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Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Evaluation Report

2016-17

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Cover photos:
Left - Dead fish on Wettupa Station in November 2016 during the unregulated flood that resulted in a hypoxic blackwater event (Photo: Peter Heath)
Middle - Edward River at Memorial Park, Deniliquin, showing stained tree trunks indicating the extent to which floodwaters extended over the bank (Photo: Julia Howitt)
Right – Turbid oxygenated water released from the Edward Escape (on right) mixing with hypoxic black water in the Edward River (Photo: CEWO)

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Contents

EXECUTIVE SUMMARY

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool River System Selected Area in 2016-17. It is the third annual report of the Long Term Intervention Monitoring (LTIM) Project (2014-2019) funded by the Commonwealth Environmental Watering Office. This project was undertaken as a collaboration among Charles Sturt University, NSW DPI (Fisheries), Monash University, NSW Office of Environment and Heritage, La Trobe University and Murray Local Land Services. Field sampling for the project was undertaken by staff from Charles Sturt University, NSW DPI (Fisheries), and NSW Office of Environment and Heritage.

This report provides details of the Commonwealth environmental watering actions, indicators and an evaluation of the ecosystem responses to flows in the Edward-Wakool Selected Area during the 2016-17 watering year. This report evaluates ecosystem responses to:

1. The large unregulated flow events from August to November 2016 that occurred following record-breaking rainfall in parts of the catchment
2. Environmental watering actions from irrigation canal escapes that commenced in late October 2016 and continued until December 2016 to provide refuges from hypoxic water for fish and other aquatic biota
3. Environmental watering actions in Yallakool creek and the Wakool River from January 2017 to provide flow recession at the end of the unregulated flow event. In Yallakool Creek this action continued into late autumn/winter 2017 to maintain base flows during winter, when under normal river operations there would be a period of cease to flow in some of the smaller streams when the regulators are shut down in winter.

Indicators monitored in 2016-17 for the Edward-Wakool selected area evaluation were: river hydrology, water quality and carbon, stream metabolism, riverbank and aquatic vegetation, fish movement, fish reproduction, and fish recruitment (Murray cod, golden perch and silver perch). The fish community was monitored in only zone three for the basin-scale evaluation. No selected area evaluation for the fish community was undertaken in 2015-16 as this is scheduled to be monitored in only years 1 and 5 of the project.

The following responses to the unregulated flood events from August to November 2016 were observed in the Edward-Wakool system:

- Extended period of overbank flows that flooded forest, cropping land, grazing and pasture lands and increased connectivity through backwaters, flood runners and anabranches
- Increased dissolved organic carbon and nutrients (especially nitrogen and phosphorous) and a rapid decrease in dissolved oxygen in October 2016 resulting in hypoxia and widespread fish deaths
- Large reduction in the cover and richness of submerged and amphibious plants during the flood and an increase in the cover and richness of terrestrial riverbank plants following the recession of the flood

- Increased movement of golden perch and silver perch over 100's of kilometres, which was an order of magnitude greater than movements during the preceding months
- Very low numbers of Murray cod larvae present compared to previous years, as the hypoxic event occurred at the time of year in which Murray cod spawn in this system
- Absence of Murray cod, silver perch and golden perch recruits following the flood
- Very high biomass of tadpoles and invertebrates observed in nets, providing a source of food for native fish and other animals.

The responses to the environmental watering actions from irrigation escapes to create local refuges from hypoxic blackwater differed between sites. The response was influenced by the extent to which the environmental water contributed to the river flow. The watering actions from the Edward escape and Wakool escape had positive outcomes, improving DO and DOC downstream of these escapes. No targeted fish monitoring was undertaken near these escapes, however landholders and Fisheries Officers observed fish congregating in the flows from these escapes, suggesting the water actions were successful in creating localised fish refuges during the hypoxic blackwater conditions. The watering action from the Niemur escape did not result in any change in indicators downstream of the escape because the environmental water contributed less than 7 % of the total flow in the Niemur River. The watering action at the Thule escape was influenced by other localised effects. The watering actions from the Niemur and Thule escapes may have provided local refuge habitat for fish and other organisms.

During the flood recession and winter environmental watering action the water quality was maintained within an acceptable range. Compared to fish spawning recorded at the same time in previous years, there was increased spawning of carp, carp gudgeon, Murray River rainbowfish, gambusia and bony herring on the recession of the flood. However, there were no fish recruits of Murray cod, silver perch or golden perch recorded in autumn 2017. There was no detectable response of aquatic vegetation on the recession of the flood or into autumn and winter 2017, because almost no aquatic vegetation survived the flood event.

The findings underpin recommendations on the timing, duration and magnitude of flow to help inform the adaptive management of future environmental flows in this system. In summary, the seven recommendations from this report are as follows:

1. If there is an imminent hypoxic blackwater event during an unregulated flow and the quality of source water is suitable for an environmental watering action, the CEWO and other relevant agencies, in partnership with local landholder and community representatives, should take action to facilitate the earlier release of environmental water on the rising limb of the flood event to create local refuges prior to dissolved oxygen concentrations falling below 2 mgL^{-1}.
2. The installation of a dissolved oxygen logger on an existing NSW Water gauge downstream of Yarrawonga and upstream of Barmah-Millewa Forest (such as Tocumwal) should be considered a priority to enable forest managers to more accurately determine and understand the influence of upstream floodplain and/or the forest on DO and DOC levels in the mid-Murray reach. Consideration should also be given to installing dissolved oxygen loggers, both upstream and

downstream of other forested areas that may influence water quality in the Edward-Wakool system, including Werai Forest.

3. Implement a second trial of continuous base environmental flows (no cease to flow) during winter 2018 in the tributaries of the Edward-Wakool system to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist the recovery of submerged aquatic plants in the system.
4. Trial the delivery of an environmental watering action in the Edward River downstream of Stevens Weir to target golden perch and silver perch spawning, supported with appropriate monitoring. This recommendation was carried forward from the 2015-16 annual report (Watts et al. 2016).
5. Continue to explore opportunities to increase the magnitude of environmental water delivered to the upper Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system. This recommendation was carried forward from the 2015-16 annual report (Watts et al. 2016).
6. Undertake in-channel habitat mapping for all key reaches of the Edward-Wakool system, which could then be combined with the hydraulic modelling undertaken to-date (see Watts et al. 2015) to also facilitate learning about this system and the outcomes being observed from the use of water.
7. The CEWO and other relevant agencies undertake a review of the 2016 flood and subsequent hypoxic blackwater event in the Murray system and support further research into understanding these events, to assist future water management.

1. INTRODUCTION

1.1 Purpose of this report

The Commonwealth Environmental Water Office (CEWO) has funded a Long-Term Intervention Monitoring (LTIM) Project in seven Selected Areas to evaluate the ecological outcome of Commonwealth environmental water use throughout the Murray-Darling Basin (MDB). The LTIM Project is being implemented over five years from 2014-15 to 2018-19 to deliver five high level outcomes:

1. Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authorities (MDBA) Environmental Watering Plan;
2. Evaluate the ecological outcomes of Commonwealth environmental watering in each of the seven Selected Areas;
3. Infer ecological outcomes of Commonwealth environmental watering in areas of the MDB that are not monitored;
4. Support the adaptive management of Commonwealth environmental water; and
5. Monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2016-17. It is the third annual report of the Long Term Intervention Monitoring (LTIM) Project funded by the Commonwealth Environmental Watering Office. This project was undertaken as a collaboration among Charles Sturt University, NSW DPI (Fisheries), Monash University, NSW Office of Environment and Heritage, and La Trobe University. Field sampling for this project was undertaken by staff from Charles Sturt University, NSW DPI (Fisheries) and NSW Office of Environment and Heritage.

1.2 Structure of this report

The purpose of this report is to evaluate of ecosystem responses to environmental watering in the Edward-Wakool system in 2016-17. This report evaluates ecosystem responses to:

1. The large unregulated flow events from August to November 2016 that occurred following record-breaking rainfall in parts of the catchment
2. Environmental watering actions that commenced in late October 2016 and continued until December 2016 to provide refuges from hypoxic water for fish and other aquatic biota
3. Environmental watering actions in Yallakool creek and the Wakool River from January 2017 to provide flow recession at the end of the unregulated flow event. In Yallakool Creek this action continued during late autumn/winter 2017 to maintain base flows during winter, when under normal river operations there would be a period of cease to flow in some of the smaller streams when the regulators are shut down in winter.

This report has 13 sections that provide an overview of results, with more detailed results and analyses provided in four appendices. This introduction (section 1) is followed by a description of the Commonwealth environmental water use objectives and watering actions for this system for 2016-17 (section 2) and an overview of the monitoring and evaluation undertaken in this system for the LTIM project (section 3). Summaries of the evaluation of responses of each indicator to Commonwealth environmental watering and flooding in 2016-17 are presented in sections four to eleven; hydrology (section 4), water quality and carbon (section 5), stream metabolism (section 6), riverbank and aquatic vegetation (section 7), fish movement (section 8), fish spawning (section 9), fish recruitment (section 10) and fish community (section 11). A synthesis of the results (section 12) underpins recommendations to help inform adaptive management of environmental water in this system in the future (section 13). Detailed descriptions of results and analyses are provided in technical appendices: Water quality and carbon (Appendix A), Stream metabolism (Appendix B), Riverbank and aquatic vegetation (Appendix C), and Fish (Appendix D).

1.3 Edward-Wakool Selected Area

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 1.1). 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 1.1).

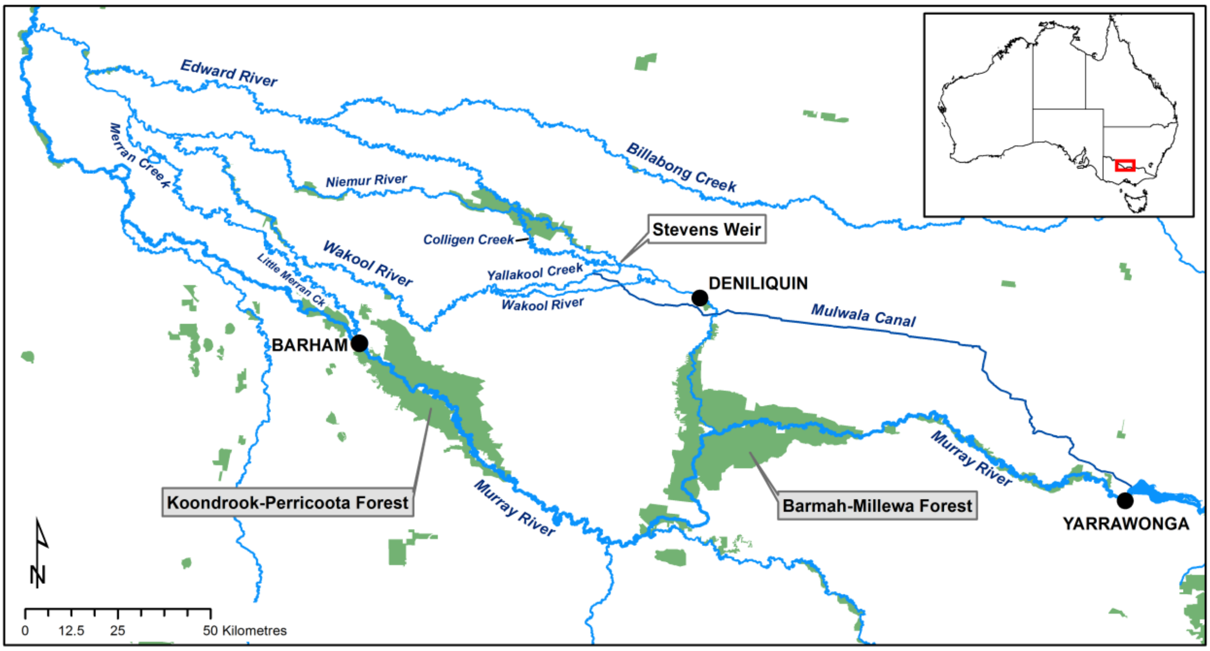


Figure 1.1 Map showing the main rivers in the Edward-Wakool system. (Source: Watts et al. 2013)

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. The Edward-Wakool system also plays an important ecological role in connecting upstream and downstream ecosystems. 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 of 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. 2015b). 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 and water quality conditions over the past 15 years, and these antecedent conditions influence the way in which the ecosystem responds to Commonwealth environmental watering.

From 1998 to 2010 south-eastern Australia experienced a prolonged drought (known as the Millenium 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. Consequently, between February 2006 and September 2010 there were periods of minimal or no flow in the Wakool River. During this period 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 River (MDBA 2011; Whitworth et al. 2012). This hypoxic blackwater event resulted in the loss of many thousands of native fish, including large individuals of Murray cod (King et al. 2012; Whitworth et al. 2012; Watts et al. 2017a). Another hypoxic blackwater event occurred in the system in 2012.

From late February to May 2016 there was a widespread bloom of the cyanobacteria *Chrysosporum ovalisporum* through the Murray River catchment that originated upstream of Yarrawonga Weir. The sharp increase in DO observed at the onset of the bloom was a result of the high rates of photosynthesis leading to oversaturation of the water column during the day. However, hypoxia was not observed following the collapse of the bloom as the bloom decreased gradually in cold water conditions (Watts et al. 2016).

In late 2016 there was a widespread flood in the southern-MDB associated with record-breaking rainfall in parts of the catchment (http://www.bom.gov.au/climate/current/annual/aus/2016/). Some areas of the floodplain were inundated that had not been flooded for more than 20 years. In the Murray catchment, inputs from the Kiewa and Ovens Rivers were the highest since 2010 and the Murray River flows at Yarrawonga in October were the highest since 1993 (MDBA River Murray Weekly Report, 7th Dec). The unregulated flows from the Murray River inundated the floodplain including Barmah Forest and Koondrook–Perricoota Forests (Figure 1.1) and agricultural land, and resulted 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. As a result of the flood, some of the environmental watering actions planned for the Edward-Wakool system in 2016-17 were not implemented, and other watering actions were undertaken. Section 2 includes an overview of previous Commonwealth environmental watering actions from 2010 – 2016, with details of Commonwealth watering actions in the Edward-Wakool River system in 2016-17.

2. Commonwealth environmental water use objectives and watering actions in the Edward-Wakool system 2016-17

2.1 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 1.1). This structure creates a weir pool that allows Commonwealth environmental water to be delivered to Colligen and Yallakool Creeks, 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 'escapes' or outfalls managed by the irrigator-owned company Murray Irrigation Limited (MIL). During a hypoxic blackwater event in 2010, water was released from three Mulwala Canal escapes to lessen the impact of hypoxia and create localised refugia with higher DO and lower DOC (Watts et al. 2017a). In addition there are numerous smaller escapes throughout the MIL network that can be used to deliver small flows to the river system.

The ability to deliver environmental water to the Edward-Wakool system will depend on water availability and circumstances in the river at any given time. Commonwealth 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. For example, in the Wakool-Yallkool 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 with environmental releases 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 into the Edward-Wakool system under regulated conditions. At times of high irrigation demand channel capacity will be shared with other water users. If the system is receiving higher unregulated flows, there may not be enough capacity to deliver environmental water (Gawne et al. 2013). Environmental flows 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 algal blooms or hypoxic blackwater events (Gawne et al. 2013; Watts et al. 2017a).

2.2 Summary of Commonwealth environmental watering actions 2010 - 2017

Commonwealth environmental watering actions have occurred in the Edward-Wakool system since 2010 (Table 2.1, Figure 2.1). Between 2010 and 2016 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 2.1). 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 2.1). To date it has not been possible for the water managers to deliver larger within channel freshes due to operational constraints within the system (currently constrained to 600 ML/d at the confluence of the Wakool River and Yallakool Creek).

The 2016-17 water year was the first time in which a 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 2.1).

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).

Table 2.1 Summary of Commonwealth environmental watering actions in the Edward-Wakool system from July 2010 to June 2017. More detailed information about environmental watering in the mid-Murray catchment is available from the CEWO website (Department of the Environment and Energy 2017)

	Type of environmental watering action						
	In-channel flows				Watering from irrigation infrastructure		Overbank flows
Water Year	Base flows and small freshes	Contribute to flow recession	Maintenance of winter base flows	Larger within channel freshes[1]	Flows from canal escapes during hypoxic blackwater events	Flows in ephemeral watercourses[2]	Watering Forests
2009-10							✓
2010-11					✓	✓	
2011-12	✓					✓	
2012-13	✓				✓	✓	
2013-14	✓	✓				✓	
2014-15	✓	✓				✓	
2015-16	✓	✓				✓	
2016-17	✓	✓	✓		✓	✓	

[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).
[2] Some of the watering actions in ephemeral creeks done jointly with NSW Office of Environment and Heritage

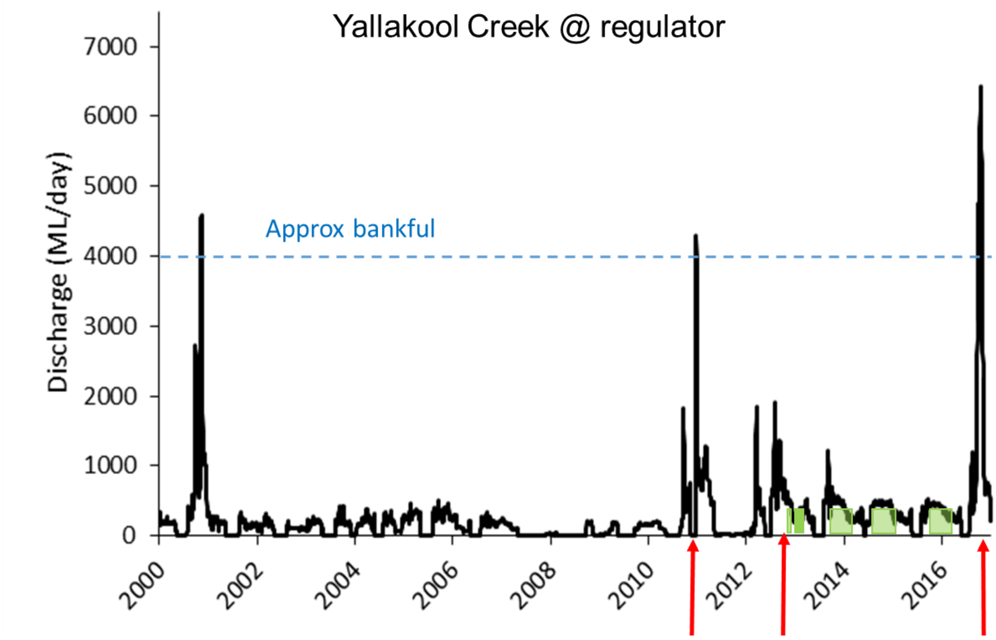


Figure 2.1 Daily discharge (ML.d^{-1}) in Yallakool Creek (gauge 409020 Yallakool Creek @ Offtake) from 2000 to 2017. There were periods of no flows and several unregulated flows between 2010 and 2016. Commonwealth environmental watering actions between 2010 and 2016 are shown in green shading with red arrows indicating periods when environmental water was delivered from irrigation canal esacpes during hypoxic blackwater events. There is an operational constraint of 600 ML d^{-1} downstream of the confluence of Yallakool Creek and the upper Wakool River. Daily discharge data was obtained from NSW Office of Water website.

2.3 Watering priorities for the Mid Murray in 2016-17

The Murray – Lower Darling Environmental Watering Priorities Statement 2016–17 (OEH 2016) states that for the Edward-Wakool system the priority in 2016-17 is to build on previous outcomes from the use of environmental flows (particularly the maintenance of in-stream native aquatic vegetation and habitat for native fish) and the target timing was spring–autumn. The Portfolio Management Plan: Mid-Murray Region 2016-17 (CEWO 2016) sets out the plans for managing within a multi-year context the Commonwealth environmental water portfolio in the Mid-Murray Region for 2016–17. It outlines water delivery scenarios, carryover potential and trade options to optimise water use across water years and to maximise environmental outcomes across the MDB. Based on these strategies and plans, and in response to best available knowledge drawing on the results of environmental watering monitoring programmes, the outcomes being targeted by environmental watering in the Mid Murray Region are summarised in Table 2.2. The objectives and targeted outcomes for water-dependent ecosystems will continue to be revised as part of the CEWO's commitment to adaptive management.

The Portfolio Management Plan: Mid-Murray Region 2016-17 (CEWO 2016) and in the Water Use Minute 10054, the 2016-17 Commonwealth environmental water use in the Edward-Wakool system was expected to contribute to achieving the following expected outcomes:

- *maintain the diversity and condition of native fish and other native species including frogs and invertebrates through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit*

- *maintain habitat quality in ephemeral watercourses*
- *support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity*
- *support inundation of low-lying wetlands/floodplains habitats within the system*
- *maintain health of riparian and in-channel aquatic native vegetation communities*
- *maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH*
- *maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.*

CEWO (2016) also states that in consideration of the expected outcomes and outcomes achieved by similar watering actions undertaken previously, it is expected that the following further improvements to the targeted assets will occur:

- *improved capacity to maintain connectivity, both within the Edward-Wakool system and between the Edward-Wakool and the wider Murray system. This will provide opportunities for native fish to move and spawn.*
- *improved capacity to maintain native vegetation condition (riparian and in-channel), and improved habitat condition to support frogs and other native fauna, including invertebrates.*
- *improved capacity to maintain water quality and mitigation of poor water quality should a hypoxic water event occur.*
- *while return flows cannot currently be accounted for in NSW, environmental water delivered through the Edward- Wakool system that returns to the River Murray will contribute to improved capacity to maintain outcomes downstream.*

During the planning phase in early 2016 the CEWO was considering supplying environmental water to the following actions for 2016–17:

<u>*Edward-Wakool System 2016-17 (options 3a – 3c)(from CEWO, 2016)*</u>

- *Permanent Waterways: The purpose of watering events would be to maintain in-stream habitat, particularly aquatic vegetation and areas supporting the various life stages of native fish. Environmental water use is most likely to contribute to in-channel base flows and freshes. It may also be used to provide a more gradual recession following periods of high flow (e.g. rain rejection flows) and improve water quality to provide refuges for aquatic plants and animals if required and where feasible to do so.*
- *Ephemeral waterways and wetlands: The purpose of watering events would be to maintain ephemeral in-stream and wetland habitat, particularly water quality, aquatic vegetation and areas supporting the various life stages of native frogs, birds and aquatic invertebrates.*
- *Edward-Wakool forests: The purpose of watering events would be to protect or maintain vegetation health and to contribute to hydrological connectivity and nutrient/carbon cycling processes*.

Table 2.2 Summary of outcomes being targeted by environmental watering in the Mid Murray Region (from CEWO 2016)

BASIN-WIDE OUTCOMES (Outcomes in red link to the Basin-wide environmental watering strategy, MDBA 2014)	EXPECTED OUTCOMES FOR MID MURRAY ASSETS						
	IN-CHANNEL ASSETS			OFF-CHANNEL ASSETS			
	River Murray from Hume Dam to Euston	Edward-Wakool River System	Gunbower Creek	Barmah-Millewa Forest	Gunbower-Koondrook-Perricoota Forest	Edward-Wakool Forests (e.g. Werai, Neimur)	Central Murray off-channel wetlands and ephemeral creeks
VEGETATION	Maintain riparian and in-channel vegetation condition. Increase periods of growth for non-woody vegetation communities that closely fringe or occur within river channels.			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 creek channels, and those that form extensive stands within wetlands and low-lying floodplains including moira grassland in Barmah–Millewa forests.			Maintain and improve condition of wetland vegetation.
WATERBIRDS	Provide habitat and food sources to support waterbird survival and recruitment, and maintain condition and current species diversity.						
				Complete naturally triggered colonial bird breeding events.			
FISH	Provide flows to support habitat (including longitudinal connectivity and bench inundation) and food sources and promote increased movement/dispersal, recruitment and survival/condition of native fish.			Provide flows to support habitat and cues for increased movement, recruitment and survival/condition of native fish (particularly for floodplain specialists).			
INVERTEBRATES	Provide habitat to support increased microinvertebrate and macroinvertebrate survival, diversity, abundance and condition.						
OTHER VERTEBRATES	Provide habitat to support survival, maintain condition and provide recruitment opportunities for frogs and turtles.						
CONNECTIVITY	Maintain lateral connectivity through contributing to an increase in the frequency of freshes, bankfull and lowland floodplain flows.						
	Maintain baseflows and increase overall flows in the River Murray. Maintain longitudinal connectivity along the River Murray to fulfil important environmental functions, such as nutrient and sediment transport, organism dispersal and water quality.			Maintain connectivity through creeks and anabranches, thereby enhancing connectivity and functioning through the length of the River Murray.			
PROCESSES	Increase primary productivity, nutrient and carbon cycling, biotic dispersal and movement. Increase transport of organic matter, salt and nutrients downstream.						
WATER QUALITY	Maintain water quality and provide refuge habitat from adverse water quality events (e.g. blackwater). Increase mobilisation and export of salt from the River Murray system.						
RESILIENCE	Provide drought refuge habitat and maintenance/condition of native biota (e.g. fish and other aquatic fauna)						

Information sourced from: MDBA (2014); Department of the Environment (2014); Department of the Environment (2011a-d); MDBA (2012a-f); DELWP (2015)

2.4 Commonwealth watering actions in Edward-Wakool River system 2016-17

Changes to initial 2016-17 watering plans

Widespread flooding in south-eastern Australia in 2016 resulted in a hypoxic (low dissolved oxygen, DO) blackwater (high dissolved organic carbon) event affecting a large area of the southern MDB. In response to this event the Commonwealth environmental watering plan to deliver base flows and freshes to the Edward-Wakool system in spring 2016 was no longer appropriate. Thus the objectives previously outlined in Water Use Minute 10054 were altered.

Environmental watering actions implemented in 2016-17

There were eight environmental watering actions in the Edward-Wakool system in 2016-17 (Table 2.3). Specific objectives for each action have been sourced from CEWO planning documents, from the WUM for the hypoxic backwater flows and from updates and newspaper placements.

In September 2016 following high rainfall in the catchment and a large increase in discharge in the system there was evidence that DO was low at many sites in the system. There was concern that prolonged low DO would result in death of aquatic fauna, similar to the event in 2010 (Watts et al. 2017a). Opportunities to create local refuge areas by releasing water with higher DO and lower DOC from irrigation canals via regulating structures (‘irrigation canal escapes’) into the Edward-Wakool system were considered. The Murray Dissolved Oxygen Group, Edward-Wakool Operations Advisory Group, and the Edward-Wakool Environmental Water Reference Group met frequently by teleconference during the event to share information, discuss options and plan watering actions and other activities to mitigate the negative impacts of the hypoxic blackwater. Landholders and the broader community were regularly consulted with respect to watering decisions.

Between October and December 2016 Commonwealth environmental watering actions were undertaken to create local refuge areas by releasing environmental flows from irrigation canals escapes into the Edward-Wakool system (Table 2.3). These watering actions were completed by the end of December 2016. Watering actions 1, 2, 3 (Table 2.3) to provide refuges from hypoxic water between October and December 2016 were evaluated in this 2016-17 Edward-Wakool LTIM report.

Watering actions 5 and 6 (Table 2.3) occurred during autumn to provide a longer flow recession at the end of the unregulated flow event. In addition, watering action 6 (Table 2.3) was implemented in Yallakool Creek in late autumn and winter to create continuity in base flows during the time of year that under normal river operations there would be a period of cease to flow, whereas at this time of the year prior to river regulation there would have been continuity of flows. These watering actions aimed to improve links with other parts of the river system. The winter watering actions commenced after the monitoring for fish larvae and fish recruitment had been completed for 2016-17 watering year. Thus, the winter watering action was not able to be evaluated for all of the indicators in this report (see Table 3.3). The winter watering action was not completed in the 2016-17 watering year, but continued into July/August 2017. Thus the winter watering action will be only partly evaluated in this 2016-17 report, but will be fully evaluated in the 2017-18 annual LTIM report.

Table 2.3 Watering actions in the Edward-Wakool system in 2016 as described in planning documents, from the Water Use Minute for the hypoxic backwater flows and from updates and newspaper placements. Actions 1, 2, 3 (shaded in grey) were evaluated in this report. Some aspects of watering actions 5 and 6 (shaded in grey) were evaluated. However the winter watering actions that continued into July and August 2017 will be fully evaluated in the 2017-18 annual report.

Action #	Water Use Minute	Asset	Primary Objectives	Other Objectives	Volume (ML)	Start Date	End Date
1	WUM10054-03	Wakool River	To provide refuges from hypoxic water for fish and other aquatic biota. Escape flows for hypoxic water refuge at the Thule, Wakool and other minor Wakool Escapes, with flows of up to 40, 500 and 45 ML/d respectively.	-	29,306.63	31/10/2016	31/12/2016
2	WUM10054-04	Edward River	To provide refuges from hypoxic water for fish and other aquatic biota. Staged approach up to 2,400 ML/d from Edward Escape. Flows to decrease by 300ML/d from 2/12/2016-8/12/2016 due to increases in upstream DO.	-	74,822.7	24/10/2016	08/12/2016
3	WUM10054-05	Colligen-Neimur	To provide refuges from hypoxic water for fish and other aquatic biota	-	3,240.67	17/10/2016	16/12/2016
4	WUM10054-06	Colligen-Neimur	Prevent a rapid return to base flows following the hypoxic event. Year 2 of 3 using CEW to determine if using longer recessions to flows promotes the recovery of in-stream aquatic vegetation in the Colligen-Niemur system (as observed in Yallakool-Wakool system) Autumn pulse and recession also to assist with movement of juvenile native fish. To provide flows to native vegetation that may occur higher on the channel/bank. Winter flows aim to: • provide more refuge areas for juvenile and small fish to find food and avoid being eaten by bigger fish • keep adult fish and water plants in good condition before spring arrives • reinstate part of the flows that would have occurred naturally (before dams) during winter-spring • improve links with other parts of the river system • allow most of the banks in the weir pool and along the creeks and rivers to dry.	To provide variability to flows and determine how the shape of the hydrograph and variability it provides can be maintained into the lower Niemur. To provide steady flow rates during fishing events so that flows do not impact adversely on fishing conditions	21,542	01/01/2017	30/06/2017

5	WUM10054-07	Wakool River	Prevent a rapid return to base flows following the hypoxic event. To provide recessions to flows of a rate and duration that contributes to ongoing recovery of instream in-stream aquatic vegetation.		TBC (Accounted as Yallakool flows)	01/01/2017	30/06/2017
6	WUM10054-08	Yallakool Creek	Prevent a rapid return to base flows following the hypoxic event. To provide recessions to flows of a rate and duration that contributes to ongoing recovery of instream in-stream aquatic vegetation. Autumn pulse and recession also to assist with movement of juvenile native fish To influence different changes in river rises that may contribute to silver perch spawning, To provide a number of peaks at a time when water temperature is suitable for silver perch spawning. To determine if river level rises timed with periods of 23°C water temperature and no moon (dark night sky conditions) has any influence on silver perch spawning response. Winter flows aim to: • provide more refuge areas for juvenile and small fish to find food and avoid being eaten by bigger fish • keep adult fish and water plants in good condition before spring arrives • reinstate part of the flows that would have occurred naturally (before dams) during winter-spring • improve links with other parts of the river system • allow most of the banks in the weir pool and along the creeks and rivers to dry.	To provide steady flow rates during the fishing events so that flows do not impact adversely on fishing conditions. To determine ability to deliver flows at a specific time and place To determine how the shape of the hydrograph can be maintained into the lower Wakool (Gee Gee Bridge to Stoney Crossing)	30,351	01/01/2017	30/06/2017
7	WUM10054-09	Merran Creek	Promote fish movement and connectivity between the Murray and the lower-Wakool		1,107	16/02/2017	28/03/2017
8	WUM10054-10	Tuppal Creek	Improvement in the ecological condition of the creek with an increase in canopy cover of stressed riparian vegetation, provision of connectivity between pools and the Edward River, and improved water quality.	-	1,320	30/03/2017	15/05/2017

3. MONITORING AND EVALUATION

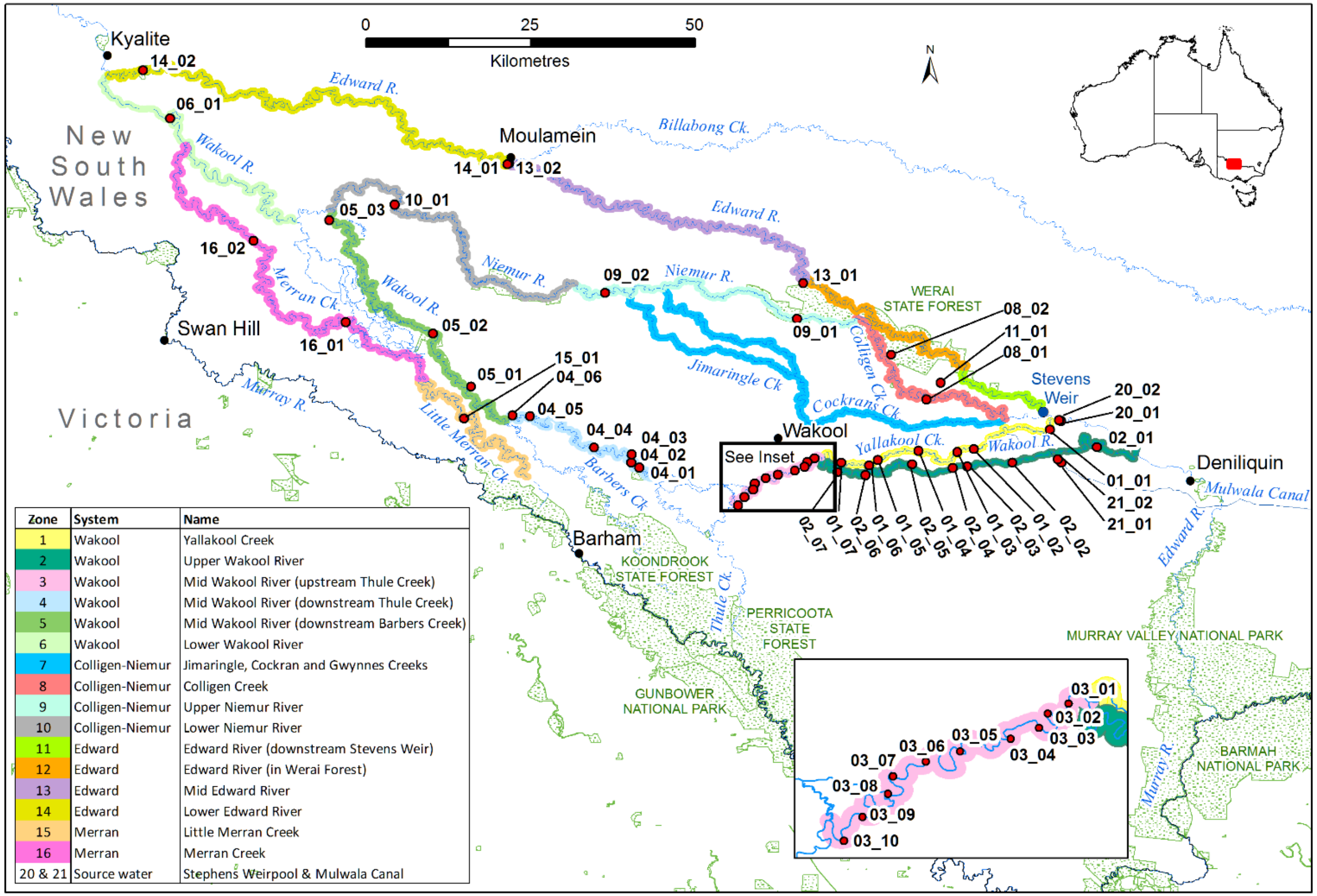
3.1 Monitoring zones and sites

The monitoring of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2016-17 was undertaken following the Edward-Wakool Long-Term Intervention Monitoring and Evaluation Plan (Watts et al. 2014). Where modifications to the monitoring design occurred due to the unregulated flooding in the system in late 2016, or for any other circumstances, these are outlined in chapters 5 to 11 and the appendices of this report.

The majority of the monitoring in the Edward-Wakool LTIM Selected Area is focussed on four hydrological zones: Yallakool Creek (zone 1), the upper Wakool River (zone 2) and mid reaches of the Wakool River (zones 3 and 4) (Figure 3.1, Table 3.1). Zones one to four are referred to as the focal zone. The reaches in zones 1 and 2 are generally more constrained, have steeper riverbanks and fewer in-channel geomorphic features (e.g. benches) than many of the reaches in zones 3 and 4 (Figure 3.2).

Additional sites throughout the Edward-Wakool system are monitored for fish movement (Figure 3.3). Fish populations are also surveyed at sites throughout the system in years 1 (2014-15) and 5 (2018-19) of the LTIM program, so will not be included in this 2016-17 annual report.

In this report we also present data from additional water quality monitoring commissioned by CEWO to be undertaken in November and December 2016 to assess the responses to the delivery of Commonwealth environmental water through Murray Irrigation Limited canal escapes. Sites for this additional monitoring were located in the Edward River upstream and downstream of the Edward River escape, in the Wakool River upstream and downstream of the Wakool escape, in Thule Creek upstream and downstream of the Thule escape, and in the Niemur River upstream and downstream of the Niemur Siphon (Figures 3.4, to 3.7). Water samples were also collected within the irrigation canal at all four of these irrigation escape sites.



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 3.1 Location of monitoring sites for the Edward-Wakool Selected Area for the Long-Term Intervention Monitoring (LTIM) Project. Zones one to four are referred to as the focal zone for the Edward-Wakool project. Hydrological gauges are located in Yallakool Creek just upstream of site 01_01 (gauge 409020, Yallakool Creek at offtake), Wakool River zone 2 just upstream of site 02_01 (gauge 409019, Wakool River offtake), and in the Wakool River zone 4 at site 04_01 (gauge 409045, Wakool River at Wakool-Barham Road). The Wakool escape is located close to site 21_01. Site names are listed in Table 3.1..

Table 3.1. List of site codes and site names for sites monitored for the Long term Intervention Monitoring 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_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
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

Prior to flood (1 Aug 2016)	Recession of flood Nov 2016 e-watering from Wakool escape	May 2016 e-watering Yallakool Creek

Yallakool Creek 1/8/16, 422 $ML.d^{-1}$ | 29/11/16, 599 $ML.d^{-1}$ (no e-water) | 16/05/17, 266 $ML.d^{-1}$ (during e-watering)

Wakool R (zone 2) 1/8/16, 115 $ML.d^{-1}$ | 29/11/16, 750 $ML.d^{-1}$ (during e-watering) | 16/05/17, 2 $ML.d^{-1}$ (cease to flow)

Wakool R (zone 3) 1/8/16, 363 $ML.d^{-1}$ | 29/11/16, 1533 $ML.d^{-1}$ (during e-watering) | 16/5/17, 213 $ML.d^{-1}$ (during e-watering)

Wakool R (zone 4) 1/8/16, 10 $ML.d^{-1}$ | 29/11/16, 1840 $ML.d^{-1}$ (e-watering) | 16/05/17, 274 $ML.d^{-1}$ (during e-watering)

Figure 3.2 Photos of study sites in the four hydrological zones in the Edward-Wakool system in 2016-17. Yallakool Creek (zone 1), Wakool River (zone 2) Wakool River upstream of Thule Creek (zone 3) and Wakool River downstream of Thule Creek (zone 4). (Photos: Sascha Healy)

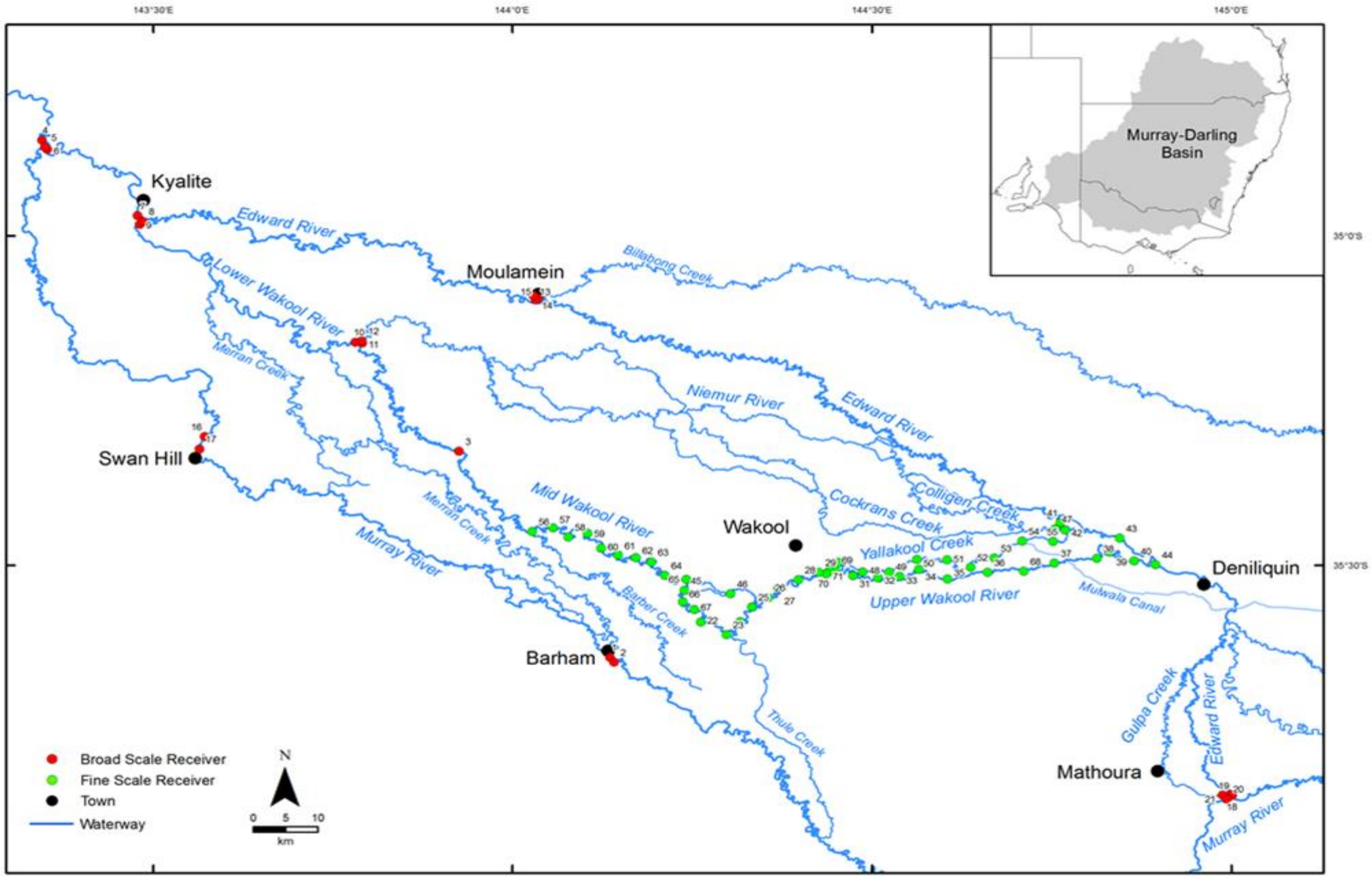


Figure 3.3 Location of acoustic telemetry receivers moored in the Edward-Wakool system to determine movements of acoustically tagged golden perch and silver perch. Green dots indicate the fine-scale acoustic receiver array of ~6 km receiver spacing in the focal study zones. An additional 20 receivers (red dots) funded by Murray Local Land Services were placed at key entry/exit points and major junctions within the wider Edward-Wakool system to monitor any potential emigration out of the system.

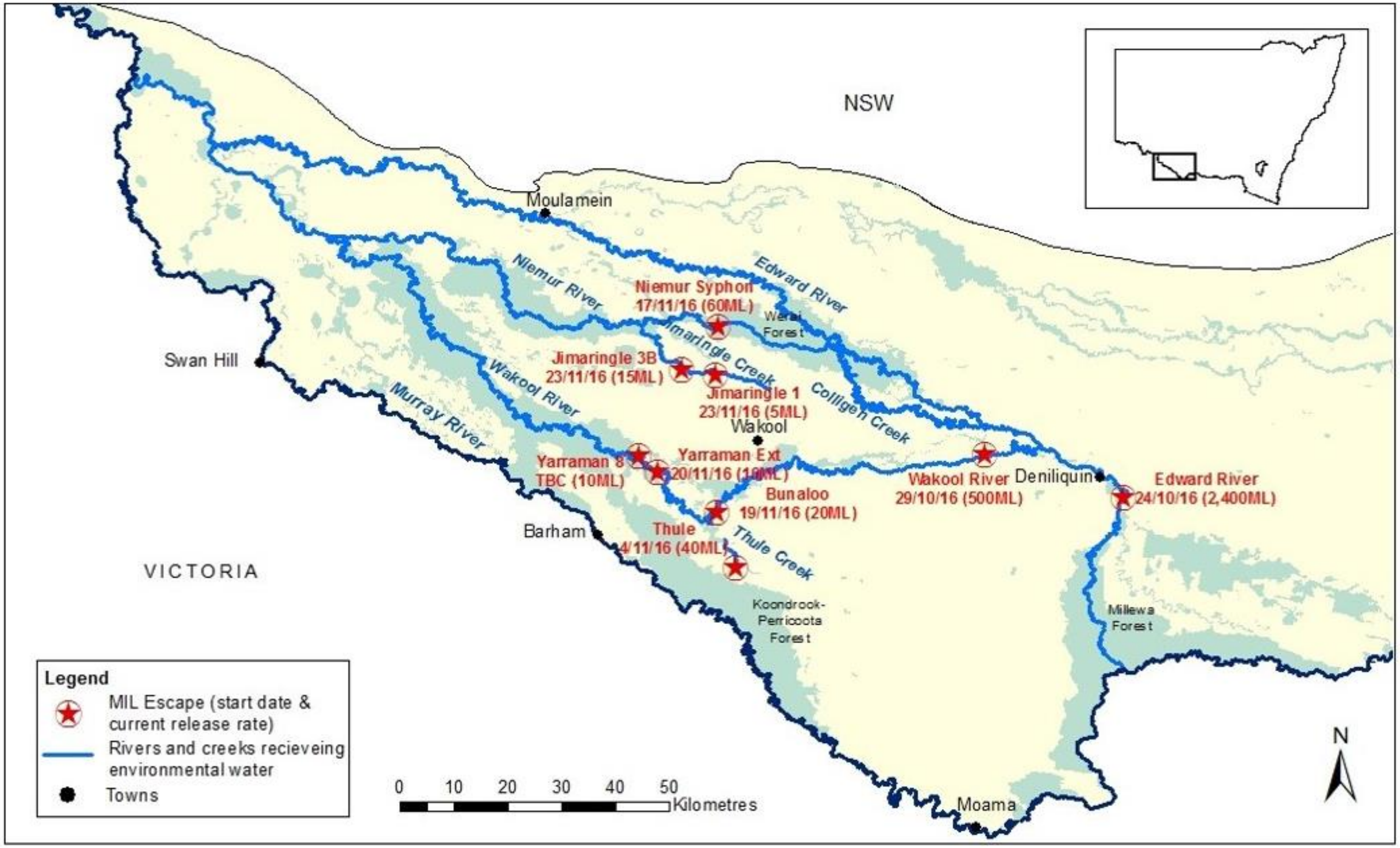


Figure 3.4 Map of the Edward-Wakool system showing location of Murray irrigation Limited canal escapes used to deliver environmental water in 2016. Monitoring was undertaken at the Edward escape, Wakool escape, Thule escape and Niemur Syphon escape. At each of these escapes samples were collected from the river upstream and downstream of the escape, and from within the canal itself.

Figure 3.5 Turbid oxygenated water released from the Wakool escape from Mulwala canal mixing with hypoxic black water in the Wakool River (Photos: left Robyn Watts, right CEWO)

Figure 3.6 Turbid oxygenated water released from the Edward Escape (right) mixing with hypoxic black water in the Edward River (Photo: CEWO)

Figure 3.7 Commonwealth environmental water being released from the Thule Escape from the Deniboota Canal (Photo: Robyn Watts)

3.2 Indicators

The rationale regarding the selection of indicators is outlined in the Edward-Wakool Long Term Intervention Monitoring and Evaluation Plan (Watts et al. 2014). Indicators were monitored to contribute to the Edward-Wakool Selected Area Evaluation and/or the Whole of Basin scale evaluation that is undertaken by the Murray-Darling Freshwater Research Centre (Hale et al. 2014). Some indicators are expected to respond to environmental watering in short time frames (< 1 year), but others (e.g. fish community assemblage) are expected to respond over a 2 to 5 year time frame. A summary of monitoring undertaken in 2015-16 is presented in Table 3.2.

There are three categories of monitoring indicators in the LTIM Project:

- **Category I** –Mandatory indicators and standard operating protocols that are required to inform Basin-scale evaluation and may be used to answer Selected Area questions. Category 1 indicators monitored in the Edward-Wakool system (Table 3.2) are: river hydrology, stream metabolism, nutrients and carbon, fish reproduction (larvae) and fish (river).
- **Category 2** –Optional indicators with mandatory standard protocols that may be used to inform Basin-scale evaluation and may be used to answer Selected Area questions. Fish movement (years 2 to 4) is the only category 2 indicator monitored in the Edward-Wakool system.
- **Category 3** – Selected Area specific monitoring protocols to answer Selected Area questions. Category 3 indicators monitored in the Edward-Wakool system (Table 3.2) are: riverbank inundation by 2D-hydraulic modelling (undertaken in year 1), additional water quality and carbon characterisation, riverbank and aquatic vegetation, fish reproduction (larvae), fish recruitment, and fish community survey (years 1 and 5).

3.3 Overview of monitoring undertaken in 2016-17

The monitoring undertaken in 2016-17 is summarized in Table 3.3. The ongoing monitoring of for river hydrology, stream metabolism, water quality, riverbank and aquatic vegetation, fish reproduction was undertaken using the same methods as in 2014-16 (Watts et al. 2015, 2016).

Additional monitoring of dissolved organic carbon and nutrients was undertaken weekly over a seven week period in November and December 2016 during the delivery of Commonwealth environmental water from Murray irrigation Limited canal escapes.

The fish community survey for the Edward-Wakool Selected Area was not undertaken in 2016-17 as this indicator is monitored only in year 1 (2014-15) and year 5 (2018-19) of the LTIM project. Fish community surveys are undertaken in zone 3 each year for the basin-scale evaluation and these will be summarised here but fully reported in a basin-scale evaluation undertaken each year by the Murray-Darling Freshwater Research Centre.

Table 3.2 Summary of indicators to be monitored in the Edward-Wakool system for the Long Term Intervention Monitoring Project from 2014-2019.

Indicator	Method	Zone	Edward-Wakool Selected Area Evaluation	Contribute to whole of basin-scale evaluation	Description
River hydrology	Cat 1	1,2,3,4	✓	✓ (zone 3)	Discharge data will be obtained from NOW website. Water depth monitored using depth loggers and staff gauges.
Hydraulic modelling	Cat 3	1,2,3,4	✓		The extent of within channel inundation of geomorphic features will be modelled for a range of different discharges.
Stream metabolism and instream primary productivity	Cat 1	1,2,3,4	✓	✓ (zone 3)	Dissolved oxygen and light will be logged continuously in each zone between August and April each year.
Nutrients and carbon	Cat 1	1,2,3,4	✓	✓ (zone 3)	Nutrients and carbon samples will be collected monthly and spot water quality monitored fortnightly.
Characterisation of carbon	Cat 3	1,2,3,4	✓		The type and source of dissolved organic carbon will be monitored monthly between August and April.
Water quality and carbon during poor water quality events	Cat 3	1,2,3,4 plus additional zones as required	✓		There is an option for additional water quality and carbon sampling during blackwater or other poor water quality events
Riverbank and aquatic vegetation	Cat 3	1,2,3,4	✓		The composition and percent cover of riverbank and aquatic vegetation will be monitored monthly.
Fish reproduction (larvae)	Cat 1 basin evaluation Cat 3 area evaluation	1,2,3,4	✓	✓ (zone 3)	The abundance and diversity of larval fish will be monitored fortnightly between September and March using light traps and drift nets.
Fish recruitment	Cat 3	1,2,3.4	✓		Young-of-year fish will be collected by back-pack electrofishing and set lines in February and March to develop growth and recruitment indices for young-of-year and age-class 1 Murray cod, silver perch and golden perch
Fish community assemblage	Cat 1 for basin evaluation Cat 3 for selected area evaluation years 1 & 5	3 (plus 15 additional sites in year 1 and 5)	✓	✓ (zone 3)	Cat 1 fish community surveys will be undertaken once annually in zone 3 between March and May. An additional 15 sites throughout the system will be surveyed in years 1 and 5 using Cat 3 methods to report on long-term change in the fish community.
Fish movement	Cat 2	1,2,3,4 (plus additional sites funded by Murray LLS)	✓		Movement of golden perch and silver perch will be monitored commencing in spring 2015

Table 3.3 Schedule of monitoring activities For Edward-Wakool Long-Term Intervention Monitoring project for 2016-17 (grey shading). The three categories of indicators are described in section 3.2.

Indicator	Cat	Zones	Schedule of activities											
			J	A	S	O	N	D	J	F	M	A	M	J
River hydrology	1	1,2,3,4	Continuous data from automated gauging stations											
Hydraulic modelling	3	1,2,3,4	Modelling undertaken in 2014-15											
Stream metabolism and instream primary productivity	1	1,2,3,4		Continuous data from loggers										
Nutrients and carbon	1	1,2,3,4		Monthly sampling										
Carbon characterisation	3	1,2,3,4		Monthly sampling										
Additional water quality and carbon characterisation associated with e-watering from irrigation escapes during hypoxic blackwater event	3	4 escapes					Weekly sampling							
Riverbank and aquatic vegetation	3	1,2,3,4		Monthly monitoring (some missing data during flood)										
Fish reproduction (larvae)	1	3					Fortnightly sampling							
Fish reproduction (larvae)	3	1,2,3,4			Fortnightly sampling (some missing data during flood)									
Fish recruitment	3	1,2,3,4												
Fish (river)	1	3												
Fish community survey	3	20 sites	Undertaken in 2014-15 and 2018-19 only											
Fish movement	2	1,2,3,4 (plus additional sites funded by Murray LLS)		Continuous data from acoustic receivers										

3.4 Evaluation of outcomes

Evaluations of the outcomes of Commonwealth environmental watering undertaken in 2016-17 were undertaken for the following indicators:

- Hydrology (Section 4)
- Water quality and carbon (Section 5, Appendix A)
- Stream metabolism (Section 6, Appendix B)
- Aquatic and riverbank vegetation (Section 7, Appendix C)
- Fish movement (Section 8, Appendix D)
- Fish reproduction (Section 9, Appendix D)
- Fish recruitment (Section 10, Appendix D)
- Fish community data for basin-scale evaluation (section 11, Appendix D).

4. HYDROLOGICAL OUTCOMES OF COMMONWEALTH ENVIRONMENTAL WATER DELIVERED IN 2016-17

4.1 Monitoring

Daily discharge data for automated hydrometric gauges were obtained from the New South Wales Office of Water website. Daily discharge data for the Wakool escape, Niemur Escape and Thule escape and daily usage of Commonwealth environmental water were obtained from WaterNSW. The hydrograph for Yallakool Creek (zone 1) is based on daily discharge data from gauge 409020 Yallakool Creek @ Offtake. The hydrograph for the Wakool River zone 2 is based on discharge data from gauge 409019 Wakool River offtake regulator added to the discharge data from the Wakool escape. The daily discharge data for Wakool River zone 3 was estimated by combining daily discharge data from Yallakool Creek regulator, the Wakool offtake and the Wakool escape 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. The daily discharge data for Wakool River zone 4 were obtained from gauge 409045 Wakool River at Wakool-Barham Road.

Depth loggers were installed at monitoring sites to monitor water levels and values for depth were calculated by calibration with an atmospheric barometric pressure logger located at zone 2 site 4. The depth (m) at bankfull at each site was determined from cross section surveys.

In November and December 2016 Commonwealth environmental water was released from a number of escapes from the Murray Irrigation Limited canal network (see chapter 2). The contribution of Commonweath environmental water to the total discharge downstream of the Edward, Wakool, Thule and Niemur escapes was estimated by calculating the percent contribution of the environmental water to the total discharge.

4.2 Findings

2016 unregulated flood event

At the beginning of the 2016-17 water year on 1 July 2016 the regulators on the Wakool River and Yallakool Creek were closed for the operational shutdown over winter. Record-breaking rainfall in parts of the catchment in July and August resulted in an extended period of overbank flows inundating the floodplain, including agricultural land and forests (Figure 4.1).

Flows from the Murray River inundated Koondrook-Perricoota (KP) Forest in early August 2016. The mid- and lower reaches of the Wakool River (including zone 4 of LTIM study area) received return flows from KP Forest via Thule Creek and Barbers Creek in late August to early September (Watts et al. 2017b), prior to the floodwaters travelling via the Edward River and through the Wakool and Yallakool regulators arriving in this part of the Wakool River (Figure 4.2, 4.3). By mid to late August the flood had extended throughout the system, with flood water entering the Wakool River and Yallakool Creek via the Edward River. The flow peak in the mid-Wakool River (zone 4) was substantially larger than that in zones 1, 2 and 3 (Figure 4.2) because this reach received flow from Wakool River and Yallakool Creek regulators as well as flow through KP Forest via Thule Creek and Barbers Creek (Watts et al. 2017b).

The rivers in the Edward-Wakool system in 2016-17 were dominated by these unregulated flows between August and early December 2016 (Figure 4.2). The small unregulated flow in mid- to late August 2016 peaked at 1,149 ML/d at the Yallakool Creek offtake, 942 ML/d at the Wakool offtake, and 1,514 ML/d in the Wakool River at zone 4 before receding (Figure 4.2). The daily discharge during this event was two to three times larger than discharges recorded in the previous two years. In mid-September 2016 there was a rapid increase in discharge resulting in a very large flood pulse. The discharge at the peak of this event was larger than any of the flood events since 2000 (Figure 2.1). While the flow pulse in August 2016 remained within the channel and inundated some low lying geomorphic features, the event in September/October resulted in overbank flows (Figure 4.1). The flows remained overbank for at least one month at some sites (Figure 4.3). This is in contrast to the regulated flows that have occurred in the Edward-Wakool system since January 2014 (Figure 2.1).

Figure 4.1 Edward River at Memorial Park, Deniliquin showing stained tree trunks, indicating the extent to which floodwaters extended over the bank (Photo: Julia Howitt)

Environmental watering from irrigation canal escapes during hypoxic blackwater event

The volume of Commonwealth environmental water delivered to the Edward-Wakool system in 2016-17 was small in comparison to the unregulated flow that dominates the hydrograph from 2014 to 2017 (Figure 4.2). However, when examined in more detail it is evident that the Commonwealth environmental water delivered from the Edward escape and Wakool Escape in November and December 2016 (watering actions 1 and 2 in Table 2.3) influenced the shape of the recession of the hydrograph at sites in zones 1, 2 , 3 and 4 downstream of the escapes, creating a period of approximately one month of relatively stable water level during late November and December at the end of the flood recession (Figure 4.3).

It is notable that during this unregulated event, the water level in zone 2 site 4 in the upper Wakool River was over bankfull or at near bankfull level from mid-September until the end of

December 2016. In contrast, in the other three zones the water was overbank during October and early November, and was well below bankfull during the Commonwealth environmental watering action from the irrigation escapes. This difference is due to channel shape, as the lower reaches of zone 2 has different geomorphology to other zones, with less steep banks and more connection with the floodplain.

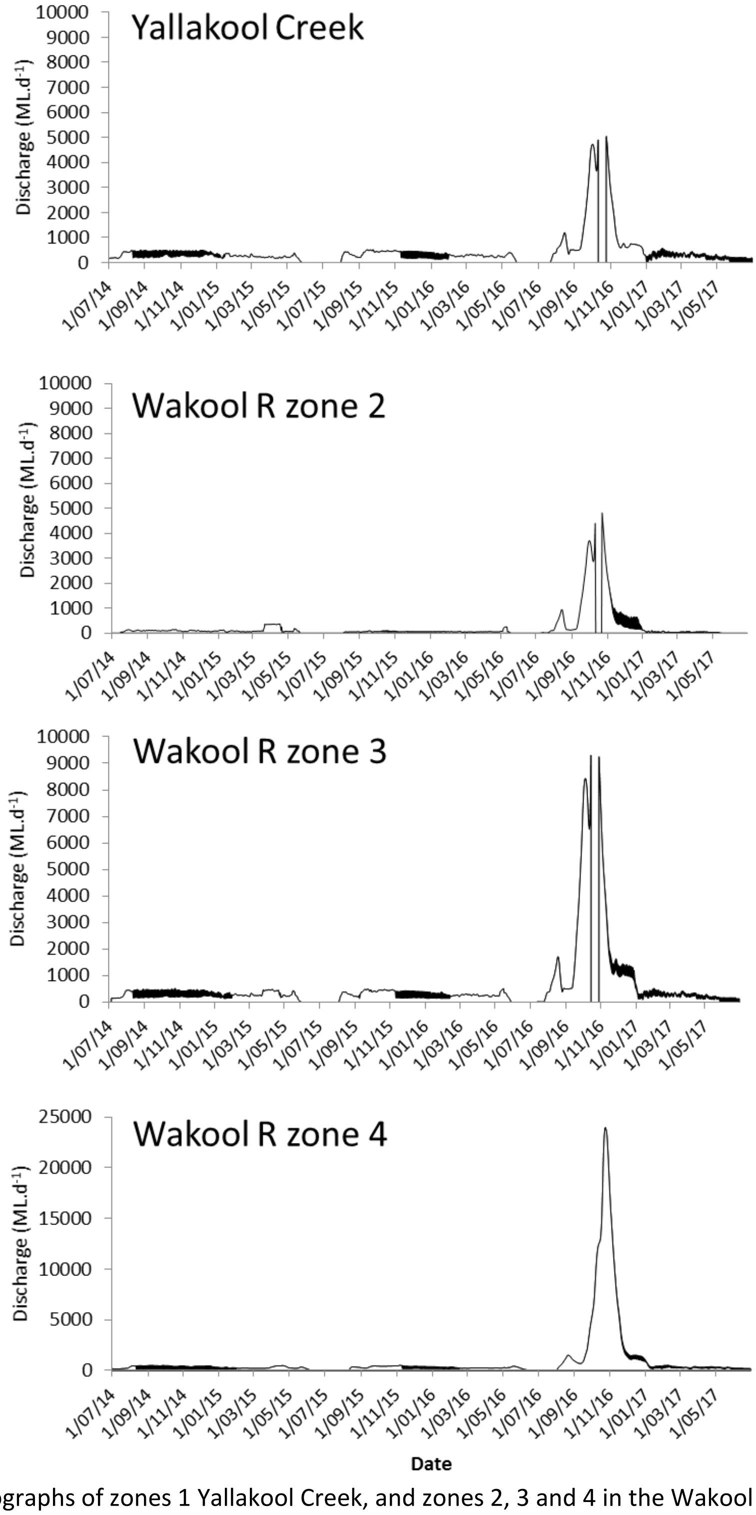


Figure 4.2 Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1 July 2014 to 30 June 2017. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water. Note that the y axis for zone 4 ranges up to 25,000 ML.d^{-1}.

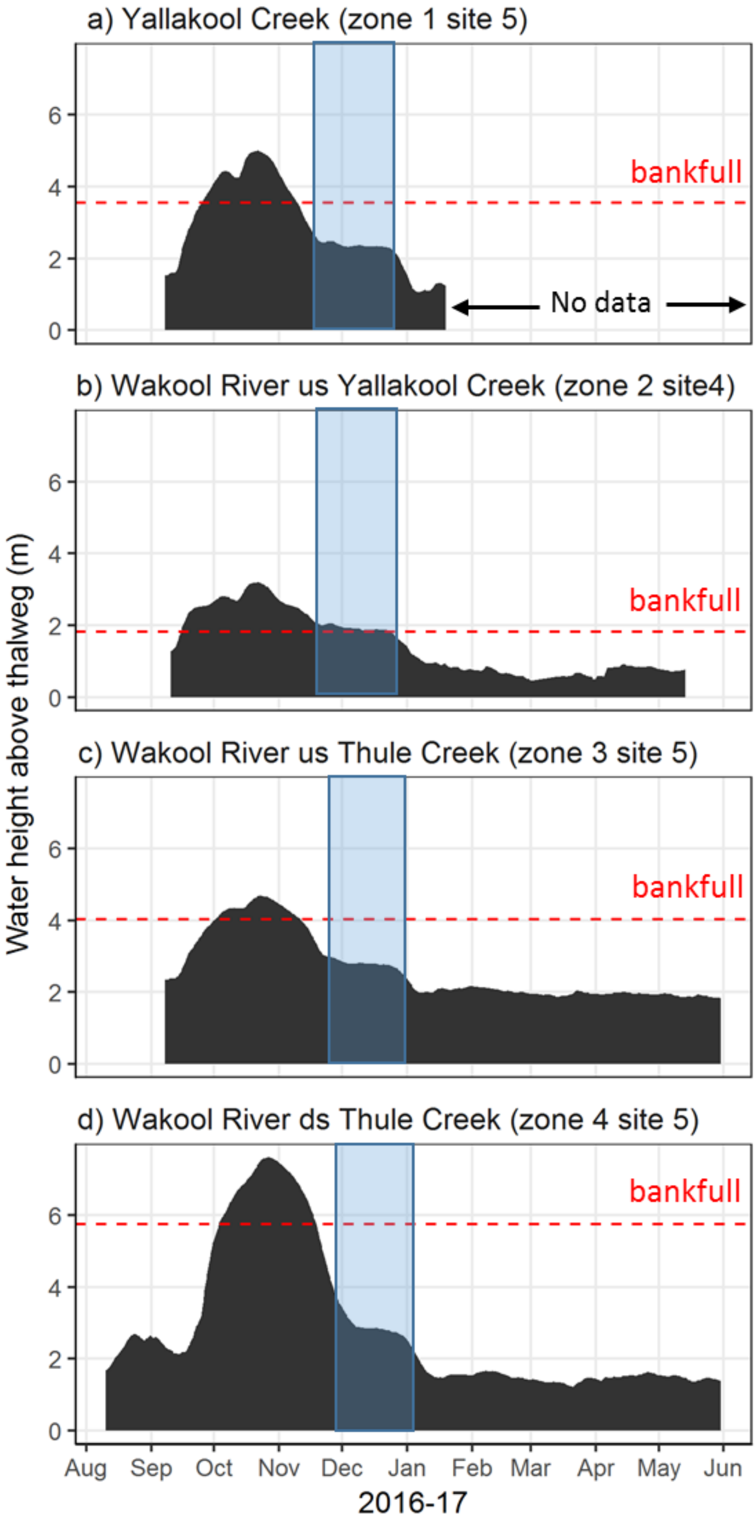


Figure 4.3 Water height above thalweg at the most downstream site in each of the four LTIM monitoring zones in the Edward-Wakool system. The area of the hydrograph indicated by blue shading is an estimate of the period when Commonwealth environmental water released from the Edward escape and Wakool Escape influenced the hydrographs at these sites.

The percent contribution of Commonwealth environmental water in river reaches downstream of irrigation escapes varied considerably over time. The release of Commonwealth environmental water from the Mulwala Canal into the Edward River commenced on the 26th of October, but until the 5th November the environmental water comprised less than 3% of the total flow and remained below 10% until 11th November (Figure 4.4). However, in early November the discharge in the Edward River was receding, so by 15th November the environmental water contributed approximately 20% of the total discharge downstream of the Edward Escape (Figure 4.4) rising to over 40% of the total flow by 17th November.

The release of environmental water from the Wakool escape commenced on 31st October and for a week contributed less than 10% of the total discharge in that system. As the discharge in the Wakool River receded the environmental water contributed up to 75% of the total discharge (Figure 4.5).

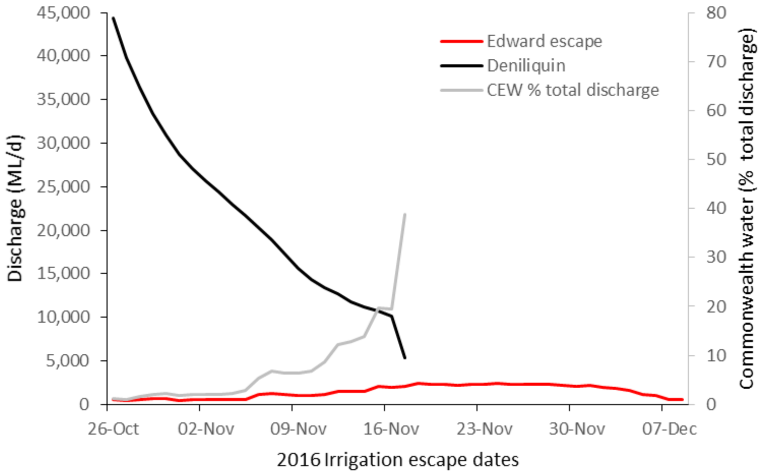


Figure 4.4 Discharge in the Edward River at Deniliquin (ML/d) and from the Edward Escape from Mulwala canal from 26 Oct to 10 December 2016. The percentage that Commonwealth environmental water contributed to the total discharge downstream of the escape is shown. There were no data for the Deniliquin gauge from 18th November to the end of the watering action.

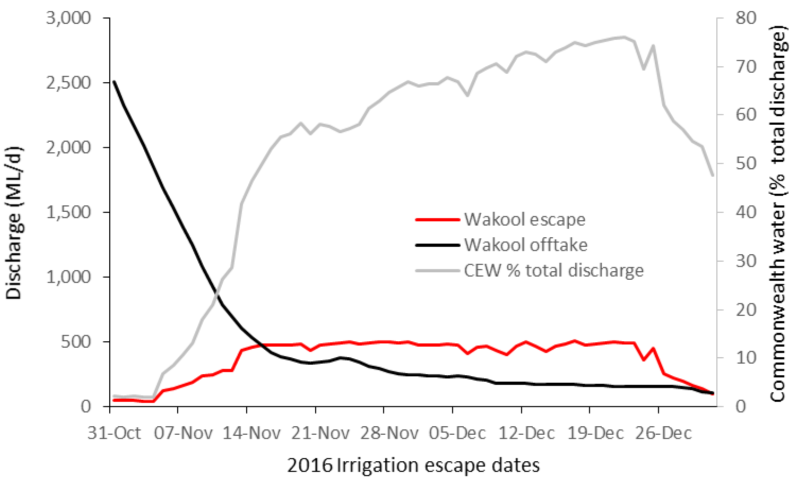


Figure 4.5 Discharge from the Wakool Offtake (ML/d) and from the Wakool Escape from Mulwala canal from 31 Oct to 31 December 2016. The percentage that Commonwealth environmental water contributed to the total discharge downstream of the escape is shown.

Similar to the Wakool escape, the release of Commonwealth environmental water from the Thule escape to Thule Creek contributed less than 10% of the total discharge in that system for a short period, but later contributed up to 56% of the total discharge (Figure 4.6).

In contrast, the Commonwealth environmental water delivered from the Niemur escape contributed less than 7 % of the total flow in the Niemur River for the duration of the watering action (Figure 4.7).

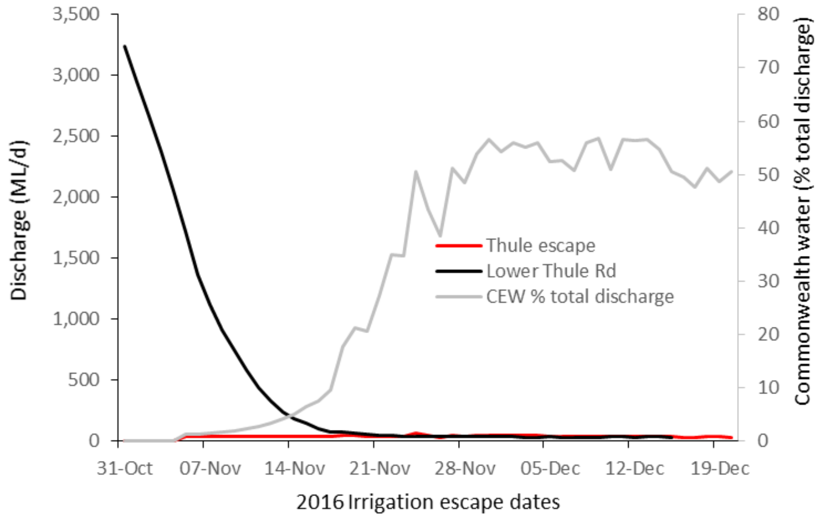


Figure 4.6 Discharge (ML/d) at the Lower Thule Road gauge on Thule Creek and from the Thule Escape from Deniboota Canal from 31 Oct to 21 December 2016. The percentage that Commonwealth environmental water contributed to the total discharge downstream of the escape is shown.

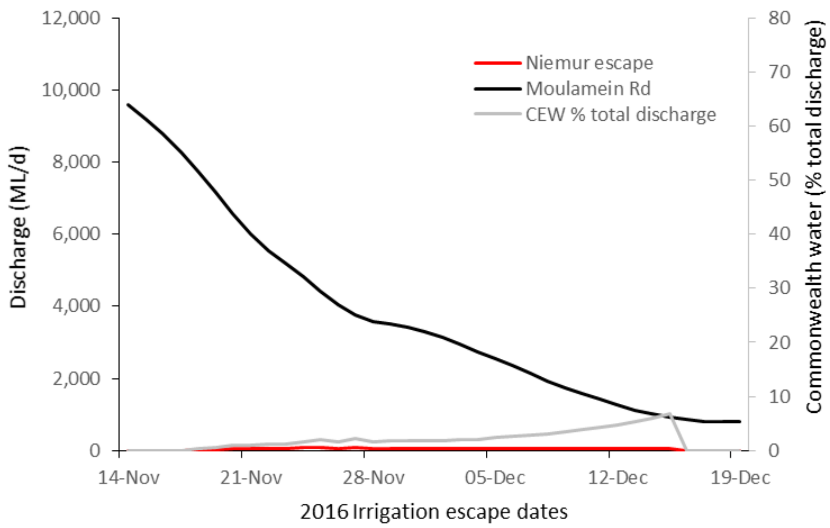


Figure 4.7 Discharge (Ml/d) in the Niemur River at the Niemur-Moulamein Road gauge and from the Niemur Escape from the canal from 14 November to 20 December 2016l. The percentage that Commonwealth environmental water contributed to the total discharge downstream of the escape is shown.

Watering actions to provide recession flows continuing into watering in Yallakool Creek during late autumn and winter 2017

Watering action 6 in Yallakool Creek (Table 2.3) was intended to create continuous base flows during late autumn and winter. Winter flows were also provided into the Colligen Creek - Niemur River system. A long standing approach to river operations would usually see these systems cease to flow (i.e. shut down) over winter. The objective of creating continuous flows was achieved in Yallakool Creek and also in study zones 3 and 4 (Figure 4.8) as well as throughout the mid and lower Wakool Rivers, including gauges at Gee Gee Bridge, Stoney Crossing. The aquatic vegetation response in the Colligen system is being monitored under a separate project funded by Murray Local Land Services and is not reported here.

In contrast, flows to the upper Wakool River (zone 2) ceased on 22 May 2017 (Figure 4.8) and recommenced on 3 August 2017, resulting in a shutdown period of 73 days in the upper Wakool River. The provision of winter flows into the upper Wakool would have required Stevens Weir pool to be kept at a higher level during winter. Maintaining a higher weir pool may have limited the ability for a period of some bank drying to occur in the wetlands adjacent to, and influenced by, Stevens Weir. The need for a period of bank drying in these wetlands was an outcome sought by the CEWO and members of the Edward Wakool Environmental Water Reference Group in planning the trial winter 2017 flows.

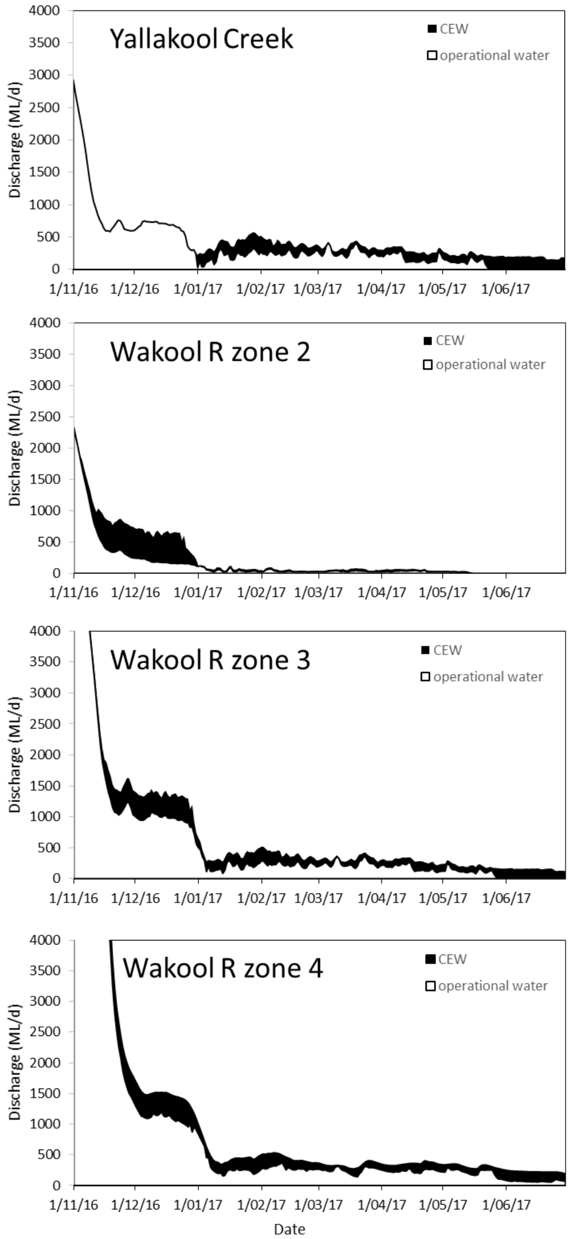


Figure 4.8 Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River for the period from 1 November 2016 to 30 June 2017, showing delivery of Commonwealth environmental water on the recession of the unregulated flow event in2016 and into 2017. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth environmental water

4.3 Evaluation

Table 4.2 Summary of Commonwealth environmental watering on hydrology and connectivity. N/A = Not applicable to this watering action

CEWO Water Planning and delivery		**Monitoring and Evaluation questions and outcomes**			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent (CEWO 2016)	**Expected outcomes of watering action (From Water Use Minute 10054-03, 10054-04 10054-05, 10054-07, 10054-08**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
CEW delivered from irrigations escapes	To provide hypoxic water refuge for fish and other aquatic biota (WUM 10054-03, 10054-04 10054-05).	*What is the effect of Commonwealth environmental water on the hydrology of the four zones in the Edward-Wakool system that were monitored for the LTIM project?*	The CEW delivered from the canal escapes created a period of approximately one month of relatively stable water level at the end of the flood recession	Calculation of percent contribution of CEW to total discharge at each escape	The CEW delivered from the Edward, Wakool and Thule escapes provded refuge, providing of 50% of the total discharge for periods of time during the hypoxic blackwater event. The CEW delivered from the Niemur escape had minimal effect on total discharge
		What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?	The CEW delivered from the canal escapes contributed to longitudinal connectivity		
		What did Commonwealth environmental water contribute to the in-channel wetted benthic area?	N/A		
		What did Commonwealth environmental water contribute to the area of slackwater, slow flowing water and fast water?	N/A		
		What did Commonwealth environmental water contribute to lateral connectivity	N/A		
Late autumn/winter watering actions	To create recession flows at the end of the unregulated flows. To reinstate part of the continuous flows that would have occurred prior to river regulation during winter-spring. To improve links with other parts of the river system (WUM 10054-07, 10054-08)	*What is the effect of Commonwealth environmental water on the hydrology of the four zones in the Edward-Wakool system that were monitored for the LTIM project?*	In Yallakool Creek the CEW maintained continuous discharge throughout autumn and winter in Yallakool Creek and in the Wakool River from the confluence with Yallakool Creek right through to Stoney Crossing and Kyalite.	Discharge at gauging stations and depth logger data	Yes, the flows provided maintained continuous discharge in the target reaches.

5. SUMMARY OF WATER QUALITY AND CARBON RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

5.1 Monitoring

Water quality parameters were assessed by a combination of continuous logging (temperature and dissolved oxygen) supplemented with spot measurements and collection of water samples (monthly) at two sites within each zone, and from Stevens Weir on the Edward River and the Mulwala Canal for laboratory measurement of: dissolved organic carbon (DOC), nutrients and absorbance and fluorescence spectroscopy for organic matter characterisation. Additional weekly monitoring was undertaken at additional sites in October and December during a hypoxic blackwater event that extended throughout southern MDB, to assess the impact of Commonwealth environmental water releases from irrigation escapes to create local refuges.

5.2 Main findings

Response to 2016 unregulated flood

Water quality in the Edward Wakool system during the 2016-17 season was largely driven by the impacts of the extensive unregulated overbank flooding and an associated hypoxic blackwater event. Dissolved organic carbon concentrations responded to both the small pulse in August and the large flood event that occurred late-September through to December 2016. Water samples from the Edward River at Stephens Weir in August 2016 had slightly elevated DOC compared to both the canal and samples from Stevens Weir during the multi-site watering in 2015 (Figure 5.1). There was a slight drop in September 2016, consistent with the fall in the hydrograph. This was also seen in Zone 1 and 2 but the effect was not observed in Zone 3 and 4 although carbon characterisation results indicate that floodplain carbon did move though the full length of the system over this period. The large flood peak in September and October 2016 inundated extensive areas of floodplain (including forested areas, cropping and grazing land and urban areas) and introduced considerable quantities of DOC into the river system, resulting in concentrations well above those measured during the algal bloom in Feb-May 2016 (Figure 5.1) but comparable to those observed during the 2010-11 blackwater event that occurred following the millennium drought (Watts et al. 2017a) and also to the majority of samples collected during the March 2012 event (Watts et al. 2013). DOC rose rapidly with the increasing hydrograph and peak concentrations were recorded in late October. Concentrations were generally higher at sites further downstream as the water continued to collect DOC as it moved through the floodplain. DOC concentrations returned to the normal range at all but the most downstream sites by 21/11/2016 although the hydrograph was still falling at this point and the DOC continued to slowly decrease through the remainder of the sampling period.

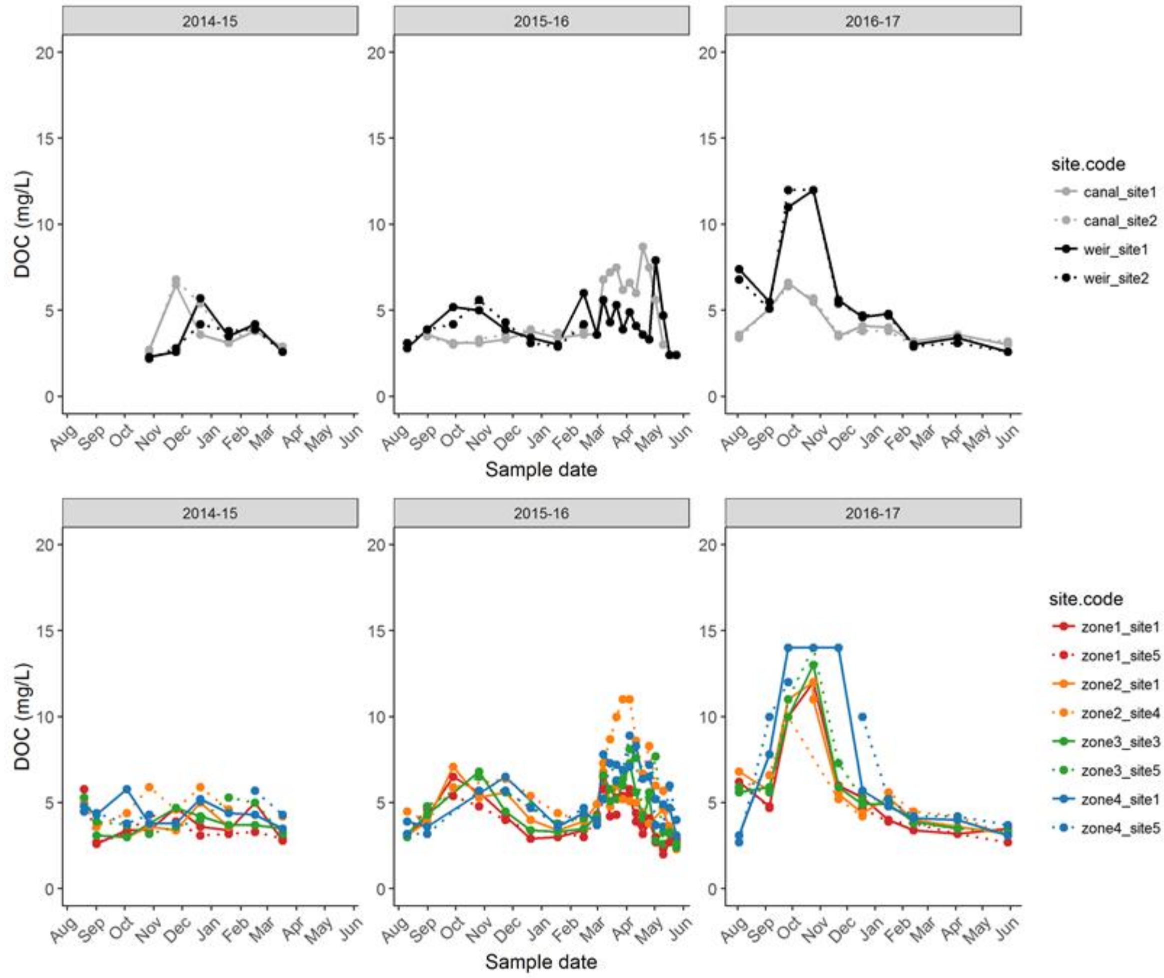


Figure 5.1 Dissolved organic carbon during the 2016-17 sampling period, with the previous two years results presented for comparison.

In response to the combination of high DOC concentrations and warming water temperatures, high rates of microbial respiration led to declines in dissolved oxygen concentrations beginning in late September. Concentrations fell below 4 mg/L at the beginning of October and then rapidly declined to below 2 mg/L by mid October (Figure 5.2). Downstream sites experienced longer periods of hypoxia than upstream sites. Considerable nutrient inputs (both N and P) were observed during the flood event, with bioavailable N at higher concentrations at the beginning and end of the flood event, but very high bioavailable P concentrations recorded during the peak of the flooding (Figure 5.3).

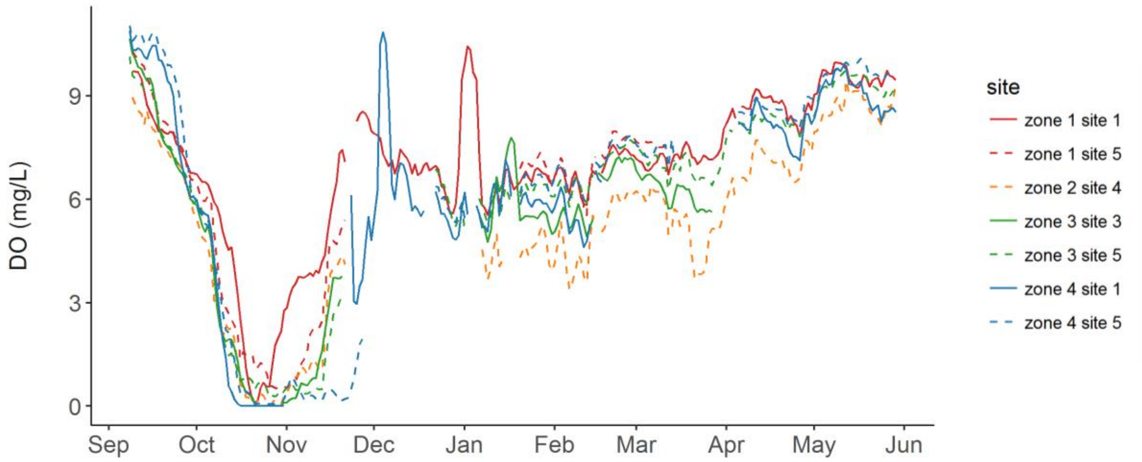


Figure 5.2 Dissolved oxygen concentrations at LTIM study sites showing extended hypoxia from mid October to November-December.

Figure 5.3 Filterable Reactive Phosphorus (FRP) concentrations over the 3 LTIM sampling seasons.

Response to environmental watering actions from irrigation canal escapes

Environmental water was used to create local oxygen refuges via release of water with higher DO and lower DOC from the irrigation canal system into the river system (on the falling hydrograph). Four sites were monitored weekly: the Edward River Escape, the Wakool Escape, Thule Creek and the Niemur River. The primary goal was to create localised refuges at the point of release, before full mixing of the water bodies had occurred. Downstream sites were also monitored to observe whether larger scale impacts occurred where volumes of canal water were sufficient to cause a dilution effect. DO results for the Wakool escape are shown in Figure 5.4. The refuge zone where canal water has not fully mixed with river water can be seen in the high turbidity region in Figure 5.5. Downstream dilution effects were seen in the Edward and Wakool Rivers when CEW made up more than 10% of the flow, but only small localised refugia could be created in the Thule and Niemur systems.

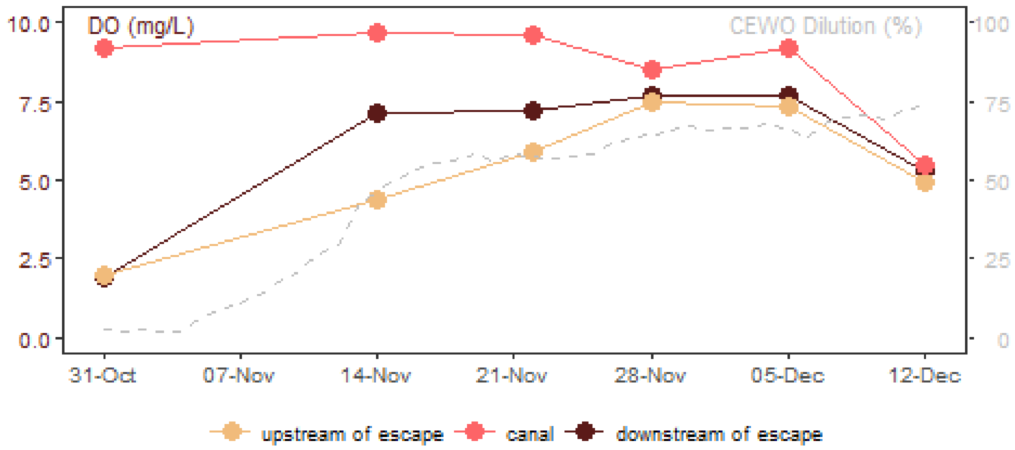


Figure 5.4 Dissolved oxygen upstream and downstream of the Wakool escape and in the Mulwala canal between 31 October and 12 December 2016. Dotted grey line indicates the percent contribution of environmental water to total discharge downstream of the escape.

Figure 5.5 Localised refuge in the Wakool River created by release of water from the Mulwala Canal. (Photo: Damian McRae, CEWO).

Response to recession flows and late autumn/winter watering action in Yallakool Creek

Water quality parameters (DO, N and P concentrations) remained in an acceptable range throughout the January-May sampling period during the autumn/winter watering action and environmental water may have supported DO concentrations in Zone 2 through later summer and early autumn, where very low flows would have occurred in the absence of CEW.

5.3 Evaluation

Table 5.1 Summary of monitoring and evaluation questions for water quality parameters during the water actions from irrigation canal escapes. Detailed findings are presented in Appendix A.

CEWO Water Planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent (CEWO 2016)	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
CEW delivered from irrigation escapes	To provide hypoxic water refuge for fish and other aquatic biota (WUM 10054-03, 10054-04 10054-05).	*What did Commonwealth environmental water contribute to temperature regimes?*	NA	Gaps in the logger data make this difficult to assess, but this was not an expected outcome of the flows	Local refuges were achieved, with greater extent around the Wakool and Edward Escapes where larger volume releases were possible. Greater impact would be achieved by starting releases earlier in future blackwater events, where possible.
		What did Commonwealth environmental water contribute to dissolved oxygen concentrations?	Some dilution effects (increased DO) downstream of Edward and Wakool Escapes during escape flows	Spot measurements and field observations	
		What did Commonwealth environmental water contribute to nutrient concentrations?	Some small dilution effects observed.	Water samples	
		What did Commonwealth environmental water contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected channel habitat?	NA- this was not a target of these flows		
		What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?	Creation of local refuges with improved water quality in the immediate vicinity of the escapes. Small downstream improvements at some sites.	Water samples, spot measurements, observations	

Late autumn/winter watering actions	To create recession flows at the end of the unregulated flows. To reinstate part of the continuous flows that would have occurred prior to river regulation during winter-spring. To improve links with other parts of the river system (WUM 10054-07, 10054-08)	*What did Commonwealth environmental water contribute to temperature regimes?*	NA- this was not a target of these flows		CEW was delivered to all study zones, making water quality impacts of the flow difficult to assess. However, the small delivery of CEW to zone 2 supported what would be an otherwise extremely low flow in this zone and is likely to have supported DO concentrations in this zone.
		What did Commonwealth environmental water contribute to dissolved oxygen concentrations?	CEW may have assisted with maintenance of DO in Zone 2 where flow would have otherwise been extremely low.	Water samples, spot measurements, observations	
		What did Commonwealth environmental water contribute to nutrient concentrations?	NA- this was not a target of these flows		
		What did Commonwealth environmental water contribute to modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected channel habitat?	NA- this was not a target of these flows		
		What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?	CEW supported the maintenance of flow following blackwater and water quality parameters remained in acceptable ranges over this period.	Water samples, spot measurements, observations	

6. SUMMARY OF STREAM METABOLISM RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

6.1 Monitoring

Monitoring of dissolved oxygen concentrations, water temperature and incident solar irradiance was performed at ten minute intervals over the period from early September 2016 until late May 2017 at seven sites in four zones within the Edward-Wakool system. Stream metabolism parameters – Gross Primary Productivity (GPP) and Ecosystem Respiration (ER) - were estimated on a daily basis using the BASEv2 model (updated from Grace et al. 2015 according to Song et al. 2016). Model fits that met LTIM-agreed acceptance criteria were then used for describing stream metabolism, and for assessing effects of watering events and other environmental factors (e.g. temperature). GPP and ER rates were also compared by considering Net Primary Production (NPP = GPP-ER) and GPP:ER ratios. The latter two variables differentiate autotrophic systems that rely on internally derived carbon sources (where NPP is consistently > 0 and GPP:ER ratios >1) from heterotrophic systems (where NPP is consistently < 0 and GPP:ER ratios < 1). In the latter case it can be inferred that external carbon sources are important to the overall patterns of energy cycling in the stream.

6.2 Main findings

A total of 450 separate daily estimates of GPP (Figure 6.1) and ER (Figure 6.2) were obtained from the seven sites in the Edward-Wakool system. This corresponds to a 34% acceptance rate for daily data – modelled fits to the rest of the data did not meet LTIM acceptance criteria. The low acceptance rate compared to 2015-16 (45%) was primarily due to the extended period of hypoxia/anoxia during the blackwater event in spring 2016.

Median GPP rates (represented by the horizontal middle line within each 'box') were relatively consistent across 6 of the 7 sites (Figure 6.1). The slightly higher value for Zone 2 downstream was primarily due to much lower discharge and water levels during much of the summer-early autumn period (see Figure 4.4) meaning more illumination of the benthic zone despite the moderate turbidity. GPP rates in this system are at the lower end of the normal published range found in river systems throughout the world (typically 3-10 mg O_2/L/day, e.g. Bernot et al. 2010), although comparison with a more recent, large, as yet unpublished data set from the USGS indicates the Edward-Wakool data are more 'typical' rather than 'low'. It is highly likely that the Edward-Wakool rates are generally constrained by the low bioavailable nutrient (N & P) concentrations. High nutrient concentrations observed during flooding generally occurred when hypoxia (a marker of very high rates of respiration) resulted in the data not meeting the requirements of the model. The high 'outliers', shown as circles in the plot, indicate that when conditions are conducive for primary production, rates can be at or above the high end of global normal rates. Figure 6.2 displays the median ER rates at the same sites over the same time period.

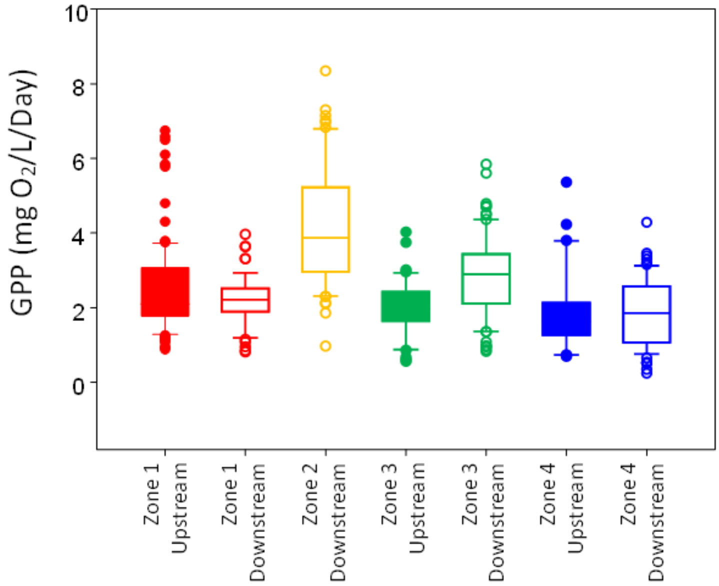


Figure 6.1. Box Plot Summary of Daily GPP rates across seven sites from September 2016 until May 2017.

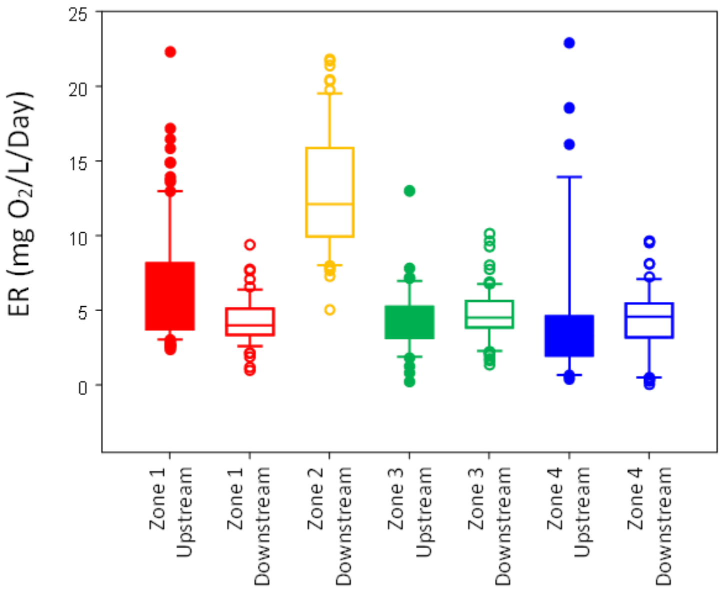


Figure 6.2 Boxplot summary of daily Ecosystem Respiration (ER) rates across seven sites from September 2016 until May 2017.

The high variation in rates of GPP and ER apparent in figures 6.1 and 6.1 can also be seen through time (Table 6.1, Figure 6.3,). Much of the overall variation appears to occur as a function of daily fluctuations in the rates of these two processes, and overall there are few strong seasonal trends. The only exception is an apparent upward trend in rates of GPP in zones 1 and 2 during the period of extended baseflow. The highest metabolic rate was recorded at the zone 2 downstream site in late summer 2017 (Figure 6.3). Comparable values were found over the same period at the upstream site in zone 1. The low flows allow build-up of vegetation and organic matter which fuels ecosystem respiration. ER rates are generally significantly higher than the corresponding GPP rates, meaning that each site is predominantly heterotrophic (P:R<1) – metabolism is driven by external sources of organic carbon rather than from that created by photosynthesis within the site. This phenomenon is also indicated by the negative NPP (net primary production rates: GPP – ER) shown in Figure 6.3. Such trends may be an indication of risk for development of algal blooms, and it will be important as part of a multi-year analysis to give consideration to whether management of baseflows can interrupt these conditions. However, blooms also require much higher nutrient concentrations to sustain elevated algal growth and the low extant nutrients in these zones indicate that the risk of blooms forming in this region is very low. It is important to note that this scenario is very different to bloom conditions being transported from upstream, such as the event that occurred in early 2016.

Heterotrophy, shown as NPP (Figure 6.3) is common in many lowland streams and rivers, but highlights the importance of non-algal derived carbon in driving ecosystem respiration in this system. Much of this respiration reflects the ongoing breakdown of organic material by bacteria, rather than respiration by higher animals, and thus further work is required to more fully understand the role that algae and detrital carbon play in supporting production by higher order consumers such as fish. Positive NPP rates (and P:R ratios) were found almost exclusively in September 2016 and are attributed to low ER rates rather than higher than normal GPP.

Using direct relationships between discharge from Commonwealth environmental watering actions and GPP or ER we could not detect significant stimulation of gross primary production (and hence basal food resources for invertebrates and fish) nor ecosystem respiration (nutrient recycling). However, it is anticipated that with extended data analysis planned for Year 4 involving calculation of the amount of organic carbon created (GPP) and consumed (ER) per river km, the benefits of even small watering actions might be determined. Nevertheless, as noted in the 2014-15 and 2015-16 annual reports, it is recommended that whenever possible some variation be introduced into the discharge over periods of a week or more during summer and early autumn. Trying to identify discharge-related increases or decreases in metabolic rates when discharge remains relatively constant is a very difficult task.

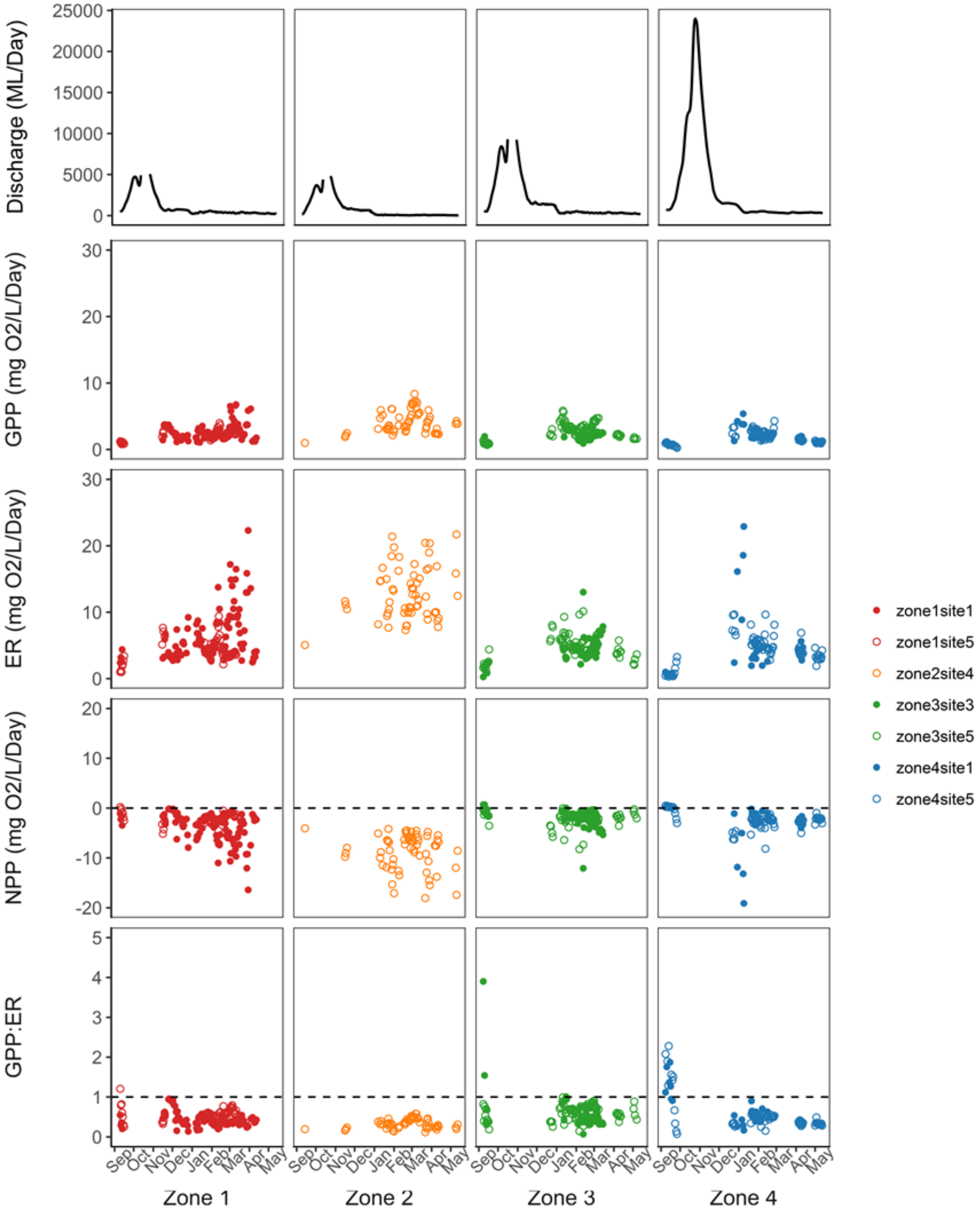


Figure 6.3 Variation in rates of Gross Primary Production (GPP), Ecosystem Respiration (ER) and Net Primary Production (NPP) across the 4 study zones over time from September 2016 until May 2017.

Table 6.1. Summary of median GPP rates, Daily ER rates and P;R rations at seven sites for each of the three years of the LTIM project.

	SITE						
	zone1 site1	zone1 site5	zone2 site4	zone3 site2(3)	zone3 site5	zone4 site1	zone4 site5
GPP							
2014-15	1.25	1.28	3.69	-	1.86	1.65	2.01
2015-16	1.75	1.37	2.78	4.09	1.57	3.15	2.61
2016-17	2.11	2.22	3.87	1.99	2.90	1.63	1.85
ER							
2014-15	2.07	2.71	6.91	-	2.47	2.04	2.27
2015-16	3.19	3.18	6.44	10.59	2.73	4.0	2.72
2016-17	5.18	4.01	12.12	4.12	4.52	3.33	4.57
P:R							
2014-15	0.56	0.48	0.43	-	0.81	0.72	0.85
2015-16	0.72	0.43	0.39	0.46	0.66	0.62	0.70
2016-17	0.40	0.57	0.32	0.46	0.64	0.51	0.48

6.3 Evaluation

Table 6.1 Summary of monitoring and evaluation questions for stream metabolism. Detailed findings are presented in Appendix B.

CEWO Water Planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent (CEWO 2016)	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
Wakool River - WUM10054-03 31/10/16 to 31/12/16 Wakool River - WUM10054-07 1/1/17 to 30/6/17 Yallakool Creek – WUM10054-08 1/1/17 to 30/6/17	To provide hypoxic water refuge for fish and other aquatic biota. Escape flows for hypoxic water refuge at the Thule, Wakool and other minor Wakool Escapes, with flows of up to 40, 500 and 45 ML/d respectively. To prevent a rapid return to base flows following the hypoxic event. To provide recessions to flows of a rate and duration that contributes to ongoing recovery of instream in-stream aquatic vegetation. Prevent a rapid return to base flows following the hypoxic event. To provide recessions to flows of a rate and duration that contributes to ongoing recovery of instream in-stream aquatic vegetation. Autumn pulse and recession also to assist with movement of juvenile native fish	*What did Commonwealth environmental water contribute to patterns and rates of decomposition? (Ecosystem respiration ER)*	Changes in ER were observed but did not correspond to variation in discharge. Changes were associated with changing season and other instream factors.	Daily estimates of stream metabolism in seven sites within four zones Measurements were undertaken from Sept 2016 until May 2017, although metabolism measurements were precluded by the hypoxia during the very high flows All daily estimates of GPP an ER that met agreed acceptance criteria were assessed for effects of discharge from environmental water (and other flow events). Due to the configuration of logger sites, it was not possible to assess the impacts of the escape flows (WUM10054-03)	The large natural flow in Spring 2016 with associated hypoxia precluded assessment of any metabolic response during this time.
		What did Commonwealth environmental water contribute to patterns and rates of primary productivity? (Gross Primary Productivity, GPP)	Changes in GPP were observed but did not correspond to variation in discharge. Changes were associated with changing season and other instream factors.		
		How does the timing and magnitude of Commonwealth environmental water delivery affect rates of gross primary productivity and ecosystem respiration in the Edward- Wakool River system?	There were no indications of any *immediate* flow-related changes in these metabolic parameters. The hypoxia associated with the large natural flow precluded metabolism modelling. There was an indication of significantly enhanced GPP just after the large flow subsided in late November-early December. It is probable this was fuelled by nutrients entrained in the floodwater.		

7. SUMMARY OF AQUATIC AND RIVERBANK VEGETATION RESPONSES TO COMMONWEALTH ENVIRONMENTAL WATERING

7.1 Monitoring

The taxonomic richness and percent cover of aquatic and riverbank vegetation were monitored from July 2016 to April 2017 at four sites in each of four hydrological zones in the Edward-Wakool system. Taxa were classified as submerged, amphibious or terrestrial. No monitoring was undertaken in August, September or October 2016 because floodwaters limited access to sites. Some sites could not be sampled in November and December 2016 due to ongoing access issues.

7.2 Main findings

A total of 51 riverbank and aquatic vegetation taxa were recorded across the sixteen sites between November 2016 and April 2017. Three of the taxa were submerged, 15 were amphibious and 34 were terrestrial (Table 7.1, Figure 7.1). Only six of the taxa were introduced (lippia, arrowhead, medic, sow thistle, yellow cress and clover) and were all in very low abundance, with the exception of lippia in zone 2.

Response to 2016 unregulated flood

When compared to the results from 2015-16, there was a notable decrease in the richness of submerged and amphibious taxa in 2016-17 following the flood (Figure 7.2). The taxa that reduced in cover following the flood included submerged algae, and the amphibious floating pond weed (*Potamogeton tricarinatus*), mud grass (*Pseudoraphis spinescens*), rush (*Juncus spp*.), spike rush (*Eleocharis spp*.) and mudwort (Figure 7.1). The reduction was most likely due to a combination of physical damage during the high flows, loss of light during the flood event and extended duration of inundation resulting in some plants dying and rotting. In contrast, there was a considerable increase in the number of terrestrial taxa from 22 taxa in 2015-16 to 34 taxa in 2016-17 (Table 7.1), particularly in transects 4 and 5 higher on the bank that was inundated for many weeks during the flood. The increase in terrestrial vegetation was observed in the months after the flood had receded.

Response to recession flows and late autumn/winter watering action in Yallakool Creek

There was no response in the cover of aquatic vegetation to the Commonwealth environmental watering actions in Yallakool Creek, because by that time there was almost zero cover of submerged and amphibious taxa at some sites. There was an increase in the cover of terrestrial plants after the recession of the flood, but this recovery was not associated with watering actions, as the recovery occurred higher up on bank than the extent of environmental flows.

Table 7.1 Number of riverbank and aquatic vegetation taxa recorded at LTIM monitoring sites in the Edward-Wakool system in years 1, 2 and 3 of the LTIM project between 2014 and 2017.

	Number of riverbank and aquatic vegetation taxa			
Year	**submerged**	**amphibious**	**terrestrial**	**total**
2014-15	3	14	17	34
2015-16	3	20	22	45
2016-17	2	15	34	51

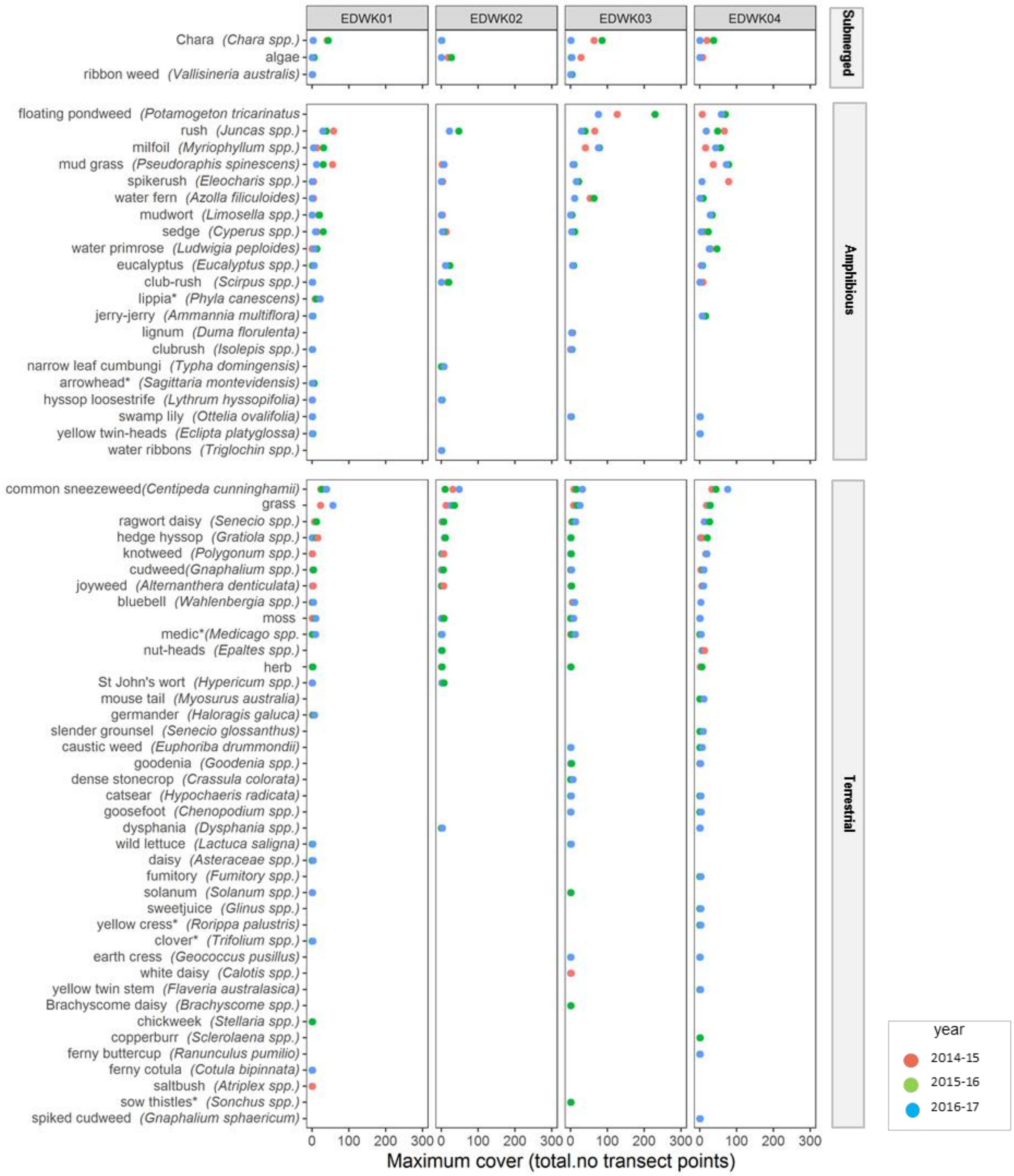


Figure 7.1 Maximum cover of riverbank and aquatic vegetation taxa monitored monthly across four hydrological zones in the Edward-Wakool system between July 2016 and April 2017. Taxa were classified as submerged, amphibious or terrestrial. Red dots indicate maximum cover in 2014-15, green dots indicate maximum cover in 2015-16, and blue dots indicate maximum cover in 2016-17. EDWK01 = Yallakool Creek zone 1, EDWK02 = Upper Wakool River zone 2, EDWK03 = Wakool River zone 3 upstream of Thule Creek, EDWK04 = Wakool River zone 4 downstream Thule Creek. * introduced taxa.

Figure 7.2 Photos of zone 3 site 1 showing change in cover of aquatic vegetation taxa from January 2015 (top), January 2016 (middle) and January 2017 (bottom) after the 2016 flood event (Photos: Sascha Healy).

7.3 Evaluation

Table 7.2 Summary of effects of Commonwealth environmental watering on aquatic and riverbank vegetation. N/A = Not applicable to this watering action. Detailed findings are presented in Appendix C.

CEWO Water Planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and inundation extent (CEWO 2016)	**Expected outcomes of watering action**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
CEW delivered from irrigations escapes	To provide hypoxic water refuge for fish and other aquatic biota (WUM 10054-03, 10054-04 10054-05).	*What has Commonwealth environmental water contributed to the recovery (species richness, cover and recruitment) of riverbank and aquatic vegetation in Yallakool Creek and the mid and upper Wakool River and how do those responses vary over time?*	N/A		Riverbank and aquatic vegetation was not monitored at sites in association with the irrigation escapes watering actions
		How do vegetation responses to Commonwealth environmental water delivery vary among hydrological zones?	N/A		
		What did CEW delivered as base flows and freshes contribute to the percent cover of riverbank and aquatic vegetation?	N/A		
		What did CEW delivered as base flows and freshes contribute to the taxonomic richness of riverbank and aquatic vegetation taxa?	N/A		
Recession flows and late autumn/winter watering action in Yallakool Creek	To reinstate part of the continuous flows during winter-spring. To improve links with other parts of the river system (WUM 10054-07, 10054-08)	*What has Commonwealth environmental water contributed to the recovery (species richness, cover and recruitment) of riverbank and aquatic vegetation in Yallakool Creek and the mid and upper Wakool River and how do those responses vary over time?*	No effect detectable	Vegetation surveys	The flood event in 2016 decreased the richness and cover of submerged and amphibious taxa and increased the richness and cover of terrestrial taxa. There was no recovery of submerged and amphibious taxa during recession flows or autumn/winter watering action
		How do vegetation responses to Commonwealth environmental water delivery vary among hydrological zones?	No difference detectable		
		What did CEW delivered as base flows and freshes contribute to the percent cover of riverbank and aquatic vegetation?	No effect detectable		
		What did CEW delivered as base flows and freshes contribute to the taxonomic richness of riverbank and aquatic vegetation taxa?	No effect detectable		

8. Summary of fish movement responses to Commonwealth environmental watering

8.1 Monitoring

A total of 71 acoustic receivers were installed in the Edward-Wakool system in August 2015 (Figure 8.1). Of these, 51 constituted the fine-scale acoustic receiver array of ~6 km receiver spacing and 20 additional receivers were placed at key entry/exit points and major junctions within the wider Edward-Wakool system to monitor any potential emigration out of the system. These additional receivers were funded by Murray Local Land Services with funding provided by the Federal government's National Landcare Programme. A total of 52 golden perch and 28 silver perch have been fitted with telemetry tags between August 2015 and April 2017. Here we report on data obtained from 51 golden perch and 13 silver perch spanning movements from August 2015 until April 2017, although we note that sample size varied throughout the study period due to emigration and possible mortality.

Movement responses of periodic fish species (golden perch and silver perch) were monitored continuously within each of the four focal LTIM hydrological zones in the Edward-Wakool system. Additionally, movements outside of the focal zones were monitored to determine the timing, direction, magnitude and drivers of large scale movements within the entire Edward-Wakool system. Movement responses in Murray cod were also monitored under a separate project with Murray LLS and are not reported in this report.

Figure 8.1 Clockwise from left: An acoustic receiver ready for deployment and an acoustic tag for scale, downloading information from tagged fish passing an acoustic receiver and, an anaesthetised silver perch undergoing surgical implantation of an acoustic tag in April 2017.

8.2 Main findings

A total of 51 golden perch and 13 silver perch contributed movement data from August 2015 until April 2017. Both golden and silver perch individuals moved sporadically from August 2015 to August 2016, generally occupying the LTIM focal zones (zones 1, 2, 3 and 4) and moving over a scale of 10's of kilometres. Emigration was not observed during this period, nor were there repeatable directional movements by the entire tagged sample.

Response to 2016 unregulated flood and watering actions from irrigation canal escapes

Rising water levels resulting from unregulated inflows in September 2016, as well as increasing water temperatures, resulted in rapid, coordinated movements of both species over 100's of kilometres, an order of magnitude greater than those observed in the preceding 12 months. Movements by the majority of individuals were persistent and directional, resulting in a net shift in the tagged population to downstream habitats on the mid and lower Wakool River (Figure 8.2).

Dissolved oxygen levels declined concurrent with the flow peak, resulting in readings at or near 2 Mg L^{-1} in mid-October and 0 Mg L^{-1} in late October 2016 in the Wakool River. The timing of these low dissolved oxygen levels coincided with the last valid detections of many tagged golden perch (n=36/51 tagged fish had their last valid detections in either September or October 2016) and silver perch (n=4/9 were fitted with tags, were within the EW system and had their last valid detections in either September or October 2016) within the Wakool River.

Commonwealth environmental water was delivered via escapes to enhance dissolved oxygen within the Edward-Wakool system. The timing of delivery was after the last valid movement records for the majority of the tagged sample of both golden and silver perch, with the exception of two tagged golden perch that remained within the focal zones during the period of environmental watering (Figure 8.2). Additional fish will be tagged in 2017 to facilitate the monitoring of fish movement in 2017.

The last detections of 39 golden perch were within the LTIM focal zones, although generally in zone 4 (i.e. downstream). Of these 39 only three individuals were detected in 2017. Nine golden perch had last detections in the lower Wakool River at either Gee Gee Bridge (n=2), at the Glenbar-Niemur junction (n=6) or at the Wakool-Edward junction (n=1). One additional golden perch was detected moving from the Glenbar-Niemur junction to the Colligen Creek-Edward River junction. Two golden perch exited the Edward-Wakool system into the Murray River near Kenley, with one of these detected on another receiver array near Mildura (travelling ~590 km). The most recent acoustic receiver download in April 2017 indicated that only three golden perch are now contributing movement data within the LTIM focal zone.

Six silver perch were successfully tracked during the 2016-17 watering season. Two individuals were last located in zone 4 in early-mid October 2016, one was last located in the Wakool River at Kyalite in late October 2016. The remaining three individuals exited the Edward-

Wakool system and entered the Murray River at Kenley from 16–24 October 2016. One of these individuals re-entered the Edward-Wakool system and was last detected at the Wakool-Edward junction in March 2017. Another of these silver perch moved upstream in the Murray River and was last detected at Picnic Point in February 2017. The third silver perch to enter the Murray River was subsequently detected on another receiver array in the lower Darling River in December 2016, having travelled downstream in excess of 700 km from its original capture location.

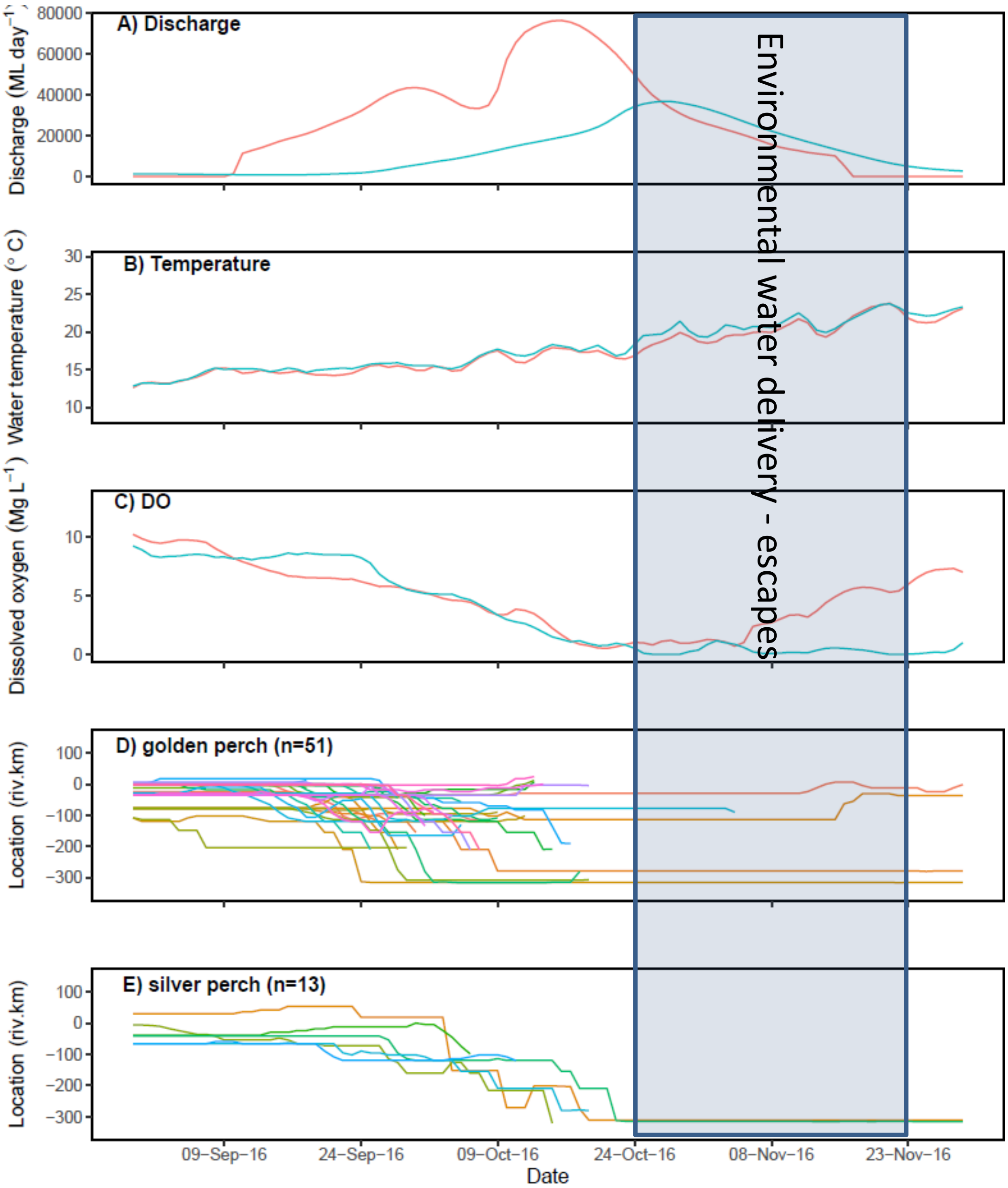


Figure 8.2 A) Mean daily river discharge, B) mean daily water temperature and, C) mean daily dissolved oxygen from the Edward River at Deniliquin (red line) and Wakool River at Gee Gee Bridge (blue line) at Wakool Reserve (Zone 3) and associated daily location of acoustically tagged D) golden perch and E) silver perch during the period of environmental water delivery in late 2016. Different coloured lines represent different tagged individuals and 0 km represents the location of Wakool Reserve, with positive numbers representing upstream locations and negative numbers downstream locations. Note that when the individual coloured lines finish this represents the last detection within the acoustic array.

8.3 Evaluation

Table 8.2 Summary of fish movement responses to Commonwealth environmental watering. N/A = Not applicable to this watering action. Detailed findings are presented in Appendix D.

CEWO Water Planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
	To provide hypoxic water refuge for fish and other aquatic biota (WUM 10054-03, 10054-04 10054-05). To reinstate part of the continuous flows during winter-spring. To improve links with other parts of the river system (WUM 10054-07, 10054-08)	*Were periodic species (golden and silver perch) present in the target reaches during Commonwealth environmental water delivery?*	Only a small proportion of the tagged sample of fish survived the hypoxic blackwater event	Location of tagged individuals within the system based on either current movements or the last valid detection	No. Timing of flow delivery was generally too late to protect the majority of individuals.
		Did periodic species remain within the target reaches during Commonwealth environmental water delivery?	Yes – see above	Location of tagged individuals within the system based on either current movements or the last valid detection	
		Did Commonwealth environmental water stimulate periodic fish species to exhibit movement consistent with reproductive behaviour?	NA	NA	
		Does Commonwealth environmental water enable periodic species to disperse from and return to refuge habitat?	NA	NA	
		Does Commonwealth environmental water protect periodic species from adverse water quality?	Possibly, although note that the timing of e-flow delivery from irrigation escapes was too late to ensure survival of many fish	Location of tagged individuals within the system based on either current movements or the last valid detection	

9. Summary of fish spawning responses to Commonwealth environmental watering

9.1 Monitoring

Fish spawning and production responses to Commonwealth environmental watering were assessed by monitoring the presence and abundance of fish larvae throughout the spring and summer of 2016-17. Larval fish were sampled fortnightly from October 2016 to March 2017 using a combination of light traps and drift nets across four study zones: Yallakool Creek (zone 1), Wakool River upstream (zone 2), mid-Wakool River upstream of Thule Creek (zone 3), and mid-Wakool River downstream of Thule Creek (zone 4).

9.2 Main findings

Seven of the ten fish species collected as larvae in the Edward-Wakool Selected Area during the 2016-17 spawning season were native, with small-bodied fish species comprising the majority of larvae collected across the four study zones. Carp gudgeon (*Hypseleotris* spp. n=11,574), were the most numerically abundant larvae caught in light traps, representing 90% of the larval collected across the spawning season. Flathead gudgeon (*Philypnodon grandiceps*, n=324) and Australian smelt (*Retropinna semoni*, n=32) larvae also detected consistently across the four study zones. Other small bodied fish found spawning during 2016-17 were Murray River Rainbowfish (*Melanotaenia fluviatilis*, n= 19) and unspecked hardyhead (*Craterocephalus stercusmascarum fulvus*, n=5), and whilst found in relative small numbers, were found in three of the four study zones. We did not detect any spawning of obscure galaxias (*Galaxias oliros*) in 2016-17, but of interest, was the large number of tadpoles collected in light traps, indicating the inundation of floodplain habitat during the 2016-17 floods promoted a strong response in frog spawning. Introduced species found spawning in 2016-17 included Carp (*Cyprinus carpio*, n=683), gambusia (*Gambusia holbrooki*, n=17) and oriental weatherloach (*Misgurnus anguillicaudatus*, n=1).

Of the large-bodied, native fish species known to Edward-Wakool River, two species, Murray cod (*Maccullochella peelii*, n=4) and bony herring (*Nematolosa erebi*, n=6), were collected as larvae, indicating local spawning had occurred within the Edward-Wakool Selected Area. It was detected as larvae in the lower section of the Focal zones – appearing in Wakool River zone 3 (upstream of Thule Creek), and Wakool River zone 4 (downstream of Thule Creek).This is the first observation of bony herring spawning in the Edward-Wakool system since short term intervention monitoring of CEWO water commenced in 2011-12. The number of cod larvae collected in light traps this year was very small compared with previous years (n=511 in 2015-16, and n=215 in 2014-15), likely reflecting the reduced adult Murray cod population in the Edward-Wakool during the spawning season as a result of the hypoxic black water that caused wide spread fish kills throughout the southern-Murray Darling Basin. There were no silver perch (*Bidyanus bidyanus*), or golden perch (*Macquaria ambigua*) eggs or larvae collected from light traps or drift nets.

Despite the reduced sampling effort caused by flooding and access issues, an order of magnitude more larvae were collected in 2016-17 compared to the first two years of LTIM monitoring – where 3,418 larvae were sampled in 2015-16, and 4,249 in 2014-15. Spawning was significantly greater in 2016-17 for carp, carp gudgeon, Murray River rainbowfish and gambusia, bony herring, compared to previous years - compared to the in-channel flow years of 2014-15 and 2015-16.

Much of the spawning that took place in the Edward-Wakool Selected Area occurred following the recovery of the system post hypoxic blackwater, coinciding with the watering action 6 on the recession of the flood when dissolved oxygen levels returned to levels over 5 mg/L (Figure 9.1). Three species, common carp, Australian smelt and oriental weatherloach were found to spawn during the hypoxic conditions, albeit in low numbers.

Commonwealth Environmental watering actions targeting silver perch spawning in the Yallakool River in autumn 2017 occurred outside the October-February monitoring period, and therefore it was not possible to directly assess if these watering actions resulted in silver perch spawning. Fish recruitment surveys to be undertaken in February 2018 will assist in establishing if these water actions resulted in successful spawning and recruitment of silver perch in the Selected Area.

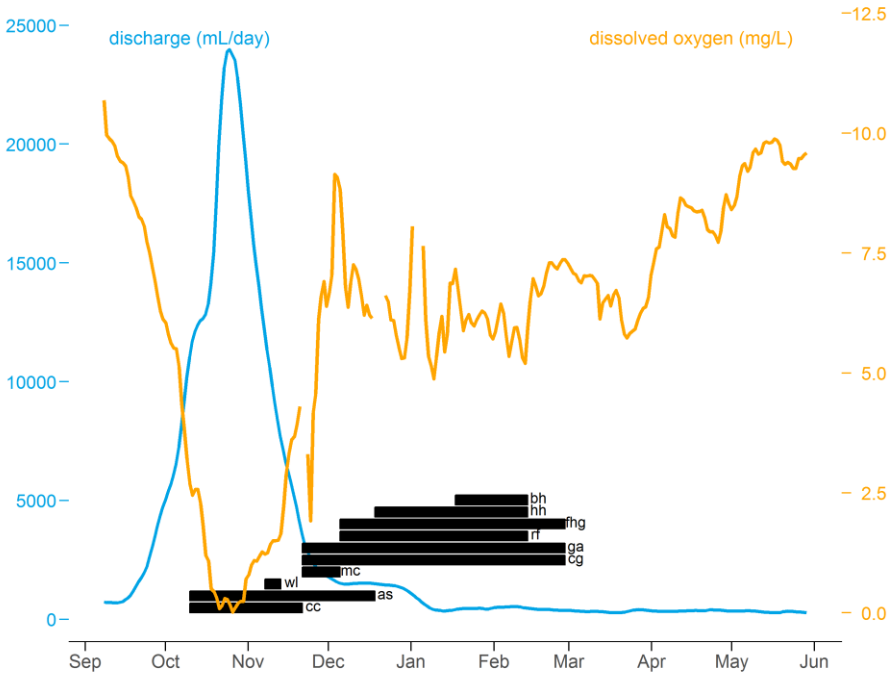


Figure 9.1 Occurrence of fish larvae in the Edward Wakool Selected Area during the 2016-17 spawning season, overlaid with mean daily discharge (mL/day) and mean daily dissolved oxygen (mg/L). Solid black bars represent duration of spawning season for individual species across all four study zones (from bottom to top): cc= common carp, as=Australian smelt, wl= Oriental weatherloach, mc = Murray cod, cg = carp gudgeon, ga= gambusia, rf=Murray river rainbowfish, fhg=flathead gudgeon, hh=unspecked hardyhead, and bh= bony herring. Discharge is measured at zone 4 site 1 (Gauge 409045, Wakool River at Barham Rd), dissolved oxygen was calculated as mean daily DO across all DO logger sites throughout the Selected Area.

Table 9.2 Summary of fish spawning responses to Commonwealth environmental watering. N/A = Not applicable to this watering action. Detailed findings are presented in Appendix D.

Fish spawning and reproduction					
CEWO Water planning and delivery		Monitoring and Evaluation questions and outcomes			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent	Expected outcomes of watering action (From Water Use Minutes and/or CEWO Acquittal report	LTIM Question	Observed outcomes	What information was the evaluation based on?	Were appropriate flows provided to achieve the expected outcome?
CEW delivered from irrigation escapes	To provide refuge from hypoxic water for fish and other aquatic biota	Could not be assessed			
Recession flows and late autumn/winter watering action in Yallakool Creek	To influence different changes in river rises that may contribute to silver perch spawning. To provide a number of peaks at a time when water temperature is suitable for silver perch spawning. To determine if river level rises timed with periods of 23°C water temperature and no moon (dark night sky conditions) has any influence on silver perch spawning response.	What did commonwealth environmental water contribute to increased spawning activity of equilibrium species (e.g. Murray cod, river blackfish?	NA (The watering actions occurred outside the time when equilibrium species usually spawn)	N/A	N/A
		What did commonwealth environmental water contribute to 'periodic' flow dependent spawning species (e.g. golden and silver perch, bony herring)	Environmental flow delivery occurred outside the monitoring period, and therefore could not be assessed. No evidence of golden perch or silver perch spawning was found during the sampling period	No eggs or larvae of golden perch or silver perch were detected with targeted fortnightly sampling, which involved using drift nets across the four study zones, from Sept to Dec 2016	High unregulated floods in 2016-17 did not trigger spawning in golden perch or silver perch in Yallakool Creek or the Wakool River. Environmental flows occurred outside the monitoring period, and therefore could not be assessed.
		What did commonwealth environmental water contribute to the spawning of 'opportunistic species' (e.g. small bodied fish)	Most opportunistic species spawned on the recession of the flood, coinciding with Commonwealth environmental watering actions	Monitoring abundance of larval fish using light traps	Watering actions on the flood recession did not specifically target spawning of opportunistic fish, but occurred at a time when spawning of these taxa usually occurs and may have benefitted these taxa

10. Summary of Murray cod, golden perch and silver perch recruitment and early life-history growth responses to Commonwealth environmental watering

10.1 Monitoring

The fish recruitment monitoring was developed specifically for the Edward-Wakool system in order to target juvenile silver perch, golden perch and Murray cod. This monitoring enables comparisons of juvenile growth rates among zones of the Edward-Wakool system and is used to determine recruitment variation of these species among years in response to environmental watering. Fish were sampled by backpack electro-fishing, standardised angling and set-lines to estimate recruitment and growth rates.

10.2 Main findings

No Murray cod, silver perch or golden perch young of year (YOY) or 1+ recruits were detected in 2016-17; the hypoxic conditions that occurred in November 2016 likely to have affected spawning and recruitment for many large bodied native fish species in 2016-17. Comparisons of relative recruitment across three years revealed that YOY Murray cod occurred throughout the system during 2014-15 and 2015-16 but was not detected in any of the zones sampled in 2016-17. Silver perch 1+ recruits were most abundant in 2015-16, as compared with 2014-15 and 2016-17 when little to no recruitment of this species was detected (Table 10.1). Golden perch recruits were not detected over the past three years in the Edward-Wakool system.

Table 10.1 Number of Young-of-Year (YOY), age-class 1 (1+) recruits and older juvenile and adults of the three target species sampled in recruitment and growth monitoring in the Edward-Wakool system for 2014-15 through 2016-17.

	2014-15		2015-16		2016-17	
Zone	YOY recruit	1+ recruit	YOY recruit	1+ recruit	YOY recruit	1+ recruit
Murray cod						
Yallakool Creek - zone 1	5	15	20	8	0	0
Wakool River - zone 2	5	11	9	16	0	0
Wakool River - zone 3	3	14	8	9	0	0
Wakool River - zone 4	7	6	5	17	0	0
Silver perch						
Yallakool Creek – zone 1	0	0	0	1	0	0
Wakool River - zone 2	0	0	0	0	0	0
Wakool River - zone 3	0	0	0	4	0	0
Wakool River - zone 4	0	1	5	15	0	0
Golden perch						
Yallakool Creek – zone 1	0	0	0	0	0	0
Wakool River - zone 2	0	0	0	0	0	0
Wakool River - zone 3	0	0	0	0	0	0
Wakool River - zone 4	0	0	0	0	0	0

10.3 Evaluation

Table 10.2 Summary of fish recruitment responses to Commonwealth environmental watering. N/A = Not applicable to this watering action. Detailed findings are presented in Appendix D.

CEWO Water Planning and delivery		**Monitoring and Evaluation questions and outcomes**			
Flow component type and target/planned magnitude, duration, timing and/or inundation extent	**Expected outcomes of watering action (From Water Use Minute 10038 and/or CEWO Acquittal report)**	**LTIM Question**	**Observed outcomes**	**What information was the evaluation based on?**	**Were appropriate flows provided to achieve the expected outcome?**
CEW delivered from irrigations escapes	To provide hypoxic water refuge for fish and other aquatic biota	*Could not be assessed*			
Recession flows and late autumn/winter watering action in Yallakool Creek	Autumn pulse and recession also to assist with movement of juvenile native fish	*Could not be assessed*			

11. Summary of fish community responses to Commonwealth environmental watering

11.1 Monitoring

Category 1 (Basin scale evaluation project) fish (river) monitoring was undertaken in the mid-Wakool River zone 3 in 2016-17 in following methods outlined in Hale et al. (2014). The Category 3 (Edward Wakool Selected Area evaluation project) monitoring of 15 additional sites throughout the Edward-Wakool Selected Area was undertaken in year 1 (2014-15)(Watts et al. 2015) and is scheduled to be undertaken again in year 5 (2018-19) of the LTIM Project, and thus was not undertaken in 2016-17.

11.2 Main findings

Category 1 fish community sampling identified eight native fish species and three alien species in zone 3 during 2017 (Table 11.1). There were significant differences in the abundance of the fish assemblage between sampling years (2017, 2016 and 2015) in zone 3. Pair-wise differences between 2017 and 2016 were driven by a reduced abundance of Murray cod and golden perch and a higher abundance of carp gudgeon and bony herring.

Bony herring captured in 2017 were significantly smaller than those captured in both 2016 and 2015, and a number of new recruits were captured. Golden perch captured in 2017 were significantly larger than those captured in 2016 and 2015 and new recruits of this species have not been captured during three years of sampling. A large proportion of common carp new recruits were captured in 2017 resulting in a significant difference in the size structure compared with both 2016 and 2015. No Murray cod new recruits were captured in 2017 and as a result the size structure was significantly larger than 2016 and 2015 (Figure 11.1).

A total of 135 Murray cod, 12 golden perch and three silver perch were collected during hypoxic blackwater fish kills in October 2016 (Figure 11.1), and otoliths were removed for later ageing to contribute to Basin-scale evaluations.

Table 11.1 Summary of fish captured during Category 1 standardised sampling in 2015, 2016 and 2017 in the Edward-Wakool LTIM project. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

Fish species	2015				2016				2017			
	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**
native species												
Australian smelt	129	2	-	**131**	52	1	-	**53**	293	10	-	**303**
bony herring	31	-	-	**31**	27	-	-	**27**	108	-	-	**108**
carp gudgeon	47	4302	51	**4400**	68	2367	15	**2450**	165	6814	66	**7045**
flatheaded gudgeon	-	-	1	**1**	-	-	3	**3**	-	-	-	**0**
golden perch	107	-	-	**107**	116	-	-	**116**	19	-	-	**19**
Murray cod	210	-	-	**210**	333	1	-	**334**	12	-	-	**12**
Murray-Darling rainbowfish	339	168	-	**507**	353	77	5	**435**	650	19	-	**669**
silver perch	5	-	-	**5**	5	-	-	**5**	3	-	-	**3**
un-specked hardyhead	86	64	-	**150**	565	35	-	**600**	510	72	-	**582**
alien species												
common carp	167	-	-	**167**	176	-	-	**176**	735	40	3	**778**
eastern gambusia	18	175	-	**193**	36	366	1	**403**	31	125	8	**164**
goldfish	21	-	-	**21**	38	-	-	**38**	73	2	-	**75**

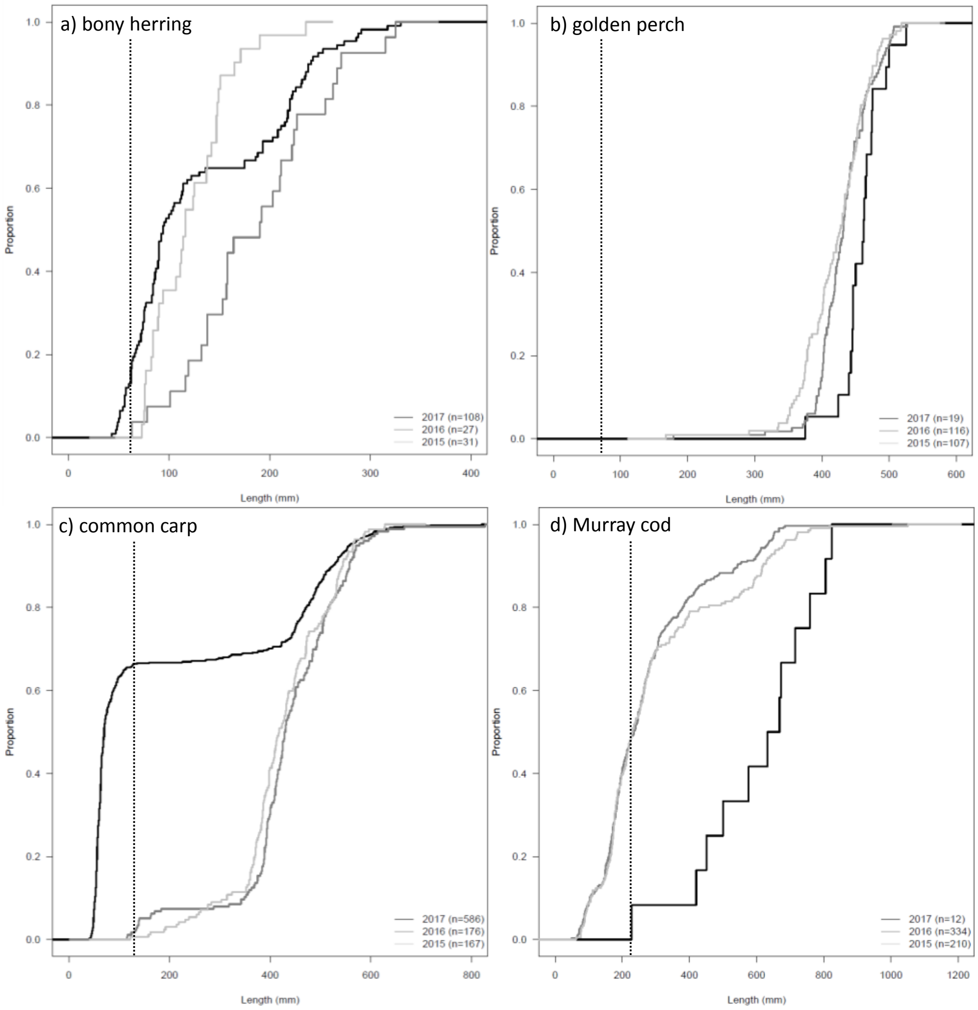


Figure 11.1. Cumulative length-frequency histograms of the four most common large-bodied species captured during Category 1 sampling in the Edward-Wakool LTIM project in 2015, 2016 and 2017. The dashed line indicates approximate length at one year of age and sample sizes are provided in the figure legend for each respective species and sampling year. Rapid vertical rises in lines (i.e. common carp <200 mm in 2017) indicate a larger proportion of fish in these size classes.

Figure 11.2 An example of Murray cod located in a backwater following a hypoxic fish kill in 2016 (left), and lined up for measurement prior to removal of otoliths (ear bones) for later ageing (right).

11.3 Evaluation

Evaluation of fish community responses to Commonwealth environmental watering in the Edward-Wakool River system for the Long Term Intervention Monitoring Project is being undertaken at the following scales:

i) Selected Area evaluation (Watts et al. 2014) will be undertaken in years 1 (2014/15) and 5 (2018/19) of the LTIM Project, and as such this report will not evaluate response questions specific to the Edward-Wakool Selected Area, and

ii) Basin scale evaluation (Hale et al. 2014) will be undertaken across short term and long term time scales. The Basin Scale evaluation involves the integration of multiple datasets from a number of different catchments, and this will be undertaken by the Murray-Darling Freshwater Research Centre and will be evaluated in a separate report.

12. SYNTHESIS

Summary of responses to 2016 unregulated flood

The following responses to the unregulated flood event were observed in the Edward-Wakool system in 2016:

- Extended period of overbank flows that flooded forest, cropping land, grazing and pasture lands and increased connectivity through connection of backwaters, flood runners and anabranches
- Increased dissolved organic carbon and rapid decrease in dissolved oxygen in October 2016 resulting in hypoxia and widespread fish deaths
- Increased concentration of nutrients, especially nitrogen and phosphorus
- Large reduction in the cover and richness of submerged and amphibious plants
- An increase in the cover and richness of terrestrial riverbank plants following the recession of the flood
- Increased movement of golden perch and silver perch over 100’s of kilometres, which was an order of magnitude greater than movements during the preceding months
- Very low numbers of in Murray cod larvae present compared to previous years, as the hypoxic event occurred at the time of year in which Murray cod spawn in this system
- Absence of Murray cod, silver perch and golden perch recruits following the flood
- Very high biomass of tadpoles and invertebrates observed in nets, that provides a source of food for native fish and other animals (Figure 12.1)

Figure 12.1 Invertebrates collected in the drift nets during the flood in the Wakool River (Photo: Nicole McCasker).

Response to environmental watering actions from irrigation canal escapes

Commonwealth watering actions were undertaken between October and December 2016 to create local refuge areas by releasing environmental flows from irrigation canal escapes into rivers in the Edward-Wakool system. The responses differed between canal escapes, largely depending on the extent to which the water released from the escape contributed to the river flow.

The watering actions from the Edward escape and Wakool escape had positive outcomes, improving DO and DOC downstream of these escapes (Table 12.1). No targeted fish monitoring was undertaken near these escapes, however landholders and Fisheries Officers observed fish congregating in the flows from these escapes (Table 12.1), suggesting the water actions were successful in creating localised fish refuges during the hypoxic blackwater conditions. The watering action from the Niemur escape did not show any change in indicators downstream of the escape, because the environmental water delivered from the escape contributed less than 7 % of the total flow in the Niemur River for the duration of the watering action (Figure 4.7). The watering action at the Thule escape was influenced by other localised effects. The watering actions from these escapes may have provided local refuge habitat for fish and other organisms.

Table 12.1 Responses to the watering actions from irrigation canal escapes in the Edward-Wakool system during the 2016 hypoxic blackwater event. No targeted fish monitoring was undertaken near these escapes. Observations of native fish activity near the escapes were noted by landholders and Fisheries Officers.

Positive response to environmental watering (green)
Mixed response; some adverse and some positive responses to environmental watering (amber)
Negative response to environmental watering (red)
No detectable response to environmental watering (neither positive nor negative response) (grey)
N/A No evaluation undertaken by this project (white)

Indicator type	Indicator	Edward Escape	Wakool Escape	Thule Escape*	Niemur Escape
Hydrology	Water from escape contributed >10% of river flow	Yes	Yes	Yes	No
Water quality	DO	Increased (improved) downstream of escape	Increased (improved) downstream of escape	Decreased (affected by other factors)	Negligible-possibly localised refuge only
	DOC	Decreased (improved) downstream of escape	Decreased (improved) downstream of escape	Increased	No clear trend
	pH	No clear trend (varies with sampling date)	Increased (within acceptable range)	Decreased (from initially high value)	No clear trend
	Nutrients	NOx increased Other nutrients decreased	Generally decreased (varied with sampling date)	No clear trend	No clear trend
Fish movement	Native fish movement	Could not be assessed because the watering action occurred after the last valid movement records for the majority of the tagged fish			
Anecdotal observations of native fish	Native fish activity	Fish observed congregating in the flows from the Edward escape	Fish observed congregating in the flows from the Wakool escape	Fish observed congregating in the flows from the Thule escape	NA - no observations

*Note Thule measurements suggest algal growth at upstream site and/or floodplain drainage between upstream and downstream sites may have occurred and disguised the impact of CEW

Response to recession flows and late autumn/winter watering action in Yallakool Creek

During the flood recession and winter watering action the water quality remained within an acceptable range. Compared to fish spawning recorded at the same time in previous years, there was increased spawning of carp, carp gudgeon, Murray River rainbowfish, gambusia and bony herring on the recession of the flood event. However, there were no fish recruits of Murray cod, silver perch or golden perch recorded in autumn 2017. There was no detectable response of aquatic vegetation on the recession of the flood or into autumn and winter 2017, because almost no aquatic vegetation survived during the flood event.

Table 12.2 Summary of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2015-16.

Positive response to environmental watering (green)
Mixed response; some adverse and some positive responses to environmental watering (amber)
Negative response to environmental watering (red)
No detectable response to environmental watering (neither positive nor negative response) (grey)
N/A No evaluation undertaken by this project (white)

Indicators	**Dependant variable**	**Short-term response to recession flows and Yallakool Creek autumn/winter flows**			
		Zone 1	**Zone 2**	**Zone 3**	**Zone 4**
Hydrology	Hydrological connectivity		Recession flow N/A winter flow		
Stream metabolism, water quality, and organic matter characterisation	Rates of gross primary productivity				
		N/A (winter flows not assessed)			
	Rates of ecosystem respiration				
		N/A (winter flows not assessed)			
	Dissolved organic matter				
	Dissolved oxygen		Recession flow N/A winter flow		
	Nutrient concentration				
Riverbank and aquatic vegetation	Percent cover and richness of submerged and amphibious plants				
	Percent cover and richness of terrestrial plants	N/A (increased cover of terrestrial plants over this period not associated with watering actions, higher on bank than e-flows)			
Fish movement	Native fish movement	N/A (there were few fish remaining in the system at this time to be able to assess movement to these flows)			
Fish spawning and reproduction	Larval abundance of 'Opportunistic' (e.g. small bodied fish) species	Positive spawning response during recession flows			
		N/A winter flows not assessed			
	Larval abundance of 'flow-dependent' spawning species (e.g. golden and silver perch)	No larvae of flow dependent species recorded			
	Larval abundance of Murray cod	N/A (outside the spawning time for Murray cod)			
Fish recruitment	Growth rate of young-of-year (YOY) and age-class 1 (1+) Murray cod, golden perch and silver perch	No fish recruits captured			
	Recruitment of young-of-year (YOY) and age-class 1 (1+) Murray cod golden perch and silver perch	No fish recruits captured			
Fish community	Fish condition	N/A (fish community assessed only year1 and year 5)			
	Fish recovery	N/A (fish community assessed only year1 and year 5)			

13. Recommendations for the adaptive management and future use of Commonwealth environmental water

Progress on recommendations from 2015-16 Edward-Wakool Annual LTIM report

Eight recommendations were outlined in the 2015-16 Edward-Wakool LTIM annual report (Watts et al. 2016) to improve the planning and delivery of Commonwealth environmental water. The extent to which these recommendations have been implemented (as of October 2017) in the Edward-Wakool system is summarised in Table 13.1.

Table 13.1 Progress on eight recommendations outlined in Edward-Wakool 2015-16 LTIM annual report

Recommendation from 15-16 report	Extent to which recommendation implemented
1. Undertake a comprehensive flows assessment for the tributaries of the Edward-Wakool system to better inform future decisions on environmental watering in this system.	Flow assessments have been undertaken by MDBA and NSW OEH comparing modelled natural with observed data. It is not yet clear to what extent these assessments underpin management decisions
2. Trial the delivery of continuous base e-flows during winter (no cease to flow) in the tributaries of the Edward-Wakool system to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist the recovery of submerged aquatic plants in the system.	In early 2016 CEWO and NSW OEH held discussions with stakeholder groups (e.g. the Murray-Lower Darling EWAG and the Edward-Wakool Environmental Water Reference Group) regarding this recommendation. A continuous winter flow was implemented in Yallakool Creek-Mid & Lower Wakool River and the Colligen Creek-Niemur River system in 2017.
3. Trial the delivery of a short duration e-watering action in late winter or spring 2017 at a higher discharge than the current operational constraint of 600 $ML.d^{-1}$ (possibly up to 1000 to 1200 $ML.d^{-1}$). This would test the hypothesis that larger in-channel environmental watering actions will increase river productivity.	CEWO and NSW OEH have facilitated discussions with stakeholders to progress a proposal to trial flows above current operational constraints, up to approximately 800 ML/day at the confluence of Yallakool Ck and Wakool R. The current proposal is to undertake the trial in autumn or winter of 2018.
4. Trial the delivery of an environmental watering action in the Edward R downstream of Stevens Weir to target golden perch and silver perch spawning.	This recommendation has not yet been implemented nor is there monitoring in place to detect a spawning response if it occurred.
5. Avoid long periods of constant flows by introducing flow variability into environmental watering actions.	This recommendation was applied in 2015-16 and 2016-17, 2017-18 in Yallakool Ck, Wakool R and Colligen Ck-Niemur R watering actions.
6. Continue to explore opportunities to increase the magnitude of environmental water delivered to the upper Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system.	This recommendation was trialled in 2015-16. Up to 100 $ML.d^{-1}$ of CEW was delivered to upper Wakool but did not produce expected outcomes. Trialling the delivery of higher flows to the upper Wakool may result in better outcomes. It may be difficult to achieve from the regulator but could be achieved in conjunction with use of the Wakool escape.
7. Continue to include a water use option in planning that enables Commonwealth environmental water to be used to mitigate adverse water quality events in the Edward-Wakool system.	This recommendation was applied to the 2015-16, 2016-17 and 2017-18 planning for the use of CEW in the Edward-Wakool River system. Contingency flows have continued to be made available to contribute to responses to hypoxic blackwater events or other poor water quality events should they occur.
8. Continue to include a water use option that enables CEW to be used to mitigate rapid recessions due to rainfall rejection in the Edward-Wakool system.	This recommendation was applied to the 2015-16, 2016-17 and 2017-18 planning for the use of CEW in the Edward-Wakool River system.

Recommendations from 2016-17 watering actions

In addition to two recommendations that have been carried over from the 2015-16 Edward-Wakool LTIM annual report, we outline three new recommendations to improve the planning and delivery of Commonwealth environmental water that are underpinned by the 2016-17 Edward-Wakool monitoring and evaluation results and findings from previous monitoring. Where applicable, a note has been included to indicate to what extent the recommendation has already been applied (as of October 2017) in the planning or use of Commonwealth environmental water in the Edward-Wakool system.

In summary, the seven recommendations are:

1. If there is an imminent hypoxic blackwater event during an unregulated flow and the quality of source water is suitable for an environmental watering action, the CEWO and other relevant agencies, in partnership with local landholder and community representatives, should take action to facilitate the earlier release of environmental water on the rising limb of the flood event to create local refuges prior to dissolved oxygen concentrations falling below 2 mgL^{-1}.
2. The installation of a dissolved oxygen logger on an existing NSW Water gauge downstream of Yarrawonga and upstream of Barmah-Millewa Forest (such as Tocumwal) should be considered a priority to enable forest managers to more accurately determine and understand the influence of upstream floodplain and/or the forest on DO and DOC levels in the mid-Murray reach. Consideration should also be given to installing dissolved oxygen loggers, either on existing NSW Water gauge or on new gauges, both upstream and downstream of other forested areas that may influence water quality in the Edward-Wakool system, including Werai Forest.
3. Implement a second trial of continuous base environmental flows (no cease to flow) during winter 2018 in the tributaries of the Edward-Wakool system to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist the recovery of submerged aquatic plants in the system.
4. Trial the delivery of an environmental watering action in the Edward River downstream of Stevens Weir to target golden perch and silver perch spawning, supported with appropriate monitoring. This recommendation was carried forward from the 2015-16 annual report (Watts et al. 2016).
5. Continue to explore opportunities to increase the magnitude of environmental water delivered to the upper Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system. This recommendation was carried forward from the 2015-16 annual report (Watts et al. 2016).
6. Undertake in-channel habitat mapping for all key reaches of the Edward-Wakool system, which could then be combined with the hydraulic modelling undertaken to-date (see Watts et al. 2015) to also facilitate learning about this system and the outcomes being observed from the use of water.
7. The CEWO and other relevant agencies undertake a review of the 2016 flood and subsequent hypoxic blackwater event in the Murray system and support further research into understanding these events, to assist future water management.

Recommendation 1: If there is an imminent hypoxic blackwater event during an unregulated flow and the quality of source water is suitable for an environmental watering action, the CEWO and other relevant agencies, in partnership with local landholder and community representatives, should take action to facilitate the earlier release of environmental water on the rising limb of the flood event to create local refuges prior to dissolved oxygen concentrations falling below 2 mgL^{-1}.

Between October and December 2016 Commonwealth environmental watering actions were undertaken to create local refuge areas by releasing environmental flows from irrigation canals escapes into the Edward-Wakool system. The decision making environment was very complex, as there was community concern that delivery of environmental water on the rising limb of the flood event would have exacerbated the flooding of private land. Thus, by the time the decision was taken to deliver environmental water via MIL irrigation escapes the DO had already dropped below 2 mgL^{-1} and some fish deaths had already occurred. Whilst it appears that these watering actions (in conjunction with community actions to install aerators to create local refuges) may have assisted the survival of some fish, earlier delivery of environmental water would most likely have resulted in a better outcome.

The Murray Dissolved Oxygen Group re-convenes when DO is around 5 mgL^{-1}. However, there is no agreed process for decision making during hypoxic blackwater events, partly due to the complexity of these events and that the circumstances leading to each event is different. However, over several of these events there have been reports of crayfish leaving the water 1-2 days prior to the first reports of fish kills and this could be taken as a trigger for immediate action if circumstances permit.

It is recommended that the CEWO and other relevant agencies examine the 2016 event in the Edward-Wakool system and determine what the impact on the hydrograph would have been if they had made on earlier release of environmental water on the rising limb of the flood event. This would facilitate stakeholder discussion around discussion of earlier release of Commonwealth environmental water during a subsequent hypoxic blackwater event during unregulated flows.

Adaptive management: Recommendation 1 has been partially implemented through the CEWO commissioning a review of hypoxic blackwater events and management actions in the MDB (CEWO 2017). In addition to the recommendations in that report, a detailed analysis of the water decision process and options for future actions could be undertaken specifically for the Edward-Wakool system to assist future decision making during imminent hypoxic blackwater events.

Recommendation 2: The installation of a dissolved oxygen logger on an existing NSW Water gauge downstream of Yarrawonga and upstream of Barmah-Millewa Forest (such as Tocumwal) should be considered a priority to enable forest managers to more accurately determine and understand the influence of upstream floodplain and/or the forest on DO and DOC levels in the mid-Murray reach. Consideration should also be given to installing dissolved oxygen loggers both upstream and downstream of other forested areas that may influence water quality in the Edward-Wakool system, including Werai Forest.

Commonwealth environmental water is provided to Barmah-Millewa Forest on an almost annual basis. During the 2016 event there were a number of questions raised by the community about the role of the forest as a source of carbon. This in turn lead to a broader discussion between natural resource management staff and the community about the extent of the 2016 flood and multiple sources of carbon, including the floodplain and agricultural land. The installation of a dissolved oxygen logger on the existing Tocumwal gauge may assist forest and river managers in obtaining data that can show the influence of the floodplain and the forest on DO and as sources of DOC. Installation of dissolved oxygen loggers, either on existing NSW Water gauges or on new gauges, both upstream and downstream of other forested areas that influence water quality in the Edward-Wakool system, including Werai Forest, should be considered.

Recommendation 3: Implement a second trial of continuous base environmental flows (no winter cease to flow) during winter 2018 in the tributaries of the Edward-Wakool system to promote the temporal availability and continuity of instream habitat to benefit fish and other aquatic animals and assist the recovery of submerged aquatic plants in the system.

Under normal operational flows there is a period of no flow during winter when the Yallakool Creek Offtake, Wakool Offtake, and Colligen Creek Offtake regulators are closed and Stevens Weir pool is lowered. In 2016 CEWO and NSW OEH held discussions with stakeholder groups (e.g. the Murray-Lower Darling EWAG and the Edward-Wakool Environmental Water Reference Group) that resulted in an environmental watering action that created a continuous winter base flow in Yallakool Creek in 2017. This was proposed to facilitate the movement of fish back into the system following the hypoxic blackwater event in late 2016. It is also hypothesised that this will assist the recovery of submerged aquatic plants by preventing the exposure of rhizomes to frost and feral animal disturbance during winter.

The 2016 flood was an extreme event and the system will take some time to recover from that. We recommend that a follow-up winter base flow be implemented in winter 2018, to facilitate further movement of native fish back into the system and facilitate a more rapid response of aquatic plants to strengthen the resilience of the system to future droughts or floods.

Adaptive management: A flow trial has already been implemented in winter of 2017. CEWO and NSW OEH have undertaken the discussions with various stakeholder groups (e.g. the Murray-Lower Darling EWAG and the Edward-Wakool Environmental Water Reference Group) regarding the implementation of a winter base flow in 2018, but a final decision regarding the implementation of that has not yet been made and will need to take into account maintenance works planned by WaterNSW on Stevens Weir.

Recommendation 4: Trial the delivery of an environmental watering action in the Edward River downstream of Stevens Weir to target golden perch and silver perch spawning, supported with appropriate monitoring.

This recommendation was carried forward from the 2015-16 annual report (Watts et al. 2016).

Golden perch and silver perch spawning, or magnitude of spawning and recruitment are thought to be associated with flow pulses (Mallen-Cooper and Stuart 2003; Roberts et al. 2008; Zampatti and Leigh 2013). The Edward-Wakool system is known to support juveniles and adults of both species (Watts et al. 2014, 2015, 2016, this report), however there is no evidence to date to suggest that spawning in these species occurs within the smaller tributaries of the Edward-Wakool system.

Recent evidence suggests that golden perch (and likely silver perch) life-history operates over large spatial scales across the southern connected Murray-Darling Basin (Zampatti et al. 2014). The inter-connectedness of Edward-Wakool golden perch and silver perch populations will be addressed under the fish movement component of the Edward-Wakool LTIM project and through other concurrent collaborations. However, more information on if, and where, these species spawn within the Edward-Wakool system is required.

Environmental watering actions in the Wakool-Yallakool system is currently constrained to a maximum of 600 $ML.d^{-1}$ and actions of this magnitude (whilst not targeting golden perch and silver perch spawning) have not triggered spawning in either species in this part of the system. The Edward River main-stem is a larger river and is similar to other larger river systems (e.g. Goulburn River) where golden perch have been observed to spawn in recent years (Koster et al. 2014). The Edward River can also receive higher flows than the Wakool-Yallakool system as it does not have the same operational constraints as the tributaries. We propose a trial environmental watering action and monitoring program be implemented in the Edward River downstream of Stevens Weir targeting perch recruitment. Stevens Weir could be operated to facilitate the delivery of a managed rise and fall in hydrograph, using results from other river systems or and available hydrological modelling for the Edward River to guide the development of a hydrograph during an environmental flow planning workshop.

This recommendation is similar to recommendation number 8 of Watts et al. (2015) and number 4 of Watts et al. (2016) but has not yet been implemented. The current LTIM Monitoring and Evaluation Plan for the Edward-Wakool system does not include monitoring of fish reproduction in the Edward River. If this flow trial were to be implemented additional monitoring in the Edward River would be required to evaluate the effectiveness of this watering action.

Adaptive management: The CEWO has included the provision of a small instream pulse in some of their watering actions in the Wakool River and Yallakool Creek, however this will be limited by the 600 MLd^{-1} operational constraint, and to date no perch spawning has been recorded.

Recommendation 5: Continue to explore opportunities to increase the magnitude of environmental water delivered to the upper Wakool River to achieve ecosystem outcomes and at the same time facilitate learning about the system

This recommendation was carried forward from the 2015-16 annual report (Watts et al. 2016).

Since 2011 the majority of Commonwealth environmental water in the Wakool-Yallakool system has been delivered via Yallakool Creek, whereas over the same period the delivery of environmental water to the upper Wakool River has been small due to the operational constraint at the confluence of Yallakool Creek and the Wakool River. The Commonwealth environmental water delivered to the upper Wakool system in 2015-16 (up to total discharge of 100 $ML.d^{-1}$) had minimal effect on the hydrological and ecological outcomes in that system. Hydraulic modelling has demonstrated that the relationship between discharge and wetted benthic area is not linear in this system (Watts et al. 2015). There is potential to considerably increase the wetted area in some reaches of the upper Wakool River if environmental water was delivered at a higher discharge than in 2015-16 but within the current operational constraint of 600 $ML.d^{-1}$. For example, the total wetted area for modelled reaches in the upper Wakool River increased by an average of 6.1% at discharge of 100 $ML.d^{-1}$ (when compared to discharge of 50 $ML.d^{-1}$), whereas at 250 $ML.d^{-1}$ and 500 $ML.d^{-1}$ the average increase in wetted benthic area in the upper Wakool River increased by 20.2% and 45.5% respectively.

The current operational constraint in this system impedes the concurrent delivery of a significant flow pulse to both Yallakool Creek and the upper Wakool River. Hydraulic modelling has shown that delivering more environmental water via the upper Wakool River has the potential to increase the outcomes in the system. Undertaking a trial whereby environmental water was delivered via the upper Wakool River instead of Yallakool Creek would facilitate understanding of responses to flows in this system by disentangling the confounding factors of river and flow. If flow is a major contributor to the responses in this system then one would expect the positive vegetation and water quality responses observed in Yallakool Creek in 2013-14 (Watts et al. 2014), 2014-15 (Watts et al. 2015) and 2015-16 (Watts et al. 2016) to be observed in the upper Wakool River if it were to receive a larger environmental flow.

Adaptive management: The recommendation in the 2014-15 Edward-Wakool LTIM annual report to deliver water via the upper Wakool River was trialled in 2015-16, and a small volume of Commonwealth environmental water (up to 100 $ML.d^{-1}$) was delivered to the upper Wakool River. However, this watering action did not produce the expected outcomes. Trialling the delivery of higher flows via the upper Wakool may result in better outcomes. This would be difficult to achieve with the current regulator, but could be achieved using a combination of the Wakool escape and Wakool regulator.

Recommendation 6: Undertake in-channel habitat mapping for all/key reaches of the Edward-Wakool system, which could then be combined with the hydraulic modelling undertaken to-date (see Watts et al. 2015) to also facilitate learning about this system and the outcomes being observed from the use of water.

Further learning about this system could be improved by undertaking mapping of in-channel habitat through key reaches of the Edward-Wakool system. The use of environmental water in this system has annually targeted outcomes for larger bodied native fish, particularly Murray cod. At present there is no assessment to use as a baseline for the amount of available habitat (such as benches or refuge holes, aquatic macrophytes and large woody habitat) that contributes to native fish, connectivity and productivity outcomes. Mapping of such habitat could be combined with the hydraulic modelling that has been completed under this LTIM project. This may provide a significant context for the observed outcomes (past, present and future) through this project. It would also assist with informing any potential investment in complimentary measures that would also contribute to the outcomes being sought from the use of environmental water.

Recommendation 7: The CEWO and other relevant agencies undertake a review of the 2016 flood and subsequent hypoxic blackwater event in the Murray system and support further research into understanding these events, to assist future water management.

In 2016, there was a major hypoxic blackwater event that resulted in death of many native fish throughout the Murray River, but particularly in the Edward-Wakool system. At the time there was much community speculation over the reasons for the severity of this event. While there is considerable knowledge about some aspects of blackwater, there are limitations to our understanding about these events and how decisions made at a broader scale influence the water quality in the Edward-Wakool system. Further targeted research is required to underpin future watering decisions.

Adaptive management: This recommendation has been partially implemented through the CEWO commissioning a review of hypoxic blackwater events and management actions in the MDB (CEWO 2017). This review recommended the development of an Emergency Management Plan. However, there does not appear to be a process or coordinated approach to improve the knowledge and science around blackwater events or to target research questions to answer the questions that the community has about these events.

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APPENDIX A: WATER QUALITY & CARBON

A.1 Background

The primary driver of water quality in the 2016-17 sampling season was extensive unregulated overbank flooding as a result of a particularly wet spring season. This was characterised by hypoxic blackwater during the late spring period where very high input of organic matter from the floodplain coincided with increasing water temperatures and oxygen depletion (hypoxia) was widespread through the southern Murray Darling Basin, including the Edward-Wakool system.

Blackwater events occur when very large quantities of organic matter enter the water in a river or wetland system and the dissolved portion of the organic matter colours the water a deep brown. These events may become hypoxic when the circumstances of the event result in the consumption of oxygen by organisms in the water exceeding the rate of production by plants and algae and reaeration from the atmosphere (Mallin et al. 2006; Howitt et al. 2007; Hladyz et al. 2011; Whitworth et al. 2012; Whitworth et al. 2014). Hypoxic events may result in deaths of fish and other aquatic organisms and are more likely to occur when water temperatures are high or very large loads of organic matter have accumulated on the floodplain, situations which are more likely to occur where unseasonal flooding occurs in warm months or the river has been disconnected from the floodplain for long periods (Howitt et al. 2007; Whitworth et al. 2012; Kerr et al. 2013; Pasco et al. 2016).

Not all dark coloured water results in hypoxia or fish kills and it is important to maintain connection between rivers and their floodplains for the transfer of organic matter and nutrients to support ecosystems (Baldwin and Mitchell 2000; Baldwin et al. 2016; Nielsen et al. 2016; Robertson et al. 2016; Wolfenden et al. 2017). High dissolved organic carbon may be a normal feature of some catchments where the water is coloured year round or as an annual event as is common in a number of Tasmanian catchments, and many rivers internationally may actually be referred to as black or brownwater catchments e.g. (Mehring et al. 2015; Leech et al. 2016; Vihermaa et al. 2016; Hensley and Cohen 2017). Water colour itself, should not be taken as a marker of harm, but it is important to consider water temperature and dissolved oxygen when high DOC concentrations are present. Oxygen depletion below 4 mg/L can result in fish and other aquatic organisms experiencing sub-lethal effects and mortality cam be observed below 2 mg/L (Gehrke 1988; Gehrke et al. 1993; King et al. 2012; Small et al. 2014).

Historical accounts of fish deaths associated with blackwater have been reported over a considerable period of time including for the Edward River at Deniliquin (Sydney Mail and New South Wales Advertiser, 23/2/1878), Lismore (Argyle Liberal and District Recorder, 15/12/1903), Campaspe River at Elmore (Weekly Times 15/3/1913 and Riverine Herald 24/2/1915), the Murray River at Murray Bridge and Renmark (Mt Barker Courier and Onkaparinga and Gumeracha Advertiser 15/11/1929) and Kananook Creek, Frankston (Army News, Darwin, Sat 26/2/1944). Hypoxia in aquatic systems is a problem that receives worldwide attention and occurs not just in riverine systems (Mehring et al. 2014; Pardo and Garcia 2016; Pasco et al. 2016; Ji et al. 2017) but in lake and wetland (Bonvillain et al. 2015; Mallin et al. 2016), coastal (Lee et al. 2017; Testa et al. 2017; Wang et al. 2017) and oceanic (Ahlgren et al. 2017; Dautovic et al. 2017) areas with complex interacting causes including natural events but also changes in river flow or coastal mixing, eutrophication (algal blooms) or direct input of urban, agricultural or industrial effluent, particulate transport and changes in water temperature and climate behaviour(Altieri and Gedan 2015).

Blackwater events do occur naturally and while we can try to reduce their frequency and severity it is not possible to prevent all occurrences. The 2016 event occurred in many rivers within the Southern Murray-Darling Basin and was associated with record spring rainfall (Bureau of Meterorology, 2017) and inundation of areas of the floodplain that had been disconnected from the river for many years (decades in some areas). The inundation of forested areas, cropping and grazing lands introduced considerable organic matter to the river system. A range of options for responding to hypoxic blackwater have been considered (Kerr et al. 2013; Whitworth et al. 2013) including dilution flows, created by releasing water from irrigation canal escapes; physical reaeration of water using paddle wheels, pumps or regulatory structures; and reaeration and dilution by diversion of blackwater into shallow off-channel storages. Whitworth et al. (2013) concluded that while all of these strategies have the potential to promote re-oxygenation of blackwater, in many cases only localised improvements in DO are expected. The release of water from irrigation escapes during previous blackwater events in the Edward-Wakool system in 2010 and 2012 has been successful for creating refuges and improving downstream water quality (Watts et al. 2017a; Watts et al. 2013). Downstream water quality improvements are very difficult to generate in an event of this scale using environmental water but creation of localised refuges and small scale improvements are still possible.

Dissolved organic matter composition in rivers includes a complex mixture of compounds with very different properties and variable availability to the microbial population. Nonhumic substances include relatively simple compounds belonging to recognised groups such as carbohydrates, proteins, peptides, fats and other low molecular weight organic compounds. However, the much larger molecules that make up the category of humic substances (including humic and fulvic acids) can dominate in many waters and in contrast are poorly characterised (Choudhry 1984). Humic substances are predominantly derived from the processing of plant residues and can involve complex chains and aromatic rings which contribute to their strong yellow-brown colour. Microbial communities do not respond to all types of organic matter in the same way (Baldwin 1999; O'Connell et al. 2000; Howitt et al. 2008) although it has been shown that bacterial communities can respond to changes in organic carbon source quite rapidly (Wehr et al. 1999). The very large, complex type of organic matter referred to as humic substances has been shown to be less available to bacterial communities than simpler non-humic carbon (Moran and Hodson 1990) although this can be altered over time with exposure to ultraviolet light (Moran and Zepp 1997; Howitt et al. 2008). These differences in microbial response to different types of organic matter mean that it is important to consider not just the total amount of dissolved organic matter in the rivers but to monitor changes in the type of organic matter present. Both absorbance and fluorescence spectra are used to examine the organic matter in this study. As a general guide, absorbance at longer wavelengths indicates larger, more complex organic matter (Bertilsson and Bergh 1999). Absorbance at a particular wavelength may be increased by increasing concentration of organic matter or a change in the type of organic matter.

The onset of the hypoxic event triggered additional monitoring of the water quality event. The monitoring was directed towards preliminary modelling using the Blackwater Intervention Assessment Tool (Whitworth and Baldwin 2016) to provide immediate advice regarding the likely outcomes of using water releases from irrigation escapes under various scenarios and additional water quality sampling. In addition to the regular monthly water quality sampling, this chapter includes data from weekly monitoring (October-December) specifically targeting water quality around four irrigation escapes where environmental water was released to provide localised refuges for aquatic species in the vicinity of the escapes. This includes additional sites on the Edward River, Thule Creek, Niemur River and the Wakool River. The use of environmental water for water quality targets concentrated on this event, however the additional data associated with irrigation escapes is presented following a detailed consideration of the water quality in the broader system in the context of the flooding. The environmental water delivered during Watering Actions 5 and 6 (Table 2.3) was not specifically targeted towards the modification of water quality or delivered in a way that allows comparison between sites that received environmental water and those that did not. Where possible, the effects of this delivery will be considered in the context of the recession of the floodwater and the overall seasonal water quality behaviour. Water quality data is not available to assess the winter flows up until June 2016, but the watering action in Yallakool Creek during winter will be considered in the 2017-18 report.

This project aims to assess changes to water quality in response to alterations in flow and to consider changes in both the quantity and type of organic matter present in the system. Specifically, this work will be addressing the questions below.

A.2 Selected Area Questions

As described above, the relationship between flow and water quality is complex and can be influenced by how changes in flow influence wetted benthic area, water depth, rate of flow and connectivity to the floodplain. Water quality parameters may be affected in different ways due to the direct effects of changes in flow, or due to interactions between the parameters. In order to obtain an understanding of the impact of environmental water deliveries to the Edward-Wakool system on the water quality in the Wakool River and Yallakool Creek we monitor a number of parameters in each site through a combination of continuous logging, spot readings on site and sample collection for laboratory analysis. Water quality will generally respond very rapidly to changes in flow but trends may also develop over a longer period, so the questions below are considered on a 1-5 year basis.

In 2016-17 the key question relating to the CEW actions was:

- *What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?*

The following questions are addressed within the context of the irrigation escapes analysis:

- *What did Commonwealth environmental water contribute to dissolved oxygen concentrations?*
- *What did Commonwealth environmental water contribute to nutrient concentrations?*

The remaining questions relate to types of watering actions/conditions that were not present in the system in 2016-17:

- *What did Commonwealth environmental water contribute to temperature regimes?*

- *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?*

A.3 Methods

Water temperature and dissolved oxygen were logged every ten minutes with two loggers located in each of zones 1, 3 and 4 and one logger in zone 2. Data were downloaded and loggers calibrated approximately once per month depending on access to survey site (extensive flooding in the system prevented access to loggers during the flood peaks and this has resulted in some gaps in the data). Light and depth loggers were also deployed and data were downloaded on a monthly basis. The data collected by the loggers was used to calculate daily average temperature and dissolved oxygen concentrations for each of the rivers from September 2016 to May 2017. Dissolved oxygen and temperature data is also presented for the Edward River at Deniliquin and Wakool River at Gee Gee Bridge and has been sourced from the NSW Department of Primary Industries loggers via the Water Info website http://waterinfo.nsw.gov.au/

From August to May water samples were collected once per month (samples slightly further apart late in the season) from two sites within each zone, and from Stevens Weir on the Edward River and the Mulwala Canal. Additional monitoring occurred weekly from 31 October to 12 December to assess the impact of Commonwealth Environmental Water releases from irrigation escapes in the Edward River, Wakool River, Thule Creek and Niemur River. On all sample dates water quality parameters (temperature (^oC), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were measured as spot recordings.

Water samples were processed according to the methods detailed in Watts et al. (2014) to measure:

- Dissolved Organic Carbon (DOC)
- Nutrients (Ammonia (NH_4^+), filtered reactive phosphorus (FRP), dissolved nitrate + nitrite (NOx), Total Nitrogen (TN) and Total Phosphorus (TP))
- Absorbance and fluorescence spectroscopy for organic matter characterisation.

Water samples were filtered through a 0.2 μm pore-sized membrane at the time of sampling and then stored on ice until returned to the laboratory. DOC and nutrient samples were frozen and sent to Monash University for analysis. Carbon characterisation samples were sent to CSU Wagga Wagga and analysed within a day of returning from the field. Estimates of DOC concentrations based on a calibration between DOC and absorbance at 250 nm established early in the event were used to provide rapid feedback on the progress of the blackwater event. Those results were generally within 1 mg/L of the accurate DOC results received later and presented in this Appendix.

Absorbance scans were 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. Absorbance is a measure of light absorbed by the sample and is a logarithmic scale. An absorbance of 1 indicates that only 10% of the light of that wavelength is transmitted through the sample. Fluorescence scans were collected using a Varian Eclipse spectrofluorometer scanning both emission and excitation wavelengths to give an excitation-emission matrix. Excitation wavelengths were scanned from 200 to 400 nm with a 10 nm step size and for each excitation wavelength, emission of light at 90^{O} to the source was recorded from 200 nm to 550 nm with a 1 nm step size. Fluorescence results were corrected for sample absorption and plotted as contour plots (Howitt et al. 2008). To correct for drift in the instrument zero position, each contour plot was scaled by subtracting the average emission intensity across the range 200-210 nm for an excitation of 250 nm from all fluorescence intensities (effectively setting this region of the contour plot to zero on all plots).

An example of a fluorescence contour plot is shown in Figure A.1. The contour plots have the excitation wavelength (light shone into the sample) on the y-axis. On the x-axis is the emission wavelength (light given off by the sample). The intensity of the fluorescence (how much light is given off, corrected for absorbance by the sample) is represented by the colours of the contour plot, with more intense fluorescence represented by the blue end of the scale. The two blue diagonal lines are artefacts of the technique and will be present in all samples- key data is found between these two lines.

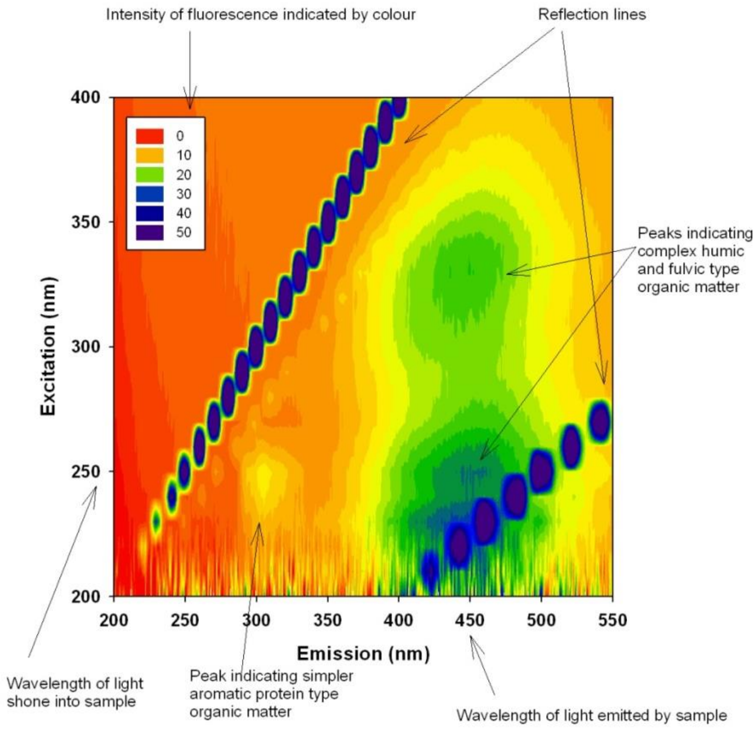

Figure A.1 Sample excitation emission contour plot indicating key features of the data. (Watts et al. 2013)

The monitoring results were assessed against the lowland river trigger levels for aquatic ecosystems in south-east Australia from the ANZECC (2000) water quality guidelines. If the concentration of a particular water quality parameter exceeds the trigger level or falls outside of the acceptable range, the guidelines are written with the intention that further investigation of the ecosystem is 'triggered' to establish whether the concentrations are causing ecological harm. Systems may vary in their sensitivity to various parameters and therefore exceeding a trigger level is not an absolute indicator of ecological harm. It is quite common for water quality parameters to briefly fall outside of guideline values during large overbank flows. The ANZECC water quality guidelines do not provide trigger levels for total organic carbon and dissolved organic carbon, and this reflects the expectation that there will be large variation in the 'normal' concentrations of organic carbon between ecosystems and also in the chemical and biological reactivity of the mixture of organic compounds making up the DOC and TOC at a particular site. Given the variable make-up of organic carbon, and the possible range of ecological responses to this mixture, a trigger level for this parameter would not be appropriate. However, trigger levels are provided for a number of nutrients and these are discussed below.

A.4 Results

Water Quality at routine monitoring zones

Dissolved Organic Carbon

Dissolved organic carbon concentrations responded to both the small pulse in August and the large flood even that occurred late-September through to December 2016. Samples collected from the weir in August have slightly elevated DOC compared to both the canal and the DOC concentrations measured at the same site during the multi-site watering in 2015 (Figure A2). There is then a slight drop in early September, consistent with the fall in the hydrograph. This is also seen in Zone 1 and 2 but the effect is not observed in Zone 3 and 4, most likely due to the timing of the sampling relative to the time taken for the pulse to transit through the system. The large flood peak that follows inundated extensive areas of floodplain (including forested areas, cropping and grazing land and urban areas) and introduced considerable quantities of DOC into the river system, resulting in concentrations well above those measured during the algal bloom in Feb-May 2016 but comparable to those observed during the 2010-11 blackwater event that occurred following the millennium drought (Watts et al. 2017a) and the majority of samples during the March 2012 event (A DOC concentration exceeding 30 mg/L was recorded in the Yallakool during that event) (Watts et al. 2013). A small peak in the canal indicates either input of DOC from sources upstream of Yarrawonga weir, or flood interactions between the water in the river system and water in the canal. In the river system, DOC rose rapidly with the increasing hydrograph and peak concentrations were measured by early October. While the flood peak occurred later, the further inundation of new floodplain appears to have sustained the DOC concentrations for a longer period rather than further increasing them. Concentrations are generally higher at sampling sites further downstream as the water continued to collect DOC as it moved through the floodplain. However, it is important to note that from a water quality perspective, in an event such as this, 4 weekly samples are very widely spaced and it is possible to miss peaks that may have moved through the system between sampling dates. Other work with different sampling frequency in this system recorded DOC in zone 4 in excess of 15 mg/L during the flood period and over 20 mg/L further downstream (Watts et al. 2017b). DOC exceeding 20 mg/L is also reported for the additional monitoring in Thule Creek (see irrigation escapes section, below), which will contribute to DOC concentrations in the Wakool downstream of

Zone 4. DOC was back into the normal range at all but the most downstream sites by 21/11/2016 although the hydrograph was still falling at this point and the DOC continued to slowly decrease through the remainder of the sampling period and remained within the range expected for the period of the autumn recession flows.

Temperature

Water temperatures have been found to be consistent across all sites for a number of monitoring seasons. In the large flood event of 2016 a number of data loggers could not be accessed for routine maintenance and the data record over this period is incomplete. Figure A3 provides water temperature records for the Edward River at Deniliquin and this is expected to be representative of all sites. During flood events water temperature is a critical parameter, as many processes affecting water quality such as rates of microbial respiration, chemical reactions (DOC leaching etc.) are temperature dependent (Howitt et al*.* 2007). Water temperatures were rising due to seasonal effects throughout the flood period, although a number of sharp increases of 2-3 degrees over a couple of days occurred during critical periods such as early October when the DOC concentrations had already reached their peak.

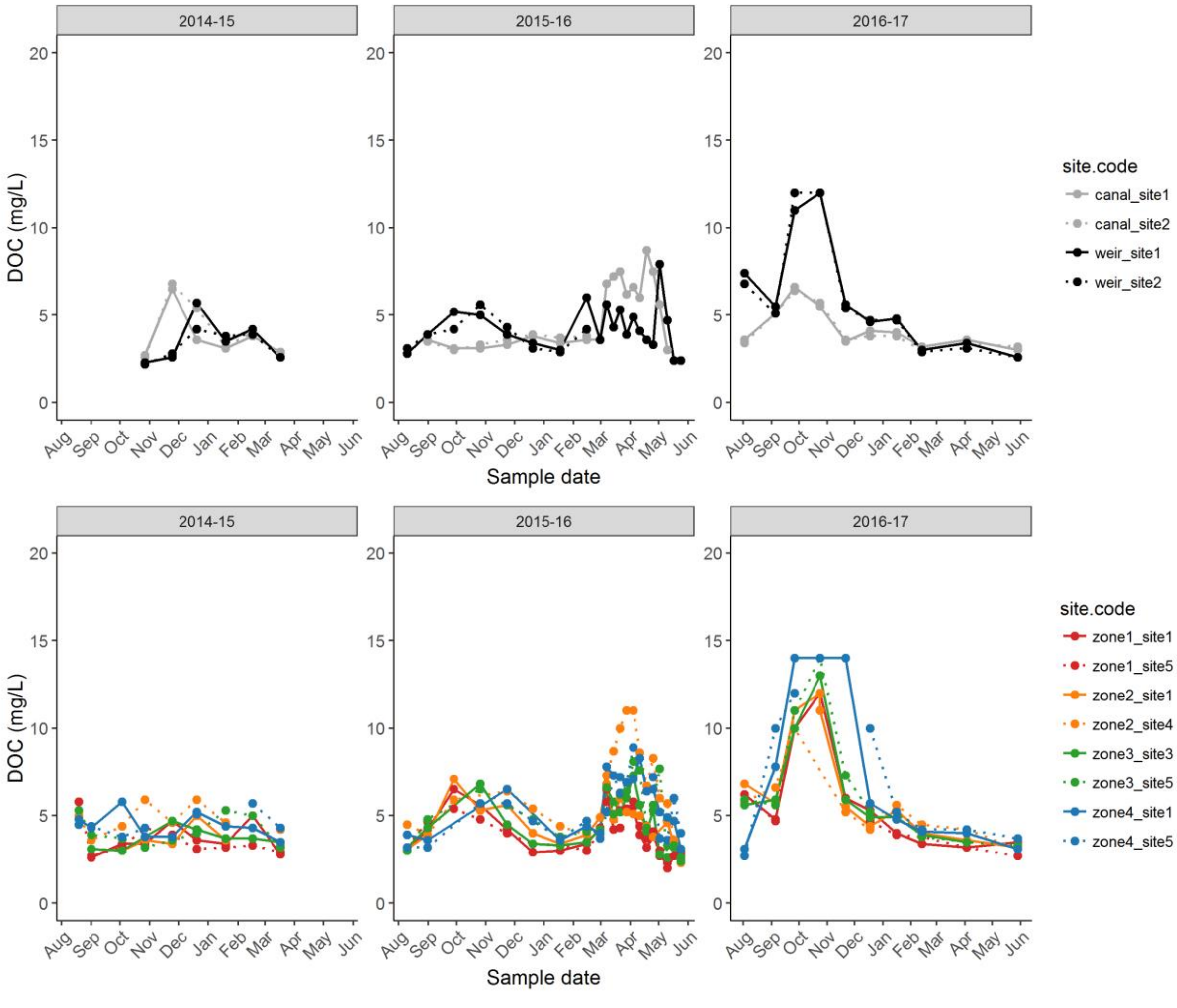

Figure A2 Dissolved organic carbon at source and LTIM sites in 2014-15, 2015-16 and 2016-17.

Dissolved Oxygen

Dissolved oxygen concentrations in both the Edward River at Deniliquin and the Wakool River at Gee Gee Bridge show a small dip in dissolved oxygen during August following the small unregulated flow at that time (Figure A 3 b, c). This is consistent with the small increase in DOC following wetting of low-lying floodplain and stimulation of productivity within the system. As this first flow occurred during cool water temperatures, even DOC as high as 10 mg/L at Gee Gee Bridge (Watts et al. 2017b) did not result in DO falling to concentrations of concern (below 4 mg/L). However, further increases in DOC with the onset of the large flood peak, combined with rising water temperatures resulted in rapid decreases in dissolved oxygen concentrations through late September to reach the threshold of concern for fish (4 mg/L) at the beginning of October, and then rapid descent into hypoxia in the first week of October. Reports of Murray Crayfish leaving the water began to be received from the 19/10/16 and the first reports of dead fish within 2 days after that (consistent with previous patterns of observations). With elevated DOC throughout the system by October, the rapid decline in DO at both ends of the study system over the same period suggest that increasing water temperatures were an important factor in this decline, rather than a pulse of already hypoxic water pushing through from upstream. However, the recovery of dissolved oxygen occurs more rapidly at the upstream site than the downstream site and is dependent on improved water quality coming in to the system from upstream and moving through, combined with the impact of further DOC inputs from the floodplain at downstream sites. The lack of dissolved oxygen loggers in the Murray River upstream of Barmah forest prevents assessment of contributions of the floodplain further upstream to the hypoxic conditions (and indirectly the DOC loads) in this report.

Figure A4 presents DO concentrations and the saturated concentration of DO at the LTIM sites, although the dataset is incomplete during the flood event due to access issues at some sites. The pattern in DO decline and recovery is consistent between both plots, indicating that the influence of temperature is not primarily one of changing oxygen solubility, but rather one of the influences changing rates of oxygen consumption in the system. Zone 1 Site 1 appears to have experienced a much shorter period of hypoxia than the other sites (including the Edward River upstream), and further consideration needs to be given to what was different at this site. It is possible patterns of water flow allowed for a higher rate of reaeration at this site once the initial pulse of highly available DOC had passed through, although this is not reflected in the next logger further downstream. The rapid recovery of DO through November corresponds with both the decline in water levels (no new areas being inundated to add further DOC) and a sharp increase in the concentrations of chlorophyll-a, suggesting an increase in photosynthesis also contributed to recovering DO concentrations.

During the autumn recession flow period all sites maintained acceptable water quality. Zone 2 has the lowest DO concentrations over this period, consistent with observations in previous years. The flow in zone 2 was very low over this period and the Commonwealth environmental water released as part of Watering Actions 5 and 6 may have supported the maintenance of acceptable DO over this period, especially in Zone 2 where flow would otherwise have been extremely low.

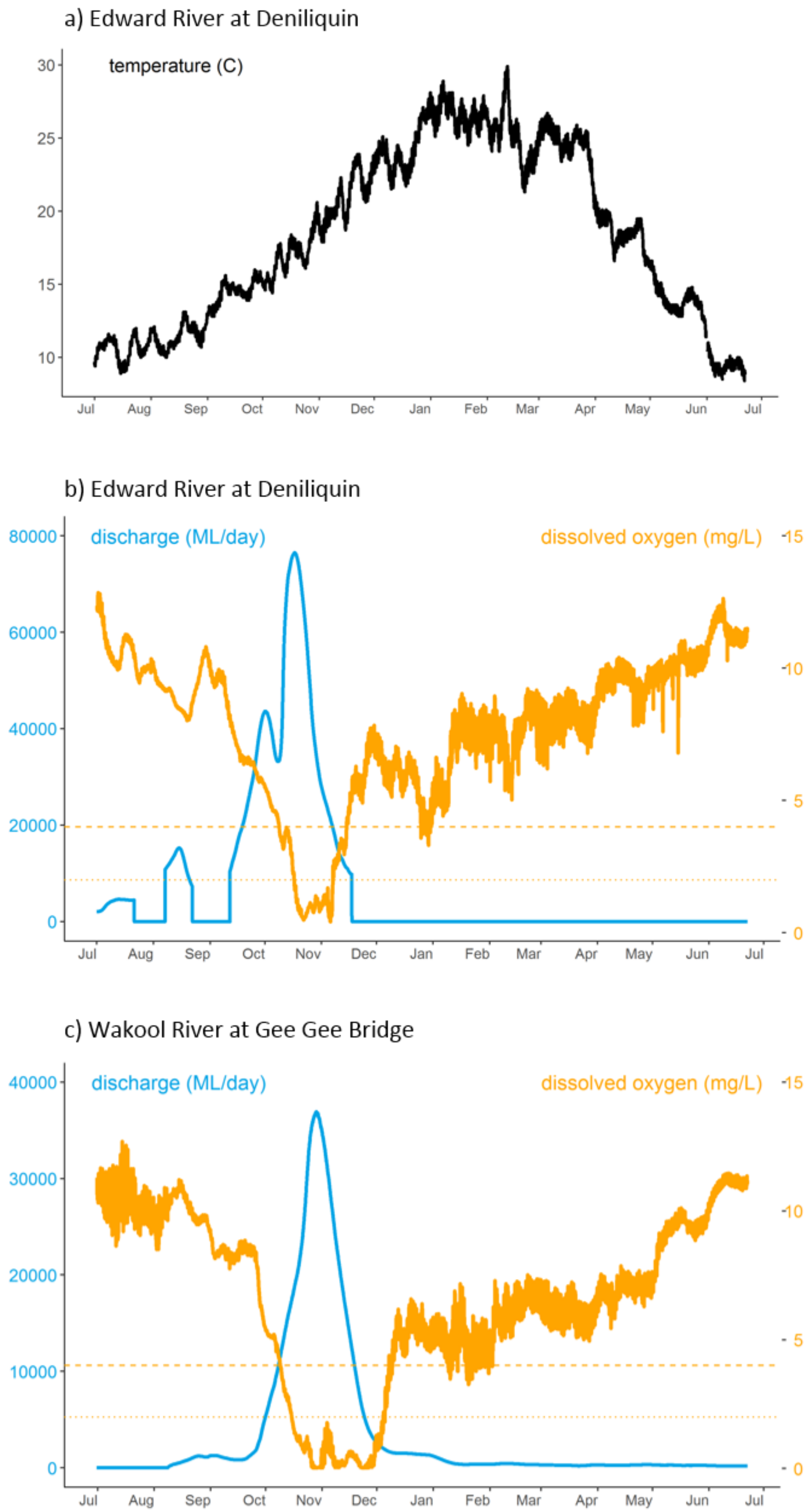

Figure A3 Temperature (a), dissolved oxygen and discharge for the Edward River at Deniliquin (b) and Wakool River at Gee Gee Bridge (c). Data: NSW DPI, Waterinfo.gov.au.

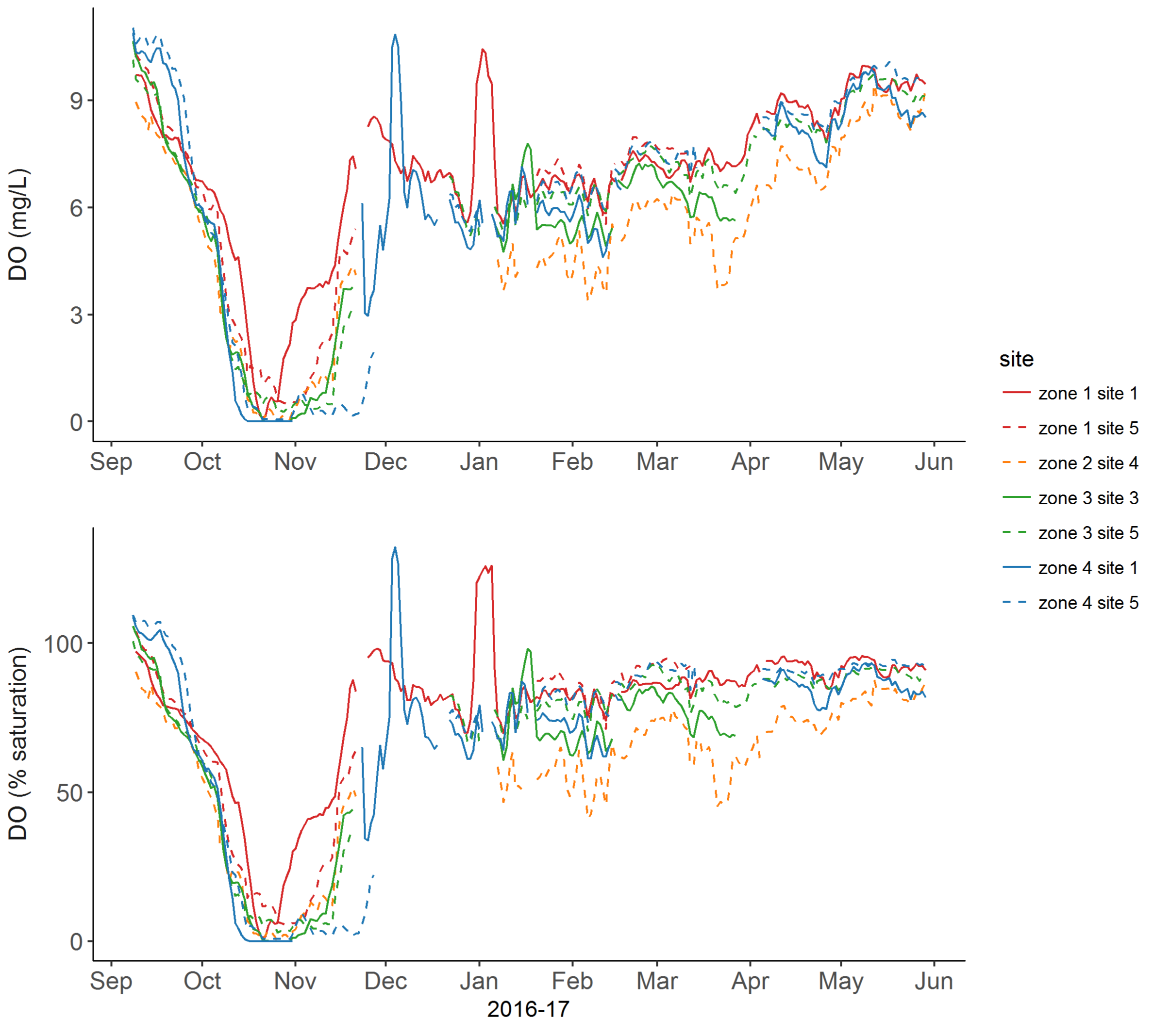

Figure A4 Dissolved oxygen (DO) concentration and % saturation at LTIM study sites.

Basic water quality parameters

The electrical conductivity of the water at all sites was unaffected by the flood event, remaining low and consistent with previous years (Figure A5). As has previously been observed, at low flows later in the season the electrical conductivity in zone 2 increases slightly, most likely an indication of groundwater intrusion. The last data point represents elevated EC during a period with no flow in Zone 2, although this value is still well below the trigger value for this parameter.

The hypoxic blackwater event resulted in a decrease in turbidity at all study sites, compared to normal patterns for that time of the year (Figure A5). This is consistent with previous blackwater events- the water becomes strongly coloured but clarity improves as the high DOC concentrations appear to encourage particles to settle out of the water column. The high concentrations of DOC also explain the decrease in pH observed during this period- DOC commonly contains organic acids. High rates of respiration will also decrease the pH of the system as dissolved carbon dioxide is also acidic.

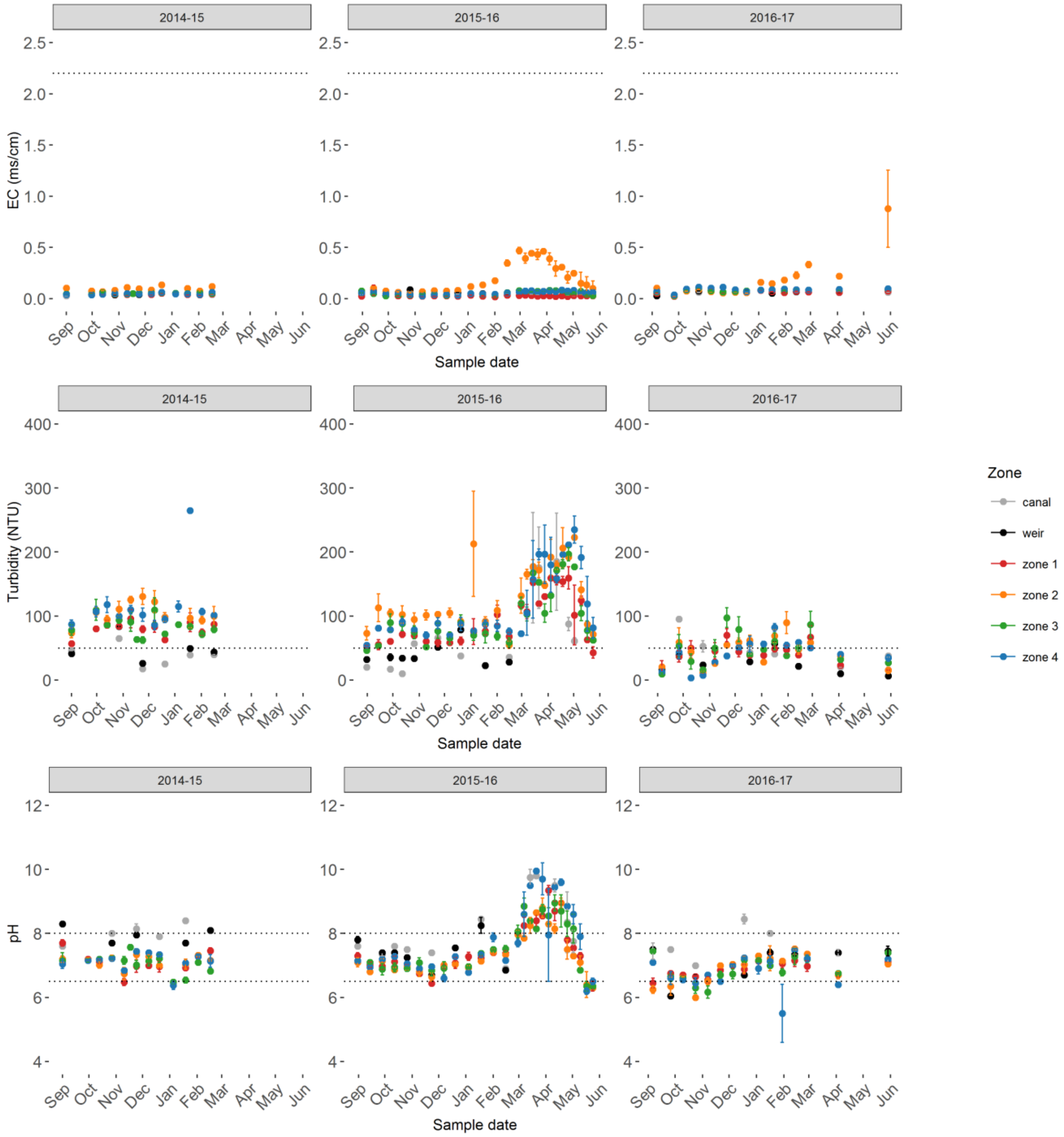

Figure A5 Electrical conductivity, turbidity and pH for LTIM sites and source water over the 2014-15, 2015-16 and 2016-17 sampling seasons.

Nutrients

The flood event was responsible for considerable transfer of nutrients from the floodplain to the river system. Figure A6 shows the nitrogen concentrations across the three LTIM study seasons. The flood resulted in a considerable increase in total N above the baseline concentrations, but not as high as was observed during the cyanobacteria bloom earlier in 2016. Nitrate and nitrite (NO_x) concentrations show a double peak- an initial increase associated with highly soluble material washing off the floodplain on first wetting, and then a later peak as the flood recedes and the water drains back off the floodplain. Note that considerably higher nutrient concentrations are recorded for Thule Creek (see Irrigation Escapes Section) late in the flood event, indicating introduction of nutrients from the floodplain as the water drains back into the river. Even higher concentrations of NO_X (up to 0.08 mg/L) were recorded for zones 3 and 4 in other work at both the beginning and end of the flood period (Watts et al. 2017b). Nitrogen concentrations rapidly return to the normal range following the flood and throughout the autumn recession flows at all study sites.

Elevated ammonia concentrations are also shown in Figure A6 for zone 1 and zone 4 with concentrations up to 0.1 mg/L, again considerably lower than those recorded for Thule Creek (see Irrigation Escapes section-Figure A13) of up to 0.75 mg/L. Other work in this area has reported concentrations up to 0.4 mg/L in Zones 3 and 4 during the flood recession (Watts et al. 2017b). Values up to 0.4 mg/L were reported during bloom collapse in the system in early 2016 (Watts et al. 2016). Microbial production of ammonia during the degradation of organic nitrogen compounds is expected with prolonged periods of hypoxia (especially in anoxic sediments) and this forms a particularly bioavailable input of nitrogen at the end of the flood recession.

Phosphorus concentrations are shown in Figure A7 for the three LTIM study seasons, and it is evident that the flood event corresponds to the largest input of phosphorus into the system over the study period, especially the bioavailable form FRP, which is normally at extremely low concentrations in this system. Comparable FRP concentrations have been seen during overbank flows such as during the 2012 blackwater event (Watts et al. 2013) and the 2010 blackwater event (Howitt, unpublished data). Peak TP concentrations are consistent with, but slightly lower than those reported elsewhere (0.4 mg/L) (Watts et al. 2017b) while FRP concentrations reported here are consistent with or slightly higher than that work. Note the different timing of the peaks of P and N, with bioavailable N most evident at the beginning and end of the flood event, and bioavailable P peaking during the flood event. This may indicate a shift from a P limited system to a N limited system during the hypoxic blackwater event. Bioavailable P returned to the normal low range immediately following the flood recession, however total P declined more gradually through autumn.

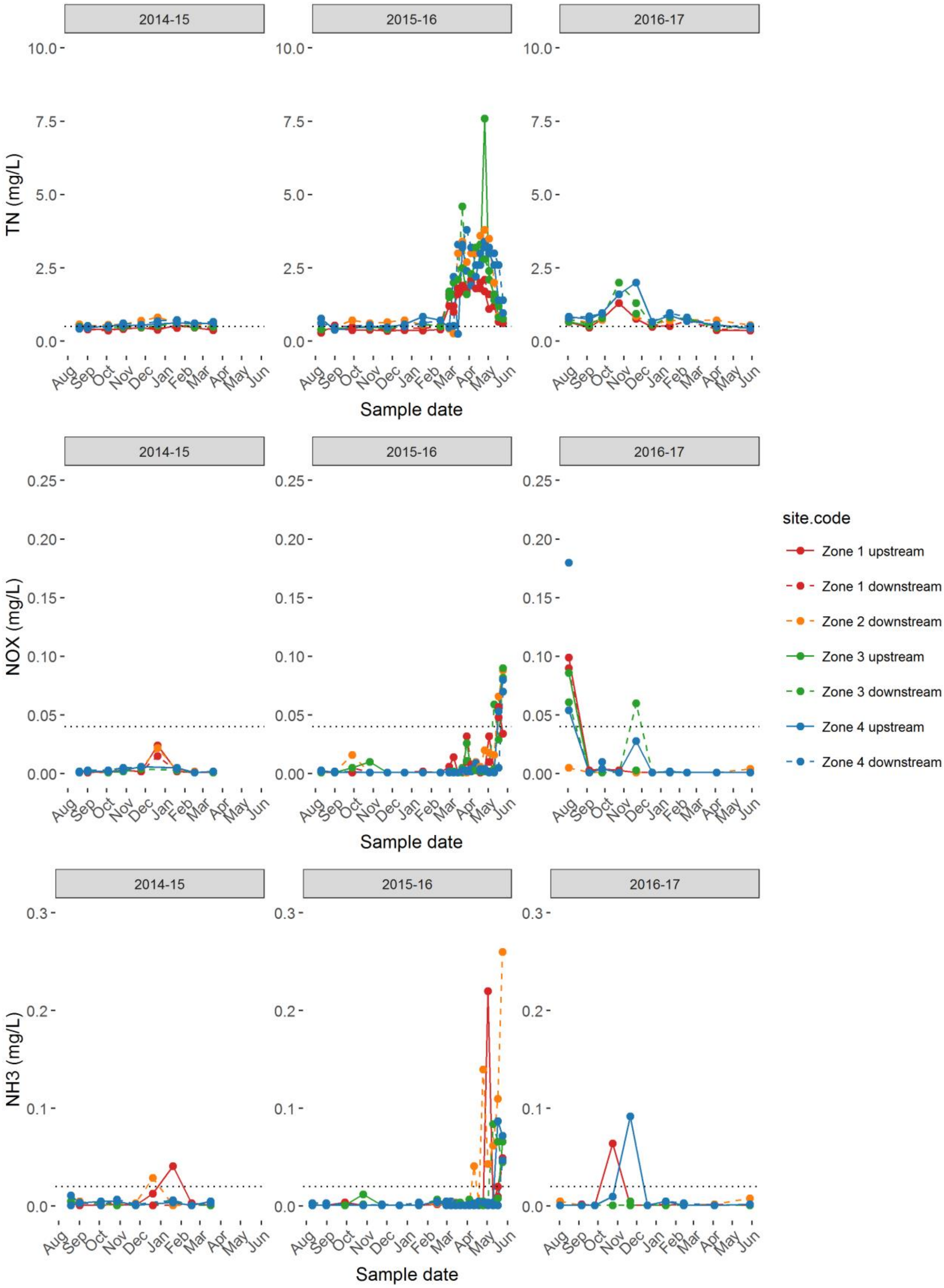

Figure A6 Nitrogen concentrations at LTIM sites for the 2014-15, 2015-16 and 2016-17 study periods.

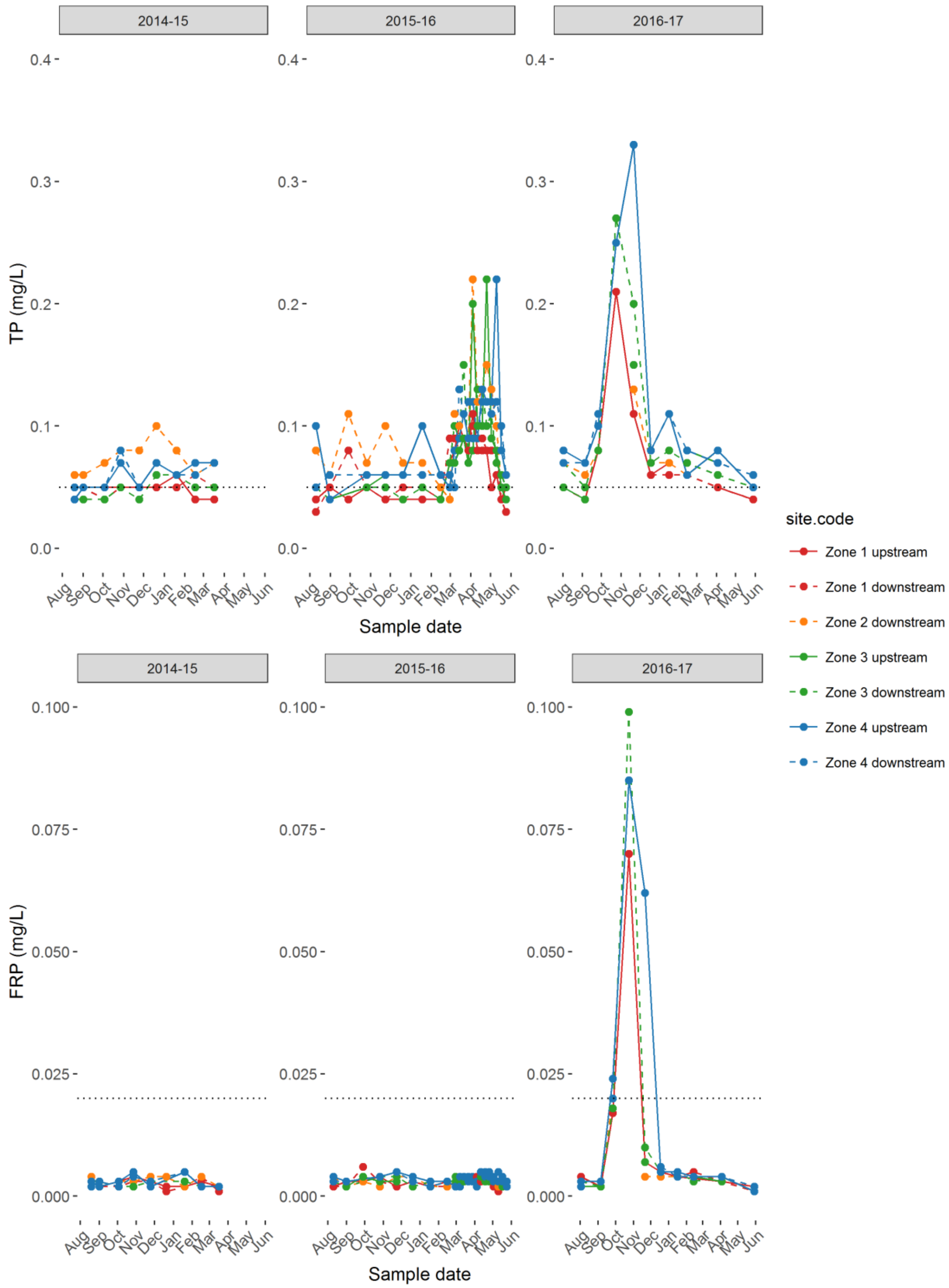

Figure A7 Phosphorus concentrations for the LTIM sites in the 2014-15, 2015-16 and 2016-17 study seasons.

Carbon Characterisation

Uv-visible absorbance scans of filtered water samples clearly show the changes in the DOC of the river and canal sites over the season with flood impacted samples (August-December) shown in Figure A8 and then more normal profiles (Figure A9) for the samples collected January-May, incorporating the period of the autumn recession flows. The samples collected in early August capture a pulse of carbon moving through the system. The Weir and Zone 1 sites have the strongest effects, followed by zone 3, suggesting the pulse is pushing through Yallakool Creek faster than the Wakool River in zone 2. The canal and zone 4 are very similar to each other and reflect the low DOC commonly found in the system in the absence of overbank flows. The different scan profiles for the upstream and downstream sites in zone 4 suggest the input of an additional source of carbon to the downstream site. As this difference is only apparent at short wavelengths, it is likely to be smaller sized organic molecules (possibly algal in origin).

As is seen in the subsequent sampling dates, the input of floodplain carbon tends to also involve increases at longer wavelength and may be indicative of larger, more complex organic substances. The samples collected in early September show the Zone 4 sites separating from the other water sites and each other. At this point in the season these sites were receiving additional inflows through the Koondrook-Perricoota Forest via Thule Creek and the differences may be due to both the tail end of the first pulse of DOC moving through the Wakool River and new DOC entering via this creek system.

The upstream sites are very similar to each other, including the canal, suggesting a very similar organic matter profile across these parts of the system (and inputs from further upstream than Yarrawonga Weir to cause the increase in the absorbance in the canal). Absorbance in the canal steadily decreases through to November and the separation of this site from the others indicates that DOC continues to enter the river system downstream of Yarrawonga during the flood period, as expected with the extensive floodplain inundation. Samples in late September, during the steeply rising portion of the hydrograph indicate all sites are increasing in organic matter but very similar in organic matter profile with the exception of Zone 4, where additional organic matter has entered the system (likely via Thule Creek). By the end of October, around the time of the flood peak, the sites in zone 3 are also separating from the upstream sites, suggestive of additional organic matter accumulation from the adjacent floodplain. November samples clearly indicate decreases in organic matter loading on the falling hydrograph, with the exception of zone 4, where inputs from Thule Creek remain important as indicated by the large difference between the zone 3 downstream site and the zone 4 upstream site. December samples show the system slowly returning to normal profiles, with more differences between sites than usual with absorbance continuing to decrease and sites converging Jan-April (Figure A9). In May there is a localised change in organic matter in zone 2 (possibly algae) and there was no flow at this site during this time.

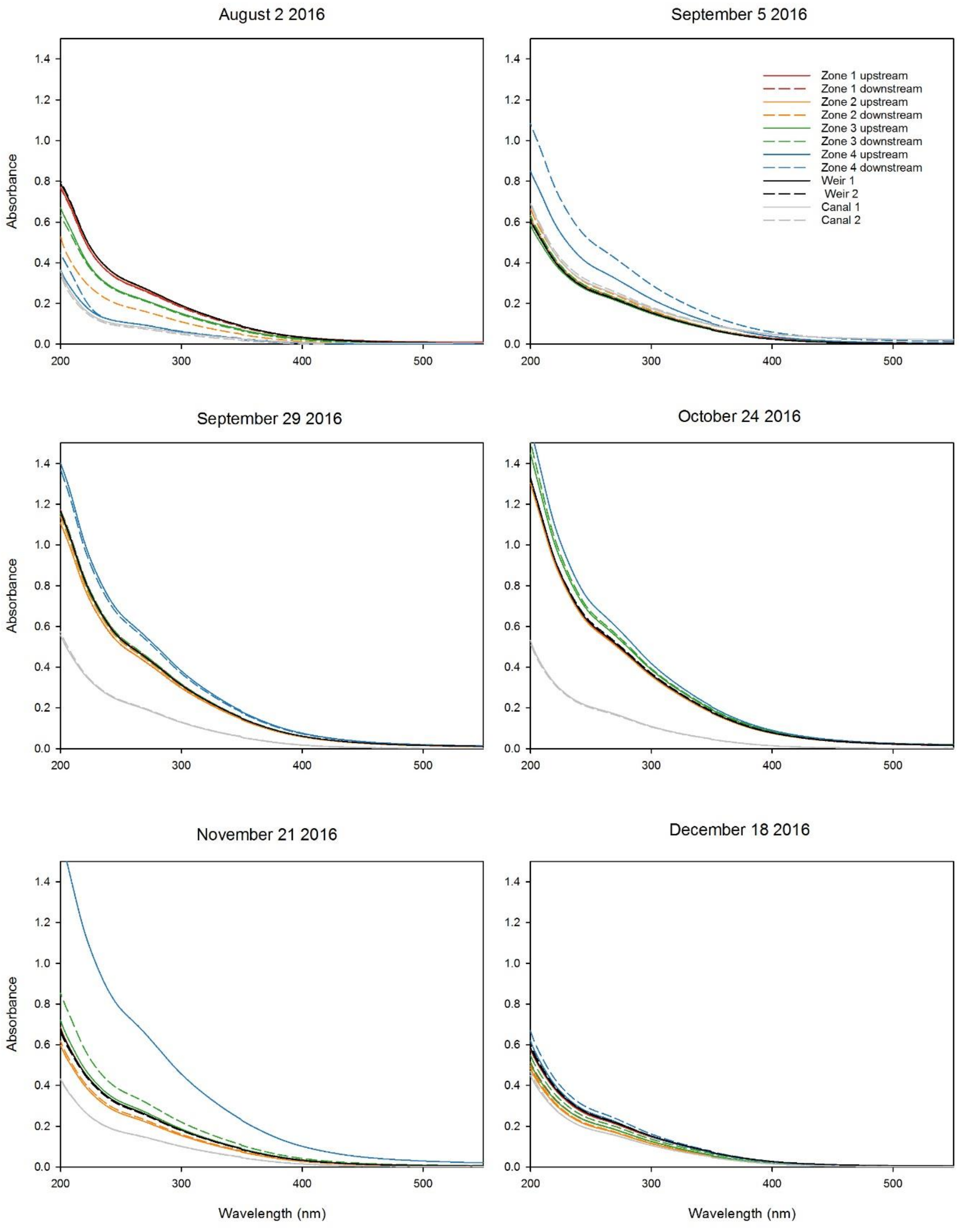

Figure A8 Absorbance scans of water samples from LTIM sites and source water during the flood period (August-December 2016).

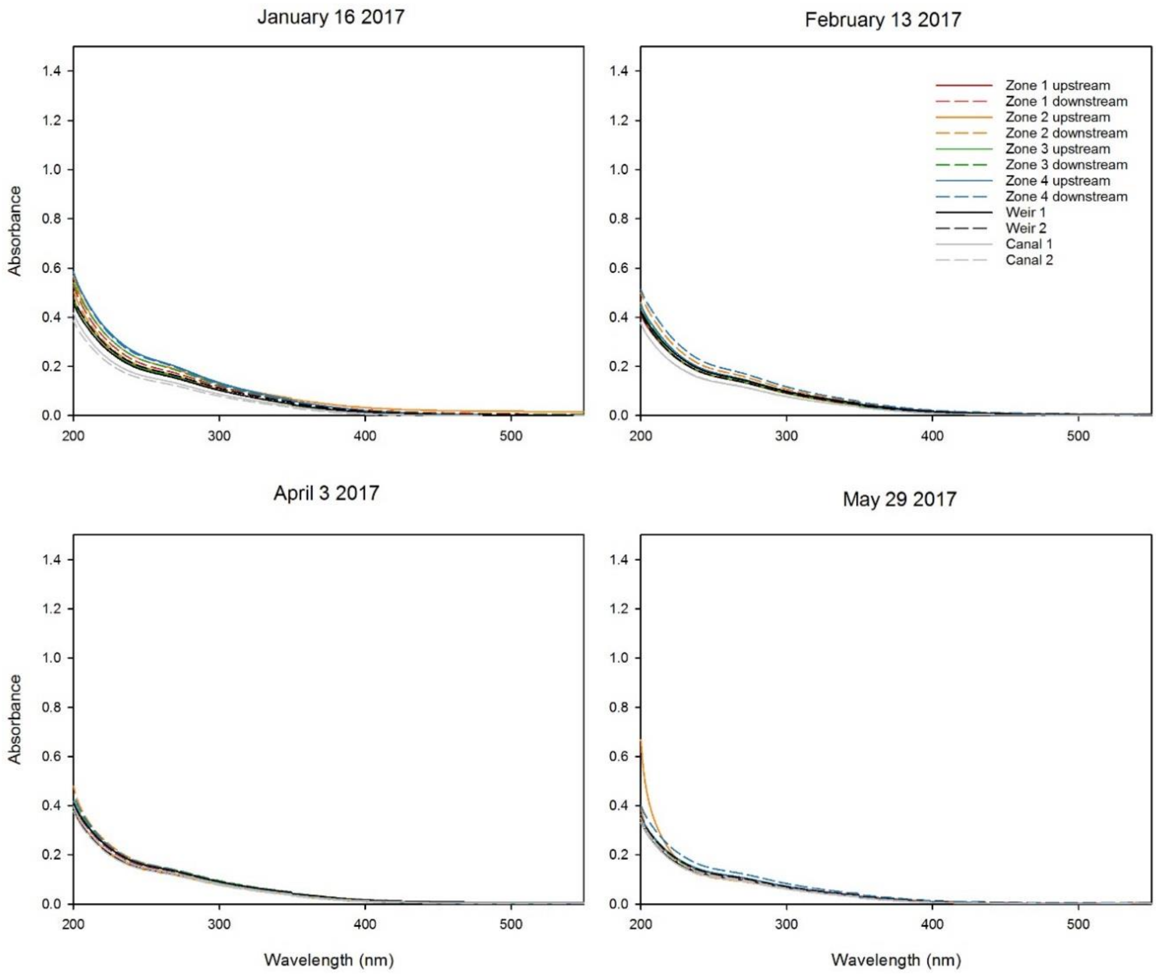

Figure A9 Absorbance scans for water samples collected at LTIM sites and sources waters January-May 2017 (post flood period).

The results of fluorescence analysis (Figures A10-A19) are consistent with the UV-vis results, although more detail regarding the fluorescent portion of the organic matter is available. In August (Figure A10) the fluorescence results suggest organic matter has a floodplain origin (fresh or possibly aged from a wetland) at all sites except the canal and zone 4. The strength of this signal is weaker at the downstream site in zone 2, supporting the suggestion of more rapid transit through the Yallakool Creek. In early September (Figure A11) all sites including the canal (to a lesser extent) show this change in organic matter character, with the stronger fluorescence at the most downstream site supporting the conclusion that a pulse with stronger fluorescence transited through the system between sampling dates and additional carbon inputs from Thule Creek may be present. During this period hypoxia was not present in the Wakool River and the organic matter was likely to stimulate productivity.

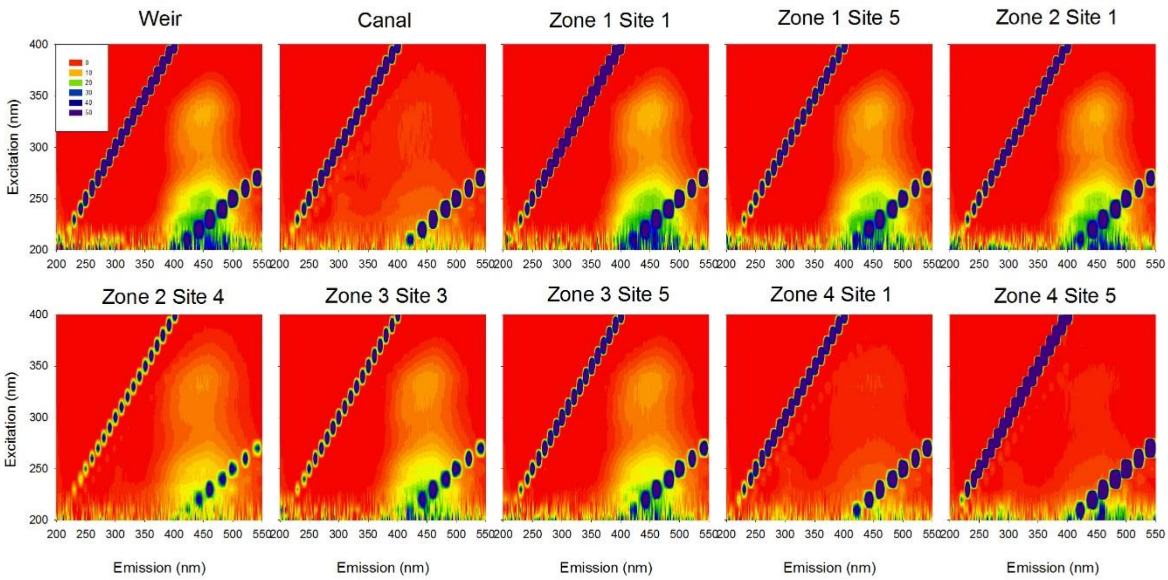

Figure A10 Fluorescence scans for water samples collected August 2nd 2016.

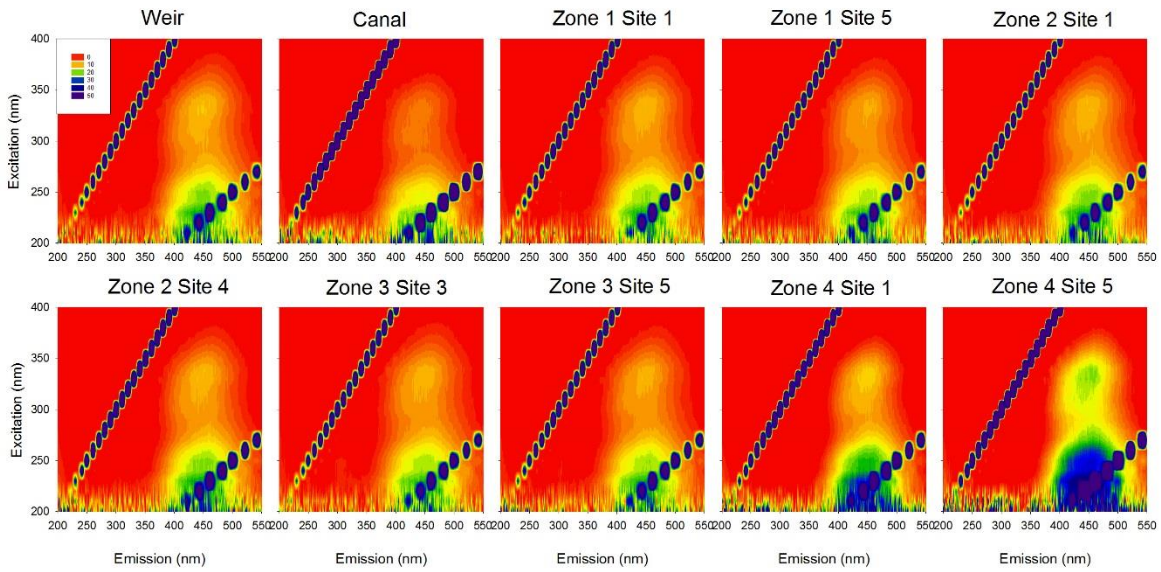

Figure A11 Fluorescence scans for water samples collected 5 September 2016.

Samples collected in late September show the organic matter profile through the system as the large flood event occurred (Figure A12). Consistent with the absorbance results, there is less fluorescent organic matter present in the canal and it has a much weaker humic and fulvic acid signature. The difference in intensity and shape of the peaks in zone 4 support the conclusion that Thule Creek is a source of (slightly different/fresher) organic matter into the lower part of the Wakool River, as noted in early September. Fluorescence scans in October (Figure A13) where available, suggest very consistent organic matter profiles at all rivers sites with strong humic and fulvic signals, slightly more intense below Thule Creek.

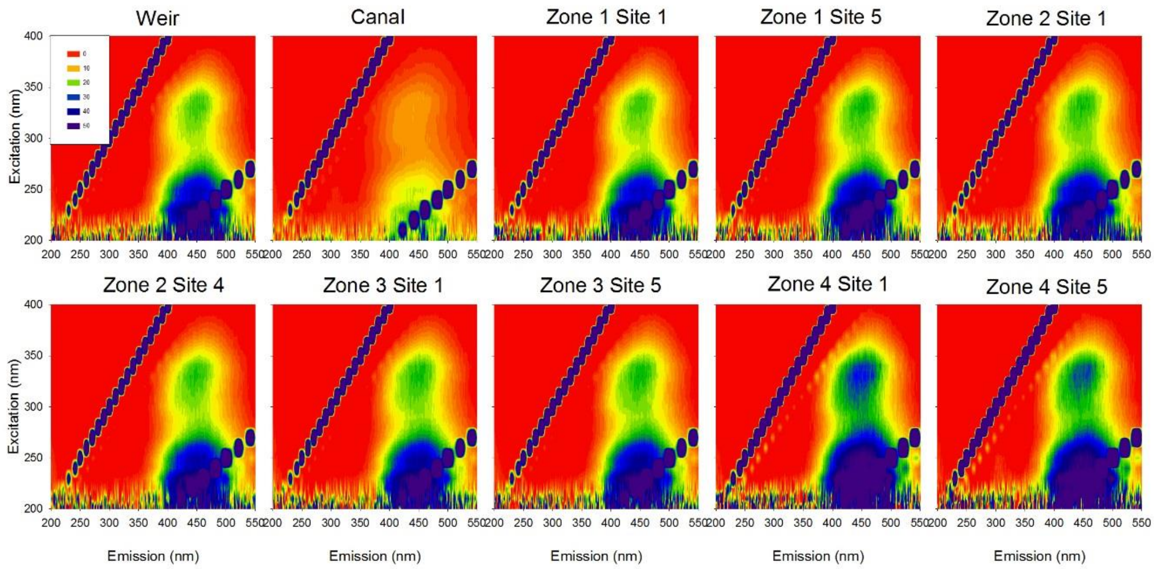

Figure A12 Fluorescence scans of water samples collected 29 September 2016.

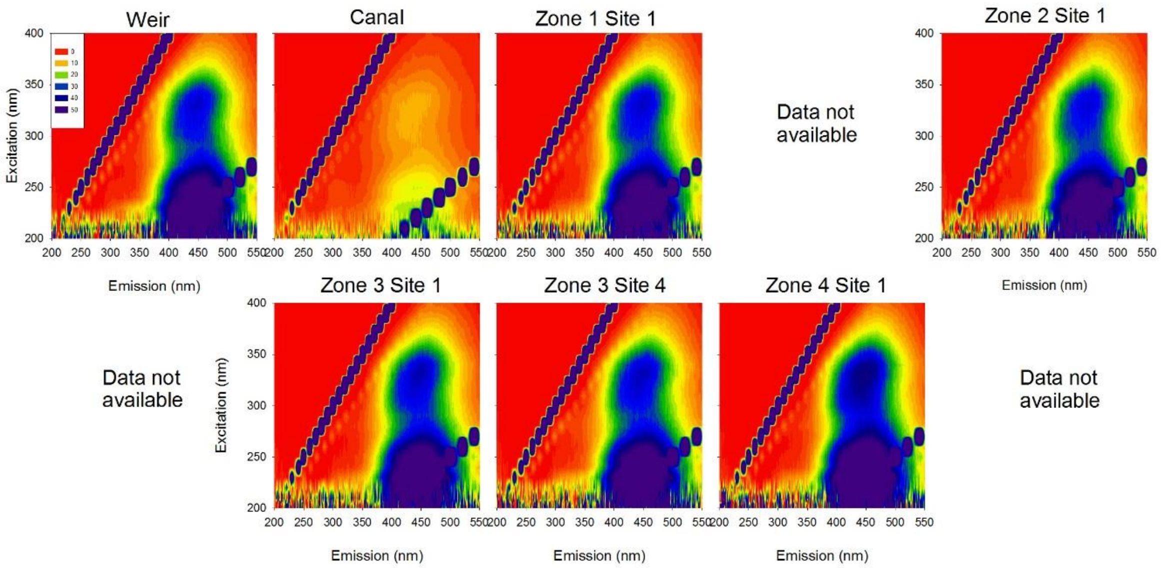

Figure A13 Fluorescence scans for samples collected 24 October 2016.

While the absorbance scans indicated clear reduction in DOC and scans converging towards a more normal profile for most sites by November, fluorescence scans (Figure A14) suggest considerable difference in DOC profiles between sites. This may reflect localised DOC sources near each of the sampling sites as floodwaters drain back into the river from different floodplain sources. The strong fluorescence in Zone 4 indicates substantial inputs of fluorescent material from Thule Creek, but may also contain instrument artefacts due to the strength of the signal. By December (Figure A15) the inter-site variability has decreased to some extent and the organic matter load has decreased. In November to January (Figure A16) a small additional peak begins to appear in the aromatic protein region, which may be an indication of photochemical changes in the organic matter, additional organic matter sources, or that the consumption of this fraction of the organic matter had begun to slow sufficiently for enough to remain in the water column and be detected. Figure A17 shows that a trend towards increased fluorescent organic matter in downstream sites is still evident, but later samples show very little difference between sites.

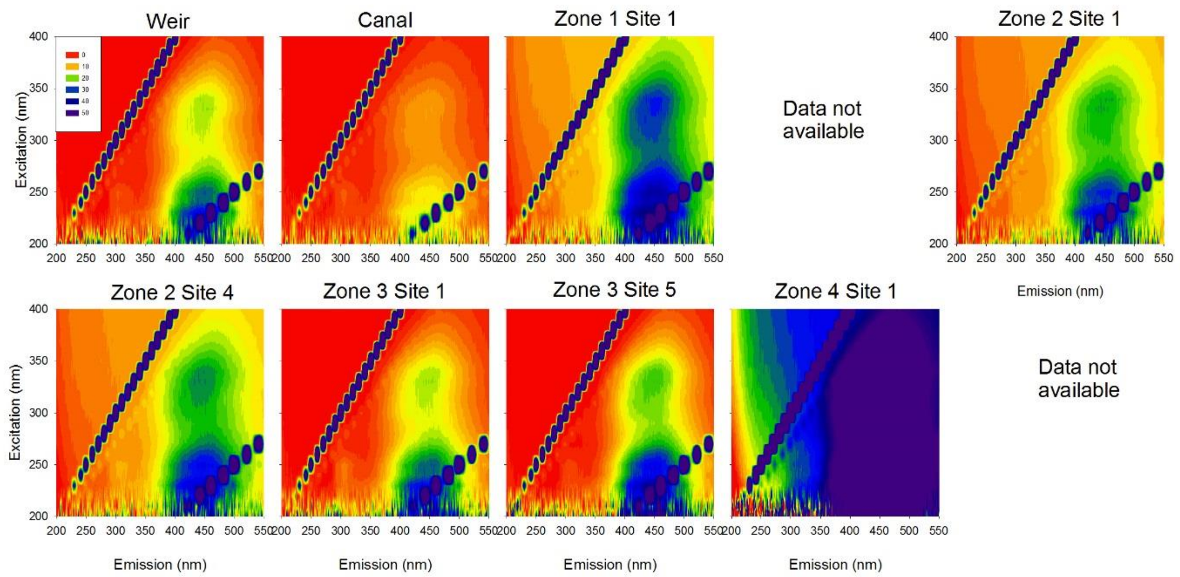

Figure A14 Fluorescence scans of samples collected on 21 November 2016.

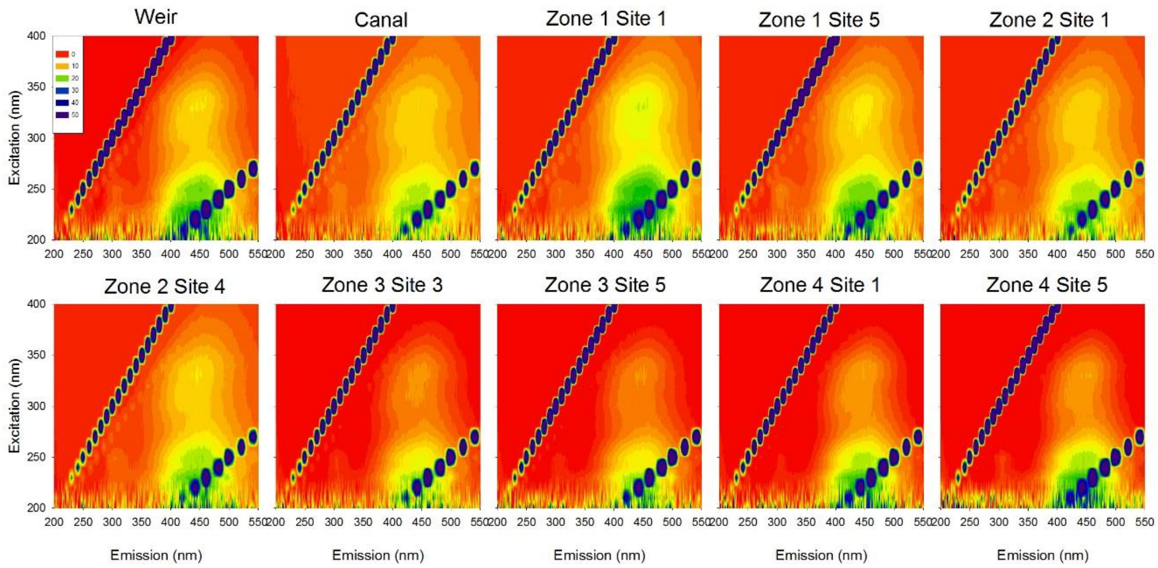

Figure A15 Fluorescence scans of water samples collected 18 December 2016.

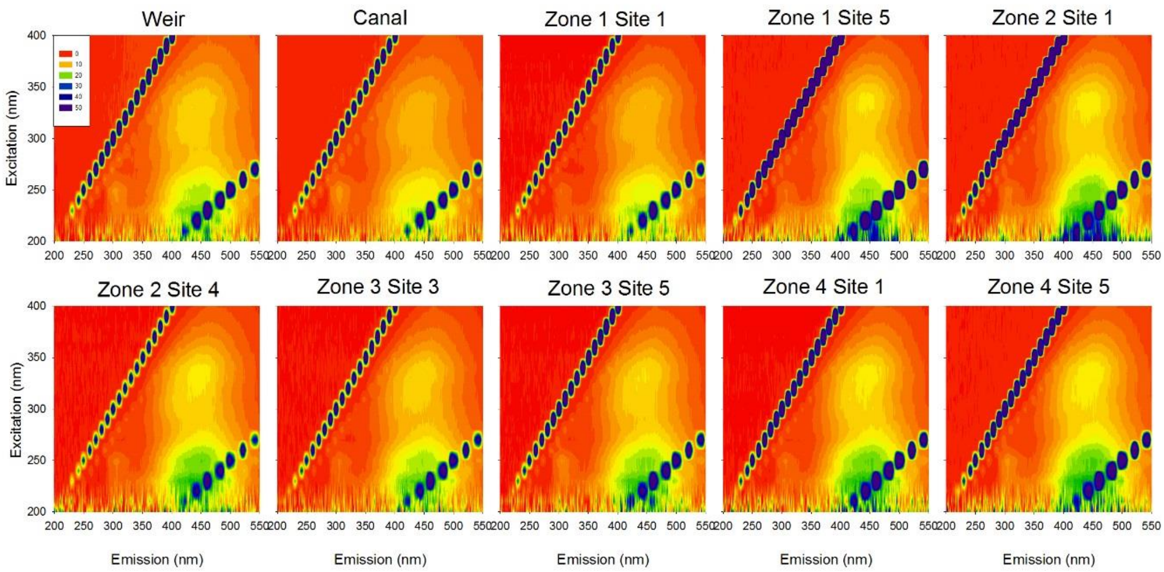

Figure A16 Fluorescence scans of water samples collected 16 January 2017.

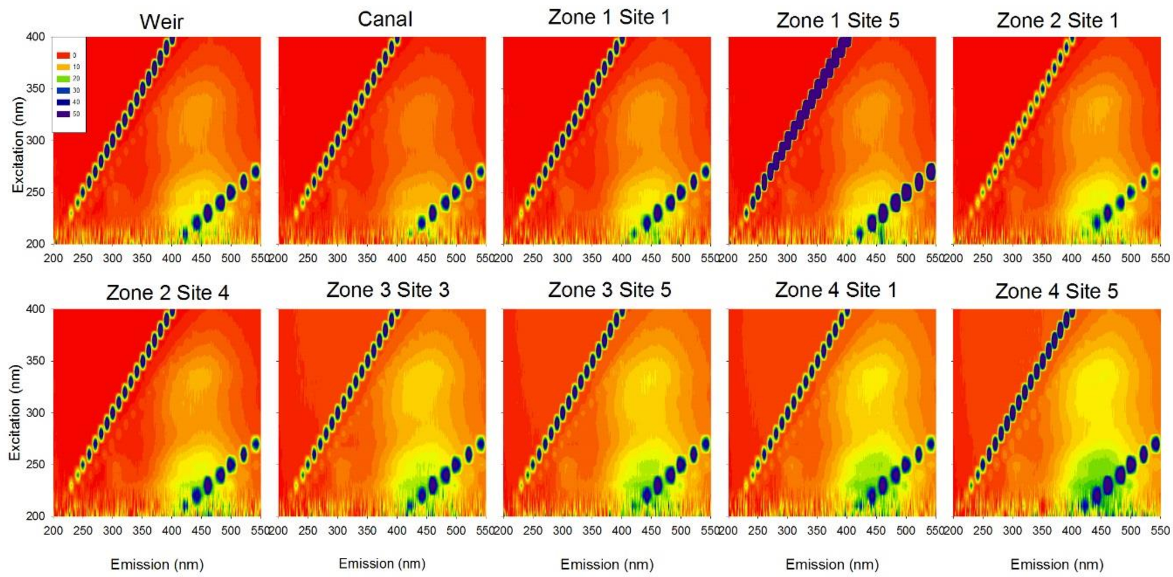

Figure A17 Fluorescence scans of samples collected 13 February 2017.

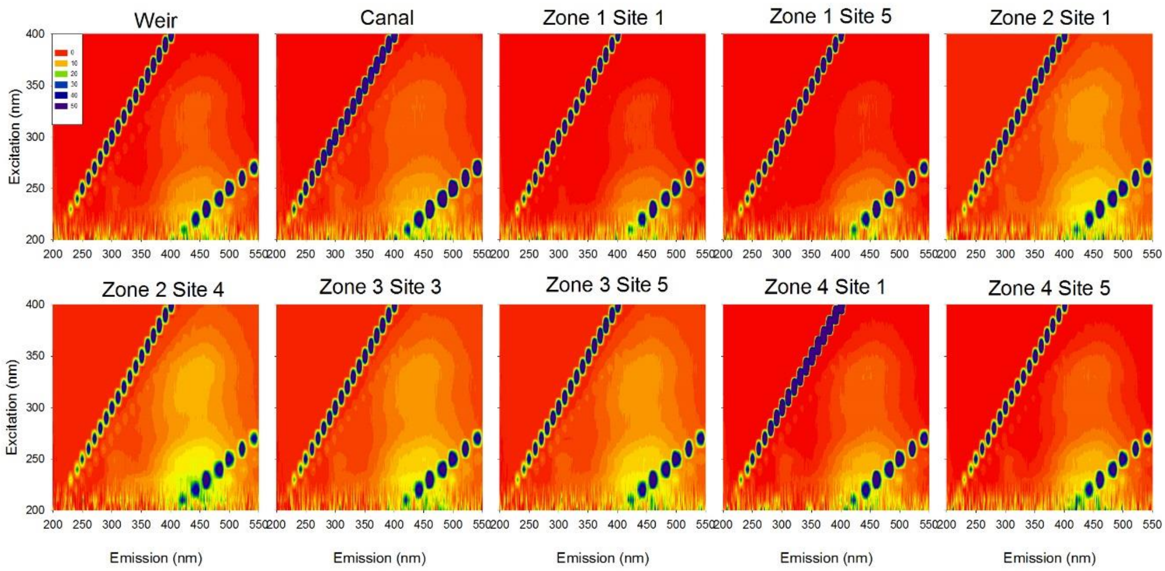

Figure A18 Fluorescence scans of samples collected 3 April 2017.

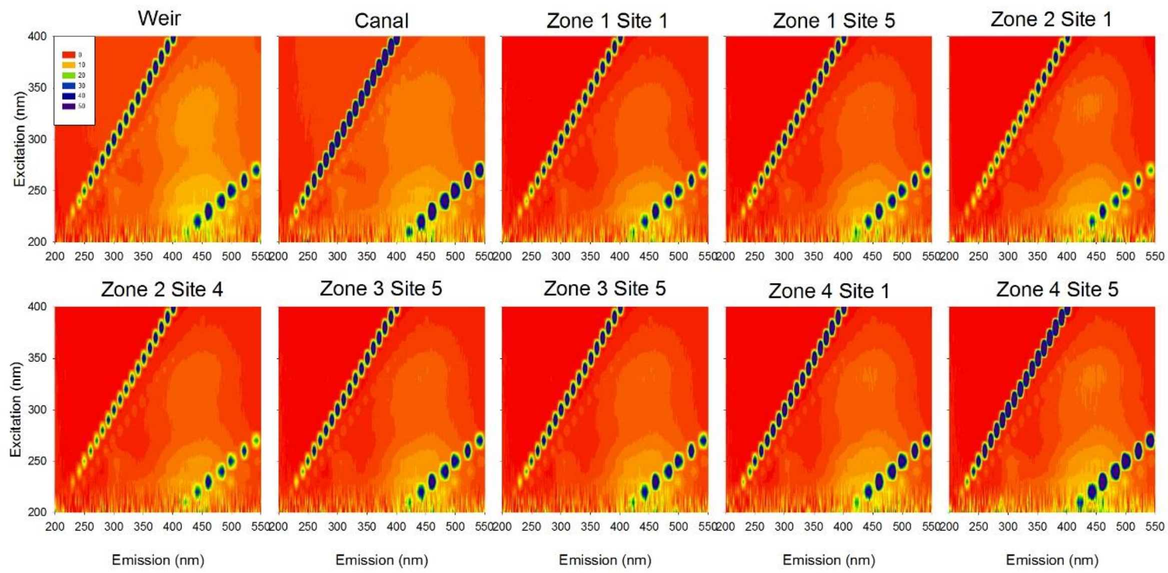

Figure A19 Fluorescence scans of samples collected 29 May 2017.

Use of Commonwealth Environmental Water via Irrigation Escapes

Preliminary modelling of environmental water releases from Murray Irrigation Limited irrigation escapes to the Edward-Wakool system to provide localised areas of refuge habitat for aquatic fauna was undertaken to assist managers make watering decisions associated with the balckwater event. The Blackwater Intervention Assessment Tool (BIAT) (Whitworth et al 2013) was used to assess the effectiveness of intervention through the delivery of Commonwealth environmental water from irrigation Murray Irrigation Limited (MIL) irrigation escapes to the Edward River, Wakool River and Thule Creek. Results of the preliminary modelling are presented in Appendix E.

In response to widespread hypoxia that developed in the system through October, Commonwealth environmental water was released from irrigation escapes to create localised refuges for fish and other aquatic species, commencing in late October. The timing and volume of the releases was managed to avoid adding additional water to the flood peak (released only when the flood was in clear recession) and to minimise impact on downstream landholders. Some sites unavoidably experienced low dissolved oxygen concentrations for several days before releases commenced.

Edward Escape

The release of Commonwealth environmental water from the Mulwala Canal into the Edward River commenced on the 26th of October, but until the 5th November the CEW comprised less than 3% of the total flow and remained below 10% until 11th November and the capacity for dilution downstream was very limited (Figure A20, A21). However, mixing of canal water with the river water does not occur immediately, so even small proportional flows have the potential to create a zone of improved water quality around the escape during this period. By the 14th November a clear improvement in DO is evident and at this point CEW makes up 14% of the total flow at the downstream sampling site. The measured DO at the downstream site is higher than would be expected by dilution alone (approx. 5 mg/L) and may also reflect improved aeration resulting from the turbulence caused at the point of release (Figure A22). The release of CEW at this site has accelerated the improvement of DO concentrations back above the 4 mg/L threshold of concern for fish. Differences between upstream and downstream data points from the 28/11/2016 onwards represent in-stream processing as CEW releases had ceased at this point. In-stream processing is also likely to be responsible for differences in ammonia concentrations between upstream and downstream samples exceeding those expected by dilution (or seen for other nutrients).

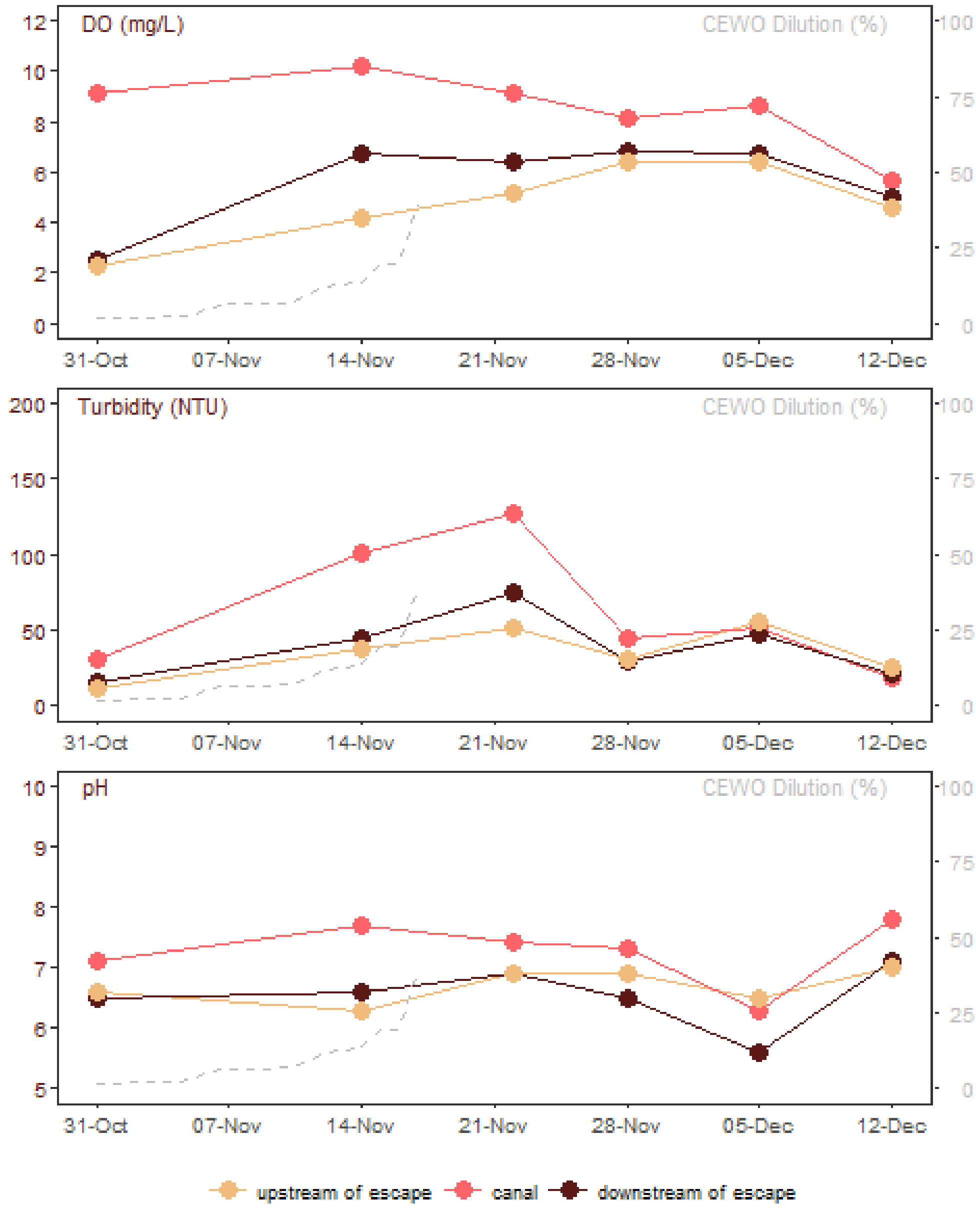

Figure A20 Dissolved oxygen, turbidity and pH upstream, and downstream of the Edward escape, showing the impact of the canal water (% dilution for the period of refuge flows shown in grey).

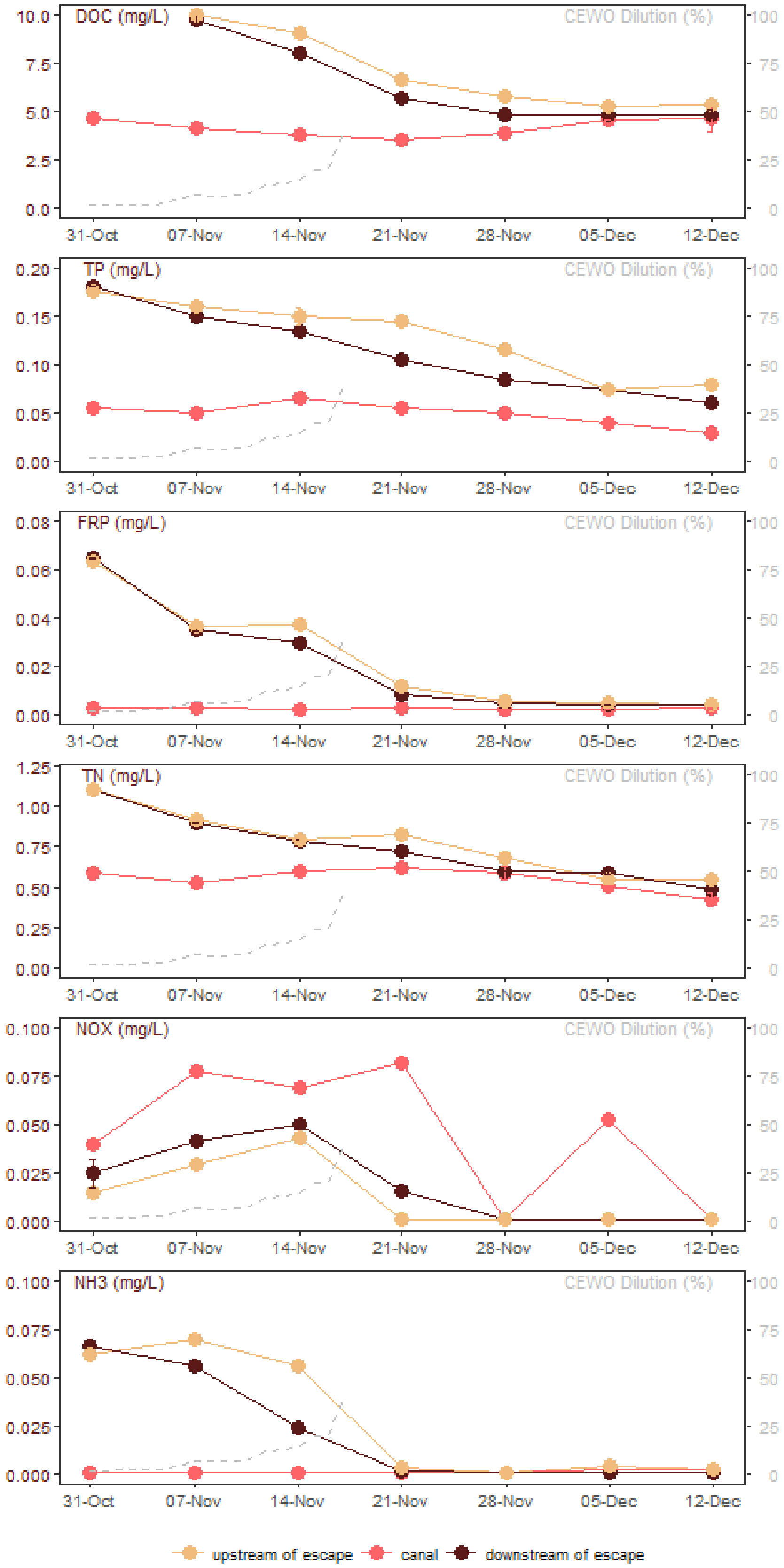

Figure A21 The impact of environmental water releases from the Mulwala canal on the DOC and nutrient concentrations of the Edward River (% dilution for the period of refuge flows shown in grey).

Figure A22 Release of CEW at the Edward escape during flows of 2400 ML/day showing both turbulence at the release point and turbidity differences between channel water (turbid) and river water (dark but clear). Photo: CEWO.

Wakool Escape

The release of Commonwealth Environmental Water from the Wakool escape commenced later than from the Edward Escape (31/10/16) and remained below 3% of the total downstream flow until 4/11/16 but then rapidly increased as a proportion of the total (due to both an increase in release and the rapidly falling upstream hydrograph) to comprise 11% of the flow by the 7/11/16 sampling date and 46% by the 14/11/16 and then to remain above 50% of the downstream flow until late December (although monitoring of the release only continued until 12/12/16). As a result of this high proportional release and the good water quality in the canal, the DO concentrations rapidly rose above the 4 mg/L threshold at the downstream site (Figure A23). Note that the oxygen demand at the downstream site will also have been reduced from the 14/11/16 onwards as a result of the higher dilutions causing measurable reductions in DOC and nutrient concentrations, accompanied by an overall decline in bioavailable nitrogen and phosphorus in the floodwaters at later sampling dates (Figure A24). In addition, the mixing at the release point creates turbulence and there is a considerable plume of unmixed water downstream of the escape which will have provided fish refuge even at the lower release volumes in early November (Figure A25).

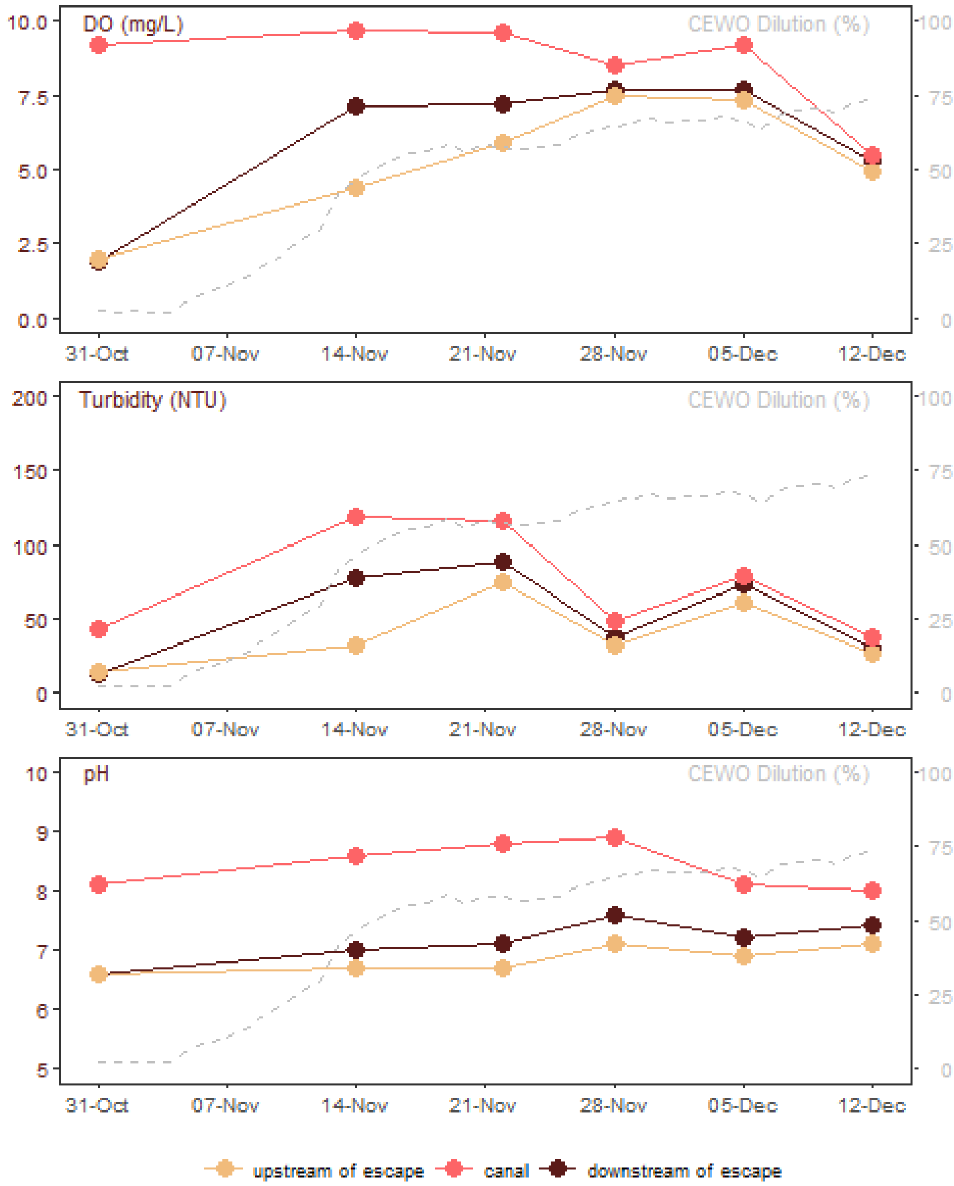

Figure A23 DO, turbidity and pH upstream and downstream of the Wakool escape, showing the effects of releasing CEW (% dilution for the period of refuge flows shown in grey).

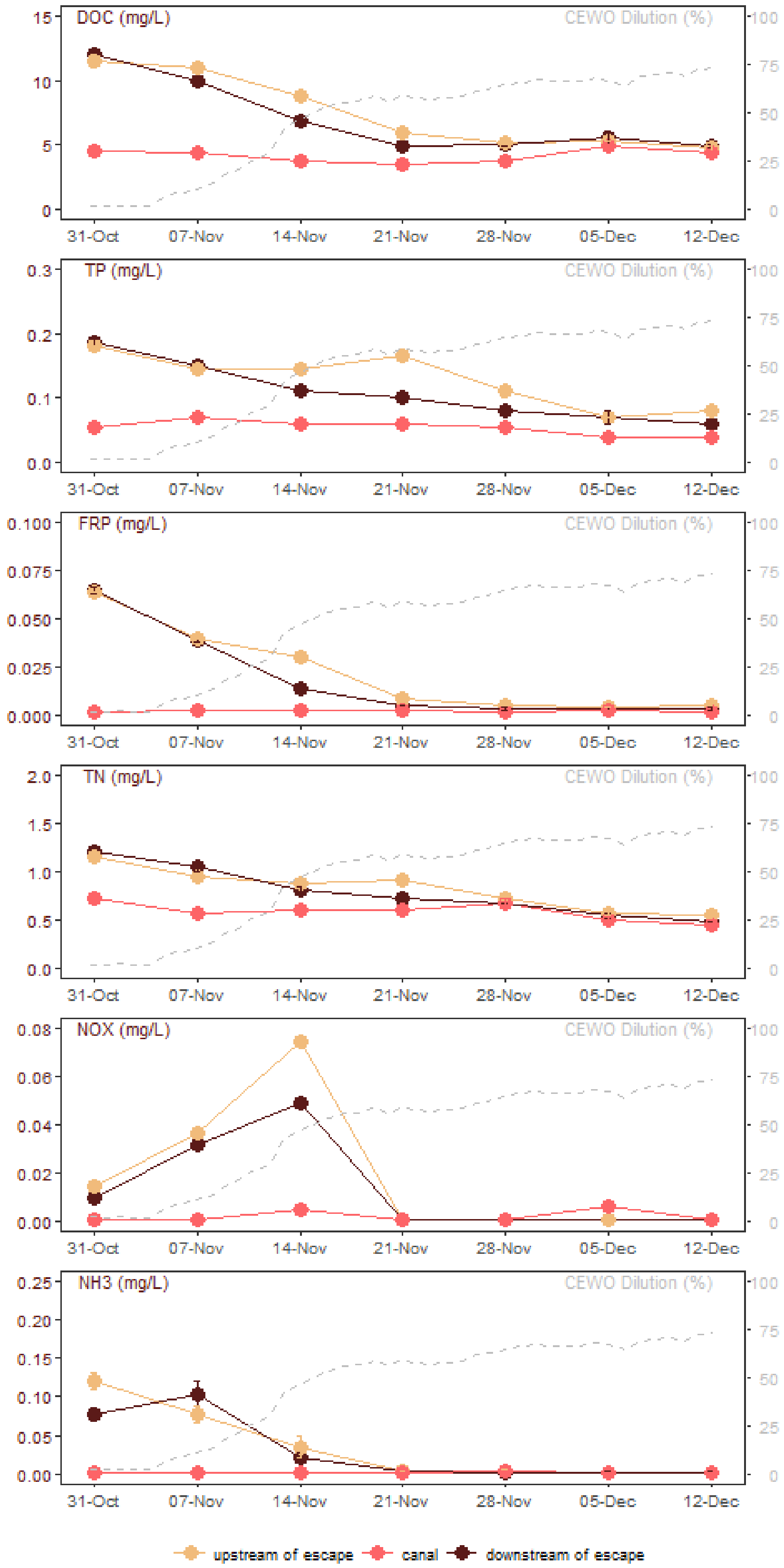

Figure A24 DOC and nutrient concentrations upstream and downstream of the Wakool escape, showing the effects of releasing CEW from the Mulwala canal (% dilution for the period of refuge flows shown in grey).

Figure A25 Images showing the release of CEW into the Wakool River at a Flow rate of 500 ML/day. Turbidity differences indicate zones of incomplete mixing where high turbidity water is expected to also have higher dissolved oxygen. Photos: Top, Damian McRae, CEWO; Bottom CEWO.

Niemur Escape

The release of Commonwealth Environmental water from the Niemur escape was much more limited at 60 ML/day, and never exceeding 7% of the overall flow. At this site the capacity for downstream dilution was very small (Figure A26, A27) however there was still potential to create a small refuge at the release site before the waters fully mixed. Releases here also occurred over a much shorter duration (18/11/16 to 14/12/16).

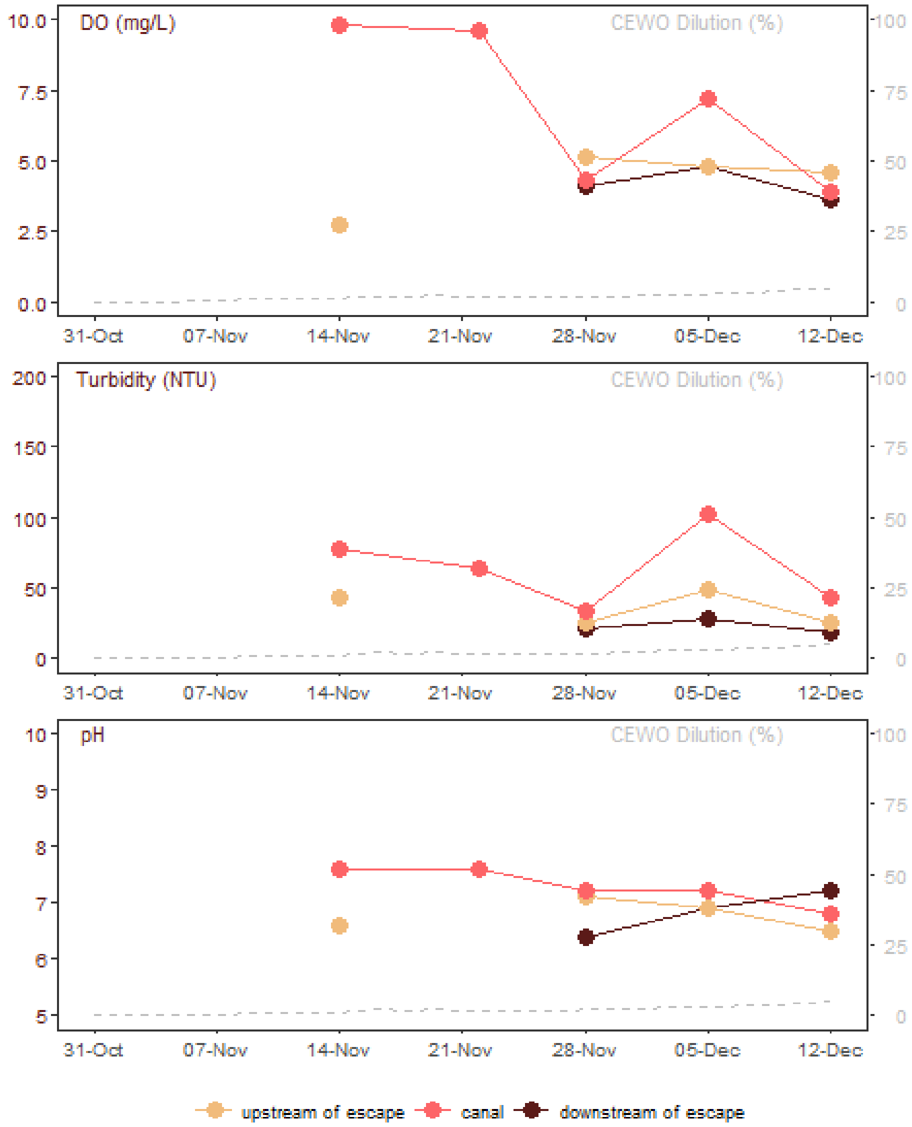

Figure A26 DO, turbidity and pH at the Niemur escape (% dilution for the period of refuge flows shown in grey).

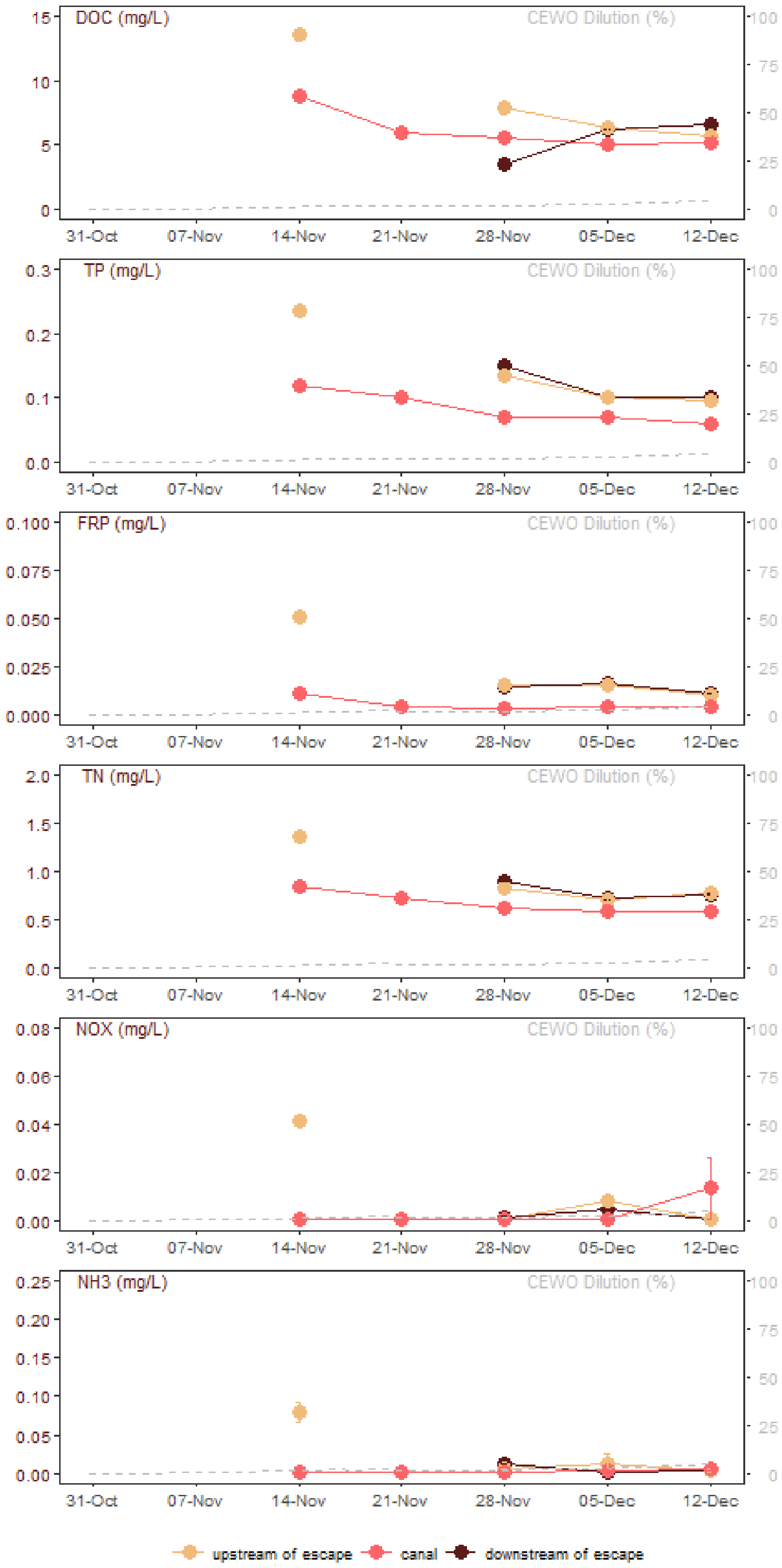

Figure A27 DOC and nutrients at the Niemur escape indicating the downstream dilution was negligible (% dilution for the period of refuge flows shown in grey).

Thule Escape

The escape at Thule Creek has a very different construction to the other sites, with water released up into the creek through a pipe, rather than being released at the surface from a channel. Releases from the Thule escape are limited to 40 ML/day and remain below 10% of the total flow until 17/11/16 after which time the decreasing flow in the creek rapidly increases the proportion of the total flow that is CEW to around 50% of the total flow. However, given this is the case the observed results (Figure A28, A29) are not what you would expect if the system was mixed at the downstream site and the rapid increase in both DO and pH at the upstream site suggest the presence of an algal bloom driving water quality at this site. DO at the downstream site is consistently lower than would be expected from the combination of canal and upstream water and suggests poor mixing at this site and ongoing consumption of DO from the water column. DOC is higher at the downstream site than would be expected from the combination of canal and upstream water and again suggests that there is either additional input of carbon before this sampling site, or that either the upstream or downstream sampling sites are not representative of the channel as a whole (e.g. sampling in an eddy, backwater or deeper hole within the channel). It is expected that the Thule Creek escape functioned primarily as a very localised refuge zone.

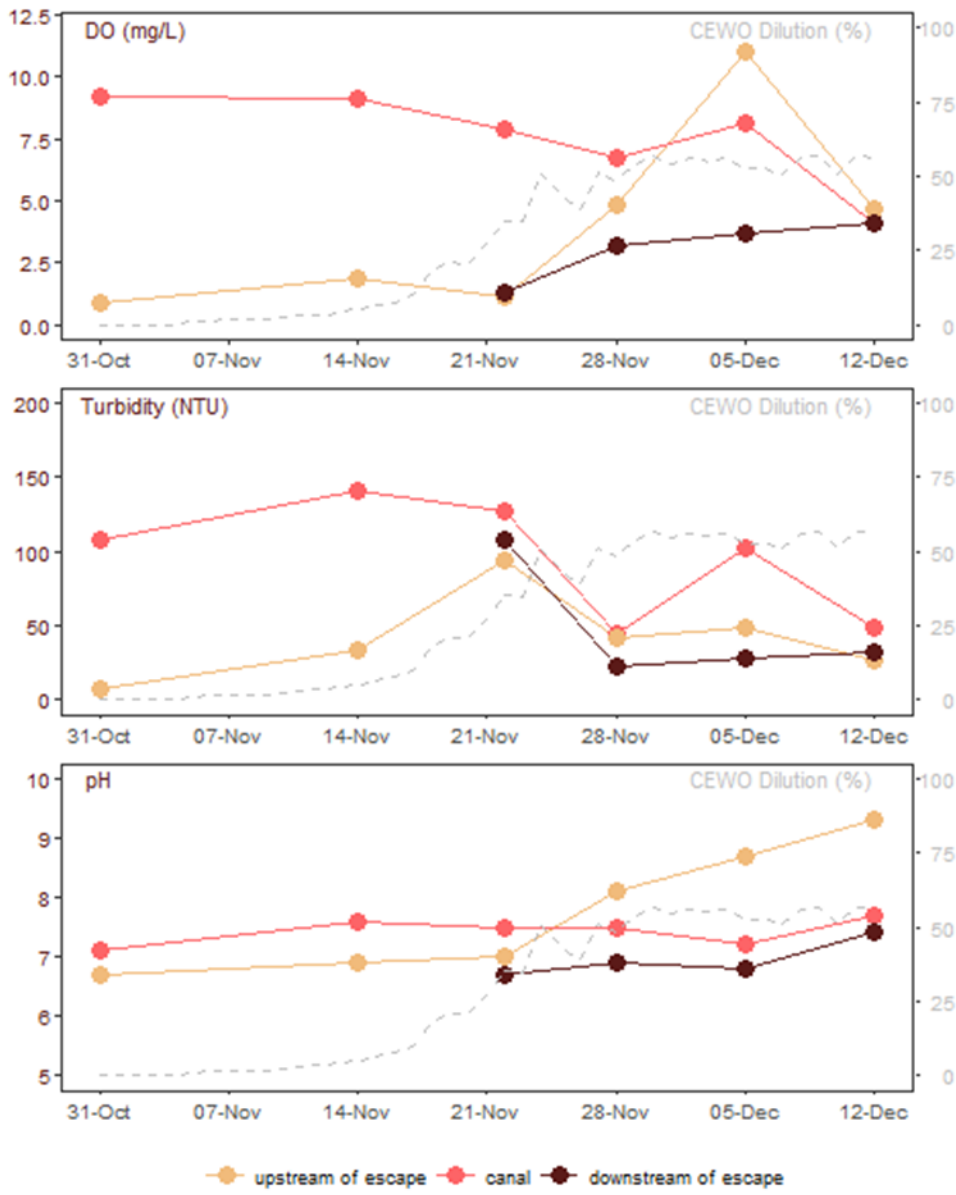

Figure A28 DO, turbidity and pH near the Thule Creek escape (% dilution for the period of refuge flows shown in grey).

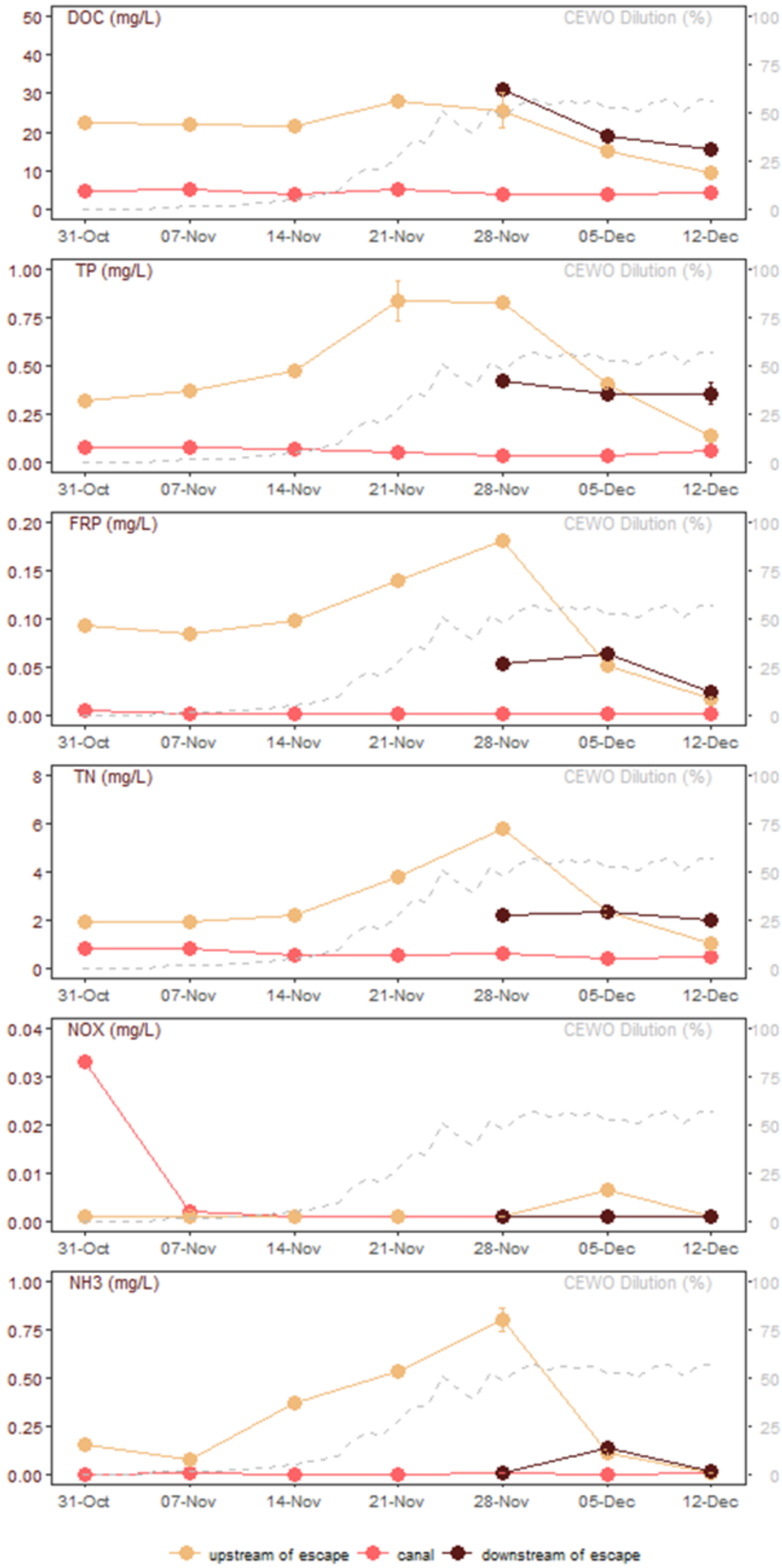

Figure A29 DOC and nutrients near the Thule Creek escape (% dilution for the period of refuge flows shown in grey).

A.5 Discussion

Flood Period

The water quality changes in the Edward-Wakool system during the 2016-17 watering year were predominantly driven by the extensive overbank flooding that occurred as a result of an extremely wet spring season- the wettest September on record for the Murray-Darling Basin following a very wet conditions from May onwards (BOM, 2017). This flooding and the hypoxic blackwater affected large areas of the southern basin, well beyond the range of the Edward-Wakool LTIM site, including in other river catchments such as the Murrumbidgee and Lachlan rivers.

Changes in water quality associated with these flows included input of large quantities of organic matter and nutrients and a decrease in turbidity and dissolved oxygen. It is noted that the smaller peak in the hydrograph during August introduced organic matter into the river system without accompanying hypoxia, however the larger peak later in the season combined warmer water temperatures with high concentrations of DOC and this caused very high rates of respiration and oxygen consumption from the water column. The long periods of hypoxia on the floodplain also resulted in considerable nitrogen cycling and release of ammonia towards the end of the flood drawdown. Organic matter characterisation showed a series of changes in organic matter mix over the course of the flooding as sources of carbon changed and material was subject to in-stream processing.

Release of CEW from Irrigation Escapes

What did Commonwealth environmental water contribute to reducing the impact of blackwater in the system?

The size and duration of the flood in 2016 limited the capacity for Commonwealth environmental water to be used to make widespread improvements in water quality and this watering action was instead focused on the creation of localised refuges for aquatic organisms around the irrigation escapes. These releases were made on the falling hydrograph to minimise impacts on downstream users and this resulted in some delay between the onset of hypoxia and the creation of the refuges. Zones of different water quality were clearly visible around the escapes and reports of fish using these sites were also received. Downstream improvements in water quality were also detected in some cases where CEW exceeded 10% of the total flow (in the Edward River and Wakool River).

What did Commonwealth environmental water contribute to dissolved oxygen concentrations?

Commonwealth environmental water contributed to increased dissolved oxygen in refuges immediately adjacent to the irrigation escape sites. In the case of the Wakool and Edward Rivers there were also downstream water quality improvements where flow exceeded 10% of the total volume and the water quality in the canal was substantially better than that in the river. The experimental design did not allow for the assessment of how far downstream this effect persisted. The effects of CEW on dissolved oxygen concentrations are believed to be a result of both dilution effects from the mixing of the waters, and additional turbulence at the point of entry allowing for additional reaeration from the atmosphere. For maximum benefit to aquatic organisms, local refuges should be created as early as possible in similar events, to allow for fish to find and congregate at these sites prior to the onset of hypoxia.

What did Commonwealth environmental water contribute to nutrient concentrations?

Commonwealth environmental water generally contributed to a decrease in nutrient concentrations, where sufficient water was added for a dilution effect to be observed. This occurred because the floodwaters had considerably elevated nutrient concentrations and the canal water was generally low in nutrients. The exception to this was at the Edward Escape, where the Mulwala canal had unusually high concentrations of NO_x on several sampling occasions and an increase was measured at the downstream site.

Recession flows and late autumn/winter watering action in Yallakool Creek.

During the autumn watering period, Commonwealth environmental water was used to slow the recession after the flooding. Water quality parameters were within the acceptable range during this time and the organic matter profile gradually shifted back to that normally seen in the study zones. Commonwealth environmental water may have supported dissolved oxygen concentrations in zone 2 where low DO is commonly observed in later summer and extremely low flows would have occurred at this site in the absence of environmental water.

Appendix B: Stream Metabolism

B.1 Background

Whole stream metabolism measures the production and consumption of dissolved oxygen gas ('DO') by the key ecological processes of photosynthesis and respiration (Odum 1956). Healthy aquatic ecosystems need both processes to generate new biomass (which becomes food for organisms higher up the food chain) and to break down plant and animal detritus to recycle nutrients to enable growth to occur. Hence metabolism assesses the energy base underpinning aquatic foodwebs. The relationships between these processes are shown in Figure B1.

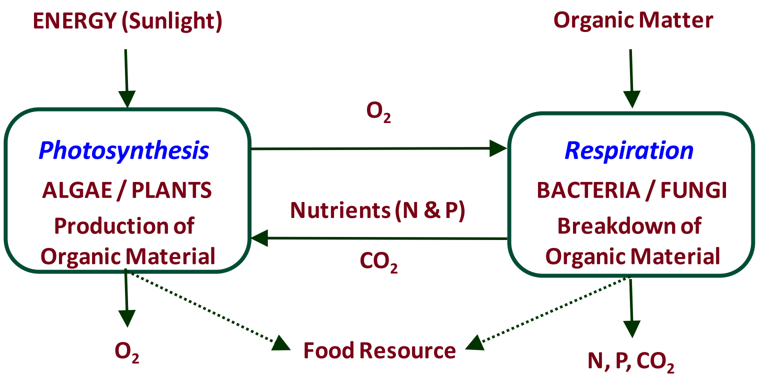

Figure B1 Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients

Metabolism is expressed as the increase (photosynthesis) or decrease (respiration) of DO concentration over a given time frame; most commonly expressed as (change in) milligrams of dissolved oxygen per litre per day (mg O_2/L/Day). Typical rates of primary production and ecosystem respiration range over two orders of magnitude, from around 0.2 to 20 mg O_2/L/Day with most measurements falling between 2–20 mg O_2/L/Day (Bernot et al. 2010; Marcarelli et al. 2011).

If process rates are too low, this will limit the amount of food resources (bacteria, algae and water plants) for consumers. This limitation will then constrain populations of larger organisms including fish and amphibians. Rates are expected to vary on a seasonal basis as warmer temperatures and more direct, and longer hours of, sunlight contribute to enhancing primary production during summer and into early autumn. Warmer temperatures and a supply of organic carbon usually result in higher rates of ecosystem respiration (Roberts et al. 2007).

In general, there is also concern when process rates are too high. Greatly elevated primary production rates usually equate to algal bloom conditions (or excessive growth of plants, including duckweed and azolla), which may block sunlight penetration, killing other submerged plants, produce algal toxins and large diel DO swings - overnight, elevated respiration rates can drive the DO to the point of anoxia (no dissolved oxygen in the water). When an algal bloom collapses, the large biomass of labile organic material is respired, often resulting in extended anoxia. Very low (or no)

DO in the water can result in fish kills and unpleasant odors. Bloom collapse often coincides with release of algal toxins; hence the water becomes unusable for stock and domestic purposes as well.

Rates of primary production will primarily depend on the characteristics of the aquatic ecosystem. Streams with naturally higher concentrations of nutrients (e.g. arising from catchment geology), especially those with very open canopies (hence a lot of sunlight access to the water) will have much higher natural rates of primary production than forested streams, where rates can be extremely low due to heavy shading and low nutrient concentrations. Habitat availability, climate and many other factors also influence food web structure and function. Uehlinger (2000) demonstrated that freshes with sufficient stream power to cause scouring can 'reset' primary production to very low rates which are then maintained until biomass of primary producers is re-established. These scouring freshes are normally found in high gradient streams and are considered unlikely to occur in lowland streams such as those in the Edward-Wakool system.

An important aspects of stream metabolism is whether the system is considered to be autotrophic or heterotrophic. In the former case, the Net Primary Production (NPP; calculated as GPP-ER) is greater than 0, and GPP:ER ratios exceed 1. Autotrophic systems (NPP>0) produce more organic matter through photosynthesis than is consumed through respiration. In contrast, heterotrophic systems consume more carbon than is captured by photosynthesis. Systems that are consistently heterotrophic can be inferred to rely on external sources of organic matter (allocthonous organic matter) to support community respiration. It is common for lowland systems to show such patterns, which is why external sources of floodplain carbon are often considered so important in helping to support lowland river foodwebs.

B.2 Selected-area questions

Evaluation of the response of stream metabolism to Commonwealth environmental watering is being undertaken in the Edward-Wakool River system at the i) Selected Area scale (Watts et al. 2014), and ii) Basin scale (Hale et al. 2014). The Basin Scale evaluation involves the integration of multiple datasets from a number of different catchments, and this will be undertaken by the Murray-Darling Freshwater Research Centre and evaluated in a separate report. The first two questions relate to the Basin Scale. The current report focusses on annual responses questions (Question 3) specific to the environmental watering actions in the Edward-Wakool system in 2016-17. These questions arise from the importance of new organic (plant) matter, created through photosynthesis, supplying essential energy to the foodweb and the critical role of respiration in breaking down organic detritus and therefore resupplying nutrients to enable such growth to occur.

Q1. What did environmental water contribute to patterns and rates of decomposition?

Q2. What did environmental water contribute to patterns and rates of primary productivity?

Q3. How does the timing and magnitude of Commonwealth environmental water delivery affect rates of gross primary productivity and ecosystem respiration in the Edward- Wakool River system?

The following hypotheses were developed, partially based on earlier previous work in the Yallakool Creek – Wakool River system (Watts et al. 2014), to directly explore these evaluation questions:

- Under extended 'cease to flow' conditions of several weeks or more, the responses of GPP and ER will greatly depend on the available nutrient supplies and the time of year. High nutrients and warm conditions may lead to very high rates associated with excessive phytoplankton growth. (Q1, Q2, Q3)
- Under normal 'base' flow, rates of GPP and ER will be constrained to the low-moderate range, typically 1-3 mg O2/L/Day. (Q3)
- With in-stream freshes, rates of GPP and ER will increase slightly to 3-5 mg O_2/L/Day. Larger increases will occur if significant backwater areas are reconnected to the main channel due to enhanced nutrient delivery. (Q3)
- Inundation and reconnection of backwater areas to the main channel during high flows will result in elevated rates of GPP and ER. (Q1, Q2, Q3)
- Primary production in the Edward-Wakool system will be limited by low phosphorus concentrations. (Q3)

B.3 Methods

The stream metabolism measurements were performed in accordance with the LTIM Standard Operating Procedure (Hale et al. 2014). After discussions at the annual LTIM forum in Sydney in July 2016, it was decided that an updated version of the BASE model (BASEv2) would be used for analysing the 2015-16 metabolism data. This change was a result of the paper published by Song et al. (2016) which showed that our BASE model could be improved by changing from stepwise progression and fitting using each data point to integrated (whole data set) fitting and progression suing modelled data.

Water temperature and dissolved oxygen were logged every ten minutes with at least one logger placed in each of the four study zones; in zones 1, 3 and 4, loggers were placed at the upstream and downstream end of these zones. Data were downloaded and loggers calibrated approximately once per month, and more frequently (often fortnightly) during summer time to avoid problems found in previous years with probe biofouling. Downloading also depended upon depending on access, as described below. Light and depth loggers were also deployed and data were downloaded on an approximately monthly basis. The data collected by the loggers was also used to calculate daily average temperature and dissolved oxygen concentrations (see Section 6) for each of the zones from mid-August 2016 to early April 2017.

Acceptance criteria for inclusion of daily results from the BASE model (Grace et al. 2015) in the data analysis presented here were established at the July 2015 LTIM Workshop and then refined at a workshop in July 2016. These criteria were that the fitted model for a day must have both an r^2 value of at least 0.90 *and* a coefficient of variation for the GPP, ER and K parameters of < 50%. With BASEv2 an additional criterion was also used which stipulated the model fit parameter PPfit must be in the range 0.1 to 0.9. Values of PPfit outside this range indicated that the 'best fit' to the data was still an implausible model. In accord with the LTIM Standard Protocol, water quality parameters (temperature (^oC), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were also measured as spot recordings fortnightly at two sites within each Zone (and one in Zone 2).

During the unregulated flows the long duration very low DO (hypoxic) and in some cases anoxic (no dissolved oxygen) conditions precluded estimation of primary production and respiration rates using the BASE model v2. This is unfortunate but metabolism models available require a positive change in % DO during daylight hours to calculate GPP. However, an estimate of ER under these hypoxic/anoxic conditions was made by assuming that ER must at least be equal to or greater than the increase in oxygen derived from reaeration. The oxygen influx from reaeration into a well-mixed water column (very likely in the main channel) was calculated by multiplying the reaeration rate (/Day) by the oxygen deficit (mg O_2/L). Approximate mean values for these parameters from late August to mid November were 2.0 /Day and 10.8 mg O_2/L at 12.5^oC respectively. The oxygen deficit is determined as the difference between 100% DO saturation at this average temperature (10.8 mg O_2/L) and the actual DO in the stream (0 mg O_2/L).

B.4 Results

Summary of data availability

Estimates of Gross Primary Production and Ecosystem Respiration for the 7 sites were produced using the BASEv2 model (updated from Grace et al. 2015 according to Song et al. 2016). Data loggers were in place from early September 2016 until late May 2017. Regular maintenance, occasional problems with some loggers and flooding meant that there were less than the maximum daily results for each site. Details of the logger deployments are given in Table B1. Two loggers, Zone 1 Site 5 and Zone 3 Site 3, had data sets truncated in March 2017 due to logger memory problems and site inaccessibility respectively. Using the acceptance criteria for each day's diel DO curve, the acceptance rate ranged from 67% of all days with data available (144 from 216) for Zone 2 Downstream, down to 14% (31 of 215) at Zone 3 Upstream. All acceptance data are shown in Table B2. A comparison is made with acceptance criteria from 2015-16.

Table B1 Summary of Logger Deployments, September 2016 - May 2017.

Hydrological Zone	Site	First Deployed	Last day Deployed	Periods of Missing Data
1 Yallakool Ck	Upstream	9/9/2016	30/5/2017	-
	Downstream	9/9/2016	11/3/2017	21/11/2016 to 20/1/2017
2 Wakool River	Downstream	9/9/2016	28/5/2017	21/11/2016 to 6/1/2017
3 Wakool River upstream Thule Creek	Upstream	8/9/2016	26/3/2017	20/11/2016 to 5/1/2017
	Downstream	8/9/2016	28/5/2017	20/11/2016 to 21/12/2016
4 Wakool River downstream Thule Ck	Upstream	8/9/2016	28/5/2017	-
	Downstream	8/9/2016	28/5/2017	27/11/2016 to 21/12/2016

Table B2 Summary of data availability for the seven data logger sites, September 2016 - May 2017.

Hydrological Zone	Site	Total Days	Days with Acceptable Data	% of Acceptable Days Year 3	% of Acceptable Days Year 2
1 Yallakool Ck	Upstream	250	105	42	59
	Downstream	122	58	48	62
2 Wakool River	Downstream	206	62	30	67
3 Wakool River upstream Thule Creek	Upstream	149	44	30	14
	Downstream	220	81	37	24
4 Wakool River downstream Thule Ck	Upstream	182	32	17	54
	Downstream	200	69	35	37

The decrease in the number of days meeting acceptance criteria is largely attributed to the extended periods of extremely low (no) dissolved oxygen from early-mid October through to mid-January December (see Table B1). The BASEv2 model relies on at least a very small increase in dissolved oxygen during the daylight period in order to determine primary production. This requirement was not met during these low DO conditions, hence the model would not resolve the metabolic parameters from the diel DO curves. Significant improvement in numbers of acceptable days was recorded for both Zone 3 sites, notwithstanding the low DO problems.

Gross Primary Productivity (GPP) and Ecosystem Respiration (ER)

Figure B displays the daily rates of GPP and ER at all 7 sites (each plot is for one zone). The gauged flow data are also included in each figure. Table B3 summarizes the daily metabolism results portrayed in Figure B2 and also includes the P/R ratio (ratio of oxygen produced by GPP to oxygen consumed by ER).

Median GPP rates for all seven sites ranged from 1.6 to 3.9 mg O_2/L/Day, and was very similar to the ranges found in 2014-15 (1.25 to 2.69 mg O_2/L/Day)(Watts et al. 2015) and in 2015-16 (1.4 to 4.1 mg O_2/L/Day)(Watts et al. 2016).

Median ER rates for all seven sites in 2016-17 ranged from 3.33 to 12.12 mg O_2/L/Day. In 2014-15 ER rates were 2.04 to 6.91 mg O_2/L/Day(Watts et al. 2015) and in 2015-16 ER rates were 2.72 to 10.59 mg O_2/L/Day (Watts et al. 2015). In 2016-17 the highest median rates occurred in zone 2 site 4.

Median P:R for all seven sites in 2016-17 ranged from 0.32 to 0.64 in 2016-17. In 2014-15 P:R ranged from 0.48 to 0.85 (Watts et al. 2015) and in 2015-16 ranged from 0.39 to 0.72 (Watts et al. 2015). In all these years median P:R were less than one, indicating that the system is heterotrophic (i.e.rely on external sources of organic matter to support community respiration).

One major change from previous years (2014-15 and 2015-16) was a large increase in many individual respiration rates and the variation in ER rates across time within each site. Many individual rates were 10 mg O_2/L/Day or significantly higher than that (Figure B2). During the unregulated flows the long duration very low DO (hypoxic) and in some cases anoxic (no dissolved oxygen) conditions precluded estimation of primary production and respiration rates using the BASE model v2. This is unfortunate but metabolism models available require a positive change in % DO during daylight hours to calculate GPP. Using the indirect method to estimate ER (as described in methods) we estimated that ER must have been at least 21 mg O_2/L/Day to maintain anoxia during the unregulated flow period.

GPP rates in 2016-17 were similar to those in 2014-15 (Watts et al. 2015) and 2015-16 (Watts et al. 2016), and are at the lower end of the 'normal' range (3-10 mg O_2/L/Day) for freshwater streams and rivers (e.g. Bernot et al. 2010; Marcarelli et al. 2011). Comparison of the median GPP and ER values with previous years (Watts et al. 2015, 2016) show that the rates in 2016-17 are typically higher in the more upstream Zones (1 & 2) and lower in the downstream Zones (3 & 4). The highest median GPP is in Zone 2 (downstream site). This zone in the Wakool River has much lower flows than the other zones, thereby enabling longer water residence times and higher rates of primary production.

Both GPP and ER varied during periods of relatively constant discharge, yet large changes in the hydrograph did not appear to engender any immediate metabolic response. As noted previously (Watts et al. 2015) an instantaneous response in GPP to discharge is not expected as time (typically weeks) is required for algal populations to increase significantly. More rapid changes in ER may occur as bacterial populations can increase over timeframes of hours to a few days to take advantage of increased concentrations of labile organic carbon.

Table B3 Summary of primary production (GPP) and ecosystem respiration (ER) rates and P/R ratios for the seven study sites, September 2016 - May 2017. 'n' is the number of days for which successful estimates of metabolic parameters were obtained. The data is separated into the four separate zones.

	Zone 1 Upstream (n = 104)			Zone 1 Downstream (n = 58)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	2.11	0.88	6.7	2.22	0.81	4.0
ER (mg O_2/L/Day)	5.18	2.38	22.3	4.01	0.99	9.4
P:R	0.40	0.14	0.95	0.57	0.23	1.2
	Zone 2 Downstream (n =62)					
	Median	Min	Max			
GPP (mg O_2/L/Day)	3.87	0.97	8.35			
ER (mg O_2/L/Day)	12.12	5.04	21.8			
P:R	0.32	0.12	0.58			
	Zone 3 Upstream (n =44)			Zone 3 Downstream (n =81)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.97	0.56	4.0	2.90	0.82	5.8
ER (mg O_2/L/Day)	4.12	0.23	13.0	4.52	1.36	10.1
P:R	0.46	0.07	3.90	0.64	0.15	0.99
	Zone 4 Upstream (n =32)			Zone 4 Downstream (n =69)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.63	0.70	5.4	1.85	0.24	4.3
ER (mg O_2/L/Day)	3.33	0.40	22.9	4.57	0.07	9.7
P:R	0.51	0.16	1.87	0.48	0.07	12.37

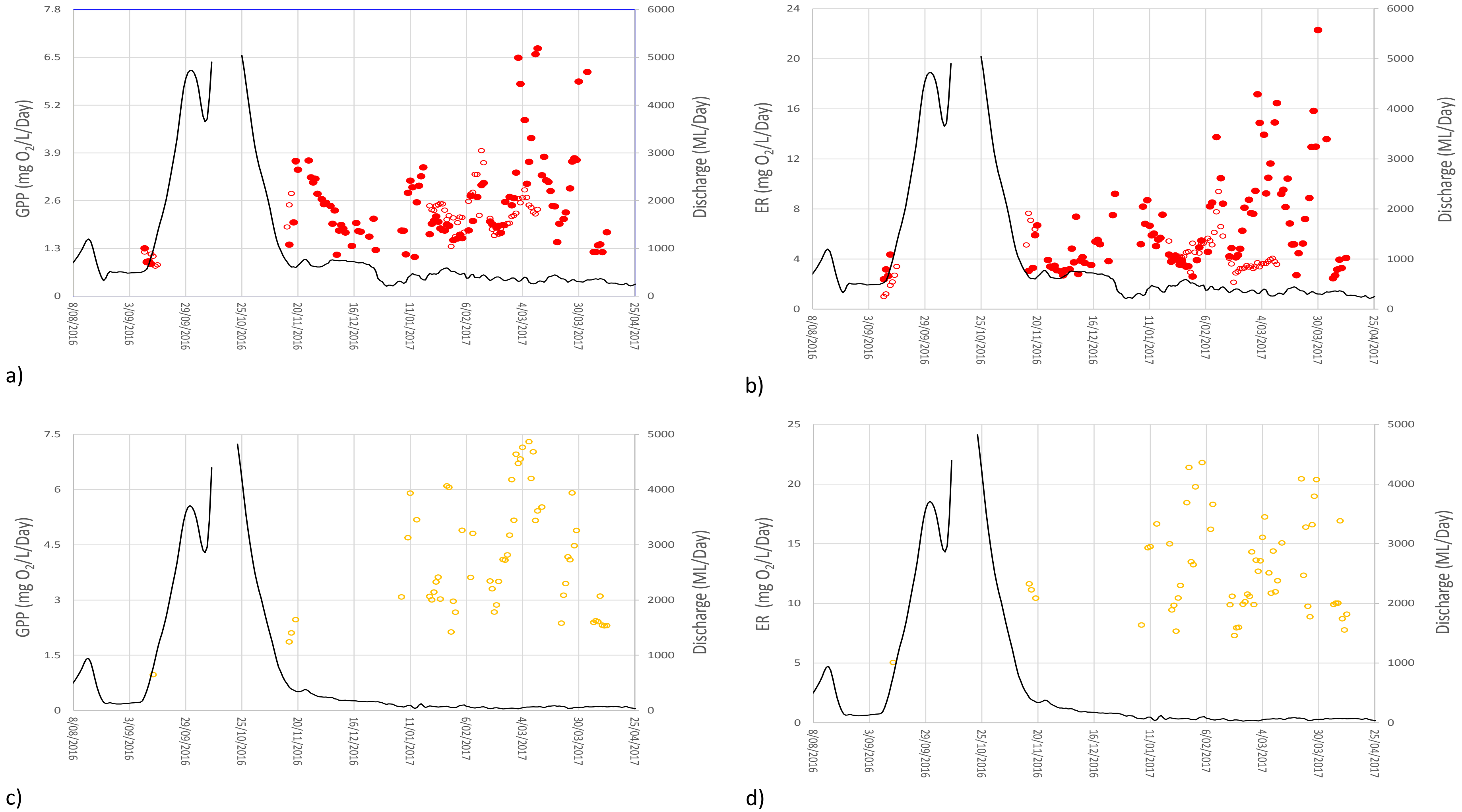

Figure B2 Relationships between Flow and Gross Primary Production (GPP) and Ecosystem Respiration (ER) from December 2016 to April 2017: a) GPP Yallakool Creek (Zone 1) b) ER Yallakool Creek (Zone 1) c) GPP Wakool River (Zone 2), and d) ER Wakool River (Zone 2). Full symbols represent the upstream site within each Zone and the hollow symbols the downstream site. NOTE: The scale of y axes varies across hydrological zones.

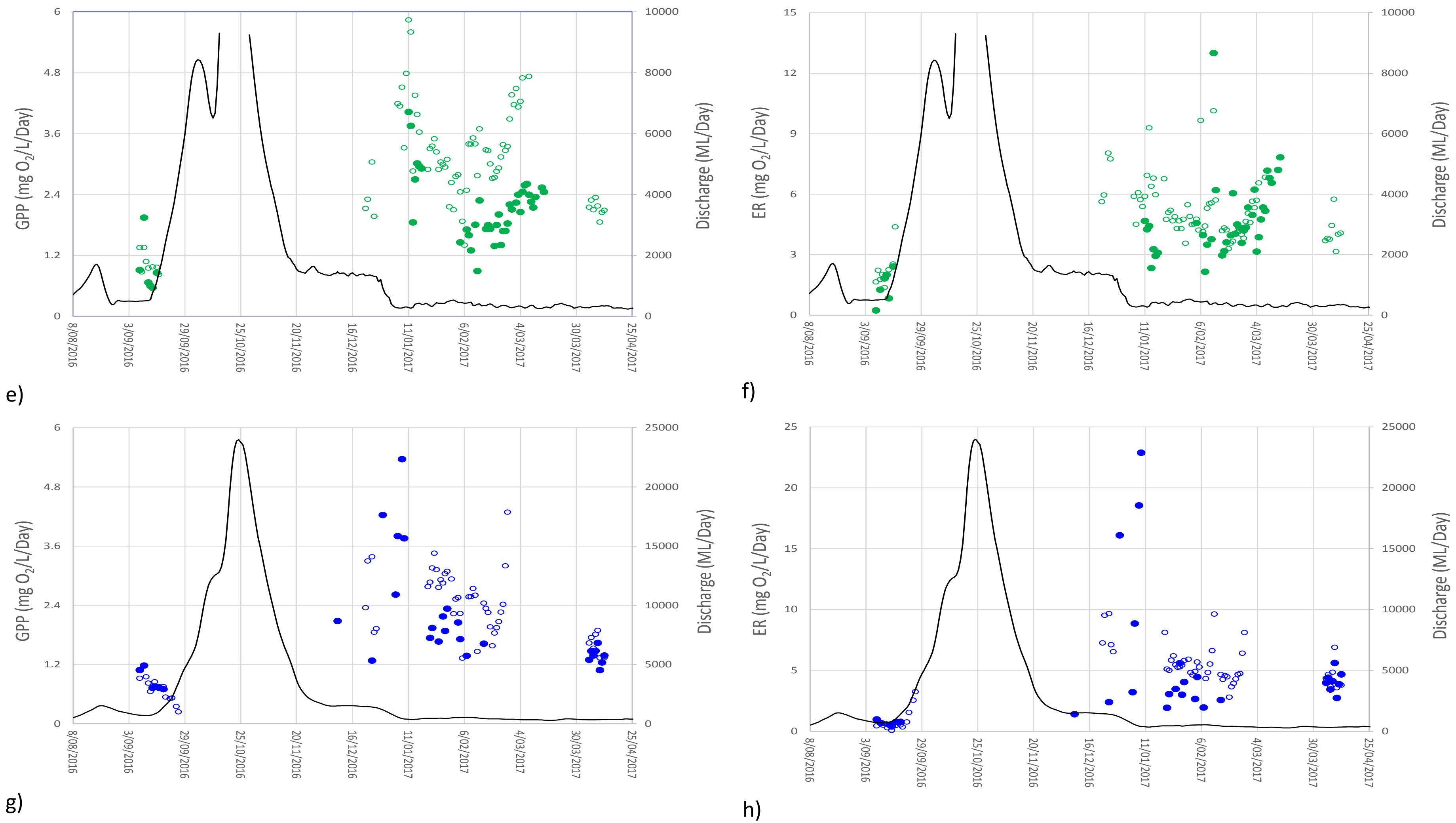

Figure B2 cont Relationships between Flow and Gross Primary Production (GPP) and Ecosystem Respiration (ER) from December 2016 to April 2017 for: e) GPP Wakool River upstream from Thule Creek (Zone 3), f) ER Wakool River upstream from Thule Creek (Zone 3), g) GPP Wakool River downstream from Thule Creek (Zone 4), and h) ER Wakool River downstream from Thule Creek (Zone 4). Full symbols represent the upstream site within each Zone and the hollow symbols the downstream site. NOTE: The scale of y axes varies across hydrological zones.

B.5 Discussion

One of the drivers of the elevated respiration rates in 2016-17 is undoubtedly the much higher dissolved organic carbon concentrations in the water column, which increased from typical values of around 5 mg C/L over almost all the LTIM monitoring period up to > 10 mg C/L and as high as 14 mg C/L (see Figure A2). The origin of the elevated organic carbon concentrations – a combination of the dissolved organic carbon measured here plus particle bound organic carbon (not quantified) – were the unregulated flows from the Murray River which inundated floodplains comprising agricultural land and the Barmah and Koondrook–Perricoota Forests. However, after recession of those high flows by mid-late November, the same relative uniformity in discharge as seen in years 1 and 2 was re-established. These relatively constant flows continued through until the end of February and into March. Consequently, it was not possible to discern any major flow-related responses in metabolism over this period. It is therefore recommended that if at all possible, serious consideration be given to providing a much more variable flow regime in the Edward-Wakool system over this period in future years. This of course may be constrained by other operational imperatives on water levels.

As found in 2015-16, all seven metabolism sites had median P/R ratios substantially < 1 (ranging from 0.32 to 0.64), thereby indicating that more organic carbon was being consumed than created within the four zones. However all sites had short periods where P/R was > 1, especially for the few readings available in early September 2016, prior to the flooding. In each of these cases, the high P/R was driven by very low respiration rates rather than elevated GPP. A continual P/R ratio of < 1 indicates that the stream environment is always consuming more oxygen than is being produced through photosynthesis. Hence if physical reaeration is insufficient to counterbalance the oxygen demand through respiration, then dissolved oxygen concentrations can fall to extremely low levels, including anoxia as was observed in all sites during spring 2016.

The median rates of GPP and ER are at the lower end of the normal range by world standards. This is possibly due to a combination of very low bioavailable nutrient concentrations and a water column that inhibits photosynthesis by limiting light penetration. Apart from the greatly elevated nutrient concentrations from September to November 2016 associated with the flooding, all bioavailable nutrient concentrations were around 0.005 mg/L or less. Importantly this included FRP – the bioavailable form of phosphorus. Some algae and cyanobacteria can fix nitrogen gas from the water to augment N supply when water column concentrations of nitrate and ammonia are low, but there is no comparable mechanism for easily obtaining bioavailable phosphorus when it is in short supply. Some microorganisms can produce enzymes to convert more complex forms of phosphorus to the bioavailable phosphate form, but measurement of this process is beyond the scope of this LTIM project. Turbidity levels at all seven sites ranged between 30 NTU and 140 NTU. This means that light penetration into the water column will be inhibited by the fine suspended particulate matter, which in turn will decrease the PAR available for photosynthesis by benthic algae and, phytoplankton.

As noted in Years 1 and 2 of the LTIM program, while using direct relationships between Commonwealth environmental watering actions and GPP or ER, we could not detect significant stimulation of gross primary production (and hence basal food resources for invertebrates and fish) nor ecosystem respiration (nutrient recycling). Again, as for Years 1 and 2, it is evident that watering actions in 2016-17 did play an important role in mitigating poor water quality (remediation of low DO in spring 2016) and preventing poor water quality in the summer of 2016-17.

Appendix C: Riverbank & Aquatic Vegetation

C.1 Background

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).

Flow management and the water regime in a river system can affect the survival, growth and maintenance of adult plants and strongly influence aspects of reproductive cycles, including flowering, dispersal, germination and recruitment. 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, such as can occur during floods or long periods of regulated flows, can reduce growth or survival of riverbank plants (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). However, a high level of sediment deposition during periods of inundation can reduce the survival of some small herbaceous riverbank species (Lowe et al. 2010).

Riverbank and aquatic taxa can be broadly categorised into three groups; submerged taxa, amphibious taxa that respond to or tolerate wetting and drying, and terrestrial taxa that typically occur in damp or dry habitats. The watering requirements of aquatic macrophytes is variable. For example, while it is critical that the submerged plant ribbon weed are re-flooded within three to four months to maintain existing plants (Roberts and Marston 2011), many amphibious taxa respond to and tolerate a broad range of wetting and drying regimes.

A long history of operational water delivery in the Edward-Wakool system combined with the prolonged millennium drought when flows in the Murray-Darling Basin were at record low levels (van Dijk 2013; Chiew et al. 2014), had negative impacts on the riverbank and aquatic vegetation in the Edward-Wakool system. Community members report there were beds of ribbon weed (*Valisineria* sp.) within the channels and other plants occurring on the banks of the Edward-Wakool system prior to the drought. In 2010 after the break of the drought the submerged and amphibious plant taxa were largely absent throughout the system, with the exception of the longer lived rush *Juncus sp*.

Environmental water has been delivered as base flows and freshes in the Edward-Wakool system since 2010 with one of the aims being to maintain the health of riparian and in-channel aquatic native vegetation communities and maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat (CEWO 2015).

Environmental watering in this system is expected to increase the area of river bank receiving periods of wetting and drying than under operational flows. This is expected to maintain the health of riparian and in-channel aquatic native vegetation and support ongoing recovery and re-establishment of native aquatic vegetation in this system (water Use Minute 10038).

In 2015-16 there were more taxa recorded in Yallakool Creek zone 1 (36 taxa) and Wakool River zone 3 (30 taxa) and zone 4 (28 taxa) that received the Yallakool Creek environmental base flow and fresh than in the upper Wakool River zone 2 (22 taxa) that received a only a small magnitude environmental watering action (Watts et al. 2016). There was a higher percent cover and taxonomic richness of riverbank aquatic vegetation growing in zones 3 and 4 that has a history of environmental watering compared to that in the Wakool River zone 2 that has received none or very small volumes of environmental water (Watts et al. 2016).

C.2 Selected Area questions

In 2016-17 the river bank and aquatic vegetation in Yallakool Creek and the upper and mid-Wakool River were monitored in four hydrological zones with different geomorphology and flow histories to address the following area-specific evaluation questions:

Long-term evaluation questions

- *What has Commonwealth environmental water contributed to the recovery (measured through species richness, plant cover and recruitment) of riverbank and aquatic vegetation in Yallakool Creek and the mid and upper Wakool River 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 evaluation questions

- *What did Commonwealth environmental water delivered as base flows and freshes contribute to the percent cover of riverbank and aquatic vegetation in Yallakool Creek and the upper and mid Wakool River?*
- *What did Commonwealth environmental water delivered as base flows and freshes contribute to the diversity of riverbank and aquatic vegetation taxa in Yallakool Creek and the upper and mid Wakool River?*

C.3 Methods

Monitoring design and field sampling

Four sites in each of four hydrological zones (Yallakool Creek, Wakool River zone 2, Wakool River zone 3 and Wakool River zone 4) were surveyed. Monitoring was undertaken in July, November and December 2016 and January to April 2017. No monitoring was undertaken in August, September or October 2016 because floodwaters limited access to sites. Zone 1 sites 4 and 5, zone 2 sites 4 and 5, zone 3 sites 3 and 5, and zone 4 sites 3 and 5 could not be accessed in November 2016 due to waters on the floodplain continuing to limit access. In December 2016 zone 1 site 5 and zone 3 site 3 could not be accessed due to remaining floodwater.

At each site six permanent 20 m long transects were established in 2014 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 was assessed using the line point intercept method along transects. At each of the transects on each sampling date a 20 m tape measure was laid out running horizontally along the riverbank between two star pickets that had been 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) were recorded. Plants were identified to species level where possible, but if the plants were very small and without seeds or flowers to enable correct identification they were identified to genus. If no vegetation was present at a point, then that point was recorded as bare ground, leaf litter or log/tree trunk. When the transects were in the water the tape measure was 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 and photos taken on every sample event.

Data analysis

Each taxa was 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 were:

a) 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.

b) Amphibious taxa, including those that tolerate wetting and drying, and those that respond to water level fluctuations, and

c) Terrestrial taxa, being those that typically occur in damp or dry habitats.

The percent cover of riverbank and aquatic vegetation was calculated for each transect for each sample date. If there were any logs or tree trunks recorded in a given transect, the percent cover for that transect was calculated out of a reduced number of points, being 40 transect points minus the number of points recorded as log or tree trunk. This is because no vegetation would have been able to grow at that point if a log or tree trunk was present. To compare cover of vegetation across the three years of the LTIM program (2014-15, 2015-16 and 2016-17) the month when the maximum cover occurred across the months of October to May was identified for each taxa, and the cover for that month was used in the comparison. The period from October to May was used because this is the main growing season.

C.4 Results

Patterns of riverbank inundation in 2016-17

The duration and depth of inundation of transects was determined by their position along the elevation gradient using data from water depth measurements undertaken on each monitoring trip. In 2016-17 transects zero and one were permanently inundated from November to April and transect two was permanently inundated for the whole year, except in zone 2. Transects 3, 4 and 5 all experienced periods of wetting during the flood followed by drying. The patterns of inundation in 2016-17 were in contrast with that observed in 2015-16, when transects 4 and 5 were dry for the entire year, and in zone two transects 2 and 3 were also dry for the entire year (Table C1).

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Table C1 Summary of water regime experienced by LTIM vegetation transects in the Edward-Wakool system zones 1 to 4 between August 2015 and April 2017. Blue – continuously inundated, green – periods of wetting and drying, amber – continuously dry.

		2015-16				2016-17			
Transect number	Height above transect zero	Yallakool Creek zone 1	Upper Wakool River zone 2	Mid Wakool River zone 3	Mid Wakool River zone 4	Yallakool Creek zone 1	Upper Wakool River zone 2	Mid Wakool River zone 3	Mid Wakool River zone 4
0	0 m	Inundated	Inundated	Inundated	Inundated	Inundated	Inundated	Inundated	Inundated
1	0.25 m	Inundated	Periods of wetting and drying	Inundated	Inundated	Inundated	Inundated	Inundated	Inundated
2	0.50 m	Periods of wetting and drying	Dry	Periods of wetting and drying	Periods of wetting and drying	Inundated	Periods of wetting and drying	Inundated	Inundated
3	0.75 m	Periods of wetting and drying	Dry	Periods of wetting and drying	Periods of wetting and drying, mostly dry	Periods of wetting and drying	Periods of wetting and drying	Periods of wetting and drying	Periods of wetting and drying
4	1.00 m	Dry	Dry	Dry	Dry	Periods of wetting and drying	Periods of wetting and drying	Periods of wetting and drying	Periods of wetting and drying
5	1.25 m	Dry	Dry	Dry	Dry	Periods of wetting and drying	Periods of wetting and drying	Periods of wetting and drying	Periods of wetting and drying

Responses of riverbank and aquatic vegetation to flow in 2016-17

A total of 51 riverbank and aquatic vegetation taxa were recorded across the sixteen sites between November 2016 and April 2017. Three of the taxa were submerged, 15 were amphibious and 34 were terrestrial. Only six of the taxa were introduced (lippia, arrowhead, medic, sow thistle, yellow cress and clover) and were all in very low abundance, with the exception of lippia in zone 2.

The emergence of floodplain responders such as common sneezeweed (*Centipeda cunninghamii),* joyweed (*Alternanthera denticulata)* and nutheads (*Epaltes australis)* were observed on the recession of flows. Common sneeze weed reduced in cover in November 2016 during the peak of the flood, but increased in cover following the recession of the event (Figure C1), responding to the inundation of the higher parts of the riverbank.

Figure C1 Mass emergence of common sneezeweed at transects 5 and above in zones one, two and three following flood recession (Photo February 2017, zone 2 site 4).

In 2016-17 the ten most abundant taxa comprised six amphibious taxa and four terrestrial taxa (Figure C2). The cover of mud grass and rush (amphibious) was notably reduced in November and December in zones 1 and 4 immediately following the flood, but increased in cover in all zones between January and April 2017 after the flood waters receded (Figure C2). Both floating pondweed and milfoil (amphibious taxa) were more than 20 percent cover in zones 3 and 4 in July 2016 prior to the flood, but reduced to very low percent cover or were largely absent from January to April 2017 after the flood. The terrestrial species lippia increased high cover in zone 1 transect 5 following the recession of the flood (Figure C2).

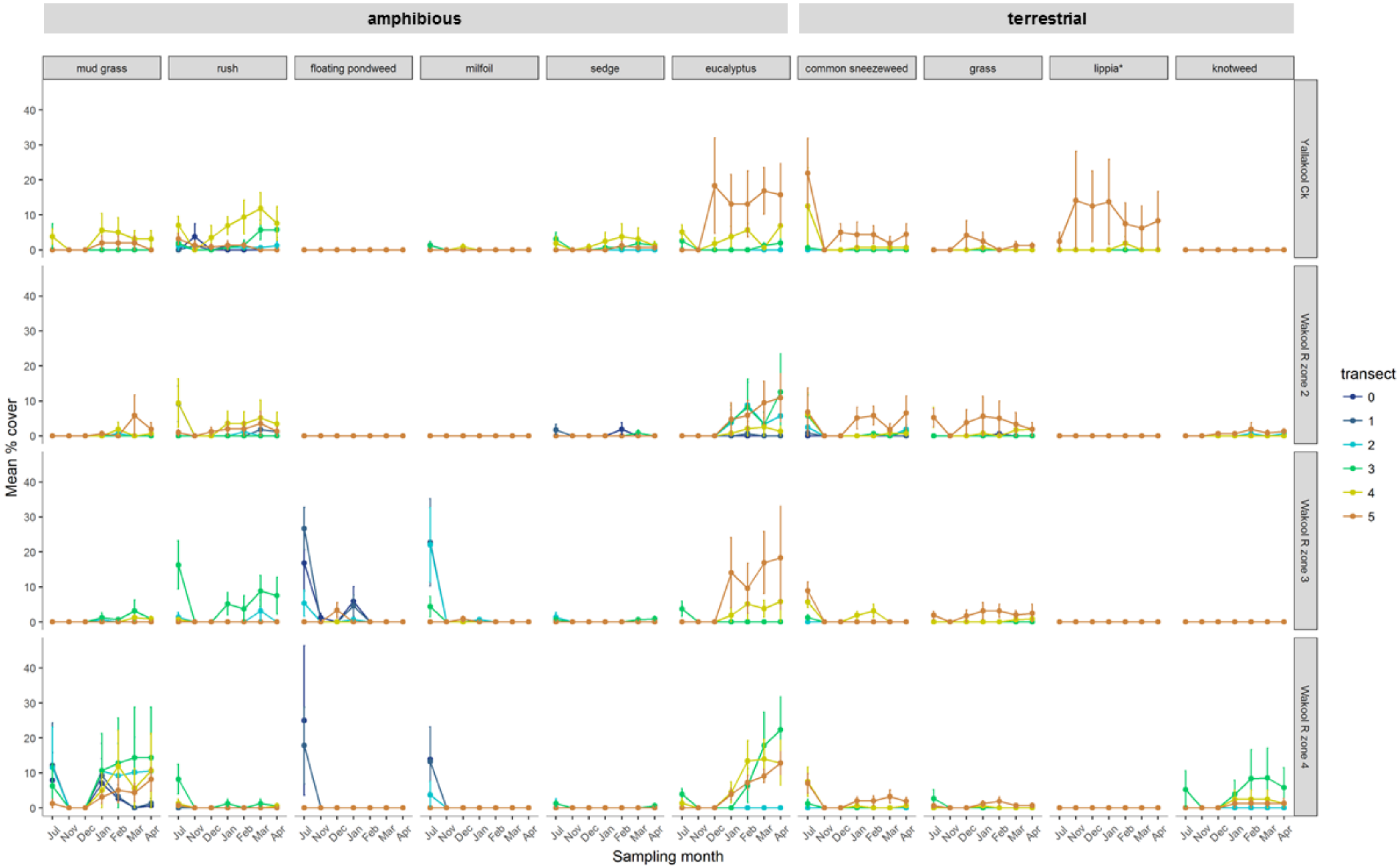


Figure C2 Mean percent cover (±SE) of ten most abundant riverbank and aquatic vegetation taxa monitored monthly at 16 sites across 4 hydrological zones in the Edward-Wakool system between November 2016 and April 2016. Transect 0 was lowest on the river bank.

Comparison of riverbank and aquatic vegetation across three years of the LTIM program

When compared to the results from 2015-16, there was a decrease in the richness of submerged and amphibious taxa in 2016-17 (Table C2, Figure C3). In contrast, there was a considerable increase in the number of terrestrial taxa from 22 in 2015-16 to 34 in 2016-17. Ten of the twelve additional terrestrial taxa recorded in 2016-17 were native taxa (Figure C4).

Table C2 Number of riverbank and aquatic vegetation taxa recorded at LTIM monitoring sites in the Edward-Wakool system in years 1, 2 and 3 of the LTIM project between 2014 and 2017.

	Number of riverbank and aquatic vegetation taxa			
Year	**submerged**	**amphibious**	**terrestrial**	**total**
2014-15	3	14	17	34
2015-16	3	20	22	45
2016-17	2	15	34	51

There were notable changes in the maximum cover of submerged and terrestrial taxa across the three years of the LTIM program. In year two there was an increase in cover of some common amphibious taxa, whereas in 2016-17 there was a notable decrease in the maximum cover of some of the amphibious taxa and all submerged taxa (Figure C3, C4).

In 2015-16 the ten most abundant taxa included one submerged taxa, seven amphibious taxa and two terrestrial taxa (watts et al 2016). In contrast, in 2016-17 the ten most abundant taxa comprised six amphibious taxa and four terrestrial taxa (Figure C2).

Figure C3. Change in the cover of aquatic vegetation from January 2015 (left), Jan 2016 (middle) to Jan 2017 (right) at zone 3 site 1 (Photos: Sascha Healy)

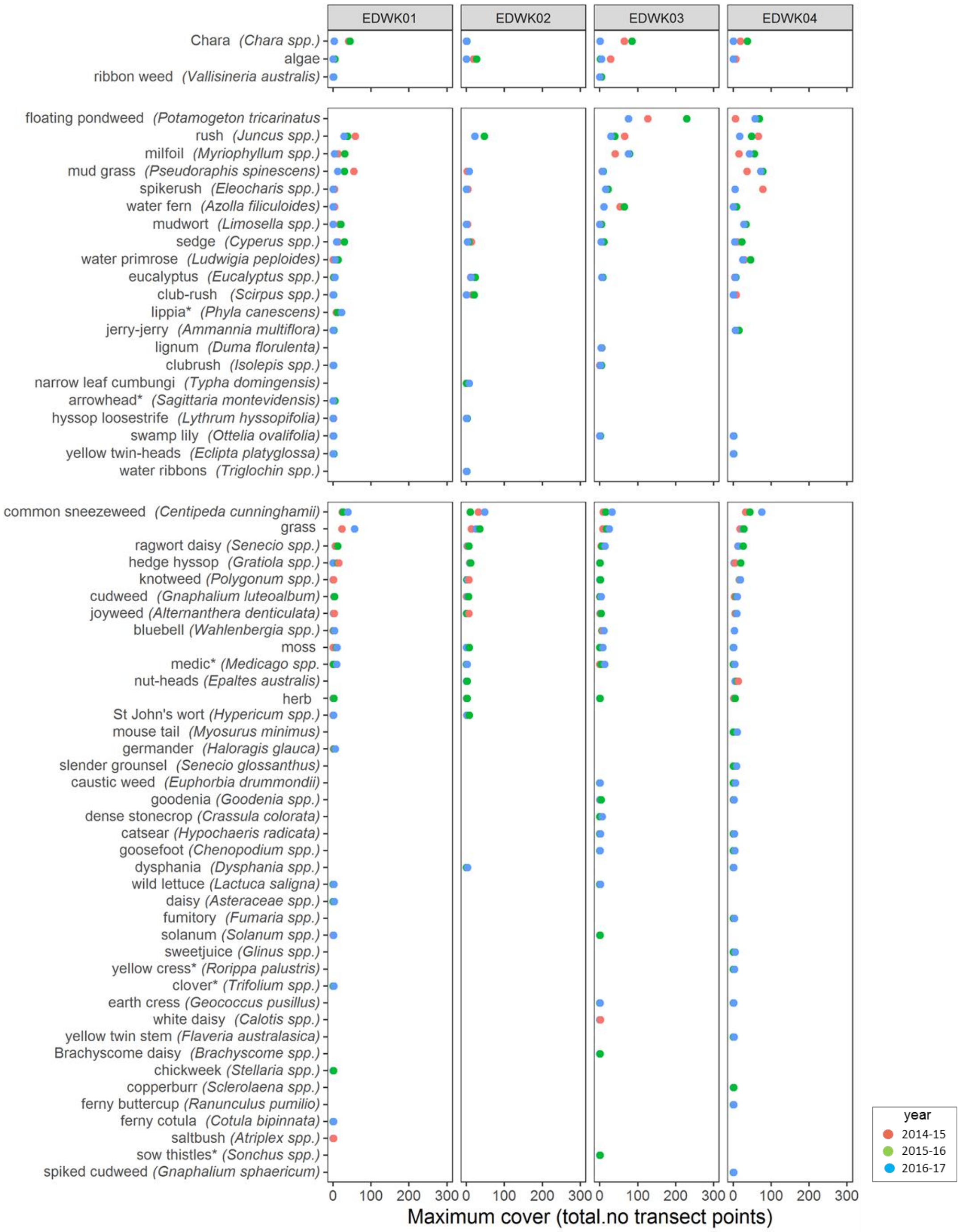


Figure C4 Maximum cover of riverbank and aquatic vegetation taxa monitored monthly across four hydrological zones in the Edward-Wakool system between October 2015 and May 2016. Taxa were classified as submerged, amphibious or terrestrial. Red dots indicate maximum cover in 2014-15, green dots indicate maximum cover in 2015-16, and blue dots indicate maximum cover in 2016-17. EDWK01 = Yallakool Creek zone 1, EDWK02 = Upper Wakool River zone 2, EDWK03 = Wakool River zone 3 upstream of Thule Creek, EDWK04 = Wakool River zone 4 downstream Thule Creek. Asterisk indicates introduced taxa.

C.5 Discussion

The floods in 2016 decreased the richness and cover of submerged and amphibious taxa throughout the Edward-Wakool system. In particular there was a reduction in the cover of submerged taxa and amphibious taxa. This may have been due to extreme physical disturbance of higher velocities and sheer stress that would have been experienced during the flood. In addition, some of the sites had overbank flows for over 1 month (chapter 4) and most riverbank transects were underwater for 4 to 5 months. This would have resulted in a nil or highly reduced light climate during the flood that would have prevented the submerged taxa and amphibious taxa that were growing at the water's edge from photosynthesising. On the recession of the flood, some plants were observed to have died and rotted during the long period of inundation. These observations are consistent with findings of previous studies that long duration of inundation, such as can occur during floods or long periods of regulated flows, can reduce growth or survival of riverbank plants (Blom et al. 1994; Johansson and Nilsson 2002; Lowe et al. 2010). The risks to recovery of the submerged and amphibious riverbank plants include disturbance by carp, disturbance by pigs when rhizomes become exposed, and damage from frost if the regulators and system is shut down during the winter.

In contrast to the reduction in submerged and amphibious taxa, there was an increased cover and number of terrestrial riverbank plant taxa following the recession of the flood. Some terrestrial taxa that have largely been observed in transects 2 and 3 in previous years had a high percent cover in transects five and six higher up on the bank following the flood. Favourable soil moisture and nutrient conditions created by a receding flood are known to encourage rapid recovery and root and shoot development, and many riparian understorey herbs often germinate on flood recession (Nicol 2004; Roberts and Marston 2011).

Short-term evaluation questions

- *What did Commonwealth environmental water delivered as base flows and freshes contribute to the diversity and percent cover of riverbank and aquatic vegetation in Yallakool Creek and the upper and mid Wakool River?*

Despite the delivery of environmental water during November and December 2016 to create a slower recession of the flow peak, there was no recovery of submerged and amphibious taxa in response to this watering action. The cover of submerged and amphibious taxa in many transects had reduced to zero, so there were no submerged or amphibious plants remaining to start the recovery process. It is possible that by the time the flood receded to expose transects zero to three it was too late in the growing season for some taxa to respond.

There was an increase in the cover of terrestrial plants after the recession of the flood, but this recovery was not associated with watering actions, as the recovery occurred higher on bank than environmental flows.

APPENDIX D: FISH

D.1 Background

The Edward-Wakool system is recognized as a priority area for fish diversity in the Murray-Darling Basin, and is part of the threatened '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 have been the main focus of Edward-Wakool system and they are a key environmental asset valued by the broader Edward-Wakool community. Historically, the Edward-Wakool system had diverse fish communities and supported extensive commercial and recreational fisheries (Rowland 1998). Twenty two native freshwater fish species are thought to have historically occupied the lowland region of the central Murray valley (Table D.1), including the recently described obscure galaxias (*Galaxias oliros*). Fourteen of these native species still occur within the system.

The overarching principle that underpins the monitoring and evaluation of Commonwealth environmental water for the Edward-Wakool Selected Area is that we are taking an ecosystem approach to evaluate to Commonwealth environmental watering. A suit of questions and indicators have been selected that all have clear linkages to other components of the monitoring and evaluation plan (see Figure D.1). The Edward-Wakool monitoring and evaluation plan has a strong emphasis on the response of fish populations to Commonwealth Environmental Watering, and includes components directly assessing fish movement, reproduction, recruitment and adult populations. In addition, many of the other indicators evaluated in this report (such as water quality, stream metabolism and aquatic vegetation are likely to have indirect influence on fish population dynamics, and thus a key goal of the long-term intervention monitoring in the Edward Wakool selected area is to improve our understanding and interpretation of these interdependences.

Table D1 Fish species of Edward Wakool River system (recorded and expected). Recorded and alien species are those that have been sampled in the region since 2010, and expected native species are species that were historically likely to have been in the lowland central Murray region. Asterisks highlight if local spawning has been detected since LTIM monitoring commenced in 2014[1]. Indicates species have been recorded in the Edward Wakool system, but outside the LTIM focal study zones.

common name	species name	spawning detected 2014-16
Native species - recorded		
Australian smelt	*Retropinna semoni*	*
carp gudgeon	*Hypseleotris* spp.	*
flathead gudgeon	*Philypnodon grandiceps*	*
Murray cod	*Maccullochella peelii*	*
Murray River rainbowfish	*Melanotaenia fluviatilis*	*
unspecked hardyhead	*Craterocephalus stercusmascarum fulvus*	*
obscure galaxias	*Galaxias oliros*	*
river blackfish	*Gadopsis marmoratus*	*
silver perch	*Bidyanus bidyanus*	
bony herring	*Nematolosa erebi*	
golden perch	*Macquaria ambigua*	
trout cod[1]	*Maccullochella macquariensis*	
dwarf flathead gudgeon[1]	*Philypnodon macrostomus*	
eel-tailed catfish[1]	*Tandanus tandanus*	
Native species - expected		
Agassiz's glassfish (olive perchlet)	Ambassis agassizii	
flathead galaxias	*Galaxias rostratus*	
Macquarie perch	*Macquaria australasica*	
mountain galaxias	*Galaxias olidus*	
Murray hardyhead	*Craterocephalus fluviatilis*	
shorthead lamprey	*Mordacia mordax*	
southern purple spotted gudgeon	*Mogurnda adspersa*	
southern pygmy perch	*Nannoperca australis*	
Alien species - recorded		
common carp	*Cyrpinus carpio*	*
eastern gambusia	*Gambusia holbrooki*	*
oriental weatherloach	*Misgurnus anguillicaudatus*	*
redfin perch	*Perca fluviatilis*	*
goldfish	*Carrassius auratus*	

Key processes that ultimately shape adult populations; movement, spawning, recruitment and growth, are being monitored and evaluated in response to the contribution of Commonwealth environmental water to native fish outcomes. Monitoring of these key elements are complementary, allowing us to assess contributions of environmental water to the key population processes that structure fish assemblages in the Edward-Wakool (Figure D1). Further, the responses measured across these key fish indicators will also be used in a multiple lines of evidence approach to evaluate competing hypotheses about underlying mechanisms driving or limiting the outcomes from environmental water delivery. For example, if watering achieves increases in production and fish spawning, but not recruitment, it may be possible to identify potential bottlenecks and strategies for overcoming those limitations as part of an adaptive management cycle. A brief description of each of the fish indicators being monitored in the Edward Wakool system follows.

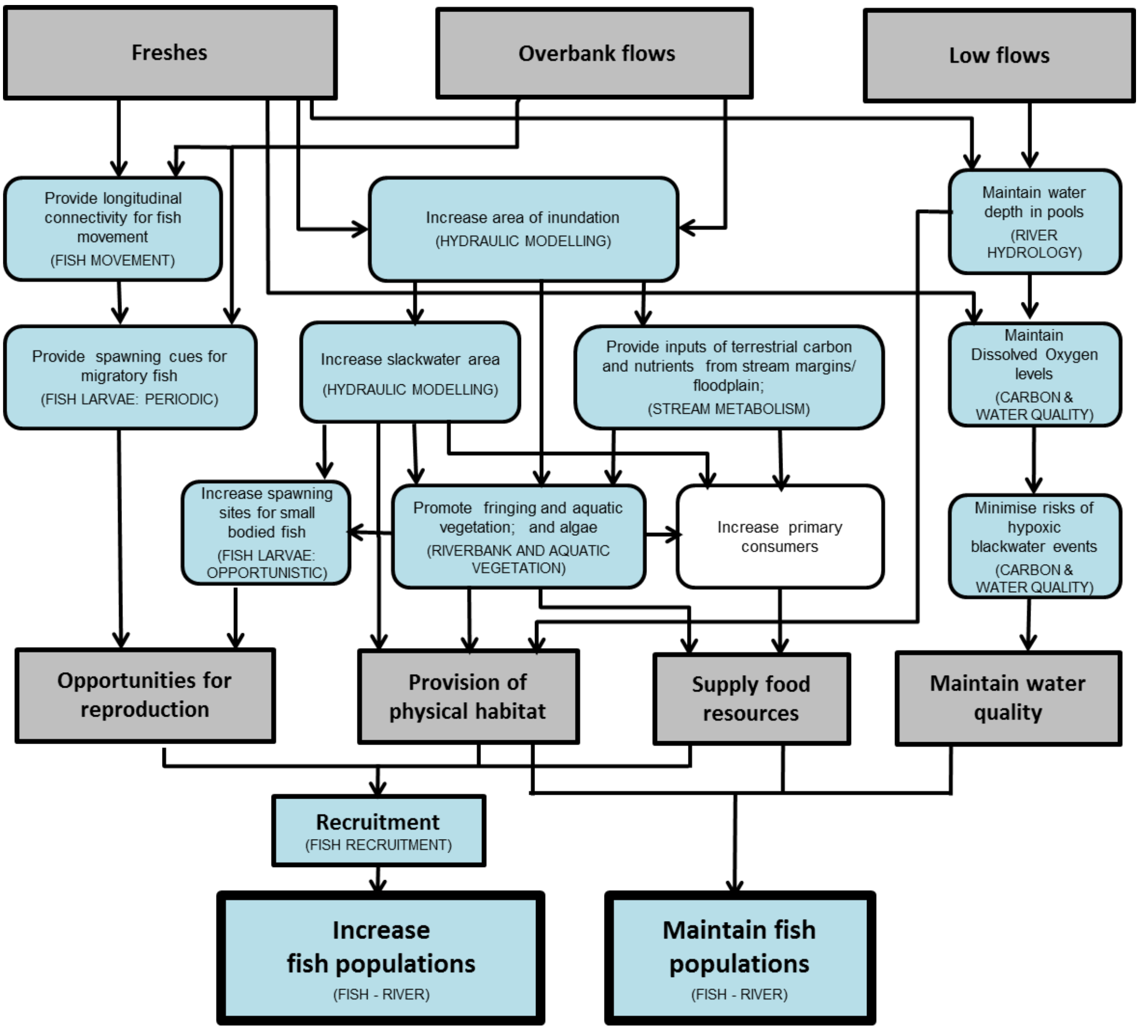


Figure D1 Conceptual diagram illustrating the linkages between different types of environmental watering (freshes, overbank flows, low flows) to fish populations via key ecological processes. Key ecological processes that are being monitored as part of the Edward-Wakool M&E plan are highlighted in blue.

Fish movement

We use acoustic telemetry methods for investigating broad-scale and fine-scale fish movement of golden and silver perch adults. This information can 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).

Fish spawning and reproduction

Monitoring the diversity and abundance of fish larvae across the spring-summer spawning period is used to identify which fish species have successfully spawned, and under what hydraulic and temperature conditions. This provides important information on the flow-spawning ecologically relationships of the Edward-Wakool fish assemblage, and will assist in future planning of environmental water delivery for fish population outcomes.

Fish recruitment

Relationships among early life-history growth and recruitment ultimately determine the abundance of many marine fish population (Pepin et al. 2015), but much less is known about how these factors contribute to populations of freshwater species. It is well established that many species of fish in the Murray-Darling basin do not require over-bank flows, or changes in water level to indicate spawning (Humphries et al. 1999), but nonetheless recruitment of all species may be affected by alternation to the natural flow regime, and environmental flows may be able to address this. The selected area fish recruitment monitoring was developed specifically for the Edward-Wakool system in order to garget juvenile silver perch, golden perch and Murray cod. This monitoring enables comparison of juvenile growth rates among zones of the Edward-Wakool and is used to determine recruitment variation of these species among years, in response to environmental watering.

Adult fish community

Evaluation of the adult fish community to Commonwealth environmental watering is being undertaken in the Edward-Wakool River system to determine long-term trajectories in the fish community assemblage in response to Commonwealth environmental watering, and to assess if movement, spawning and recruitment responses ultimately lead to positive responses (condition, biomass, abundance, diversity) in the adult fish community both within and outside of the LTIM focal area. It is anticipated that changes to the fish community both will occur over longer time scales, and as such a broad-scale monitoring program of the fish community is scheduled for years 1 and 5. Additionally, annual fish community censuses are undertaken within a single focal zone (Wakool River, zone 3) to provide data for Basin-scale evaluation of fish communities and these data are incorporated into our selected area evaluation, where relevant.

D.2 Specific environmental flows delivered for fish outcomes

Eight Commonwealth environmental watering actions were delivered in the Edward-Wakool system in 2016-17. Three of these had primary objectives towards delivering positive outcomes for native fish populations (CEWO 2016).

Wakool River Escape Environmental Watering Action 31/10/2016 to 31/12/2016 (WUM10054-03)

- To provide hypoxic water refuge for fish and other aquatic biota

Wakool River Autumn Recession flows Environmental Watering Action 1/1/2017 to 30/6/2017 (WUM10054-07)

- To prevent a rapid return to base flows following the hypoxic event
- These flows are targetting silver perch spawning and aquatic vegetation

Yallakool River Autumn pulse and Recession flows Environmental Watering Action 1/1/2017 to 30/6/2017 (WUM10054-08)

- To assist with movement of juvenile native fish from the Murray River and Merran Creek systems into the Edward-Wakool system (linked to the same approach used in the Goulburn River-Murray River autumn pulse that was targeting similar objectives)
- To provide a number of peaks at a time when water temperature is suitable for silver perch spawning
- To determine if river level rises time with periods of 23° water temperature and no moon (dark night sky conditions) has any influence on silver perch spawning response

D.3 Selected Area questions

Evaluation of the fish community responses to Commonwealth environmental watering is being undertaken in the Edward-Wakool River system to determine long-term trajectories in the fish community in response to Commonwealth environmental watering. Data from the Edward-Wakool system is being evaluated at the Selected Area scale and contribute to Basin scale evaluation. Basin-scale evaluation involves the integration of multiple datasets from a number of different catchments (Hale et al. 2014), and this will be undertaken by the Murray-Darling Freshwater Research Centre and will be evaluated in a separate report.

This is the third year of a five year monitoring project, and as such this report will provide a benchmark which will be used by LTIM program to determine if there is a system-wide change in the fish community assemblage structure in the Edward-Wakool system with respect to environmental water delivery. The short and long term Selected Area evaluation questions, as outlined in the Monitoring and Evaluation Plan for the Edward-Wakool system (Watts et al. 2014a) are outlined in Table D2 This report will evaluate environmental water against the short-term questions, with long-term evaluation questions to be further asses in 2019.

Table D2 Selected-area evaluation questions relating to the effect of Commonwealth environmental water on Edward-Wakool fish population.

Indicator	Key components	Selected area-scale evaluation questions
Edward Wakool selected area fish population	Fish movement (acoustic telemetry)	*Short-term and long-term evaluation questions* • Were periodic species (golden and silver perch) present in the target reaches during Commonwealth environmental water delivery? • Did periodic species remain within the target reaches during Commonwealth environmental water delivery? • Did Commonwealth environmental water stimulate periodic fish species to exhibit movement consistent with reproductive behaviour? • Does Commonwealth environmental water enable periodic species to disperse from and return to refuge habitat? • Does Commonwealth environmental water protect periodic species from adverse water quality?
	Fish spawning and reproduction (larval fish sampling)	*Short-term and long term evaluation questions* • What did Commonwealth environmental water contribute to the spawning of 'Opportunistic' species? • What did Commonwealth environmental water contribute to spawning in ‘flow-dependent’ spawning species?
	Recruitment and growth of young of year (young of year sampling)	*Short-term and long term evaluation 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?
	Adult fish population demographics (adult fish sampling)	*Short-term evaluation questions* • Does Commonwealth environmental water contribute to maintain or enhance fish condition in the Edward-Wakool river system? • Does Commonwealth environmental water contribute to the recovery of fish communities following negative conditions within the Edward-Wakool river system? *Long-term evaluation questions* • Does Commonwealth environmental water contribute to maintain or enhance existing levels of fish recruitment in the Edward-Wakool river system? • Does Commonwealth environmental water contribute to maintain or increase native fish diversity and abundance in the Edward-Wakool river system? • Does Commonwealth environmental water contribute to maintain or increase native fish biomass in the Edward-Wakool river system?

D.4 Methods

Fish movement

A total of 71 acoustic receivers (VEMCO VR2W) were installed in the Edward-Wakool system in August 2015. Of these, 51 constituted the fine-scale acoustic receiver array (Figure D2) of ~6 km receiver spacing and 20 additional receivers were placed at key entry/exit points and major junctions within the wider Edward-Wakool system to monitor any potential emigration out of the system. The installation of these receivers was supported by the local community and undertaken by funds received by Murray Local Land Services through the National Landcare Programme. A total of 52 golden perch and 28 silver perch have been fitted with telemetry tags between August 2015 and April 2017. Acoustic tag implantation procedures followed those outlined by Hale et al. (2014). Here we report on data obtained from 51 golden perch and 13 silver perch, although we note that sample size varied throughout the study period due to emigration and possible mortality.

Acoustic receiver downloads are undertaken quarterly (Figure D.3). Downloaded acoustic tag detection data and meta-data are uploaded into a custom SQL database. Data were subsequently screened and all duplicates, false detections and orphan tags quarantined prior to storage. Individual movements of fish were recreated over time to determine 1) location within the Edward-Wakool system at any given time and, 2) timing and distance of movements. As receivers were spaced at ~6 km intervals, this represents the minimum distance of movements within the receiver array and detection on multiple receivers is required to determine location and direction of movement. Individual fish were assigned a location based on their previous location until any new location (i.e. detection at a new/different location) was determined. Where a new location was not determined (i.e. an individual was never detected again), individual records were truncated to the last verified detection location and date. This data may represent emigration from the acoustic array (and hence the entire Edward-Wakool system), an individual between two receivers and not moving, or mortality.

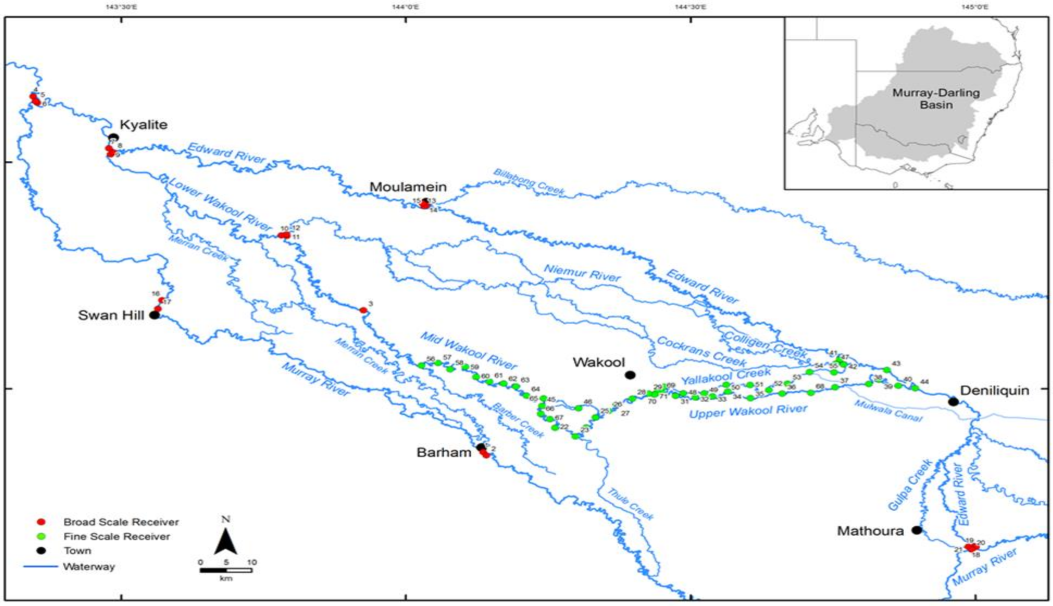


Figure D2 Location of acoustic telemetry receivers (green dots) moored in the Edward-Wakool system to determine movements of acoustically tagged golden perch and silver perch. Red dots indicate the 20 additional receivers placed at key entry/exit points and major junctions to monitor any potential emigration out of the system. The installation of these receivers was supported by the local community and undertaken by funds received by Murray Local Land Services through the National Landcare Programme.

Figure D3 Clockwise from left: An acoustic receiver ready for deployment and an acoustic tag for scale, downloading information from tagged fish passing an acoustic receiver and, an anaesthetised silver perch undergoing surgical implantation of an acoustic tag in April 2017.

Fish spawning and reproduction

Field sampling

Fish larvae were sampled fortnightly within the Edward-Wakool Selected area from the week of 26 September 2016 to the 2 March 2017 (n=12 sampling trips). A combination of modified quatrefoil light traps, and drift nets, were used to cover both Cat 1 Basin Matters sampling and Cat 3 Selected Area sampling, and were used in all four study zones; Yallakool Creek (Zone 1), Upper Wakool River (Zone 2), Mid Wakool River u/s of Thule Creek (Zone 3), and Mid Wakool River d/s of Thule Creek (Zone 4)

As part of the routine fish larval sampling for the Edward Wakool Selected area (cat 3), three light traps were deployed overnight at each of the five sites within the four study zones each trip. The occurrence of fish larvae throughout an given river reach is patchy, and so to account for this, the three light traps deployed per site were pooled to create one composite light trap sample.

Drift nets were also used for sampling larvae for both cat 1 and cat 3 methods, albeit over a shorter period of time (n=7 sampling trips). Drift nets are used in addition to the light traps, as they are more effective in picking up the passively drifting eggs and fish larvae of flow-dependent spawning species, such as golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*). Cat 3 drift net sampling remained unchanged to that in the 2015-16 season (sensu Watts et al. 2016), with drift nets deployed fortnightly for 5 sampling trips from 24 October - 2016 – 21 December 2017. Here, three drift nets were deployed overnight at one site in each of the four study zones. The volume of water filtered by the nets was calculated using Oceanic® flow meters positioned at the mouth of each drift net. Volume sampled by the net was estimated as $\pi r^2 \cdot v \cdot t$, where *r* is radius in metres, *v* is mean velocity in m/s, and *t* is time set in seconds.

High rainfall and flooding during the first half of the 2016-17 field season mean that we were not able to access our full complement of sites for the routine light trap sampling. Table D3 provides a breakdown of the light trap sampling effort that took place at each zone, on each sampling occasion. Wet weather during September 2016 meant that the first scheduled field trip (12-15 September 2017) had to be cancelled, and limited site accessibility for the following trip (26-30 September) meant that only drift nets could be deployed. Routine light trap sampling commenced on the 10 October 2017). From October – December on average 2-3 sites could only be accessed at each zone, however by the 3 Jan 2017 we were able to get back to our full sampling program of deploying light traps at 5 sites per each zone. The full complement of Cat 3 drift sampling effort was able to be undertaken during 2016-17. This was because we only required access to one site in each zone for deploying nets on any one sampling trip.

Table D3 Nunber of sites able to be accessed in each zone for each trip during the 2016-2017 sampling period. There are a total of 5 sites in each zone. Light green highlights when 1-3 of the sites could be accessed, dark green highlights when 4 or 5 of the sites could be accessed.

	12-9-16	26-9-16	10-10-16	24-10-16	7-11-16	21-11-16	5-12-16	18-12-16	3-1-17	16-1-17	30-1-17	13-2-17	27-2-17	Total effort
Zone 1	0	0	3	2	2	2	5	5	5	5	5	5	5	44/65
Zone 2	0	0	3	2	2	3	3	4	4	5	5	5	5	42/65
Zone 3	0	0	3	3	3	3	3	3	5	5	5	5	5	43/65
Zone 4	0	0	2	2	2	2	3	4	4	4	5	5	5	38/65

Laboratory methods and data analysis

All eggs/larvae collected in light trap and drift net samples were identified to species according to Serafini and Humphries (2004), and enumerated. Carp gudgeon larvae were identified to genus level (*Hypseleotris* spp.) only. Results of PCR amplification on cod larvae collected from the Selected Area in 2015-16, were all found to Murray cod, and so from here on we consider all cod larvae collected in the study zone to be Murray cod. The developmental stage of each individual was recorded as either larvae, or juvenile/adult, according to classifications of Serafini and Humphries (2004).

Larval catch rates from light traps were compared across years, to determine if the catch in 2016-17 that was characterised by high flows and overbank flooding, was significantly different to 2014-15 and 2015-16 when river flows persisted within channel. We used generalised linear mixed-effects models to test differences of larval catch between years, where 'year' was treated as a fixed effect (2014-15, 2015-16, 2016-17), 'zone' (zone 1, zone 2, zone 3, zone 4) as a random effect and total larval catch for each species as the response variable. Distribution of larval counts were non-Gaussian so Poisson distributions were used in the statistical models. Overdispersion was tested for, and if greater than 1, negative binomial models were used instead. Statistical analyses were carried out using R (version 3.3.2, R core team 2016) and the R package lme4 (Bates et al. 2017). Wald χ^2 tests were used to test a null hypothesis of no effect of the year on larval catch rates. P-values of <0.05 were used to determine the significance of each test.

Fish recruitment

Four sites were sampled in each of four river zones within the Edward-Wakool system: Yallakool Creek, Wakool River Zone 2, Wakool River Zone 3 and Wakool River Zone 4. Each of the 16 sites were sampled once in a randomly selected order between February and March for three years: 2014-15; 2015-16 and 2016-17. Given the timing of these surveys, the influence of winter 2017 flows on the recruitment of the 2016-17 year class will not be known until surveys are completed later in 2017 and reported on in the 2017-18 report.

Three sampling methods including backpack electrofishing, standardised angling and baited set-lines were undertaken to sample recruits of Murray cod, golden perch and silver perch at each of the 16 sites. A sub-sample of less than 50 fish per zone and species were euthanized and frozen to determine the age and growth rate of recruits, while all other fish were released alive.

Continuous backpack electrofishing, using a 12 V DC battery with a Smith-Root unit, was undertaken at each site by an operator and one person equipped with a 5 mm mesh dip-net. Each site was sampled for a minimum of 3000 seconds of backpack-on electrofishing time, which resulted in a sampling distance of more than 25 times the average wetted-width at each site and 100 times the average wetted width for each zone. Presence of non-target species was recorded at each site, while total length measurements and counts were made for all individuals of the three target species and common carp.

Standardised angling was carried out by two anglers with the specific aim of targeting young silver perch and golden perch. Standardised angling at each site consisted of two anglers fishing on the bank for two hours. Angling gear was matched to the specifications commonly used by local fisherman with worms and cheese used as bait. Species and length were recorded for all individuals caught.

Ten set-lines, each with a 3-10 m (100 lb) monofilament main-line and two 0.5-1.5 m (4 lb) leaders were set at each site. Lines were set, baited with worms and cheese and hauled hourly during day-light hours for 5-7 hours at each site. Hook type and bait matched those in the standardised angling section. Species and length were recorded for all individuals caught.

Laboratory methods and data analysis

To determine the annual age of 1+ recruits and daily age of YOY, sagittal otoliths were extracted, embedded in a polyester resin and sectioned in the transverse plane to approximately 100 µm thick and mounted on a microscope slide. Final age estimates were based on samples with matching age readings from three reads. All otolith sections were checked under a fluorescence stereomicroscope fitted with an excitation filter to identify the presence of Calcein marks to discriminate hatchery released and wild recruits (Crook et al. 2011).

The daily growth rate (mm) of Murray cod YOY recruits and TL of 1+ recruits was compared statistically among zones and years 2014/15 - 2016/17 using Generalized Linear Mixed Effects Model's (GLMM's), whereby year and zone were fixed effects and site was a random effect. Insufficient catches of golden perch and silver perch recruits among zones and years prevented a comparison of growth rates.

Recruitment catch per unit effort (CPUE; number of recruits per 10,000 s of sampling) indices of YOY and 1+ Murray cod and 1+ silver perch, were calculated from catch and effort data from backpack electrofishing, set-lines and angling. The GLMM's were used to test whether CPUE of YOY and 1+ recruits varied significantly in relation to the fixed effects of sampling gear type, zone, and year. Separate models were run for each species and recruitment stage (YOY or 1+) and site was incorporated as a random effect. Insufficient catches of golden perch and YOY silver perch prevented a comparison years.

Adult fish community

A system-wide fish community survey will be undertaken in years 1 and 5 of the Edward-Wakool LTIM project (Watts et al. 2014). In the absence of fish community data for this current monitoring year we present Category 1 fish community standardised survey data from Zone 3. Additional data is presented from fish collected that died as a result of a hypoxic blackwater event in October and November 2016. These fish were opportunistically collected from Billabong Creek, Merribit Creek and the Wakool River. Extracted otoliths will be used to determine annual ages, supplementing previous age-length datasets required as part of the fish matter basin-scale evaluation (Category 1; Stoffels et al. 2016).

Standardised sampling was undertaken in May 2017, and each site was sampled once using a suite of passive and active gears including boat-electrofishing (n=32 operations, each consisting of 90 seconds 'on-time'), unbaited bait traps (n=10) and small fyke nets (n=10) (Hale et al. 2014). All captures (fish and other non-target taxa) were identified to species level and released onsite. Where large catches of particular species occurred, a sub-sample of individuals was measured and examined for each gear type. The sub-sampling procedure consisted of firstly measuring all individuals in each operation until at least 50 individuals had been measured in total. The remainder of individuals in that operation were also measured, although any individuals of that species from subsequent operations of that gear type were only counted.

To determine differences among years (2015, 2016 and 2017) abundance data were analysed using one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al. 2008). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which years differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities between years. To determine whether the size structure of large-bodied fish differed between sampling years (2015, 2016 and 2017), thus indicating potential cohorts among years, species-specific pair-wise cumulative distribution functions were compared using Kolmogorov-Smirnov two-sample tests using the Fisheries Stock Analysis package (FSA; Ogle 2015) in R (version 3.2.0; R Core Team 2015).

D.5 Results

Fish movement

A total of 51 golden perch and 13 silver perch contributed movement data from August 2015 until April 2017. However, on any given day sample sizes of tagged fish contributing to movement data reached a maximum of 41 golden perch and seven silver perch (Figure D4). The possible explanations reasons for this include emigration, mortality, angler harvest or simply occupation of a habitat between two receivers. Both golden and silver perch individuals moved sporadically from August 2015 to August 2016, generally occupying the LTIM focal zones (zones 1, 2, 3 and 4) and moving over a scale of 10's of kilometres (Figures D5 and D6). Emigration was not observed during this period, nor were there repeatable directional movements by the entire tagged sample (Figures D5 and D6).

In comparison, rising water levels resulting from unregulated inflows in September, as well as increasing water temperatures, resulted in rapid, coordinated movements of both species over 100's of kilometres, an order of magnitude greater than those observed in the preceding 12 months (Figure D6). Movements by the majority of individuals were persistent and directional, resulting in a net shift in the tagged population to downstream habitats on the mid and lower Wakool River (Figure D6). Movement pathways were predominantly via the main Wakool River channel, although multiple routes were taken around Bookit Island.

Dissolved oxygen levels declined concurrent with the flow peak, resulting in readings at or near 2 Mg L^{-1} in mid-October 2017 and 0 Mg L^{-1} in late October in the Wakool River. The timing of these low dissolved oxygen levels coincided with the last valid detections of many tagged golden perch (n=36/51 tagged fish had their last valid detections in either September or October 2016) and silver perch (n=4/9 were fitted with tags, were within the EW system and had their last valid detections in either September or October 2016) within the Wakool River. Commonwealth environmental water was delivered via escapes to enhance dissolved oxygen within the Edward-Wakool system. The timing of delivery was after the last valid movement records for the majority of the tagged sample of both golden and silver perch, with the exception of two tagged golden perch that remained within the focal zones during the period of environmental watering (Figure D6).

The last detections of 39 golden perch were within the LTIM focal zones, although generally in zone 4 (i.e. downstream). Of these 39 only three individuals were detected in 2017. Nine golden perch had last detections in the lower Wakool River at either Gee Gee Bridge (n=2), at the Glenbar-Niemur junction (n=6) or at the Wakool-Edward junction (n=1). One additional golden perch was detected moving from the Glenbar-Niemur junction to the Colligen Creek-Edward River junction. Two golden perch exited the Edward-Wakool system into the Murray River near Kenley, with one of these detected on another receiver array near Mildura (travelling ~590 km). The most recent acoustic receiver download in April 2017 indicated that only three golden perch are now contributing movement data within the LTIM focal zone.

Six silver perch contributed movement data during the 2016-17 watering season. Two individuals were last located in zone 4 in early-mid October 2016, one was last located in the Wakool River at Kyalite in late October 2016. The remaining three individuals exited the Edward-Wakool system and entered the Murray River at Kenley from 16–24 October 2016. One of these individuals subsequently re-entered the Edward-Wakool system and was last detected at the Wakool-Edward junction in March 2017. Another of these silver perch moved upstream in the Murray River and was last detected at Picnic Point in February 2017. The third silver perch to enter the Murray River was subsequently detected on another receiver array in the lower Darling River in December 2016, having travelled downstream in excess of 700 km from its original capture location.

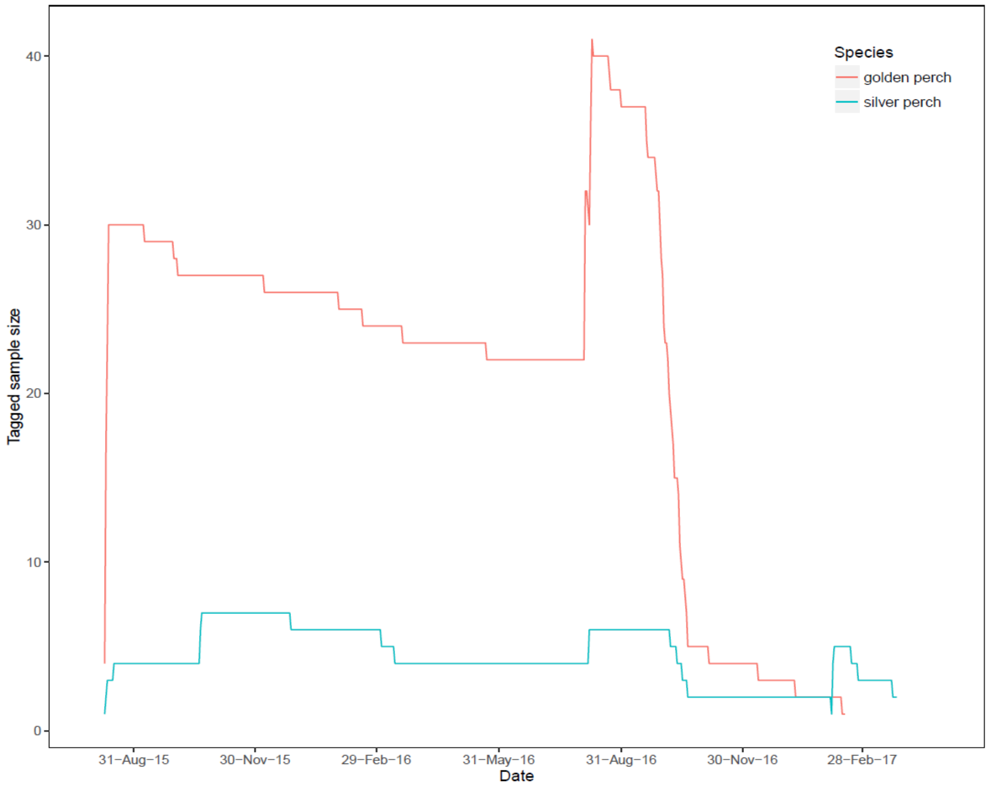


Figure D4 The sample sizes of golden perch (red) and silver perch (blue) fitted with acoustic tags and contributing to fish movement data on any given day in the Edward-Wakool system. Note that individual records are truncated to the last valid detection on an acoustic receiver, and after this period individuals may have either left the array, may occupy a position between two receivers, or may be considered a mortality.

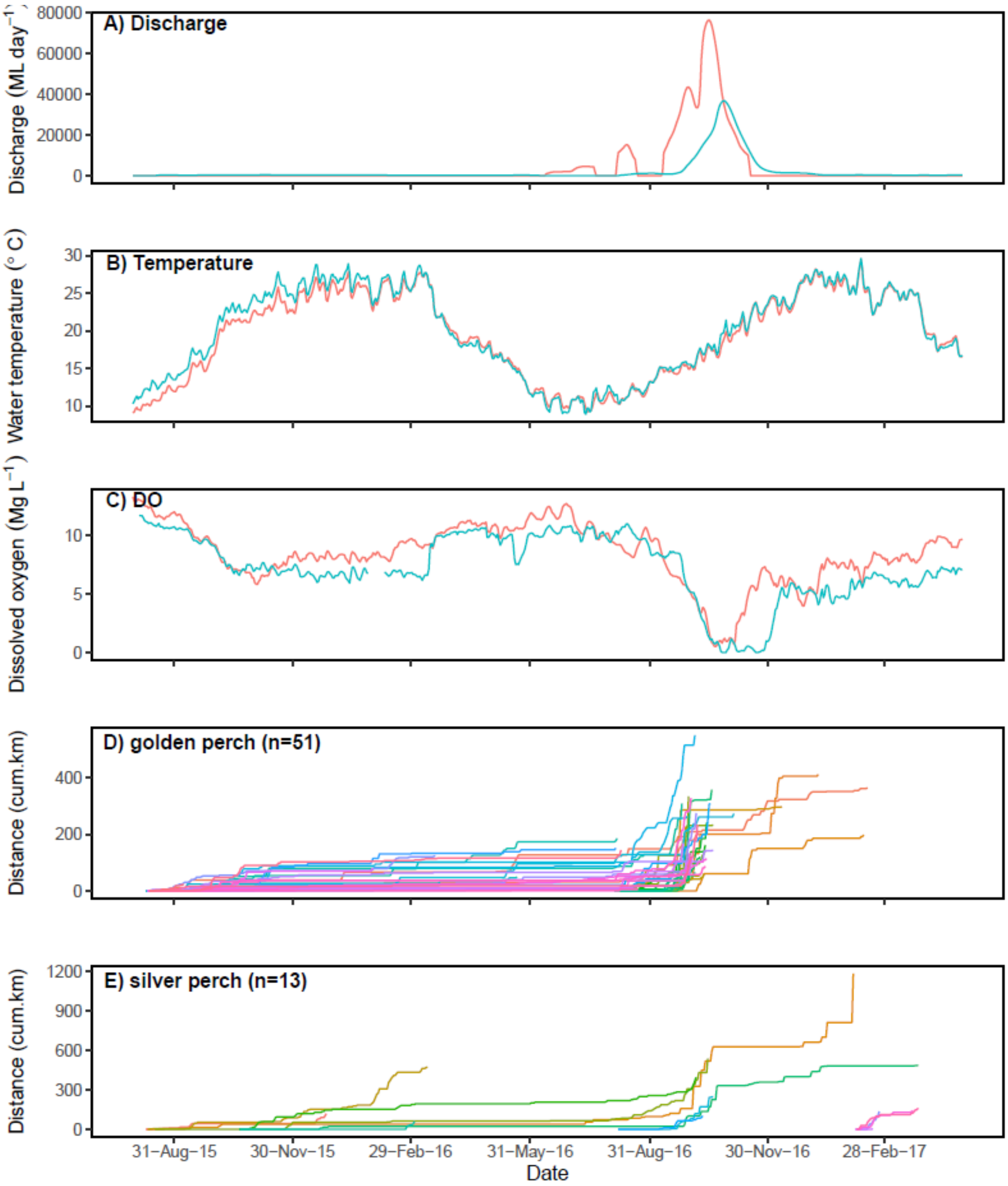


Figure D5 A) Mean daily river discharge, B) mean daily water temperature and, C) mean daily dissolved oxygen from the Edward River at Deniliquin (red line) and Wakool River at Gee Gee Bridge (blue line) at Wakool Reserve (Zone 3) and associated cumulative daily distance (irrespective of direction) of acoustically tagged D) golden perch and E) silver perch. Different coloured lines represent different tagged individuals and 0 km represents the first detection of an individual fish. Note that when the individual coloured lines finish this represents the last detection of this individual fish within the acoustic array. Golden perch and silver perch do not share a common y-axis (distance) due to differences in the scales of movement between the two species.

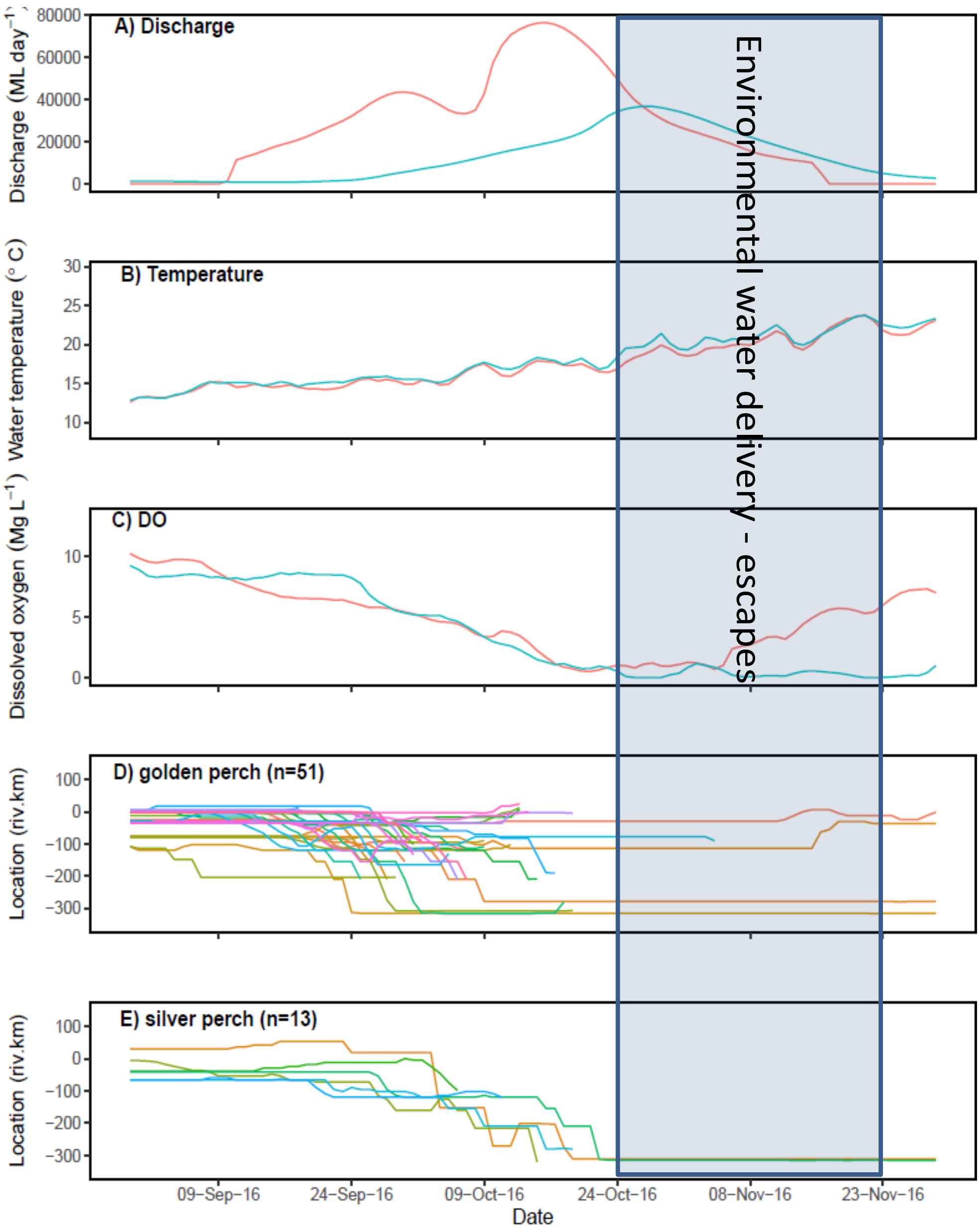


Figure D6 A) Mean daily river discharge, B) mean daily water temperature and, C) mean daily dissolved oxygen from the Edward River at Deniliquin (red line) and Wakool River at Gee Gee Bridge (blue line) at Wakool Reserve (Zone 3) and associated daily location of acoustically tagged D) golden perch and E) silver perch during the period of environmental water delivery in late 2016. Different coloured lines represent different tagged individuals and 0 km represents the location of Wakool Reserve, with positive numbers representing upstream locations and negative numbers downstream locations. Note that when the individual coloured lines finish this represents the last detection within the acoustic array.

Fish spawning and reproduction

A total of 12, 667 fish larvae, representing ten species, were collected in the 2016-17 study period from light traps (n=12,665) and drift nets (n=2) combined. Across the four study zones, the greatest number of larvae were collected throughout Wakool River Zone 3 (49% total light trap catch), followed by Wakool River Zone 4 (40 %), Yallakool Creek Zone 1 (6%), and Wakool River Zone 2 (5%), respectively. Despite the reduced sampling effort caused by flooding and access issues, a magnitude order more larvae were collected in 2016-17 compared to the first two years of LTIM monitoring – where 3,418 larvae were sampled in 2015-16, and 4,249 in 2014-15.

Seven of the ten fish species collected as larvae were native, with small-bodied fish species comprising the majority of larvae collected across the four study zones (Table D4); a pattern observed in both 2014-15 and 2015-16 (Note: because only very few species were collected in drift nets (n=3), we limit our results from here on in to trends observed from light trap sampling). Carp gudgeon (*Hypseleotris* spp. n=19,728), were the most numerically abundant larvae caught in light traps, representing 90% of the larvae catch. Flathead gudgeon (*Philypnodon grandiceps*, n=355) and Australian smelt (*Retropinna semoni* n=219) larvae were also detected consistently across the four study zones. Other small bodied fish found spawning during 2016-17 were Murray River Rainbowfish (*Melanotaenia fluviatilis*, n= 20) and unspecked hardyhead (*Craterocephalus stercusmascarum fulvus*, n=7). We did not detect any spawning of obscure galaxias (*Galaxias oliros*) this year, but of interest, was the large number of tadpoles collected in light traps when the river heights were overbank, indicating the inundation of floodplain habitat promoted a strong response in frog spawning. Introduced species found spawning in 2016-17 included Carp (*Cyprinus carpio*, n=724), gambusia (*Gambusia holbrooki*, n=28) and oriental weatherloach (*Misgurnus anguillicaudatus*, n=1).

Of the large-bodied, native fish species known to Edward-Wakool River, two species, Murray cod *(Maccullochella peelii,* n=4) and bony herring (*Nematolosa erebi*, n=7), were collected as larvae, indicating local spawning had occurred within the Edward-Wakool Selected Area. This is the first observation of bony herring spawning in the Edward-Wakool system since short term intervention monitoring of CEWO water commenced in 2011-12. Bony herring larvae were collected in the lower section of the Selected Area only – appearing in Wakool River zone 3 (upstream of Thule Creek), and Wakool River zone 4 (downstream of Thule Creek). There were no river black fish (*Gadopsis marmoratus*), silver perch (*Bidyanus bidyanus*), and golden perch (*Macquaria ambigua*) eggs or larvae collected from light traps or drift nets.

Table D4 Total abundance of fish larvae sampled using light traps (LT) and Drift nets (DN) in the four study zones of the Edward-Wakool River system in Spring/Summer 2016-17. Grand totals of species catch provided in the far right column. Total amount of water filtered across the nets in each study zone; Yallakool Ck – 1.7 ML, Wakool River Zone 2 – 2.6 ML, Wakool River Zone 3 – 0.7 ML, and Wakool River Zone 4 – 1.4 ML. Fish species listed are those known to occur in the Edward-Wakool river system; however trout cod are the only species detected in the Edward Wakool Selected Area, but not in the study zones.

Common name	Yallakool Ck		Wakool R Z2		Wakool R Z3		Wakool R Z4		Total	
	LT	DN	LT	DN	LT	DN	LT	DN	LT	DN
Native										
Australian smelt	6	-	14	-	10	1	2	-	32	1
carp gudgeon	481	-	376	-	5909	1	4808	-	11574	1
flathead gudgeon	26	-	65	-	27	-	206	-	324	-
unspecked hardyhead	-	-	-	-	1	-	4	-	5	-
Murray River rainbowfish	2	-	-	-	4	-	13	-	19	-
obscure galaxias	-	-	-	-	-	-	-	-	-	-
bony herring	-	-	-	-	3	-	3	-	6	-
silver perch	-	-	-	-	-	-	-	-	-	-
golden perch	-	-	-	-	-	-	-	-	-	-
river blackfish	-	-	-	-	-	-	-	-	-	-
trout cod	-	-	-	-	-	-	-	-	-	-
Murray cod	1	-	1	-	2	-	-	-	4	-
Introduced										
gambusia	-	-	1	-	8	-	8	-	17	-
oriental weatherloach	1	-	-	-	-	-	-	-	1	-
redfin perch	-	-	-	-	-	-	-	-	-	-
carp	258	-	208	-	159	-	58	-	683	-
goldfish	-	-	-	-	-	-	-	-	-	-
Other										
tadpoles	3	-	5	3	52	-	1	2	61	5

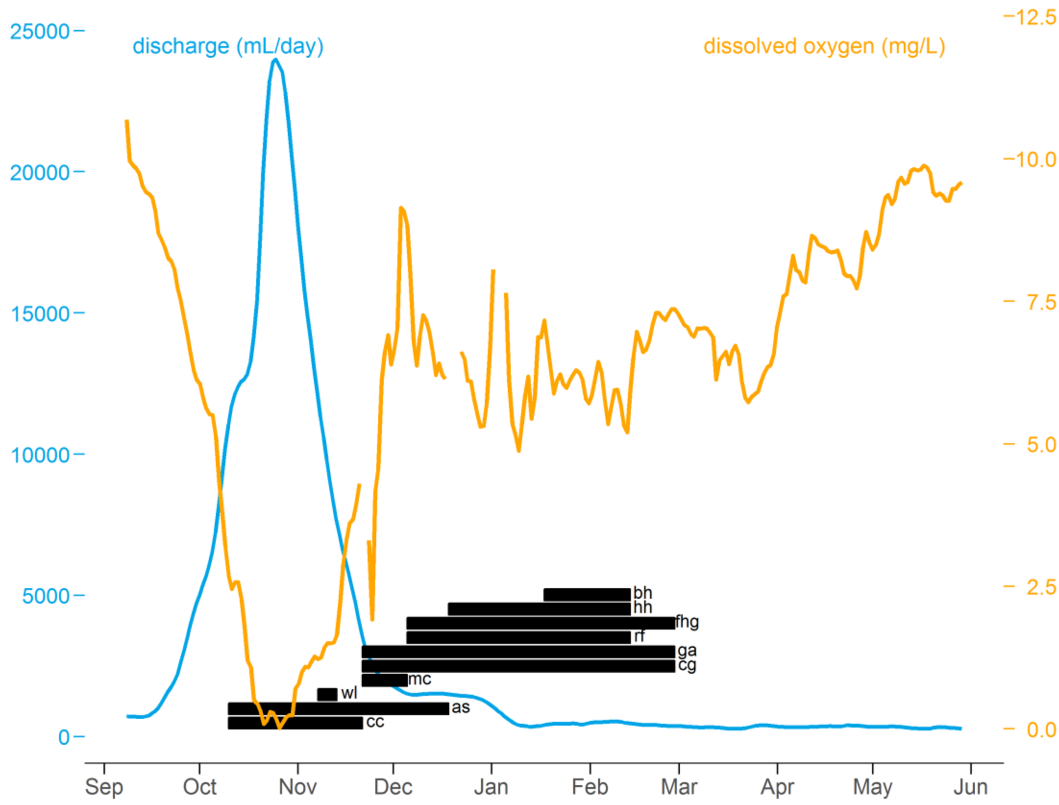


Figure D7 Occurrence of fish larvae in the Edward Wakool Selected Area during the 2016-17 spawning season, overlaid with mean daily discharge (mL/day) and mean daily dissolved oxygen (mg/L). Solid black bars represent duration of spawning season for individual species (from bottom to top): cc= common carp, as=Australian smelt, wl= Oriental weatherloach, mc = Murray cod, cg = carp gudgeon, ga= gambusia, rf=Murray river rainbowfish, fhg=flathead gudgeon, hh=unspecked hardyhead, and bh= bony herring. Discharge is measured at zone 4 site 1 (Gauge 409045, Wakool River at Barham Rd), Dissolved oxygen was calculated as mean daily DO across all DO logger sites throughout the Selected Area.

Comparisons of larval catch across years revealed differing responses of fish species to the flood conditions of 2016-17 with those of the previous two years were flows did not exceed bankfull. Overall, a magnitude order more larvae were collected in 2016-17 compared to the first two years of LTIM monitoring – where 3,418 larvae were sampled in 2015-16, and 4,249 in 2014-15.

Of the periodic 'flow-cued' species, significantly greater numbers of carp larvae were collected in 2016-17 year compared with the previous two years where flows were constrained to within channel (Table D.5, Figure D.9a). Carp larvae were one of the first species detected as larvae in the 2016-17 spawning season, and appearance coincided with the initial rise in the hydrograph, prior to rivers experiencing bank full conditions (Figure D.7). The presence of carp larvae (albeit in low numbers) when river water was hypoxic in October-November indicates that both adults and larvae may be less sensitive to low oxygen levels than many native fish species. As mentioned earlier, this is the first year larvae of bony herring have been found in the Edward Wakool River system, however counts were too low to facilitate formal statistical comparison across years.

Similarly to 2014-15 and 2015-16, we did not detect a golden or silver perch spawning event in the Edward-Wakool in 2016-17. Under non-hypoxic flood conditions, we would have hypothesed that spawning in these two species would be highly probable; however the hypoxic conditions which characterized the peak flows mean conclusions to what conditions golden and silver perch would need to spawn in Edward Wakool River system remain elusive. Subsequent watering actions post flood were carried out by the CEWO in Yallakool River post flood in late Summer-Autumn 2016-17 with aims to illicit a silver perch spawning response, however this occurred after the routine larval monitoring period had already finished up, and so we were unable to directly assess if these watering actions resulted in a success breeding event. Instead, we will use the targeted February 2018 fish recruitment surveys to detect if new silver perch recruits are present in the region.

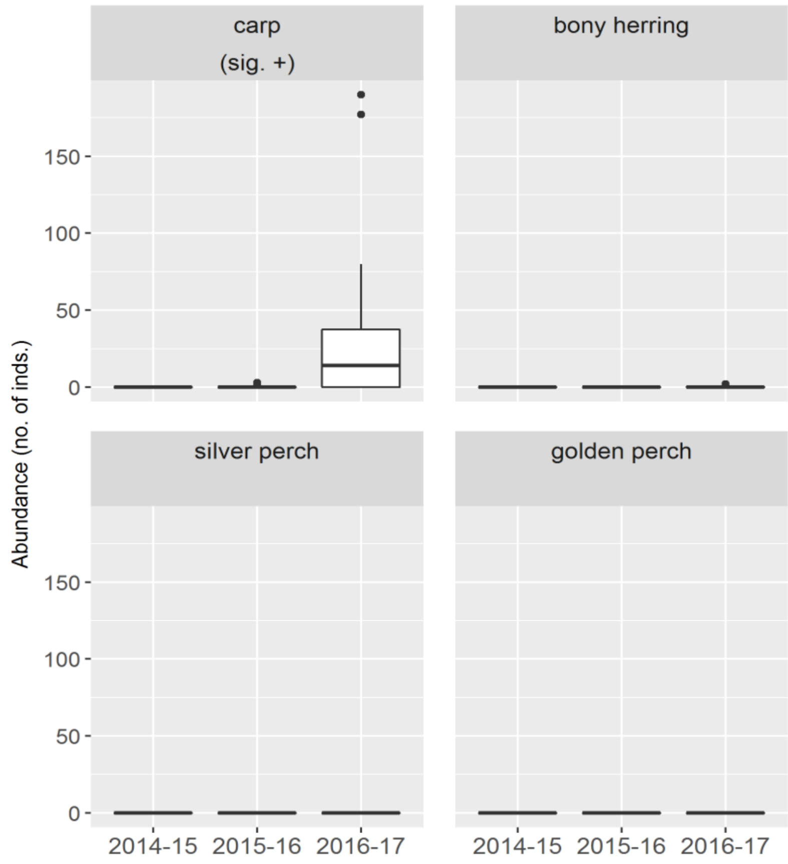
Of the Equilibrium species, there was a significant decline in the number of Murray cod larvae sampled in 2016-17 compared with previous two years (Table D5, Figure D9b). Numbers of river blackfish larvae collected were also less in 2016-17 than in previous years (Figure D9b). The timing of for spawning in equilibrium species like Murray cod and river blackfish is typically more fixed than the more flexible spawning of periodic species, and less protracted than for opportunistic species, leaving these species at a greater risk of spawning failure under conditions such as those experienced in 2016-17, when the hypoxic conditions occurred at the same time as the normal spawning window for these species (late October to mid-December). The impact of the hypoxic blackwater on adult fish population of Murray cod was also evident in the fish kills observed in the area as early as October 2016, and this would have had a substantial impact on the number of Murray cod in spawning condition in the area during the normal spawning period.

We observed a diverse response to the 2016-2017 floods conditions by small-bodied opportunistic species. Species which exhibited significantly greater numbers of larvae collected in 2016-17 compared to previous years were carp gudgeon and flathead gudgeon. Murray River rainbowfish, gambusia and weatherloach also show trends of high numbers collected in 2016-17 (Figure D9c), however abundances were too low to allow formal statistical comparisons. Fewer Australian smelt larvae were caught in 2016-17 than previous years (Figure D9c), but this trend may be a reflection of the reduced sampling effort early on in the season when smelt are typically spawning, because of limited site access during the floods.

Table D5 Results of mixed-models which tested for significance differences in total annual catch of fish larvae across years, for each species. Models where only run when n>50, and significance was determined using Wald χ^2. *P* values <0-05 used to determine significance. Significance codes: ***<0.0001, **<0.01, *<0.05. ^denotes alien species.

Fish species	n	d.f	χ^2 statistic	*P* value	significance
Periodic species					
common carp^	688	2	34.56	<0.0001	***
bony herring	6				
golden perch	0				
silver perch	0				
equilibrium species					
Murray cod	733	2	80.23	<0.0001	***
river blackfish	24				
Opportunistic species					
carp gudgeon	15975	2	19.78	<0.0001	***
flathead gudgeon	502	2	7.44	0.024	*
Australian smelt	398	2	27.48	<0.0001	***
Murray river rainbowfish	23				
gambusia^	21				
unspecked hardyhead	16				
obscure galaxias	5				
oriental weatherloach^	1				

a) Periodic species



b) *Equilibrium species*

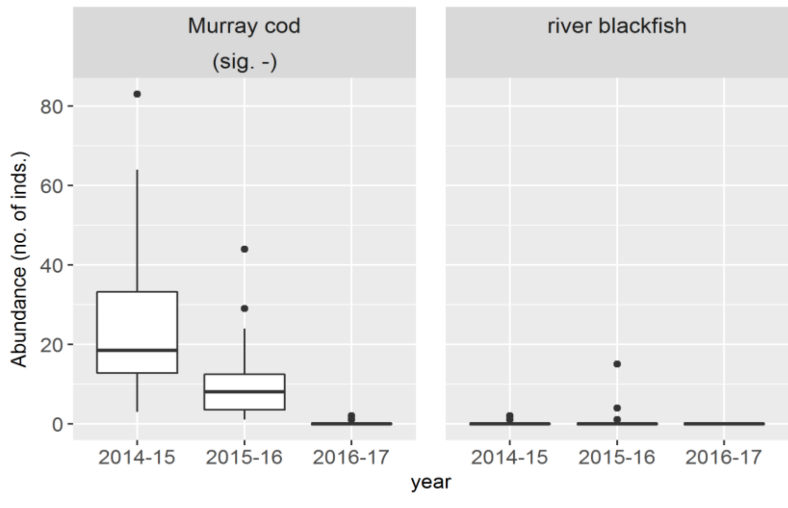


Figure D9 Boxplots of the annual total abundance of fish species collected as larvae for the three years of LTIM to date. Species are grouped according to their life history a*) periodic species* (those expected to spawn in relation to certain flow conditions) b) *equilibrium species* (large, long lived species whose spawning is independent of flow) and c) *opportunistic species* (short lived, protracted spawning species whose spawning may benefit from particular flow conditions). sig. = significant difference in mean catch between years. Trends between years ae classified as '+' (significantly higher catch in 2016-17), '-' (significantly lower catch in 20-16-17) . **(Continued next page)**

c) Opportunistic species

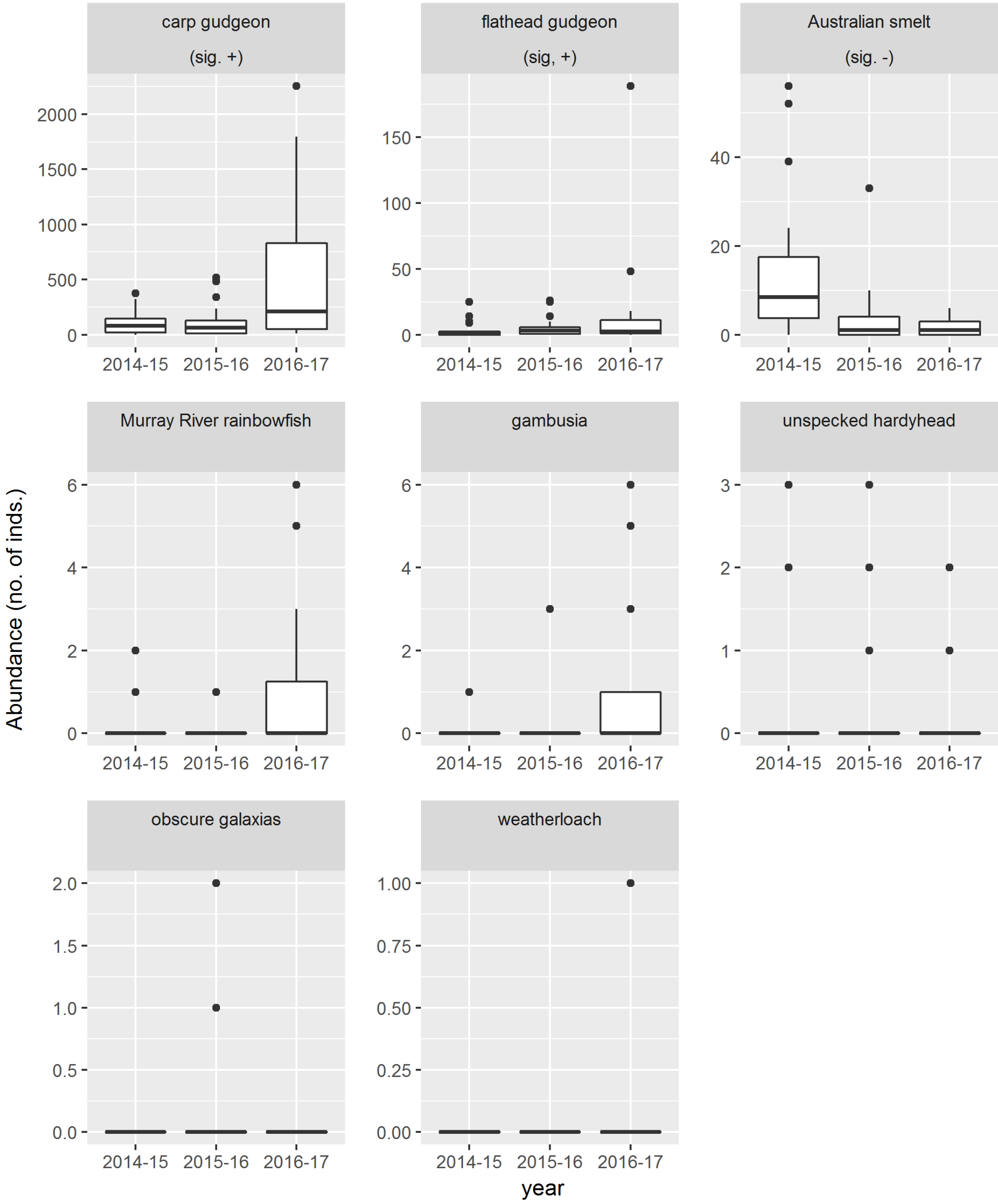


Figure D9 (continued) Boxplots of the annual total abundance of c) opportunistic fish species collected as larvae for the three years of LTIM to date. Species are grouped according to their life history a*) periodic species* (those expected to spawn in relation to certain flow conditions) b) *equilibrium species* (large, long lived species whose spawning is independent of flow) and c) *opportunistic species* (short lived, protracted spawning species whose spawning may benefit from particular flow conditions). sig. = significant difference in mean catch between years. Trends between years ae classified as '+' (significantly higher catch in 2016-17), '-' (significantly lower catch in 20-16-17).

Fish recruitment

A total of nine native fish species and five alien species were sampled between 2014/15 and 2016/17 as part of fish recruitment monitoring. The notable presence of river blackfish, present only in the Wakool River Zone 2, site 2 during each of the three years indicates a self-sustaining but localized sub-population. Golden perch recruits were not present, or were not detected by monitoring, during any of the three sampling years in the Edward-Wakool. Recruits of silver perch occurred sporadically during 2015-16 in the lower reaches of the Wakool River, while adult silver perch (Table D6) were consistently present among all years and zones.

Murray cod were the most abundant of the three species being targeted as part of fish recruitment monitoring (Table D6). Indices of YOY and 1+ recruitment of Murray cod (Figure D10) were developed for the Edward-Wakool system and compared among zones and years (Table D7), taking into account significant differences in sampling gear catch efficiency. Backpack electrofishing was the most effective gear for sampling YOY (GLMM value = 4.37 ± 0.77; t = 5.66; P<0.001) and 1+ recruits (GLMM value = 4.98 ± 0.85; t = 5.83; P<0.001).

Recruit growth

No Murray cod, Silver perch or Golden perch recruits were detected in 2016-17 and therefore no samples were available for growth analyses.

Table D6 Number of Young-of-Year (YOY), age-class 1 (1+) recruits and older juvenile and adults of the three target species sampled in recruitment and growth monitoring in the Edward-Wakool system for 2014-15 through 2016-17.

	2014-15			2015-16			2016-17		
	Stage of development			Stage of development			Stage of development		
Zone	YOY recruit	1+ recruit	Other Juvenile or Adult	YOY recruit	1+ recruit	Other Juvenile or Adult	YOY recruit	1+ recruit	Other Juvenile or Adult
Murray cod									
Yallakool Creek	5	15	17	20	8	10	0	0	0
Wakool River Zone 2	5	11	11	9	16	19	0	0	0
Wakool River Zone 3	3	14	13	8	9	16	0	0	0
Wakool River Zone 4	7	6	14	5	17	11	0	0	0
Silver perch									
Yallakool Creek	0	0	7	0	1	5	0	0	12
Wakool River Zone 2	0	0	2	0	0	3	0	0	3
Wakool River Zone 3	0	0	6	0	4	9	0	0	13
Wakool River Zone 4	0	1	1	5	15	14	0	0	7
Golden perch									
Yallakool Creek	0	0	0	0	0	0	0	0	0
Wakool River Zone 2	0	0	0	0	0	0	0	0	0
Wakool River Zone 3	0	0	1	0	0	3	0	0	0
Wakool River Zone 4	0	0	2	0	0	1	0	0	0

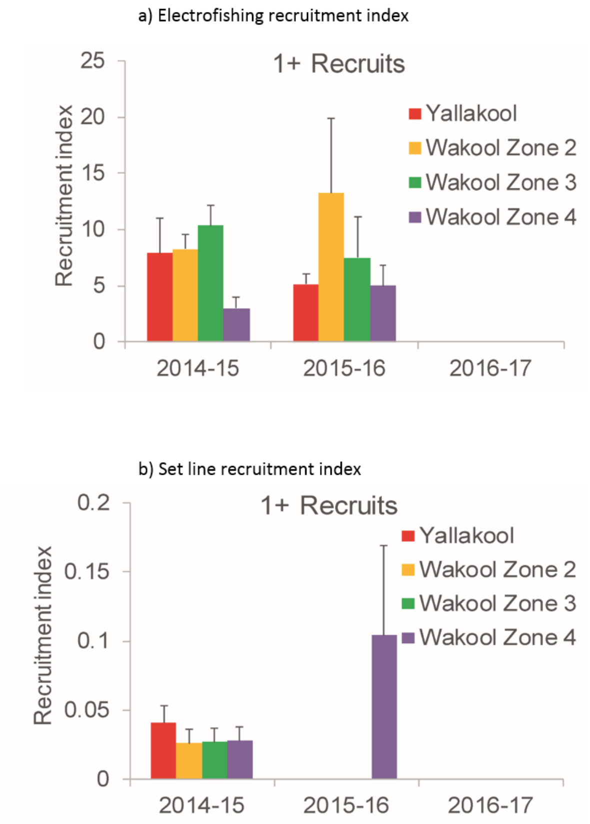


Figure D10 Variation in recruitment (#/10,000 seconds of sampling) of 1+ Murray cod from *a)* backpack electrofishing and *b)* set lines in the Edward-Wakool river system between 2014-15 and 2016-17. Values and error bars (+SE).

Table D7 Statistical results of GLMM's evaluating differences in recruitment of Murray cod and silver perch among four zones of the Edward-Wakool between 2014-15 and 2016-17. NS = Not significant.

Species	Response variable	Factors	DF	F-value	P value
Murray cod	YOY recruitment	Sampling gear	2	21.4	< 0.0001
		Year	2	7.1	< 0.001
		Zone	3	0.8	NS
		Zone:Year	6	3.6	< 0.05
	1+ recruitment	Sampling gear	2	22.8	< 0.0001
		Year	2	5.9	< 0.001
		Zone	3	0.8	NS
		Zone:Year	6	0.5	NS
Silver perch	1+ recruitment	Sampling gear	2	2.01	NS
		Year	2	6.26	< 0.001
		Zone	3	3.16	NS
		Zone:Year	6	3.79	< 0.05

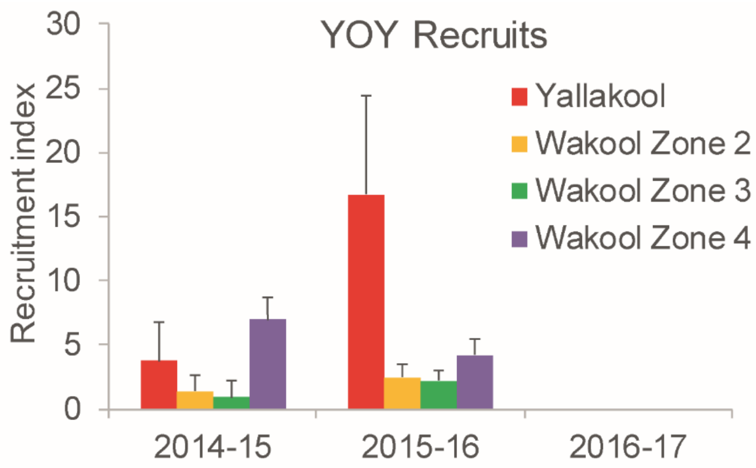


Figure D11 Variation in recruitment (#/10,000 sec of sampling) of young-of-year (YOY) Murray cod from backpack electrofishing in the Edward-Wakool river system between 2014-15 and 2016-17. Values and error bars (+SE).

Recruitment of YOY Murray cod (Figure D11) occurred throughout the system during 2014-15 and 2015-16 but was not detected within any of the zones sampled during 2016-17 (Table D6), resulting in highly significant differences in recruitment among years (Table D7). Backpack electrofishing was the only method which sampled YOY Murray cod. There were no differences in YOY recruitment among zones, or among zones within any of the years except for a significantly higher level of YOY recruitment detected within Yallakool Creek during 2015-16 (GLMM value = 5.25 ± 2.18; t = 2.40; P<0.05).

Silver perch 1+ recruits were more abundant in 2015-16, as compared with 2014-15 and 2016-17 where little to no recruitment was detected (Figure D12). Due to the low and inconsistent sample size of YOY silver perch, recruitment statistics were only calculated for 1+ recruits (Table D7). All silver perch recruits detected were sampled using angling or set line sampling methods. The significant increase in recruitment of 1+ silver perch in 2015-16 (GLMM value = 0.82 ± 0.16; t = 5.02; P<0.0001) was attributable to elevated catches in Wakool River Zone 4 (Figure D12).

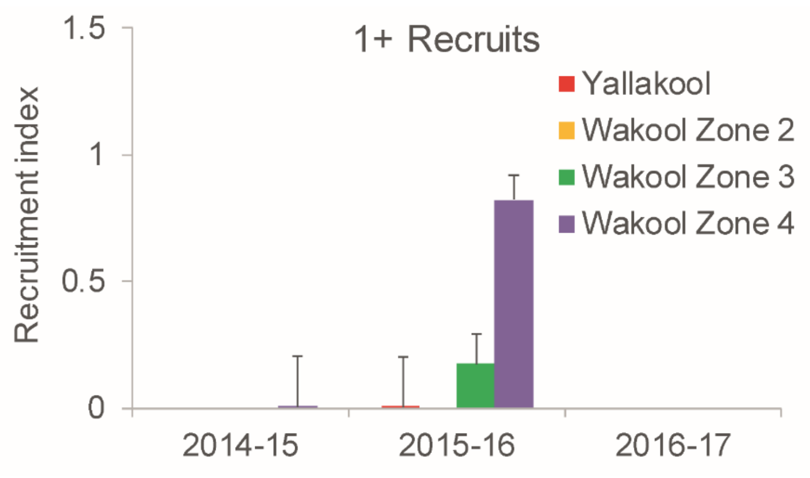


Figure D12 Variation in recruitment (#/10,000 s of sampling) of 1+ Silver perch from the Edward-Wakool river system between 2014-15 and 2016-17. Values and error bars (SE).

Adult fish community

Category 1 fish community sampling identified eight native fish species and three alien species in zone 3 during 2017 (Table D8). Flathead gudgeon were not captured in 2017, although were previously captured at low abundance in both 2016 and 2015 (Table D8). There were significant differences in the abundance of the fish assemblage between sampling years (2017, 2016 and 2015) in zone 3 (Pseudo-$F_{2,27}$ = 8.504, p<0.001). Pair-wise differences between 2017 and 2016 (t=3.526, p<0.001) were driven by a reduced abundance of Murray cod and golden perch (contribution to dissimilarity between groups 17.7 and 10.1%, respectively) and a higher abundance of carp gudgeon and bony herring (contribution to dissimilarity between groups 11.8 and 10.3%, respectively).

Table D8 Summary of fish captured during Category 1 standardised sampling in 2015, 2016 and 2017 in the Edward-Wakool LTIM project. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

Fish species	2015				2016				2017			
	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**	BE	SFN	BT	**Total**
native species												
Australian smelt	129	2	-	**131**	52	1	-	**53**	293	10	-	**303**
bony herring	31	-	-	**31**	27	-	-	**27**	108	-	-	**108**
carp gudgeon	47	4302	51	**4400**	68	2367	15	**2450**	165	6814	66	**7045**
flathead gudgeon	-	-	1	**1**	-	-	3	**3**	-	-	-	**0**
golden perch	107	-	-	**107**	116	-	-	**116**	19	-	-	**19**
Murray cod	210	-	-	**210**	333	1	-	**334**	12	-	-	**12**
Murray-Darling rainbowfish	339	168	-	**507**	353	77	5	**435**	650	19	-	**669**
silver perch	5	-	-	**5**	5	-	-	**5**	3	-	-	**3**
unspecked hardyhead	86	64	-	**150**	565	35	-	**600**	510	72	-	**582**
alien species												
common carp	167	-	-	**167**	176	-	-	**176**	735	40	3	**778**
eastern gambusia	18	175	-	**193**	36	366	1	**403**	31	125	8	**164**
goldfish	21	-	-	**21**	38	-	-	**38**	73	2	-	**75**

Length-frequency distributions indicated that bony herring captured in 2017 were significantly smaller than those captured in both 2016 (p<0.001) and 2015 (p=0.038), and a number of new recruits were captured (Figure D.13a). Golden perch captured in 2017 were significantly larger than those captured in 2016 (p=0.001) and 2015 (p=0.001) and new recruits of this species have not been captured during three years of sampling (Figure D.13b). A large proportion of common carp new recruits were captured in 2017 resulting in a significant difference in the size structure compared with both 2016 ($p<0.001$) and 2015 ($p<0.001$) (Figure D13c). No Murray cod new recruits were captured in 2017 and as a result the size structure was significantly larger than 2016 ($p<0.001$) and 2015 ($p<0.001$) (Figure D13d).

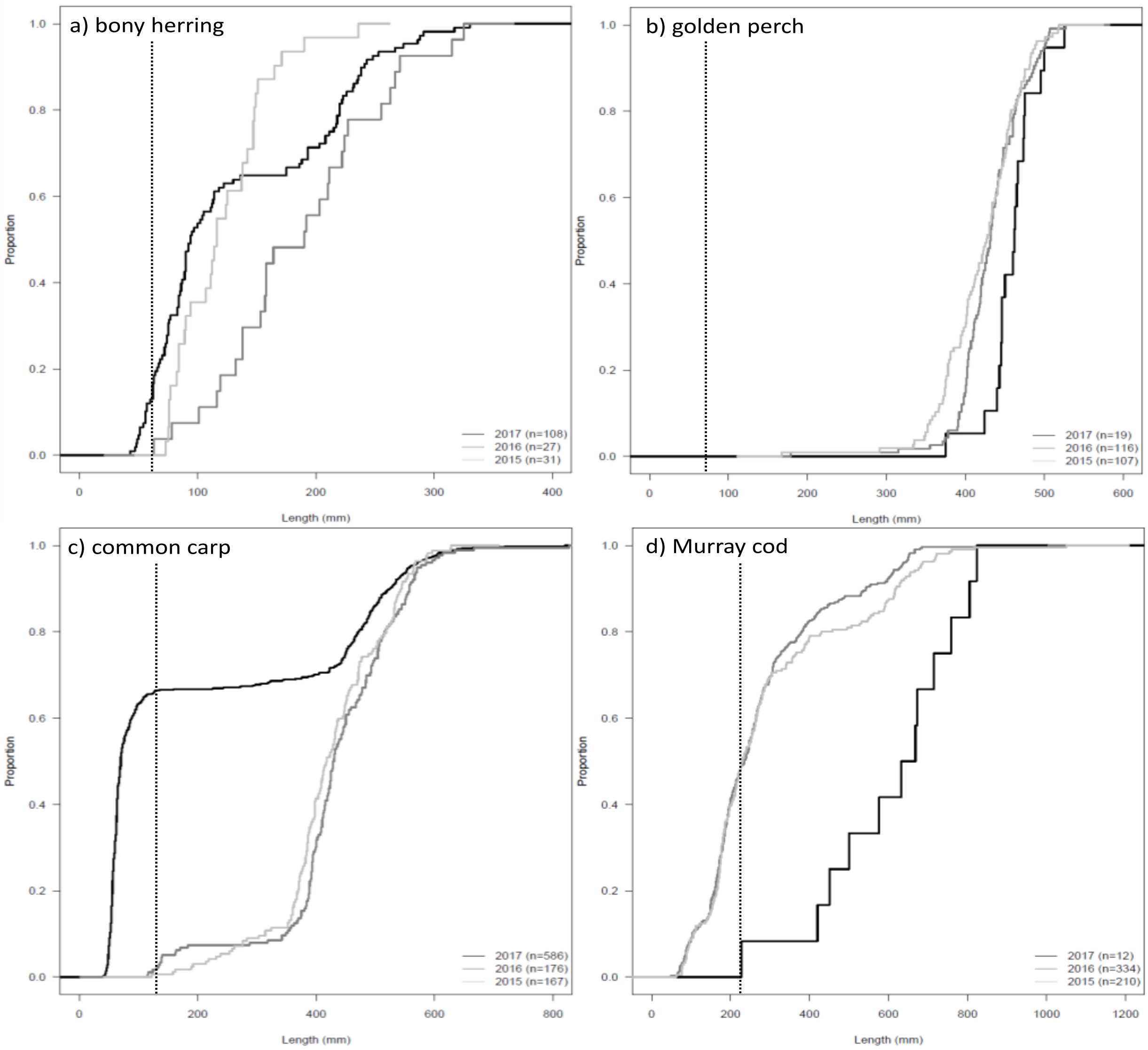


Figure D13 Cumulative length-frequency histograms of the four most common large-bodied species captured during Category 1 sampling in the Edward-Wakool LTIM project in 2015, 2016 and 2017. The dashed line indicates approximate length at one year of age and sample sizes are provided in the figure legend for each respective species and sampling year.

A total of 135 Murray cod, 12 golden perch and three silver perch were collected during hypoxic blackwater fish kills and otoliths removed. Collections of Murray cod were size-biased (i.e. abundance of smaller fish is generally higher than that of larger fish) towards large fish as these are often conspicuous following fish kills (Figure D14). Nevertheless, the Murray cod collected spanned a broad range of size classes, ranging from 252–1098 mm in length (Figure D15).

Figure D14 An example of Murray cod located in a backwater following a hypoxic fish kill in 2016 (left), and lined up for measurement prior to removal of otoliths (ear bones) for later ageing (right).

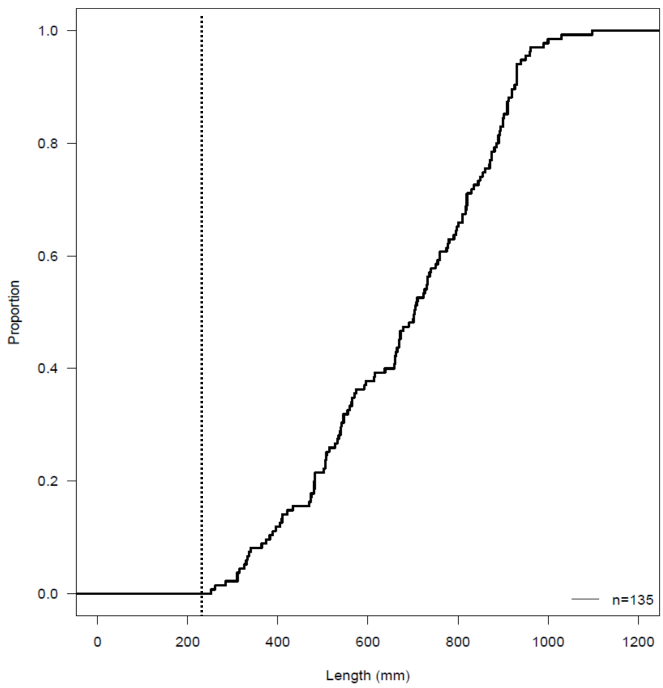


Figure D15 Cumulative length-frequency histogram Murray cod collected following hypoxic blackwater fish kills in late 2016 in the Edward-Wakool and lower Billabong systems. The dashed line indicates approximate length at one year of age and sample size is provided in the figure legend.

D.6 Discussion

Extensive floodplain inundation resulting from unregulated inflows in late 2016 resulted in hypoxic blackwater and subsequent widespread fish kills in the Edward-Wakool river system. While the magnitude of the fish kills remain unquantified, substantial numbers of large bodied fish including Murray cod, and to a lesser extent golden perch and silver perch, were affected. Here, we bring together our results across the movement, spawning, recruitment and adult sampling to provide an overview of how the fish community in the Edward-Wakool responded to the high unregulated flows, the subsequent hypoxic conditions in spring, and the return to base flows in autumn.

Periodic species (e.g. golden perch, silver perch)

Periodic species are characterised as relatively large, long-lived species that have high fecundity and low investment in offspring (i.e. a lot of small eggs and no parental care) (King et al. 2013). Within the Edward-Wakool system, bony herring, golden perch and silver perch are representatives of this group. Spawning and recruitment in all three species is thought to benefit from higher flow events and even over-bank flooding (King et al. 2013), and as such the group represents an excellent target for environmental water delivery. However, it should be noted that existing flow-ecology relationships aren't definitive and substantial flexibility has been documented through all species' distributional ranges (e.g. Mallen-Cooper and Stuart 2003; Balcombe et al. 2006; Balcombe and Arthington 2009). Regardless of the conjecture, there is a general agreement that substantial reductions in populations, particularly of golden perch and silver perch, have resulted from alteration of the seasonal timing and magnitude of river flows as a result of water resource development within the Murray-Darling Basin (Lintermans 2007).

The 2016-17 watering year was characterised by overbank flooding which preceded a hypoxic blackwater event and ultimately resulted in extensive fish kills of a number of large-bodied native species. Prior to low dissolved oxygen levels, acoustic telemetry was used to identify the direction and scale of movements exhibited by silver perch and golden perch. Both species exhibited persistent and directional movements (generally in a downstream direction and out of the LTIM focal zones) associated with increasing water temperatures and river flows, a result consistent with previous studies. For example, Koster et al. (2014) demonstrated downstream pre-spawning movements of golden perch in the Goulburn River, Victoria. O'Connor et al. (2005) identified both downstream and upstream pre-spawning movements in Murray River golden perch, including the relocation of a number of fish to an area near the junction of the Wakool and Murray rivers. More recently, Koster et al. (2017) developed probabilistic models of golden perch movement over multiple years for Goulburn River fish and identified that prior to spawning, movements primarily occurred in response to elevated flows and in a downstream direction. Collectively, the results from this study and others fit our conceptual model of the life history requirements for the two species. Namely that the spatial scales adults of each species can operate over is vast (at least 100's of kilometers), that the direction of movements is relative to the system individuals occupy (i.e. not necessarily upstream), and that high flows and rising water temperatures can induce large-scale pre-spawning movements. As the movements of both species were interrupted by hypoxic blackwater in 2016-17, the spatial extent of the movements and possible responses to flows in the absence of hypoxia were not able to be quantified.

Consistent with previous sampling conducted in 2014-15 and 2015-16, there was no evidence of spawning for either golden perch or silver perch in the Edward-Wakool in 2016-17. In comparison, bony herring larvae were captured in the system, indicating that localised spawning occurred for this species in January and February 2017. The result of localised spawning in bony herring is unsurprising given that juveniles of this species are regularly captured in the lower reaches of the system. Conversely, neither eggs, larvae nor juvenile golden perch have been captured in the past three years of monitoring in the Edward-Wakool system, and indeed captures of juveniles from other monitoring programs are rare. Thiem et al. (2017) captured few juvenile golden perch at hypoxic blackwater affected sites within the system and identified that immigration into the system was the most likely explanation for the presence of older golden perch (i.e. pre-blackwater events). While spawning of golden perch in the Murray River is regularly documented (e.g. Gilligan et al. 2003, King et al. 2005, Koster et al. 2014), recent evidence suggests that larger scale processes such as immigration of juveniles from the Darling River during flood years may be driving recruitment processes (Zampatti et al. 2014). Subsequently, we recommend future use of CEW should focus on objectives centered on movement, growth and survival of adults within the Edward-Wakool system, continuing to target end of system attraction flows to promote immigration of juveniles and adults into the system from the Murray River.

Despite the presence of both YOY and 1+ silver perch recruits within the Edward-Wakool system in 2015-16, these age classes were not detected within the LTIM focal zones in 2016-17. This result is unsurprising given the magnitude and extent of hypoxic blackwater fish kills within the Murray region in late 2016. However, a number of juvenile and adult silver perch were captured during recruitment sampling in February 2017 and fish community surveys in May 2017. Telemetry data indicates that silver perch regularly move 100's of kilometers in response to river level rises, and the presence of these individuals within the Edward-Wakool system may reflect rapid recolonisation following the hypoxic blackwater event in late 2016, or alternatively survival during the hypoxic event. The Edward-Wakool is part of the mid-Murray region that supports the strongest remnant population of silver perch in the Murray-Darling Basin. This population exhibits regular spawning and recruitment (except in years of hypoxic blackwater), reflected by a balanced size and age structure (Tonkin et al. 2017). Recent evidence suggests that year-classes of this species are strongest in low-average Murray River discharge years, and which are preceded by widespread flooding (Tonkin et al. 2017). In other words, flooding promotes survival and dispersal of 1+ silver perch rather than YOY silver perch in non blackwater years. While an environmental watering action was delivered to Yallakool Creek in autumn to encourage silver perch spawning, the event was unmonitored as water delivery occurred outside of our larval fish monitoring program. Subsequently the outcome of this action could not be assessed. It is worthwhile noting that the presence of any YOY and 1+ silver perch in the system in 2018 may be a result of either localised spawning or immigration from the Murray River, subsequently retrospective evaluations will not provide definitive evidence of the watering action.

Equilibrium species (e.g. Murray cod, river blackfish)

Equilibrium species are characterised by medium-late maturation, exhibit low fecundity and have a high energetic investment in offspring (i.e. few but large eggs and parental care) (King et al. 2013). Examples of equilibrium species in the Edward-Wakool system are river blackfish, freshwater catfish and Murray cod. While the actual act of spawning does not require flowing water, there is evidence to suggest that flowing water habitats are required to promote larval survival (Rowland 1983). All three species occur within the broader Edward-Wakool system, although Murray cod are the only species regularly captured as larvae, juveniles and adults and are considered abundant.

In 2016/17, the presence of hypoxic blackwater resulted in extensive kills of large numbers of Murray cod in the mid-Murray region including the Edward-Wakool system. A number of telemetry tagged individuals residing in zone 3 (Wakool River) moved upstream through both Yallakool Creek and the upper Wakool River and into the Edward River during river levels rises and prior to hypoxia, although these individuals have not since returned (Jason Thiem, *Unpublished data*). A small number of Murray cod larvae were captured in zones 1, 2 and 3 in Yallakool Creek and the Wakool River in late 2016, and while abundance of larvae was substantially reduced compared with previous years, the result is promising. No Murray cod were captured in the recruitment sampling, although a small number of Murray cod representing a range of size classes (excluding YOY) were present within zone 3 during fish community sampling in May 2017.

Substantial fish kills associated with widespread flooding occurred in parts of the southern Murray Darling Basin in 2010/11, including the Edward-Wakool system (Hladyz et al. 2011; King et al. 2012; Whitworth et al. 2012). Encouragingly, recent evidence from the Edward-Wakool system indicates that recovery of the Murray cod population from the 2010/11 fish kills was predominantly driven by localised spawning and recruitment originating from surviving remnant adults (Thiem et al. 2017). Given evidence of a number of remnant adult Murray cod, as well as documented localised spawning in preceding monitoring years under this LTIM program, it is anticipated that natural processes are the most likely recovery pathway for this species. Environmental water can be used to facilitate these natural recovery pathways through the provision of flows that promote pre-spawning movements, provide stable flowing water habitats that maximise nest site inundation and support productivity to enhance larval and juvenile survival (including the provision of winter flows/avoiding cease to flow conditions – see recommendations), growth and recruitment into the adult population to recover the species.

Opportunistic species (e.g. gudgeons, Murray River rainbowfish, hardyheads)

Opportunistic fish species are characterised by being small bodied and having fast growth rates, small eggs and frequent reproduction over an extended spawning season (Winemiller and Rose 1992). There are six native small bodied opportunistic species known to the Edward-Wakool selected area: Australian smelt, carp gudgeon, flathead gudgeon, unspecked hardyhead, Murray River rainbowfish and obscure galaxias. These species will spawn and recruit under a range of flow conditions, however the early life stages of these species are commonly found in slow flowing slackwater waters, suggesting that shallow, low flow environments are important nursery areas for this group of fish (Humphries et al. 1999, Lyon et al. 2010, Bice et al. 2014). Such conditions occur under two contrasting flow conditions, during spring/summer base flows, and during high flows if new suitable habitats are created through temporary inundation and connectivity of floodplain habitats including ephemeral creeks, backwaters, oxbow billabongs and the floodplain proper. When flooded, these areas create slow flowing, shallow habitats which provide protection from larger bodied predators, and increased food resources due to increased microinvertebrate abundance which are a key prey resource. Subsequently, flows that provide a significant increase in slackwater habitat are likely to result in an increase larval production and subsequent adult abundance (Humphries et al. 1999, Lyon et al. 2010).

We observed a mixed response spawning response by opportunistic species to the 2016-17 hydrological conditions. Generally, the flood conditions that occurred in 2016-17 either favoured, or had no effect on degree of spawning. Of the eight small bodied opportunistic species known to spawn in the Edward-Wakool region, only two had significantly less larvae in 2016-17 compared with previous years; Australian smelt and obscure galaxias. Australian smelt generally spawn in the Edward-Wakool river system from early spring until late December. The timing of the hypoxic event throughout our study zones coincided with the species spawning period, and may explain the lower numbers of smelt caught in 2016-17. In the case of obscure galaxias, captures of larvae are too low to make any definitive conclusions about their long-term population trends in the Edward-Wakool.

Overall, populations of opportunistic species within the Edward-Wakool system were not negatively affected by hypoxic blackwater event in 2016. Monitoring of larvae and adult fish populations showed several species responded positively to the high flows experienced in the area (e.g carp gudgeon, Murray River rainbowfish), while the majority of species still exhibited similar spawning responses to that of previous years. Opportunistic species typically spawn over several months from spring through to summer, and so many species still had the opportunity for spawning post blackwater throughout the summer months. Monitoring of adult catches of opportunistic species in 2017-18 will be important to increasing our understanding on what the flow on effects of the floods in 2016-17 will be for the adult populations of these species.

Conclusion

Extensive floodplain inundation resulting from unregulated inflows in late 2016 resulted in hypoxic blackwater and subsequent widespread fish kills in the Edward-Wakool river system, as well as in other parts of the southern Murray-Darling Basin. While the magnitude of the fish kills remain unquantified, substantial numbers of Murray cod, and to a lesser extent golden perch and silver perch, were affected. Despite the hypoxia, spawning was detected in a number of small-bodied and two large-bodied native species (Bony herring, Murray cod) in the Edward-Wakool system during the 2016-17 watering season (Table D.9). Further, whilst the abundance and biomass of golden perch and Murray cod were reduced, subsequent surveys indicated the presence of adults comprising a representative range of size classes of both species within the affected reaches. While the exact mechanisms (survival or immigration) contributing to the presence of a range of native species within the system so soon after the hypoxic event remain unclear, their presence alone is promising and provides a good foundation for recovery.

Table D9 Summary of 2016-17 results from fish sampling in the Edward-Wakool River Selected area of species known to occur in the area prior to 2016. For 2016-17 sampling season - ticks denote the presence of larvae (indicating successful spawning), recruits (indicating successful recruitment) and adults (indicating either tolerance to hypoxic conditions of spring 2016, or subsequent movement back into the selected area in May 2017). ^ denote introduced species. [1] Indicates species have been recorded in the Edward Wakool system, but outside the LTIM focal study zones.

2014-16	2016-17		
Adults	Larvae	Recruits	Adults
periodic species			
bony herring	✓	✓	✓
golden perch			✓
silver perch			✓
common carp^	✓	✓	✓
redfin perch^			
goldfish^		✓	✓
equilibrium species			
Murray cod	✓		✓
river blackfish			✓
trout cod[1]			
eel-tailed catfish[1]			
opportunistic species			
Australian smelt	✓	✓	✓
carp gudgeon	✓	✓	✓
Murray river rainbowfish	✓	✓	✓
flathead gudgeon	✓		✓
unspecked hardyhead	✓	✓	✓
dwarf flathead gudgeon[1]			
galaxias oliros			
gambusia^		✓	✓
oriental weatherloach^			

Monitoring within the Edward-Wakool system has documented recovery of large-bodied native fish populations from previous hypoxic events. Recent data indicates that Murray cod most likely repopulate through localised spawning and recruitment from remnant adults (Thiem et al. 2017). In contrast, golden perch (and presumably silver perch) populations appear to operate over much larger spatial scales and immigration of juveniles and adults into the Edward-Wakool system from the Murray River are most likely driving localised population dynamics (Zampatti et al. 2015; Thiem et al. 2017; Tonkin et al. 2017). Nevertheless, the Edward-Wakool system still provides a diverse array of available habitats to these and other native freshwater fish. The habitat mapping proposed earlier in this report and other recommendations would guide how to best improve the quality of these habitats through the use of environmental water and other complimentary measures, such as re-snagging.

APPENDIX E: PRELIMINARY MODELLING OF ENVIRONMENTAL WATER RELEASES FROM MURRAY IRRIGATION LIMITED ESCAPES

Preliminary modelling of environmental water releases from Murray Irrigation Limited irrigation escapes to the Edward-Wakool system to provide localised areas of refuge habitat for aquatic fauna

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Background

Aquatic organisms require oxygen that is dissolved in the water for respiration. When dissolved oxygen (DO) levels become depleted it becomes increasing difficult for these organisms to obtain sufficient oxygen to meet their metabolic requirements and they become stressed. Hypoxia is defined as a level of dissolved oxygen at which an organism experiences stress (Whitworth et al., 2011). The level at which hypoxia is reached will vary between aquatic species and at differing water temperatures. With the effect of oxygen depletion on aquatic organisms further exacerbated at high temperatures when both the metabolic demand for oxygen is increased and the solubility of oxygen in water reduced(McNeil & Closs, 2007).

General guidelines for the levels of hypoxic water in the lowland rivers systems in the Murray Darling Basin were developed during previous hypoxic events (Whitworth et al. 2011; Whitworth et al. 2013). These guidelines are;

- 'normoxic' (not hypoxic): >6 mg/L
- 'low DO': 4-6 mg/L
- 'hypoxic': 2-4 mg/L
- 'severely hypoxic': <2 mg/L

These levels have been used by government departments and natural resource management agencies as a guide to the varying levels of DO and used as trigger to initiate management actions to try to either improve DO levels or reduce the impacts of low DO levels.

The Edward-Wakool system is a large anabranch system in the mid reaches of the Murray River in the southern Murray-Darling Basin (MDB) that has a highly altered flow regime due to river regulation and extraction of water for agriculture. During periods of flooding the dissolved oxygen and dissolved carbon concentration in the Edward-Wakool system is influenced by water flowing through large river red gum forests (Barmah-Millewa Forest and Koondrook Perricoota Forest) that are upstream of the system. Under certain conditions this can result in hypoxic blackwater in the Edward-Wakool system. It was one of the areas in the MDB that experienced hypoxic blackwater during flood events in 2010-2011 and 2012.

Irrigation escapes

The Edward-Wakool system is intersected by an extensive irrigation network owned and operated by Murray irrigation Limited (MIL). The network is fed by the Mulwala Canal that diverts water from Lake Mulwala on the Murray River to create the head required to distribute water via gravity fed irrigation canals to irrigation areas. There are over 100 escapes from the MIL irrigation network, the majority of them having a delivery capacity of approximately 20 ML/day. The modelling in this report was undertaken for three of the larger irrigation canal escapes in the MIL irrigation network (Figure 1); the Edward Escape from the Mulwala Canal to the Edward river upstream of the town of Deniliquin (flow capacity 2400 ML/day), the Wakool Escape from the Mulwala Canal to the Wakool River downstream of the Wakool offtake regulator (500 ML/day), and the Thule Escape from the Denniboota Canal into the Thule Creek, downstream of Koondrook Forest (40 ML/day).

During hypoxic blackwater events the Mulwala Canal and associated irrigation network often has higher dissolved oxygen and lower dissolved carbon concentration than the rivers in the Edward-Wakool system because canal water is diverted from Lake Mulwala upstream of the redgum forests. The irrigation escape are a useful mechanism for providing high dissolved oxygen refuges for fish and other aquatic fauna during overbank hypoxic blackwater events.

Irrigation escapes from the MIL network have been used during previous hypoxic blackwater events to deliver environmental water to the system to create refuge. During a blackwater event in 2010/11 Commonwealth environmental water was released from three Mulwala Canal escapes (Edward escape, Wakool escape, Yallakool escape) to lessen the impact of hypoxia and create localised refugia with higher DO and lower organic carbon (Whitworth et al. 2013; Watts et al. in press). In 2014 the NSW Office of Environment and Heritage trialled the use of the MIL Thule escape to deliver environmental water into the Thule Creek, downstream of the forest.

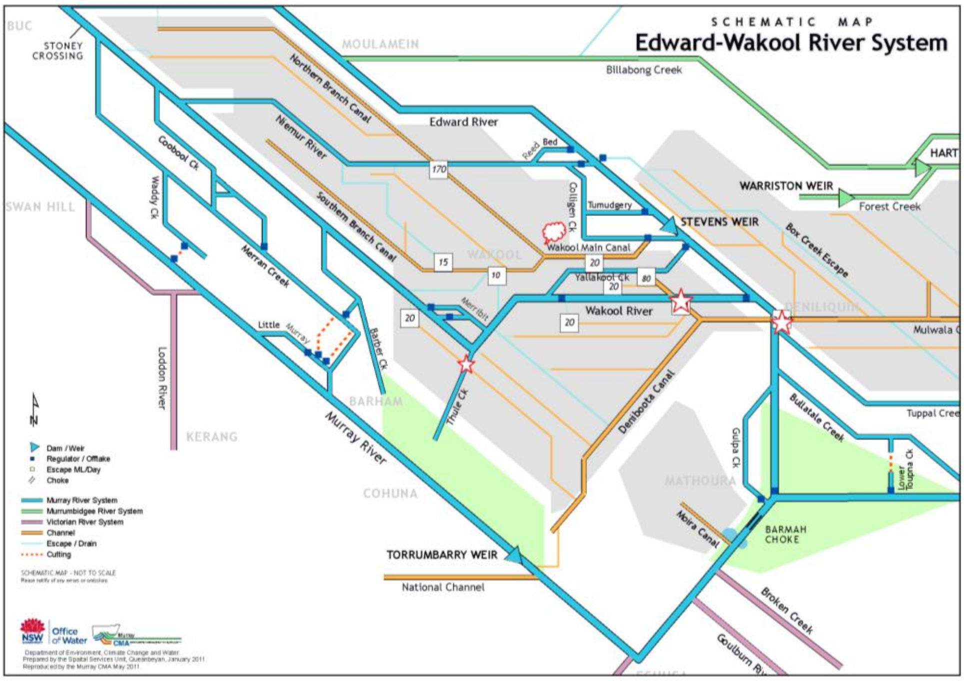

Figure 1 Schematic map of the Edward-Wakool system. Red stars indicate the locations of the Edward Escape, Wakool escape and Thule Escape with respect to the river and irrigation canal network.

Blackwater Interventional Assessment Tool

The Blackwater Intervention Assessment Tool (BIAT) (Whitworth et al 2013) was used to assess the effectiveness of intervention through the delivery of Commonwealth environmental water from irrigation Murray Irrigation Limited (MIL) irrigation escapes to the Edward River, Wakool River and Thule Creek. The BIAT is a model that can be used to assess the potential effectiveness of a range of intervention activities (dilution, mechanical re-aeration, lake/wind re-aeration) that could be undertaken during a hypoxic blackwater event (Whitworth et al 2013).

For dilution flows, the model requires the following input parameters:

- Characteristics of blackwater upstream of the irrigation escape
    - Discharge
    - Dissolved oxygen (DO) concentration
    - Dissolved organic carbon (DOC) concentration
    - Water temperature
- Characteristics of dilution water in the irrigation canal
    - dilution water discharge
    - DO concentration
    - DOC concentration
    - Water temperature
- Characteristics of the river downstream of the escape
    - Average channel depth
    - Average channel width

Data sources

- Dissolved oxygen concentrations and temperature data used in the modelled scenarios were taken from the DPI real time data website for the Edward River at Deniliquin and Wakool River at Gee Gee Bridge (19/10/2016) and data collected by CSU staff at Mulwala Canal (18/10/2016) and Thule Creek (17/10/2016).

- DOC and absorbance data for three dates in mid- late August 2016 including water samples from the Wakool River, Thule and Barber's Creek were used to create a calibration between absorbance and DOC so that absorbance measurements from samples collected this week could be used to estimate DOC currently in the system. The most recent measurements for the Edward River were taken in the last week of September. To provide more up-to-date results the DOC values used for this site have been modelled on those currently found in the Wakool River.

- Maximum width, maximum depth and average depth of the receiving river immediately downstream of the escapes were estimated from a number of sources including cross section surveys based on river discharge/heights in ratings tables.

Results

The results for the scenarios presented in Table 1 are based on the current water quality conditions (water temperature, DO concentration, and DOC concentration). The water quality will change over time and the models will need to be updated when the river discharge has receded to lower levels and as water temperature rises.

Local outcomes

- The model predicts an improvement in DO at the site of mixing for all of the Wakool Escape scenarios, small improvement in local DO in the Edward River (but best for scenarios with 10% or higher dilution), and minimal change in Thule Creek until discharge reduces to 1000 ML/day or less.

- Although some of the scenarios suggest there will be minimal improvement in DO, there may be a local effect at the point of delivery due to incomplete mixing leaving a zone of water that predominantly reflects the water quality in the canal. A plume of higher DO water coming out of the canal escape may sustain a local refuge.

Downstream outcomes

- The downstream effects of dilution flows are very difficult to predict as there are a lot of assumptions in the time series component of the BIAT model that need to be considered and tested with field data before the time series models could be used to underpin management decisions

- Depending on the temperature of the water, amount of biological activity, amount and type of carbon, depth and width of channel (influencing rate of reaeration) the DO could improve, remain the same or decrease as the canal water moves downstream. In 2010/11 we observed that the DO increased immediately at the point of delivery but then remained stable for 40km downstream of the escape.

- Preliminary modelling of downstream effects indicate that that a deeper average channel scenario results in much slower recovery of the dissolved oxygen as the water moves downstream although estimates of channel depth do not alter the result at the point of mixing. Higher DOC also slows the recovery of oxygen concentrations over time. Very preliminary modelling within the current scenarios over a DO range of 16-30 mg/L suggests that DO will not reduce after the point of mixing unless water temperatures rise above 20 degrees (in the absence of additional inputs of carbon downstream).

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Table 1. Results of preliminary modelling of environmental water releases from irrigation escapes to provide localised areas of refuge for aquatic fauna

Wakool escape

	Upstream escape				**Wakool Escape**				**Downstream escape**					**Local outcome**	
scenario	Discharge (ML/d)	DO (mg/L)	DOC (mg/L)	Temp (°C)	Discharge (ML/d)	DO (mg/L)	DOC (mg/L)	Temp (°C)	Discharge (ML/d)	Predicted DO (mg/L)	Max width (m)	Max depth	Av depth (m)	% dilution	Change in DO (mg/L)
1	5,000	1.0	16	17	500	8.05	5	16.6	5,500	1.6	120	5.7	1.7	9.1	+ 0.6
2	4,500	1.0	16	17	500	8.05	5	16.6	5,000	1.7	50	5.5	2.4	10.0	+ 0.7
3	2,000	1.0	16	17	500	8.05	5	16.6	2,500	2.4	28	3.9	1.9	20.0	+ 1.4

Edward escape

	Upstream escape				**Edward Escape**				**Downstream escape**					**Local Outcome**	
scenario	Discharge (ML/d)	DO (mg/L)	DOC (mg/L)	Temp (°C)	Discharge (ML/d)	DO (mg/L)	DOC (mg/L)	Temp (°C)	Discharge (ML/d)	Predicted DO (mg/L)	Max width (m)	Max depth	Av depth (m)	% dilution	Change in DO (mg/L)
1	60,000	0.9	16	17.4	2,500	8.05	5	16.6	62,500	1.2	130	9.8	5.4	4.0	+ 0.3
2	60,000	0.9	16	17.4	1,000	8.05	5	16.6	61,000	1.0	130	9.8	5.4	1.6	+ 0.1
3	22,500	0.9	16	17.4	2,500	8.05	5	16.6	25,000	1.6	90	7.4	5.0	10.0	+ 0.7
4	15,000	0.9	16	17.4	2,500	8.05	5	16.6	17,500	1.9	80	6.6	4.0	14.3	+ 1.0
5	15,000	0.9	16	17.4	1,000	8.05	5	16.6	16,000	1.3	75	6.4	4.0	6.3	+ 0.4
6	10,000	0.9	16	17.4	2,500	8.05	5	16.6	12,500	2.3	75	5.9	4.0	20.0	+ 1.4

Thule escape

	Upstream escape				**Thule Escape**				**Downstream escape**					**Local Outcome**	
scenario	Discharge (ML/d)	DO (mg/L)	DOC (mg/L)	Temp (°C)	Discharge (ML/d)	DO (mg/L)	DOC (mg/L)	Temp (°C)	Discharge (ML/d)	Predicted DO (mg/L)	Max width (m)	Max depth	Av depth (m)	% dilution	Change in DO (mg/L)
1	5,000	1.6	19	17.6	40	8.05	5	16.6	5,040	1.7	30	2.8	2.8	0.8	0.0
2	2,000	1.6	19	17.6	40	8.05	5	16.6	2,040	1.7	30	1.9	1.9	2.0	+ 0.1
3	1,000	1.6	19	17.6	40	8.05	5	16.6	1,040	1.9	30	1.4	1.4	3.8	+ 0.3
4	500	1.6	19	17.6	40	8.05	5	16.6	540	2.1	30	1.1	1.1	7.4	+ 0.5
5	250	1.6	19	17.6	40	8.05	5	16.6	290	2.5	30	0.8	0.8	13.8	+ 0.9

APPENDIX F: REFERENCES FOR APPENDICES

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