and Environment Plan

The Workplace Health, Safety and Environment Plan (HSEP) for the Edward-Wakool Selected Area (Watts et al. 2014c) has been developed in line with the current MER Plan, but will be revised when indicators to be monitored in the Edward-Wakool Selected Area have been finalised. The HSEP is in line with Charles Sturt University policy and existing frameworks, including Work Health and Safety (WHS) Act 2011, Occupational Health and Safety Regulation, 2001 (NSW), Occupational Health and Safety Act, 1989 (ACT) and Occupational Health and Safety Regulations, 1991 (ACT). The plan describes the procedures and requirements for minimizing the risk of injury to persons and harm to the environment in relation to the LTIM Project.

Work Health and Safety (WHS) at CSU supports the identification, development and implementation of strategically based health and safety programs. These programs aim to ensure compliance with relevant health and safety legislation, as well as to assist managers and employees to maintain a workplace that is free from risk to health, safety and welfare and promotes staff health and wellbeing. These programs focus responsibilities and resources in the areas of accident and injury prevention, hazard removal and control, health and welfare preservation, the development of safe and healthy work practices, the promotion of health and safety awareness, the provision of training in safe and healthy work practices, the compliance with health and safety legislation and regulations, the rehabilitation of injured employees and consultative mechanisms.

All staff and students have a general responsibility in terms of the WHS Act (2011) to ensure a safe and healthy work environment. The broad parameters of these specific responsibilities are set out in the policy document Occupational Health, Safety and Welfare Objectives and Responsibilities.

To monitor and assist with the implementation of this policy, Occupational Health and Safety Committees have been established at each Campus pursuant to the provisions of the WHS Act 2011. Each Committee reports to the Executive Director, Division of Human Resources. The Presiding Officers of each OH&S Committee represent these committees on the University-wide Environment and Safety Management Committee established to coordinate occupational health and safety matters across the University.

Where Charles Sturt University has a presence at sites other than a designated campus, it is the responsibility of the management of that site, or the coordinating senior officer of the University in regard to joint ventures, to ensure the operations at that site are compliant with applicable health and safety legislation.

The CSU Safety Management System and framework is centered on a number of policies, procedures and induction/training modules, including:

- Driving hours policy and Guidelines
- First aid policy
- Occupational Health & Safety Consultation Statement
- Occupational Health, Safety and Welfare Objectives and Responsibilities
- Occupational Health and Safety Policy
- Occupational Health, Safety and Welfare Objectives and Responsibilities
- Safety Management Plan Policy
- Accidents and incidents reporting
- CSU Risk Management Policy and Risk Register
- OH&S Induction and ELMO OHS Online Training

Charles Sturt University also has specific policies and procedures relating to the management of OH&S related risks including:

- New staff safety induction processes (ELMO)
- Ergonomics
- Manual Handling
- Electrical Safety
- Thermal comfort
- Accidents and incidents reporting

All persons in charge of workplaces at CSU coordinate the production of an annual Safety Management Plan by the commencement of May each year. This Plan details all planned WHS activities and targets for the current financial period. Longer term planning can also be incorporated where management of safety, needs to be staged over a number of years.

The HSEP includes information relating to the provision of safety information, the need for instruction, and the need for generic, specialist or on-the-job safety training in the coming year. The Plan includes objectives and targets to minimise risks resulting from hazards identified through observation, inspections, hazard reports, incident investigations and where changes occur to facilities or processes or through identified non-compliance with legislation, policies or standards. The planning and programming of risk assessments and risk control measures, including the production of administrative controls such as operating procedures are also included in the Plan when required. Emergency and contingency planning may also need development or improvement within the Plan.

Safety Management Plans form an essential part of the safety system at each workplace and active records of these plans are kept for the current plan and the previous four plans. Archived records to cover a span not exceeding 5 years are also kept.

The CSU team operates under the auspice of the Faculty of Science and will follow a number of faculty specific WHS policies and procedures through the delivery of this project. These include:

- Faculty of Science Risk Assessment Procedure , outlining the formal risk assessment process used by the Faculty of Science to ensure all activities conducted in on campus and off campus localities used for work, research or study implement controls to mitigate and/or reduce the risks of incidents, injury or damage
- Laboratory safety and standard operating procedures.
- Field work procedures, including the completion of project safety risk assessments to be completed and approved prior to any project field work being undertaken; in particular the project safety risk assessment covers potential hazards relating to field sites and their access as well as well as field activities (e.g. night trawls) and the controls in place to minimize risks
- Emergency response; the field work procedure includes a subset relating to the procedure that is to be followed in case of an emergency and will be detailed in the final HSEP; whilst working in the laboratory, staff are to follow existing building emergency procedures (these are detailed as part of new staff induction processes)
- More specific Job Safety and Environment Assessment (JSEA) for all laboratory and field activities if not covered under existing Faculty of Science procedures; specific standard operating procedures are developed for the project and will include a safety aspect component

- First aid training; the final HSEP will include a list of first aid training requirements, in particular for field work, as well as a record of staff first aid qualification; training records will be reviewed and updates on a quarterly basis as a minimum
- Incident reporting; the project team will follow CSU Incident Reporting and Management procedures which will be detailed in the final HSEP

All organisations sub-contracted by CSU will operate under CSU HSEP, with the exception of Fisheries NSW, which has developed a separate HSEP. Fisheries NSW will submit their HSEP to the project manager for review. As a requirement of CSU sub-contracting procedures Fisheries NSW HSEP is to be approved by the CSU project manager prior to NSW DPI commencing work on the project.

10.6 Equipment

The Edward-Wakool Team have established capital capacity that support the efficient delivery of monitoring, evaluation and research in the Edward-Wakool Selected Area. The project team has fully established capital capacity, including field equipment and access to fully equipped research laboratories. The project team also have access to a wide range of scientific analytical facilities and field sampling equipment at CSU, DPI Fisheries Narrandera, La Trobe University and NSW Office of Environment and Heritage.

Existing capital assets that assist with communication among the team and with other stakeholders include videoconference facilities, high-end IT equipment and networks. The CSU cloudstor and data storage is used as a repository for active datafiles and facilitates the sharing of data among the project team. CSU has a Spatial Analysis Unit which has assisted with inundation mapping and other mapping for the project.

Charles Sturt University has all field equipment required to undertake the two year MER project in the Edward-Wakool river system. Key equipment includes logging equipment to continuously monitor water quality, water depth and light conditions at selected river reaches. In addition, CSU has field vehicles, small boats, drift nets (equipped with flow meters), and fish light traps that can be dedicated to this project. The CSU Albury-Wodonga campus has a fully equipped laboratory with microscopes for larval fish identification and equipment for processing of phytoplankton biomass.

Fisheries NSW have a fleet of five electrofishing boats which have been purchased and are available for use by the project on an operating cost recovery basis. Fisheries NSW have also previously deployed an acoustic array and have implanted tags into Murray cod, golden perch and silver perch in the Edward-Wakool river system to monitor and track long distance migrations in response to flow delivery. This infrastructure could also be accessed by the project on an operating cost recovery basis. DPI also has access to larval nets, flow meters, laboratory facilities, punts and light traps which can be brought to the project provided any routine maintenance is covered.

For assessment of water quality and stream metabolism this includes water quality loggers, and access to laboratory instrumentation at Charles Sturt University including a Varian Cary 4000 UV-visible spectrophotometer and a Varian Cary Eclipse fluorescence spectrophotometer. The NATA-certified laboratory within the CSIRO Laboratory based at the Charles Sturt University Albury campus will undertake the nutrient and organic carbon analyses for the water quality monitoring component of the project.

As the project team has a long history of working in the Edward-Wakool river system we have access to a wide range of complementary data sets and intellectual property that will support the efficient delivery of monitoring and evaluation in the Selected Area.

11. Data management

All data collected as part of this project will conform to the data structure defined in the LTIM Project Data Standard (Brooks and Wealands 2014). The data standard provides a means of collating consistent data that can be managed within the LTIM Project Monitoring Data Management System (MDMS).

Data Management protocols will be followed as outlined in the Edward-Wakool Quality Management Plan (Watts et al. 2014a) and will be subject to annual audit. This includes document Management, record keeping, data storage and management.

CSU has a well-established document management system ‘Total Records and Information Management’ (TRIM). TRIM is an Electronic Document and Records Management System software solution for managing records of all formats. All controlled copies of accepted documents and reports are to be recorded in TRIM. In addition such documents and reports will also be recorded in Research Master. Financial data is recorded on Banner Finance, which in turn feeds financial information into Research Master. Data stored on Banner Finance is used to generate the relevant financial reports and acquittal for both internal and external purposed.

The Edward-Wakool Project Team anticipates that the MDMS may not provide all the needs of selected area. In addition we will use an online cloudstor data storage system for data storage in addition to the MDMS. The CSU cloudstor and data storage will be used as a repository for active and archived datafiles and facilitates the sharing of data among the project team.

The Edward-Wakool Project team will store and manage access to primary data for the duration of the MER Project. The Project Leader and Assistant Project Leader will be responsible for ensuring the team members all comply with the management and storage of all primary data. All field and laboratory primary data sheets will be scanned and stored within the CSU data management system as image files using tagged image file format at a minimum 300 dpi resolution. This will include trip reports, audit reports and any other relevant data or documents.

All derived data that supports shared evaluation will adhere to LTIM Project data standards and be traceable to primary data sets held on the Interact site. The Edward-Wakool team will submit data that supports shared evaluation into the Project Monitoring Data Management System according to protocols established by CEWO.

12. References

Agostinho, A.A., Gomes, L.C., & Pelicice, F.M. (2007) Ecology and management of fish resources in reservoirs in Brazil. Eduem.

Allan, C. and Watts, R.J. (2017) Revealing Adaptive Management of Environmental Flows. *Environmental Management*. doi:10.1007/s00267-017-0931-3

ARMCANZ (2000) National Water Quality Management Strategy: Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Baldwin, D., Howitt, J., & Edwards, M. (2001) Blackwater Event. *Austasia Aquaculture*, 15, 21.

Barnett, A., Abrantes, K.G., Stevens, J.D., Bruce, B.D., & Semmens, J.M. (2010) Fine-scale Movements of the Broadnose Sevengill Shark and Its Main Prey, the Gummy Shark. *PLoS ONE*, 5(12), e15464. doi:10.1371/journal.pone.0015464

Baumgartner, L.J., Conallin, J., Wooden, I., Campbell, B., Gee, R., Robinson, W.A., & 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.*

Blom, C.W.P.M., Voesenek, L.A.C.J., Banga, M., Engelaar, W.M.H.G., Rijnders, J.H.G.M., Vandesteeg, H.M., & Visser, E.J.W. (1994) Physiological ecology of riverside species - adaptive responses of plants to submergence. *Annals of Botany*, 74(3), 253-263.

Blom, C.W.P.M. and Voesenek, L.A.C.J. (1996) Flooding - the survival strategies of plants. *Trends in Ecology & Evolution*, 11(7), 290-295.

Brock, M.A. and Casanova, M.T. (1997) Plant life at the edges of wetlands: ecological responses to wetting and drying patterns. In: Frontiers in Ecology; Building the Links (Eds N. Klomp & I. Lunt), pp. 181-192. Elsevier Science, Oxford.

Brooks, S. and Wealands, S. (2014) Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Data Standard. Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre, MDFRC Publication 29.3/2013 Revised Jan 2014.

Bunn, S.E. and Arthington, A.H. (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental management*, 30(4), 492-507.

Bureau of Meteorology (2017) Special Climate Statement 58- record September rains continue wet period in much of Australia, Bureau of Meteorology, No 58. http://www.bom.gov.au/climate/current/statements/scs58.pdf

Campana, S.E. (2001) Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Fish Biol*, 59(2), 197-242.

Campbell, H.A., Watts, M.E., Dwyer, R.G., & Franklin, C.E. (2012) V-Track: software for analysing and visualising animal movement from acoustic telemetry detections. *Marine and Freshwater Research*, 63(9), 815-820.

Casanova, M.T. (2011) Using water plant functional groups to investigate environmental water brequirements. *Freshwater Biology*, 56, 2637-2652.

Chessman, B.C. (2011) Declines of freshwater turtles associated with climatic drying in Australia's Murray-Darling Basin. *Wildlife Research*, 38, 664-671.

Chiew, F.H.S., Potter, N.J., Vaze, J. Petheram, C., Zhang, L., Teng, J., & Post, D.A. (2014) Observed hydrologic non-stationarity in far south-eastern Australia: implications for modelling and prediction. *Stochastic Environmental Research Risk Assessment*, 28, 3-15.

Clements, S., Jepsen, D., Karnowski, M., & Schreck, C.B. (2005) Optimization of an acoustic telemetry array for detecting transmitter-implanted fish. *North American Journal of Fisheries Management*, 25(2), 429-436.

Commonwealth Environmental Water Office (2019) Commonwealth environmental water holdings in the Murray catchment https://www.environment.gov.au/water/cewo/about/water-holdings

David, B.O. and Closs, G.P. (2002) Behavior of a stream-dwelling fish before, during, and after high-discharge events. *Transactions of the American Fisheries Society*, 131(4), 762-771.

Davies, P.E., Harris, J.H., Hillman, T.J., & Walker, K.F. (2010) The sustainable rivers audit: assessing river ecosystem health in the Murray–Darling Basin, Australia. *Marine and Freshwater Research*, 61(7), 764-777.

Deniliquin Local Aboriginal Land Council. (2016). Turtle Project. Government Report.

Denzin, N.K. and Lincoln, Y.S. (2003) Collecting and interpreting qualitative materials. Thousand Oaks: Sage Publications.

Department of the Environment and Energy (2017 online) Wateruse in catchments – Mid Murray. URL http://www.environment.gov.au/water/cewo/catchment/mid-murray/history#werai

Department of Environment and Energy (2019). NSW Central Murray Forests http://www.environment.gov.au/cgi-bin/wetlands/ramsardetails.pl?refcode=64

de Souza, L.S., Godwin, J.C., Renshaw, M.A., & Larson, E. (2016) Environmental DNA (eDNA) Detection Probability Is Influenced by Seasonal Activity of Organisms. *PLoS ONE*, 11(10), e0165273. doi:10.1371/journal.pone.0165273

Foster, N., Ison, R., Blackmore, C., & Collins, K. (2019) Revisiting deliberative policy analysis through systemic co-inquiry: some experiences from the implementation of the Water Framework Directive in England. *Policy Studies*, 1-24. doi:10.1080/01442872.2019.1618816

Freeman, D.M. (2000) Wicked Water Problems: Sociology and Local Water Organizations in Addressing Water Resources Policy. *Journal of the American Water Resources Association*, 36(3), 483-491.

Furlan, E.M. and Gleeson, D. (2017) Improving reliability in environmental DNA detection surveys through enhanced quality control. *Marine and Freshwater Research*, 68(2) 388-395

Gawne, B., Brooks, S., Butcher, R., Cottingham, P., Everingham, P., Hale, J., Nielson, D., Stewardson, M., & Stoffels, R. (2013) Long Term Intervention Monitoring Logic and Rationale Document Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre, MDFRC Publication 01/2013, May, 109pp.

Gilligan, D.M., Vey, A., & Asmus, M. (2009) Identifying drought refuges in the Wakool system and assessing status of fish populations and water quality before, during and after the provision of environmental, stock and domestic flows. 58 pp.

Green, D. (2001) The Edward-Wakool System: River Regulation and Environmental Flows. Department of Land and Water Conservation. Unpublished Report.

Hale, J. and SKM. (2011) Environmental Water Delivery: Edward-Wakool. Prepared for Commonwealth Environmental Water, Department of Sustainability, Environment, Water, Population and Communities.

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S., & Gawne, B. (2014) Commonwealth Environmental Water Office Long Term Intervention Monitoring Project – Standard Methods. Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre, MDFRC Publication 29.2/2014, January, 182 pp.

Hinlo, R., Gleeson, D., Lintermans, M., & Furlan, E. (2017) Methods to maximise recovery of environmental DNA from water samples. *PLoS ONE*, 12(6), e0179251. doi:10.1371/journal.pone.0179251

Hladyz, S., Watkins, S.C., Whitworth, K.L., & Baldwin, D.S. (2011) Flows and hypoxic blackwater events in managed ephemeral river channels. *Journal of Hydrology*, 401(1-2), 117-125.

Howitt, J.A., Baldwin, D.S., Rees, G.N., and Williams, J.L. (2007) Modelling blackwater: predicting water quality during flooding of lowland river forests. *Ecological Modelling*, 203(3-4), 229-242.

Howitt, J.A., Baldwin, D.S., Rees, G.N., & Hart, B.T. (2008) Photodegradation, interaction with iron oxides and bioavailability of dissolved organic matter from forested floodplain sources. *Marine and Freshwater Research*, 59(9), 780-791.

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

Humphries, P. and Lake, P.S. (2000) Fish larvae and the management of regulated rivers. *Regulated Rivers: Research & Management*, 16(5), 421-432.

Humphries, P., Serafini, L.G., & King, A.J. (2002) River regulation and fish larvae: variation through space and time. *Freshwater Biology*, 47(7), 1307-1331.

Humphries, P., Cook, R.A., Richardson, A.J., & Serafini, L.G. (2006) Creating a disturbance: manipulating slackwaters in a lowland river. *River Research Applications*, 22, 525-542.

Ison, R.L., Alexandra, J., & Wallis, P.J. (2018) Governing in the Anthropocene: are there cyber-systemic antidotes to the malaise of modern governance? *Sustainability Science*. doi:10.1007/s11625-018-0570-5

Johansson, M.E. and Nilsson, C. (2002) Responses of Riparian Plants to Flooding in Free-Flowing and Regulated Boreal Rivers: an Experimental Study. *Journal of Applied Ecology*, 39, 971-986.

King, A.J., Humphries, P., & 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.

King, A.J., Ward, K.A., O'Connor, P., Green, D., Tonkin, Z., & Mahoney, J. (2009) Adaptive management of an environmental watering event to enhance native fish spawning and recruitment. *Freshwater Biology*, 55, 17-31

Leigh, S.J. and Zampatti, B.P. (2013) Movement and mortality of Murray cod, *Maccullochella peelii*, during overbank flows in the lower River Murray, Australia. *Australian Journal of Zoology*, 61(2), 160-169.

Lowe, B.J. (2002) Impacts of altered flow regime on riverbank vegetation in a lowland floodplain river. Unpublished PhD thesis, Charles Sturt University.

Lowe, B.J., Watts, R.J., Roberts J., & Robertson, A. (2010) The effect of experimental inundation and sediment deposition on the survival and growth of two herbaceous riverbank plant species. *Plant Ecology*, 209(1), 57-69.

Lucas, M.C., Baras, E., Thom, T.J., Duncan, A., & Slavík, O. (2001) Migration of freshwater fishes.

Lyon, J., Stuart, I., Ramsey, D., & 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.

Mackay, M., Allan, C., Colliver, R., & Howard, J. (2014) Systems Approaches Enable Improved Collaboration in Two Regional Australian Natural Resource Governance Situations. *International Journal of Systems and Society*, 1(2), 1-21. doi:10.4018/ijss.2014070101

Maheshwari, B.L., Walker, K.F., & McMahon, T.A. (1995) Effects of regulation on the flow regime of the river Murray, Australia. *Regulated Rivers Research and Management*, 10, 15-38.

Mallen-Cooper, M. and Stuart, I.G. (2003) Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications*, 19(7), 697-719.

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 01/2013, May, 163pp.

Moama Local Aboriginal Land Council. (2016). Koondrook-Perricoota Cultural Knowledge Project Turtle Monitoring Report: An Indigenous Partnerships Project Under The Living Murray Initiative. Government Report.

Murray Darling Basin Authority (2011) Murray-Darling Basin Authority Annual Report 2010-11. MDBA publication No. 218/11. MDBA, Canberra.

Murray Darling Basin Authority (2014) Basin-wide environmental watering strategy. Murray-Darling Basin Authority.

Murray-Darling Basin Commission (2004) Native fish strategy for the Murray-Darling Basin 2003-2013. Murray-Darling Basin Commission Publication No. 25/04.MDBC, Canberra, Australia.

NSW Office of Environment and Heritage (2018). NSW Central Murray Forests. https://www.environment.nsw.gov.au/topics/water/wetlands/internationally-significant-wetlands/nsw-central-murray-forests

Nicol, J. (2004) Vegetation Dynamics of the Menindee Lakes with Reference to the Seed Bank. PhD Thesis. The University of Adelaide, Adelaide, SA.

O'Connell, M., Baldwin, D.S., Robertson, A.I., & Rees, G. (2000) Release and bioavailability of dissolved organic matter from floodplain litter: influence of origin and oxygen levels. *Freshwater Biology*, 45, 333-342

O'Connor, J.P., O'Mahony, D.J., & O'Mahony, J.M. (2005) Movements of *Macquaria ambigua*, in the Murray River, south-eastern Australia. *Journal of Fish Biology*, 66(2), 392-403.

Pahl-Wostl, C., Vörösmarty, C., Bhaduri, A., Bogardi, J., Rockström, J., & Alcamo, J. (2013) Towards a sustainable water future: shaping the next decade of global water research. *Current Opinion in Environmental Sustainability*. doi:10.1016/j.cosust.2013.10.012

Peig, J. and Green, A.J. (2009) New perspectives for estimating body condition from mass/length data: the scaled mass index as an alternative method. Oikos, 118, 1883-1891.

Petrov, K., Lewis, J., Malkiewicz, N., Van Dyke, J.U., & Spencer, R.J. (2018) Food abundance and diet variation in freshwater turtles from the mid-Murray River, Australia. *Australian Journal of Zoology*, 66, 67-76.

R Development Core Team (2013) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Reynolds, L.F. (1983) Migration patterns of five fish species in the Murray-Darling River system. *Marine and Freshwater Research*, 34(6), 857-871.

Roberts, D.T., Duivenvoorden. L.J., & Stuart, I.G. (2008) Factors influencing recruitment patterns of Golden Perch (*Macquaria ambigua oriens*) within a hydrologically variable and regulated Australian tropical river system. *Ecology of Freshwater Fish*, 17, 577-589

Roberts, J. and Marston, F. (2011) Water regime for wetland and floodplain plants: A source book for the Murray-Darling Basin. National Water Commission, Canberra.

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

Santori, C., Spencer, R.J., Van Dyke, J.U., & Thompson, M.B. (2018) Road mortality of the eastern long-necked turtle (Chelodina longicollis) along the Murray River, Australia: an assessment using citizen science. *Australian Journal of Zoology*, 66, 41-49.

Secor, D.H., Dean, J.M., & Laban, E.H. (1992) Otolith removal and preparation for microstructural examination. In Otolith Microstructure Examination and Analysis. Edited by D.K. Stevensen and S.E. Campana. *Canadian Special Publication in Fisheries and Aquatic Science*. 117. pp. 19-57.

Serafini, L.G. and Humphries, P. (2004) A preliminary guide to the identification of the larvae of species of freshwater fish from the Murray-Darling Basin. CRC for Freshwater Ecology, February 2004.

Simpson, R.R. and Mapleston, A.J. (2002) Movements and habitat use by the endangered Australian freshwater Mary River cod, *Maccullochella peelii mariensis*. *Environmental Biology of Fishes*, 65(4), 401-410.

Spencer, R.J. and Thompson, M.B. (2005) Experimental analysis of the impact of foxes on freshwater turtle populations. *Conservation Biology*, 19, 845-854.

Steyaert, P. and Jiggins, J. (2007) Governance of complex environmental situations through social learning: a synthesis of SLIM's lessons for research, policy and practice. *Environmental Science & Policy*, 10(6), 575-586. doi:10.1016/j.envsci.2007.01.011

Summerfelt, R.C. and Smith, L.S. (1990) Anesthesia, surgery and related techniques. Pages 213-272 In C. B. Schreck and P. B. Moyle, (eds.) Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Taylor, M.K. and Cooke, S.J. (2012) Meta-analyses of the effects of river flow on fish movement and activity. *Environmental Reviews*, 20(4), 211-219.

Thiem, J.D., Hatin, D., Dumont, P., Van Der Kraak, G., & Cooke, S.J. (2013) Biology of lake sturgeon (Acipenser fulvescens) spawning below a dam on the Richelieu River, Quebec: behaviour, egg deposition, and endocrinology. *Canadian Journal of Zoology*, 91(3), 175-186.

Thompson, M.B. (1983) Populations of the Murray River Tortoise, Emydura (Chelodina): the effect of egg predation by the Red Fox, Vulpes vulpes. *Australian Wildlife Research*, 10, 363-371.

Thompson, M.B. (1993) Hypothetical considerations of the biomass of chelid tortoises in the River Murray and the possible influences of predation by introduced fox., Pages 219-224 in D. Lunney, and D. Ayes, eds. Herpetology in Australia. Sydney, NSW, Australia, Surrey Beatty and Sons.

Thoms, M.C. and Sheldon, F. (2000) Lowland rivers: an Australian introduction. *Regulated Rivers: Research & Management*, 16(5), 375-383.

Toner, M. and Keddy, P. (1997) River hydrology and riparian wetlands - a predictive model for ecological assembly. *Ecological Applications*, 7(1), 236-246.

van Dijk, A.I.J.M., Beck, H.E., Crosbie, R.S., de Jeu, R.A.M., Liu, Y.Y., Podger, G.M., Timbal, B., & 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, doi:10.1002/wrcr.20123.

Van Dyke, J.U., Ferronato, B., & Spencer, R.J. (2018) Current conservation status of Australian freshwater turtles. *Australian Journal of Zoology*, 66, 1-3.

Van Dyke, J.U., Spencer, R.J., Thompson, M.B., Chessman, B., Howard, K., & Georges, A. (2019) Conservation implications of turtle declines in Australia's Murray River system. *Scientific Reports*, 9, 1-12.

Walsh, C.T., Reinfelds, I.V., Ives, M.C., Gray, C.A., West, R.J., & van der Meulen, D.E. (2013) Environmental influences on the spatial ecology and spawning behaviour of an estuarine-resident fish, *Macquaria colonorum*. *Estuarine, Coastal and Shelf Science*, 118, 60-71.

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., Hall, A., Osborne, W., & 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.

Waters, C.N., Zalasiewicz, J., Summerhayes, C., Barnosky, A.D., Poirier, C., Gałuszka, A., & Wolfe, A.P. (2016) The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* (New York, N.Y.), 351(6269). doi:10.1126/science.aad2622

Watts, R., Kopf, R.K., Hladyz, S., Grace, M., Thompson, R., McCasker, N., Wassens, S., Howitt, J.A., Burns, A., & Conallin, J. (2013) Monitoring of ecosystem responses to the delivery of environmental water in the Edwards-Wakool river system, 2011-2012. Report 2. . Institute for Land, Water and Society.

Watts, R.J., McCasker, N., Baumgartner, L., Bond, N., Bowen, P., Conallin, A., Grace, M., Healy, S., Howitt, J.A., Kopf, R.K., Scott, N., Thiem, J., & Wooden, I. (2014a) Monitoring and Evaluation Plan for the Edward-Wakool Selected Area. Insititute for Land, Water and Society, Charles Sturt University. Prepared for Commonwealth Environmental Water Office.

Watts, R.J., McCasker, N., Thiem, J., Howitt, J.A., Grace, M., Healy, S., Kopf, R.K., Dyer, J.G., Conallin, A., Wooden, I., Baumgartner, L., & Bowen, P. (2014b) Monitoring the ecosystem responses to Commonwealth environmental water delivered to the Edward-Wakool river system, 2013-14. Institute for Land, Water and Society, Charles Sturt

Watts, R.J., Scott, N., Bowen, P., Conallin, A., Grace, M., Healy, S., Abell, J., & Thiem, J. (2014c) Workplace Health and Safety and Environment Plan for the Edward-Wakool Selected Area. Commonwealth of Australia.

Watts, R., McCasker, N., Thiem, J., Howitt, J., Grace, M., Kopf, R., & Healy, S. (2015) Commonwealth Environmental Water Office Long Term Intervention Monitoring project: Edward-Wakool Selected Area Synthesis Report 2014-15. Canberra, ACT, Australia, Institute for Land, Water and Society, Charles Sturt University.

Watts, R.J., McCasker, N., Howitt, J.A., Thiem, J., Grace, M., Kopf, R.K., Healy, S., & Bond, N. (2016) 'Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Evaluation Report, 2015-16'. Report prepared for Commonwealth Environmental Water Office. Commonwealth of Australia.

Watts, R.J., Kopf, R.K., McCasker, N., Howitt, J.A., Conallin, J., Wooden, I., & Baumgartner, L. (2017a) Adaptive management of environmental flows: Using irrigation infrastructure to deliver environmental benefits during a large hypoxic blackwater event in the southern Murray-Darling Basin. Environmental Management. DOI 10.1007/s00267-017-0941-1.

Watts, R.J., McCasker, N., Howitt, J.A., Thiem, J., Grace, M., Kopf, R.K., Healy, S., & Bond, N. (2017b) 'Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Evaluation Report, 2016-17'. Report prepared for Commonwealth Environmental Water Office. Commonwealth of Australia

Watts, R.J., Wolfenden, B., Howitt, J.A., Jenkins, K., & McCasker, N. (2017c) Contribution of Koondrook-Perricoota floodplain runoff to the productivity of the Wakool River – Draft report. Report prepared for Forestry Corporation of New South Wales.

Watts, R.J., McCasker, N., Howitt, J., Trethewie, J., Thiem, J., & Grace, M. (2018) Addendum: Monitorig and Evaluation Plan for the Edward-Wakool Selected Area, Commonwealth of Australia 2014'. Report trepared for the Commonwealth Environmental Water Holder. Charles Sturt University, May 2018.

Webb, J.A., Watts, R.J., Allan, C., & Conallin, J.C. (2018) Adaptive Management of Environmental Flows. *Environmental Management*. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/29362893. doi:10.1007/s00267-017-0981-6

Wengraf, T. (2001) Qualitative research interviewing. London: Sage Publications.

Whitworth, K.L., Baldwin, D.S., & Kerr, J.L. (2012) Drought, floods and water quality: drivers of a severe hypoxic blackwater event in a major river system (the southern Murray-Darling Basin, Australia). *Journal of Hydrology*, 450-451(0), 190-198.

Yarkuwa Indigenous Knowledge Centre (no date). Sustainable Indigenous use of the natural resources. Information sheet published by Yarkuwa Indigenous Knowledge Centre.

13. Budget

The budget has been removed for Commercial in Confidence reasons.

Appendices

1. **Workplace Health & Safety Plan**
2. **Progress report template**