Australian Government
Commonwealth Environmental Water Office

Institute for Land, Water and Society
Charles Sturt University

research for a sustainable future

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

2017-18

Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Technical Report 2017-18

Project no:	OPA 101022
Document title:	Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Technical Report 2017-18
Date:	27/09/2018
Client name:	Commonwealth Department of the Environment and Energy
Project manager:	Robyn Watts
Authors:	Robyn J Watts, Nicole G McCasker, Julia A Howitt, Jason D Thiem, Mike R Grace, John A Trethewie, Sascha Healy, Nick R Bond

Institute for Land, Water and Society
Charles Sturt University
PO Box 789
Albury, NSW 2640
ABN 83 878 708 551

Cover photos:

Left - Larval freshwater catfish *(Tandanus tandanus*) caught in the Wakool River in December 2017 (Photo: J Trethewie)

Middle – Wakool River Barham Bridge (zone 4 site 1) on 8 June 2017 during the winter environmental watering action (Photo: S Healy)

Right – Silver perch eggs collected from drift nets deployed in Yallakool Creek, 6 December 2017 (Photo N McCasker)

Copyright © Copyright Commonwealth of Australia, 2018

'Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Technical Report, 2017-18 is licensed by the Commonwealth of Australia for use under a Creative Commons By Attribution 3.0 Australia licence with the exception of the Coat of Arms of the Commonwealth of Australia, the logo of the agency responsible for publishing the report, content supplied by third parties, and any images depicting people. For licence conditions see: http://creativecommons.org/licenses/by/3.0/au/

Citation: This report should be attributed as

Watts R.J., McCasker N.G., Howitt J.A., Thiem J.D., Grace M.R., Trethewie J.A., Healy S., Bond N.R. (2018). 'Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Technical Report, 2017-18'. Report prepared for Commonwealth Environmental Water Office. Commonwealth of Australia.
The Commonwealth of Australia has made all reasonable efforts to identify content supplied by third parties using the following format '© Copyright.

Disclaimer:
The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the Australian Government or the Minister for the Environment. While reasonable efforts have been made to ensure that the contents of this publication are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

Institute for Land, Water and Society, Charles Sturt University	Institute for Land, Water and Society Charles Sturt University PO Box789, Albury, NSW 2640
NSW Department of Primary Industries	NSW Department of Primary Industries Narrandera Fisheries Centre, PO Box 182, Narrandera NSW 2700
MONASH University	Water Studies Centre Monash University Clayton, Victoria, 3800
NSW Office of Environment & Heritage	NSW Office of Environment and Heritage PO Box 363, Buronga NSW 2739
LA TROBE UNIVERSITY	School of Life Sciences La Trobe University PO Box 821,Wodonga 3689

Contents

Executive summary 5

1 Introduction 12

2 Environmental water use objectives and watering actions in 2017-18 14

3 Monitoring and evaluation 21

4 Hydrology 30

5 Water quality and carbon 46

6 Stream metabolism 69

7 Aquatic and riverbank vegetation 90

8 Fish 102

Recommendations 145

Acknowledgements 152

References 153

Appendices 159

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 2017-18. It is the fourth annual report of the Long Term Intervention Monitoring (LTIM) Project (2014-2019) funded by the Commonwealth Environmental Watering Office. The project was undertaken as a collaboration among Charles Sturt University (CSU), NSW DPI (Fisheries), Monash University, NSW Office of Environment and Heritage (OEH), and La Trobe University. Field monitoring for the project was undertaken by staff from CSU, NSW Fisheries and OEH.

This report focusses on Commonwealth environmental watering actions in the Edward-Wakool Selected Area from 1 May 2017 (start of watering action 1) until 30 June 2018. In 2017-18 six environmental watering actions were planned for the Edward-Wakool system (Table i). Watering actions 1, 2, 4, 5 and 6 were delivered. Watering action 3 was not delivered due to unregulated flows occurring above channel capacity at the time of this planned action.

Table i Planned Commonwealth environmental watering actions in the Edward-Wakool system in 2017-18

	Planned watering action	Type of action	Dates	Rivers	Objectives
1	Winter watering action	base flow	1 May - 23 Aug 2017	Yallakool Creek, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to reinstatement of the natural hydrograph, connectivity, condition of in-stream aquatic vegetation and fish recruitment
2	Early spring fresh at beginning of e-flow with flow recession	small fresh and flow recession	7 Sept - 22 Oct 2017	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to connectivity, water quality, stimulating growth of in-stream aquatic vegetation, pre-spawning condition of native fish, spawning in early spawning native fish
3	Maintain e-flow	small fresh	Not delivered*	N/A	To maintain nesting habitat for Murray cod and inundation for aquatic vegetation growth
4	Summer fresh at end of e-flow with flow recession	small fresh and flow recession	3 - 29 Jan 2018	Yallakool Creek, mid and lower Wakool River	To encourage fish movement and assist dispersal of larvae and juveniles of fish species.
5	Autumn fresh with flow recession	small fresh with flow recession	28 Mar - 1 May 2018	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To encourage fish movement and dispersal of juveniles of a number of fish species.
6	Summer fresh	small fresh	11 Jan – 11 Feb 2018	Niemur River	To improve water quality (in response to a heatwave driven low DO event)

*Watering action 3 was not implemented due to an unregulated fresh occurring at the time of this planned action

This report documents the monitoring and evaluation of environmental watering actions and watering regimes the Edward-Wakool Selected Area in 2017-18 for the following indicators:

- River hydrology
- Water quality and carbon
- Stream metabolism
- Riverbank and aquatic vegetation
- Fish movement
- Fish reproduction
- Fish recruitment (Murray cod, golden perch and silver perch)
- Fish community (monitored in only zone three for the basin-scale evaluation. No selected area evaluation for the fish community was undertaken in 2017-18 as this is scheduled to be monitored in only years 1 and 5 of the project).

Responses to Commonwealth environmental water were evaluated in two ways:

i) Indicators that respond quickly to flow (e.g. hydrology, water quality and carbon, stream metabolism, fish movement, fish spawning) were evaluated for their response to specific watering actions. This was undertaken by examining responses during the period of the specific watering actions. The hydrological indicators were calculated on the discharge data with and without the environmental water.

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

Key results

Key results from environmental watering in the Edward-Wakool system in 2017-18 are presented in Table ii.

A summary of key outcomes for each of the watering actions and in response to the longer-term watering regime is presented in table iii.

Table ii Key results for each indicator in response to environmental watering in the Edward-Wakool system in 2017-18

Theme	Indicator	Key result
Hydrology	Maximum and minimum discharge	Watering action 1 (winter 2017) and action 5 (autumn fresh) increased the maximum discharge in Yallakool Creek (zone 1), the mid and lower Wakool River (zones 3 and 4). Action 1, 5 and 6 increased the maximum discharge in Colligen Creek. Actions 1, 2, 4, 5 and 6 increased the minimum, mean and median discharge in reaches receiving environmental water compared to operational flows.
	Flow variability	Watering action 1 (winter 2017) and action 2 (spring fresh) reduced the coefficient of variation of discharge (CV) in Yallakool Creek and the mid- and lower Wakool River (zones 3 and 4). Actions 5 and 6 had no effect on the CV in Yallakool Creek, the mid and lower Wakool River and Colligen Creek. The unregulated flows during November and December 2017 increased the range of discharge in zones 1, 3 and 4 when compared with spring watering actions in previous years.
	Longitudinal connectivity	Watering action 1 in winter 2017 maintained longitudinal connectivity in Yallakool Creek, the mid and lower Wakool River and Colligen Creek. In contrast, the upper Wakool River zone 2 (no e-watering) experienced 72 days cease to flow in winter 2017.
	Lateral connectivity	Watering action 2 provided a small in-channel fresh that increased the duration of lateral connectivity in zones 1, 3 and 4 compared to operational flows. Watering action 5 provided a small in-channel fresh that increased the extent and duration of lateral connectivity in zones 1, 3 and 4 and Colligen Creek compared to operational flows. Watering action 6 in Colligen Creek increased the extent of lateral connectivity compared to operational flows.
	Flow recession	Watering action 2 increased the duration of the recession to 32 days in Yallakool Creek and other downstream reaches compared with what would have been a rapid reduction in discharge from 460 ML/d to 200 ML/d over 3 days under operational flows. Action 5 increased the duration of lateral connectivity in zones 1, 3 and 4 and Colligen Creek compared to operational flows.
	Hydraulic diversity	Watering actions 2, 5 and 6 increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows.
Water quality and carbon	Dissolved oxygen concentration	Watering action 6 supported dissolved oxygen concentrations in the Colligen-Niemur system during January and February 2018 by increasing flow to minimise the period where DO concentrations fell below 4 mg/L and prevented DO concentrations falling below 2 mg/L. Over the 4 years of LTIM DO concentrations were consistently higher during late summer and early autumn seasons in zones 1, 3 and 4 receiving environmental water than in zone 2 that has received none or minor environmental watering actions.
	Nutrient concentrations	There was no detectable effect of environmental watering actions on this indicator in 2017-18. Nutrient concentrations remained within the expected range throughout the system during this sampling season. The absence of overbank flows meant that substantial nutrient inputs were not expected in the system
	Temperature regimes	None of the watering actions targeted temperature. Water temperatures in the system were primarily controlled by the prevailing weather conditions.
	Type and amount of dissolved organic matter	There was no detectable effect of environmental watering actions on this indicator in 2017-18. The watering actions in 2017-18 did not specifically target the transport of dissolved organic matter.

Table ii (continued) Key results for each indicator in response to environmental watering in the Edward-Wakool system in 2017-18

Theme	Indicator	Key result
Stream metabolism	Gross Primary Production (GPP) and Ecosystem Respiration (ER)	Watering actions almost uniformly decreased the rates of gross primary production (mg O_2/L/day) simply through a dilution effect. However, when GPP was calculated as the amount of organic carbon ('fish food') produced per day (kg C/day) then watering actions had a beneficial effect (more 'food' is better), with significant differences between sites. The size of the beneficial impact was largely related to the proportion of total flow that came from the watering action – carbon production was enhanced by between 1% and 218% per day, with a median across all sites and watering actions of 41% more carbon produced during Commonwealth environmental watering actions compared to no Commonwealth environmental water.
	Production: respiration (P/R)	As with GPP, watering actions almost uniformly decreased the rates of ecosystem respiration (mg O_2/L/day) simply through a dilution effect. However, when ER was calculated as the amount of organic carbon consumed per day (kg C/day), then watering actions had a beneficial effect, with significant differences between sites. A higher amount of organic carbon consumed means more nutrient recycling and hence greater nutrient supply to fuel GPP. At no stage did the environmental watering actions create so much respiration that dissolved oxygen dropped below 'safe' values for aquatic biota.
Riverbank and aquatic vegetation	Total species richness	Riverbank and aquatic vegetation showed some recovery since the flood of 2016, however the total species richness in 2017-18 was lower than in 2015-16 prior to the 2016 flood. Over the 4 years of LTIM there was higher species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that has received none or minor environmental watering actions.
	Richness of functional groups	There has been some recovery of the richness of submerged and amphibious taxa in 2017-18 but the richness of submerged and amphibious taxa in 2017-18 was lower than in 2015-16 prior to the 2016 flood. There were more amphibious vegetation taxa in zones 1, 3 and 4 that have received base flows and freshes each year since 2014 and have greater lateral connectivity, than in zone 2 that has received minimal or no environmental water.
	Percent cover of functional groups	The percentage cover of submerged and amphibious taxa in 2017-18 was low compared to 2014-15 and 2015-16 prior to the flood. In 2017-18 there was no difference in cover among the zones.
Fish movement	Movement of golden perch and silver perch	Watering action 1 (winter base flow) facilitated movement of silver perch throughout the LTIM zones, which is different to previous years when the winter operational shutdown restricted their movements. Watering actions 2 and 4 facilitated connectivity among LTIM focal zones and enabled movement of golden and silver perch. Tagged adult silver perch were present in Yallakool Creek (zone 1) concurrent with the detection of spawning in this system in December 2017.

Table ii (continued) Key results for each indicator in response to environmental watering in the Edward-Wakool system in 2017-18

Theme	Indicator	Key result
Fish spawning	Larval abundance of equilibrium species	Numbers of Murray cod larvae in 2017-18 were similar to numbers collected in 2014-15, and 2015-16. Murray cod larval counts were significantly lower in 2016-17 due to the hypoxic event and associated fish kills during the spawning season for this species. The increase in larval Murray cod counts in 2017-18 suggests that adults have successfully moved back into the Edward-Wakool system to spawn. CEW winter base flows in 2017 may have assisted in facilitating movement of Murray cod back into the system prior to spawning. Freshwater catfish larvae were detected in the Wakool River downstream of Thule Creek (zone 4) for the first time in 2017-18. Winter base flows providing permanency of water throughout river reaches will be important in providing persistence of habitat year round for this species.
	Larval abundance of periodic species	Silver perch were detected to have spawned in Yallakool Creek, the first time spawning has been detected in the study zones since monitoring commenced in 2015. The timing of the presence of silver perch eggs coincided with water temperature >21 °C, peak of a fresh where the change in water height was approximately 23 cm over 4 days, full moon, and a large area of channel in Yallakool Creek having fast water velocities (> 0.3 ms^{-1}).
	Larval abundance of opportunistic species	Watering action 2, an early spring fresh, aimed to enhance the spawning of early spawning fish species. The abundance of Australian smelt larvae was significantly higher in zones that received this watering action (zones 1, 3 and 4) than in zone 2 (almost no environmental water).
Fish recruitment	Murray cod, silver perch and golden perch recruitment	Murray cod recruits were detected in 2018 throughout the Edward Wakool system, in contrast to the absence of Murray cod recruits in 2017 following the 2016 hypoxic blackwater event. This suggests there has been some recovery of this species in 2018. There were no silver perch YOY or 1+ recruits detected in 2017-18, whereas there was one recruit in 2014-15 and 25 in 2015-16. Golden perch recruits have not been detected by monitoring during any of the four sampling years in the Edward-Wakool Selected Area.
Fish populations	Adult fish populations	The relative abundance of large-bodied native fish, including bony herring, golden perch and Murray cod, increased in comparison to 2016-17. Recruits of Murray cod and bony herring were captured at similar proportions to pre-hypoxia (2016 flooding), indicating successful (albeit reduced) spawning and recruitment in 2017-18.

Table iii Summary of key outcomes from environmental watering in the Edward-Wakool system for each of the watering actions in 2017-18 and in response to the longer-term environmental watering regime in Yallakool Creek, the Wakool River and Colligen Creek.

Watering action		Key outcomes
1	Winter watering action in Yallakool creek and Colligen Creek (base flow)	• Increased maximum, minimum, mean and median discharge in zones 1, 3, 4 and Colligen Creek compared to operational flows • Reduced the coefficient of variation of discharge (CV) in zones 1, 3 and 4 compared to operational flows • Maintained longitudinal connectivity in zones 1, 3, 4 and Colligen Creek • Large increase in carbon production in zones 3 and 4 compared to operational flows • Facilitated movement of silver perch throughout the zones, which is different to previous years when the winter operational shutdown restricted their movement • Increased larval Murray cod counts in 2017-18 suggests that winter flows may have assisted movement of cod back into the system prior to spawning
2	Early season fresh at beginning of e-flow with flow recession	• Increased the minimum, mean and median discharge in zones 1, 3, 4 and Colligen Creek compared to operational flows • Reduced CV in zones 1, 3 and 4 compared to operational flows • Increased the duration of lateral connectivity in zones 1, 3 and 4 compared to operational flows • Increased the duration of the recession to 32 days in Yallakool Creek and other downstream reaches compared with what would have been a rapid reduction from 460 ML/d to 200 ML/d over 3 days under operational flows • Increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows • Small increase in carbon production in all zones compared to operational flows • Facilitated movement of golden and silver perch • The abundance of Australian smelt larvae was significantly higher in zones that received this watering action (zones 1, 3 and 4) than in zone 2
3	Maintain e-flow	• This action was not delivered due to unregulated flows. The availability of CEW assured the outcomes in the absence of the unregulated flows
4	Summer fresh with flow recession	• Increased the minimum, mean and median discharge in zones 1, 3 and 4 and Colligen Creek compared to operational flows • Small increase in carbon production in zones 1, 3 and 4 compared to operational flows. Zone 2 did not receive environmental water during this action. • Facilitated movement of golden and silver perch
5	Autumn fresh in Yallakool Creek and Colligen Creek with flow recession	• Increased the maximum, minimum, mean and median discharge in zones 1, 3 and 4 and Colligen Creek compared to operational flows • The recession increased the extent and duration of lateral connectivity in zones 1, 3 and 4 and Colligen Creek compared to operational flows • Increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows • Increase in carbon production in zones 1, 3 and 4 compared to operational flows
6	Summer fresh in Colligen-Niemur system	• Increased the max, min, mean and median discharge compared to operational flows • Increased the extent of lateral connectivity compared to operational flows • Increased the hydraulic diversity compared to modelled operational flows • Supported dissolved oxygen concentrations during January and February 2018 by increasing flow to minimise the period where DO concentrations fell below 4 mg/L and prevented DO concentrations falling below 2 mg/L
	Multi-year environmental watering in zones 1,3 and 4	• Over 4 years DO concentrations were consistently higher during late summer/early autumn in zones 1, 3 and 4 (e-water) than in zone 2 (no or minor e-water) • Over the 4 years of LTIM there was higher total species richness, higher amphibious species richness, and higher percent cover of submerged and amphibious vegetation taxa in zones 1, 3 and 4 that received freshes and a winter base flow in 2017 than in zone 2 that has received none or minor environmental watering actions

Recommendations

We continue to endorse the recommendations from previous from the previous Edward-Wakool LTIM annual reports (Watts et al. 2015, 2016, 2017c). In addition, we outline five recommendations to improve the planning and delivery of Commonwealth environmental water in the Edward-Wakool system. Where applicable a comment has been included to indicate to what extent the recommendation has already been applied (as of October 2018) in the planning or use of Commonwealth environmental water in the Edward-Wakool system.

Recommendation 1: Implement environmental watering actions for freshes in spring and early summer (October to December) that include flow variability up to a magnitude of + 125 to 150 ML/d. Undertake trials to improve understanding of the magnitude of variability that provides beneficial ecosystem outcomes.

Adaptive management: Watering actions are currently planned for spring 2018 that include multiple pulses in Yallakool Creek with discharge ranging from 430 to 550 ML/d, over a range of approximately 20 cm change in water level.

Recommendation 2: Implement a second trial of continuous base winter environmental flow (no winter 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.

Adaptive management: Following the successful implementation of the winter flow trial in winter 2017, a winter flow could not be delivered in 2018 due to maintenance of Stevens Weir. CEWO have undertaken the discussions with various stakeholder groups regarding the implementation of a winter base flow in 2019, 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 3: 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.

Recommendation 4: In collaboration with stakeholders explore options to implement environmental watering actions that include a short duration flow peak that is higher than the current constraint of 600 ML/d at the Wakool-Yallakool confluence. This would facilitate a test of the hypothesis that a higher discharge in-channel environmental watering action will result in increased river productivity.

Adaptive management: A flow trial with discharge of 800 ML/d at the Wakool-Yallakool confluence was implemented in spring 2018 (to be reported in 2018-19 Edward-Wakool LTIM report). The outcomes of the 2018 flow trial will be included on the agenda for future meetings of the Edward-Wakool Environmental Water Reference Group and will underpin discussions of future flow actions. Social research on the communities' perceptions, concerns and understanding of the flow trial and environmental watering is being undertaken to assist discussions about future watering actions.

Recommendation 5: Trial a carefully managed environmental watering action through Koondrook-Perricoota Forest via Barbers Creek to improve the productivity of the mid and lower Wakool River system.

1 INTRODUCTION

1.3 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 outcomes:

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

This technical report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system during the 2017-18 watering year from 1 May 2017 when the first winter watering action commenced until 30 June 1018 at the end of the watering year. It is the fourth 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.

This report has nine sections that provide detailed results for the indicators. This introduction (section 1) is followed by a description of the Commonwealth environmental water use objectives and watering actions for this system for 2017-18 (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 2017-18 are presented in sections four to eight; hydrology (section 4), water quality and carbon (section 5), stream metabolism (section 6), riverbank and aquatic vegetation (section 7), and fish movement, fish spawning, fish recruitment and fish community (section 8). Recommendations to help inform adaptive management of environmental water in this system in the future is presented in section 9. A summary report (Watts et al. 2018b) provides an overview of the monitoring and key findings of the ecosystem responses to environmental watering actions in the Edward-Wakool system in 2017-18.

1.2 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).

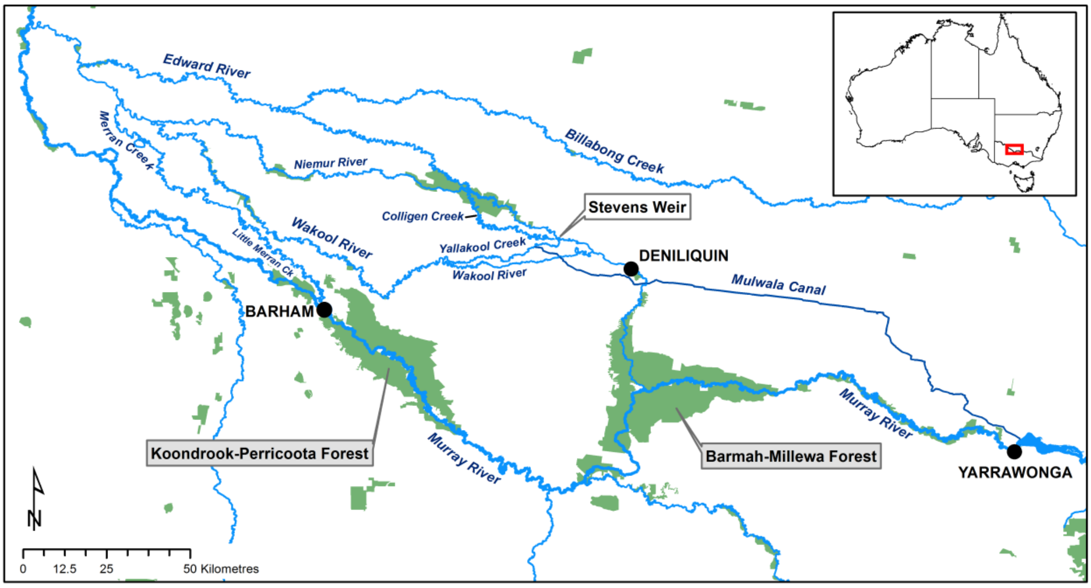


Figure 1.1 Map showing the main rivers in the Edward-Wakool system. (Source: Watts et al. 2013)

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.

2 ENVIRONMENTAL WATER USE OBJECTIVES AND WATERING ACTIONS IN 2017-18

2.1 Expected outcomes from Basin-wide Environmental Watering Strategy relevant to the Mid-Murray Region

Expected outcomes from the Basin-wide Environmental Watering Strategy (MDBA 2014) that are relevant to the Mid Murray Region are listed below and in Table 2.1 and 2.2.

River flows and connectivity

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

Vegetation

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

Fish

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

Table 2.1 Important Basin environmental assets for native fish in the Mid Murray (from MDBA 2014)

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

Table 2.2 Key species for the Mid Murray (Source: MDBA 2014)

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

2.2 Water Quality targets

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

2.3 Environmental Watering Priorities for 2017-18

OEH watering priorities statement for the Murray – Lower Darling

The Murray – Lower Darling Environmental Watering Priorities Statement 2017–18 (OEH 2017) states that moderate to dry resource availability scenario were proposed for the Murray and Lower Darling in 2017-18. Under a dry resource availability scenario, the aims were to maintain river functioning and to maintain key functions of high priority wetlands (OEH 2017). Under a moderate resource availability scenario the aims were to improve ecological health and resilience, and to improve opportunities for plants and animals to breed, move and thrive (OEH 2017). Key planned actions for 2017-18 relevant to the Edward-Wakool systems as outlined by OEH (2017) were:

- "To expand the watering program (7 GL) into areas of the central Murray that are currently stressed and affected by salinity. Flows (6 GL) are planned to enhance the condition of vegetation along the Jimaringle, Cockran and Gwynnes and Murrian-Yarrien creeks, improving water quality and reconnecting with receiving streams like the Niemur and Wakool rivers"
- "Fish flows (60 GL) in the Edward–Wakool River will be used to provide benefits for native fisheries, vegetation growing in the river (in-stream vegetation) and productivity. As well as delivering freshwater (110 GL) via the Murray Irrigation system to provide refuge habitat for native fish (especially Murray cod) if a blackwater event (low levels of dissolved oxygen) was to occur".

CEWO Portfolio management Plan for the Mid-Murray in 2017–18

The CEWO aims to contribute to the expected outcomes in the Basin-wide environmental watering strategy. The CEWO Portfolio Management Plan for the Mid-Murray in 2017–18 (CEWO 2017) states that CEWO will not inundate private land without prior approval from land holders while contributing to the Basin annual environmental watering priorities.

The 2017–18 Basin annual environmental watering priorities relevant to the Mid Murray Region as outlined by the CEWO (2017) were to:

- "Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales for the southern connected Basin.
- Support viable populations of threatened native fish and opportunities for range

expansion and the establishment of new populations.

- Improve the abundance and diversity of the Basin's waterbird population.
- Improve the condition and extent of Moira grass in Barmah-Millewa Forest.
- Enable recruitment of trees and support growth of understorey species within river red gum, black box and coolibah communities on floodplains that received overbank flooding during 2016 by inundating the floodplains again."

CEWO Portfolio management Plan for the Edward-Wakool in 2017–18

In 2017-18 the CEWO considered supplying environmental water to the following watering actions in the Edward-Wakool system:

> "*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."

2.4 Practicalities of environmental watering in the Edward-Wakool system

The main source of Commonwealth environmental water for the Edward-Wakool system is from the Murray River through the Edward River and Gulpa Creek. During high flow events in the Murray River, water can also flow from the Murray River through Koondrook-Perricoota Forest and into the Wakool River via Thule and Barber Creeks. The main flow regulating structure within the Edward-Wakool system is Stevens Weir, located on the Edward River downstream of Colligen Creek (Figure 1.1). This structure creates a weir pool that allows Commonwealth environmental water to be delivered to Colligen Creek-Niemur River system, Yallakool Creek, the Wakool River, the Edward River and Werai Forest.

Water diverted into the Mulwala Canal from Lake Mulwala can also be delivered into the Edward-Wakool system through 'escapes' or outfalls managed by the irrigator-owned company Murray Irrigation Limited (MIL). During a hypoxic blackwater event in 2010, environmental water was released from Mulwala Canal escapes to lessen the impact of hypoxia and create localised refugia with higher DO and lower DOC (Watts et al. 2017a). There are numerous smaller escapes throughout the MIL network that can be used to deliver small flows to the river system. Escapes were also used to deliver environmental water as refuge flows in response to the 2016 hypoxic blackwater event (Watts et al. 2017c).

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

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

Delivery of instream flows to the Edward River, Wakool River, Yallakool Creek, Colligen Creek, Niemur River and Merran River system are managed within regular operating ranges as advised by river operators to avoid third party impacts. For example, in the Wakool-Yallakool system the operational constraint is 600 ML d^{-1} at the confluence of the Wakool River and Yallakool Creek. Thus, the types of flow components that can be achieved under current operating ranges are in-channel baseflows and freshes (Gawne et al. 2013). Environmental watering may also be constrained due to the limitations on how much water can be delivered under regulated conditions. At times of high irrigation demand channel capacity will be shared with other water users. If the system is receiving higher unregulated flows, there may not be enough capacity to deliver environmental water (Gawne et al. 2013). Environmental water may be delivered to contribute to the slower recession of freshes, delivered during low flow periods to provide refuge habitat, or delivered to manage water quality issues, such as hypoxic events (Gawne et al. 2013; Watts et al. 2017a).

2.5 Commonwealth environmental watering actions 2009-2018

Commonwealth environmental watering actions have occurred in the Edward-Wakool system since 2009 (Table 2.3). Between July 2009 and June 2018 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 2.3). 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 2.3). To date it has not been possible to deliver large within channel freshes or overbank flows due to operational constraints in the system (current constraint 600 ML/d at confluence of the Wakool River and Yallakool Creek). The winter of 2017 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 2.3).

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 2.3 Summary of Commonwealth environmental watering actions and unregulated overbank flows in the Edward-Wakool system from July 2010 to June 2018. More detailed information about environmental watering in the mid-Murray catchment is available from the CEWO website (Department of the Environment and Energy 2017)

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

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

2.5 Commonwealth watering actions in Edward-Wakool River system 2017-18

There were six water delivery actions planned in 2017-18 (Table 2.4). Watering actions 1, 2, 4, 5 and 6 (Table 2.4) were delivered. Watering action 3 was not delivered, as this was unnecessary due to unregulated flows occurring above channel capacity between 10th October and 24th December.

Table 2.4 Planned environmental watering actions in the Edward-Wakool system in 2017-18. Details of the watering strategies as described in CEWO planning documents and the Water Use Minute are presented in Appendix 1.

	Planned watering action	Type of action	Dates	Rivers	Objectives
1	Winter watering action	base flow	1 May - 23 Aug 2017	Yallakool Creek, mid and lower-Wakool River, Colligen Creek-Niemur River	To contribute to reinstatement of the natural hydrograph, connectivity, condition of in-stream aquatic vegetation and fish recruitment
2	Early spring fresh at beginning of e-flow with flow recession	small fresh and flow recession	7 Sept - 22 Oct 2017	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to connectivity, water quality, stimulating growth of in-stream aquatic vegetation, pre-spawning condition of native fish, spawning in early spawning native fish
3	Maintain e-flow	small fresh	Not delivered*	NA	To maintain nesting habitat for Murray cod and inundation for aquatic vegetation growth
4	Summer fresh at end of e-flow with flow recession	small fresh and flow recession	3 - 29 Jan 2018	Yallakool Creek, mid- and lower Wakool River	To encourage fish movement and assist dispersal of larvae and juveniles of fish species.
5	Autumn fresh with flow recession	small fresh	28 Mar - 1 May 2018	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To encourage fish movement and dispersal of juveniles of a number of fish species.
6	Summer fresh	small fresh	11 Jan –11 Feb 2018	Niemur River	To improve water quality (in response to a heatwave driven low DO event)

*Watering action 3 was not implemented due to an unregulated fresh occurring at the time of this planned action

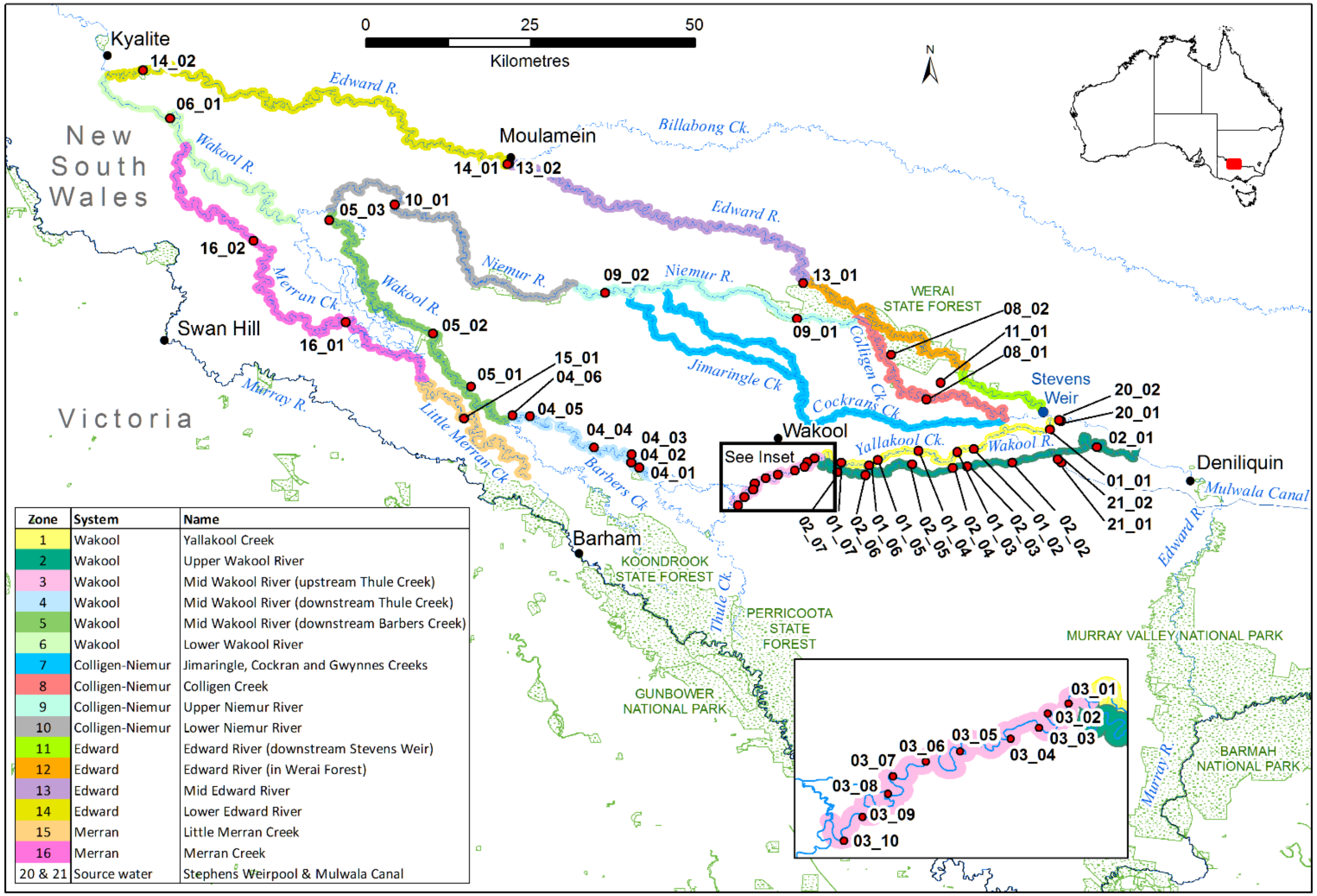
3 MONITORING AND EVALUATION

3.1 Monitoring zones and sites

The monitoring of ecosystem responses to Commonwealth environmental watering in the Edward-Wakool system in 2017-18 was undertaken following the Edward-Wakool Long-Term Intervention Monitoring and Evaluation Plan (Watts et al. 2014a) and Monitoring and Evaluation Plan Addendum (CEWO 2018).

The majority of the monitoring in the Edward-Wakool LTIM Selected Area is focussed on four hydrological zones, which together are referred to as the focal zone: 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). 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 2017-18 annual report.



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 1-4 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

Winter watering action 1 (June 2017 | Watering action 2 (Sept-Oct 2017) | Winter shutdown (May 2018)

Yallakool Creek 192 ML.d^{-1} 8/6/17 | 5/10/17, 385 ML.d^{-1} (e-flow) | 24/05/18 cease to flow

Wakool R (zone 2) cease to-flow 8/6/17 | 5/10/17, 68 ML.d^{-1} | 24/05/18 cease to flow

Wakool R (zone 3) 186 ML.d^{-1-}7/6/17 | 6/10/17, 388 ML.d^{-1} (e-flow) | 23/05/18 cease to flow

Wakool R (zone 4) 230 ML.d^{-1-} 8/6/17 | 6/10/17, 467 ML.d^{-1} (e-flow) | 26/05/18 cease to flow

Figure 3.2 Photos of study sites in the four hydrological zones during the environmental watering action 1 winter flow (June 2017), watering action 2 (Sept-Oct 2017), and in the winter operational shutdown period in May 2018 (cease to flow). 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).

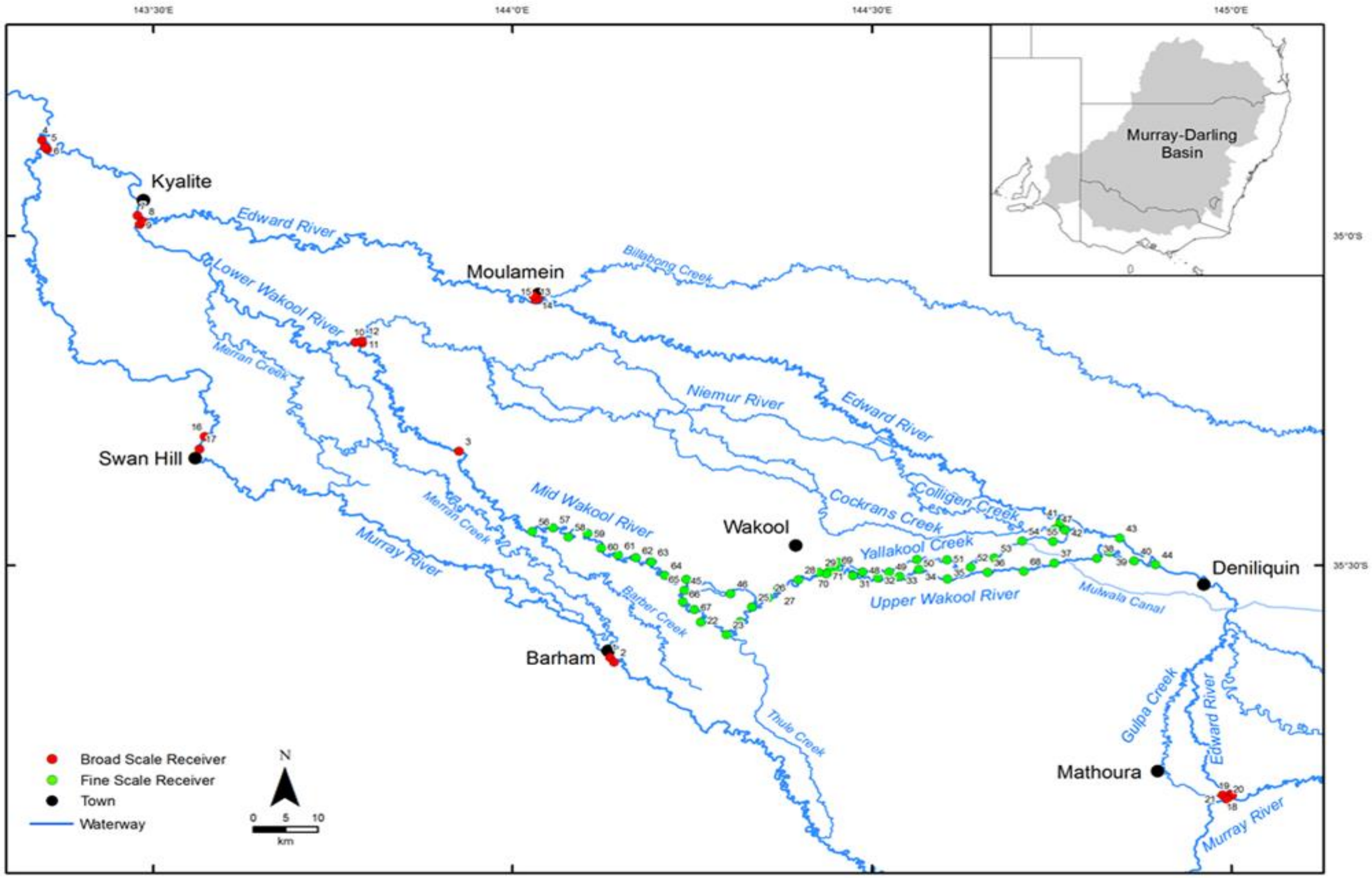


Figure 3.3 Location of acoustic telemetry receivers moored in the Edward-Wakool system to determine movements of acoustically tagged golden perch and silver perch. Green dots indicate the fine-scale acoustic receiver array of ~6 km receiver spacing in the focal study zones. An additional 20 receivers (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..

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. 2014a). Indicators are 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 longer time frames (e.g. 2 to 5 years). A summary of monitoring undertaken in 2017-18 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).

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

3.3 Overview of monitoring undertaken in 2017-18

The monitoring undertaken in 2017-18 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 2014-17 (Watts et al. 2015, 2016, 2017c).

The fish community survey for the Edward-Wakool Selected Area was not undertaken in 2017-18 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 3.3 Schedule of monitoring activities For Edward-Wakool Long-Term Intervention Monitoring project for 2017-18 (grey shading). The three categories of indicators are described in section 3.2.

<table>
<tr><th rowspan="2">Indicator</th><th rowspan="2">Cat</th><th rowspan="2">Zones</th><th colspan="12">2017-18 schedule of activities</th></tr>
<tr><th>J</th><th>A</th><th>S</th><th>O</th><th>N</th><th>D</th><th>J</th><th>F</th><th>M</th><th>A</th><th>M</th><th>J</th></tr>
<tr><td>River hydrology</td><td>1</td><td>1,2,3,4</td><td colspan="12">Continuous data from automated gauging stations</td></tr>
<tr><td>Hydraulic modelling</td><td>3</td><td>1,2,3,4</td><td colspan="12">Modelling undertaken in 2014-15</td></tr>
<tr><td>Stream metabolism and instream primary productivity</td><td>1</td><td>1,2,3,4</td><td></td><td colspan="11">Continuous data from loggers</td></tr>
<tr><td>Nutrients and carbon</td><td>1</td><td>1,2,3,4</td><td></td><td colspan="10">Monthly sampling</td><td></td></tr>
<tr><td>Carbon characterisation</td><td>3</td><td>1,2,3,4</td><td></td><td colspan="10">Monthly sampling</td><td></td></tr>
<tr><td>Riverbank and aquatic vegetation</td><td>3</td><td>1,2,3,4</td><td></td><td colspan="11">Monthly surveys</td></tr>
<tr><td>Fish reproduction (larvae)</td><td>1</td><td>3</td><td></td><td></td><td></td><td></td><td colspan="3">Fortnightly sampling</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fish reproduction (larvae)</td><td>3</td><td>1,2,3,4</td><td></td><td></td><td colspan="7">Fortnightly sampling</td><td></td><td></td><td></td></tr>
<tr><td>Fish recruitment</td><td>3</td><td>1,2,3,4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td><td></td><td></td><td></td></tr>
<tr><td>Fish (river)</td><td>1</td><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fish community survey</td><td>3</td><td>20 sites</td><td colspan="12">Undertaken in 2014-15 and 2018-19 only</td></tr>
<tr><td>Fish movement</td><td>2</td><td>1,2,3,4 (plus additional sites funded by Murray LLS)</td><td></td><td colspan="11">Continuous data from acoustic receivers</td></tr>
</table>

3.4 Evaluation of outcomes

Evaluations of the outcomes of Commonwealth environmental watering undertaken in 2017-18 were undertaken for the following indicators:

- Hydrology (Section 4)
- Water quality and carbon (Section 5)
- Stream metabolism (Section 6)
- Aquatic and riverbank vegetation (Section 7)
- Fish movement (Section 8)
- Fish reproduction (Section 8)
- Fish recruitment (Section 8)
- Fish community data for basin-scale evaluation (section 8). No selected area evaluation for the fish community was undertaken in 2017-18 as this is scheduled to be monitored in only years 1 and 5 of the project.

Responses to Commonwealth environmental water were evaluated in two ways:

i) Indicators that respond quickly to flow (e.g. hydrology, water quality and carbon, stream metabolism, fish movement, fish spawning) were evaluated for their response to specific watering actions. This was undertaken by examining responses during the period of the specific watering actions. The hydrological indicators were calculated on the discharge data with and without the environmental water.

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

4 HYDROLOGY

Key findings	
Maximum and minimum discharge	Watering action 1 (winter 2017) and action 5 (autumn fresh) increased the maximum discharge in Yallakool Creek (zone 1), the mid and lower Wakool River (zones 3 and 4). Action 1, 5 and 6 increased the maximum discharge in Colligen Creek. Actions 1, 2, 4, 5 and 6 increased the minimum, mean and median discharge in reaches receiving environmental water compared to operational flows.
Flow variability	Watering action 1 (winter 2017) and action 2 (spring fresh) reduced the coefficient of variation of discharge (CV) in Yallakool Creek and the mid- and lower Wakool River (zones 3 and 4). Actions 5 and 6 had no effect on the CV in Yallakool Creek, the mid and lower Wakool River and Colligen Creek. The unregulated flows during November and December 2017 increased the range of discharge in zones 1, 3 and 4 when compared with spring watering actions in previous years.
Longitudinal connectivity	Watering action 1 in winter 2017 maintained longitudinal connectivity in Yallakool Creek, the mid and lower Wakool River and Colligen Creek. In contrast, the upper Wakool River zone 2 (no e-watering) experienced 72 days cease to flow in winter 2017.
Lateral connectivity	Watering action 2 provided a small in-channel fresh that increased the duration of lateral connectivity in zones 1, 3 and 4 compared to operational flows. Watering action 5 provided a small in-channel fresh that increased the extent and duration of lateral connectivity in zones 1, 3 and 4 and Colligen Creek compared to operational flows. Watering action 6 in Colligen Creek increased the extent of lateral connectivity compared to operational flows.
Flow recession	Watering action 2 increased the duration of the recession to 32 days in Yallakool Creek and other downstream zones compared with what would have been a rapid reduction in discharge from 460 ML/d to 200 ML/d over 3 days under operational flows. Action 5 increased the duration of lateral connectivity in zones 1, 3 and 4 and Colligen Creek compared to operational flows.
Hydraulic diversity	Watering actions 2, 5 and 6 increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows.

4.1 Background

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

The Edward-Wakool system has experienced a wide range of flow conditions over the past 15 years, and these antecedent conditions will influence the way in which the ecosystem responds to Commonwealth environmental watering.

From 1998 to 2010 south-eastern Australia experienced a prolonged drought (referred to as the Millennium drought) and flows in the MDB were at record low levels (van Dijk 2013; Chiew et al. 2014). During this period the regulators controlling flows from the Edward River into tributary rivers such as Yallakool Creek and the Wakool River were closed for periods of time. 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 (MDBA 2011; Whitworth et al. 2012).

In late 2016 there was a widespread flood in the southern-MDB associated with record-breaking rainfall in the catchment. Some areas of the floodplain were inundated that had not been flooded for more than 20 years. In the Murray catchment, Murray River flows at Yarrawonga in October were the highest since 1993 (MDBA River Murray Weekly Report, 7th Dec 2017). The unregulated flows from the Murray River inundated the floodplain including Barmah Forest and Koondrook–Perricoota Forests and agricultural land, 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.

The 2017-18 water year did not include any major hydrological or climatic events, such as the droughts, floods and algal blooms of previous years. This chapter reports on the hydrology of the Edward-Wakool system from 1 May 2017 to 30 June 2018.

4.2 Environmental watering actions targeting hydrology outcomes

Six commonwealth environmental watering actions were delivered in the Edward-Wakool system in 2017-18 (Tables 2.4, 4.1). Two of these had primary objectives specifically related to hydrology.

Table 4.1 Commonwealth environmental watering actions in 2017-18 in the Edward Wakool River system that had objectives targeting hydrology.

	Watering action	Type of action	Dates	Rivers	Objectives
1	Winter watering action	base flow	1 May - 23 Aug 2017	Yallakool Creek, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to reinstatement of the natural hydrograph, connectivity, condition of in-stream aquatic vegetation and fish recruitment
2	Early spring fresh at beginning of e-flow with flow recession	small fresh and flow recession	7 Sept - 22 Oct 2017	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to connectivity, water quality, stimulating growth of in-stream aquatic vegetation, pre-spawning condition of native fish, spawning in early spawning native fish

4.3 Selected Area evaluation questions

- *What was 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?*
- *What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?*
- *What did Commonwealth environmental water contribute to lateral connectivity?*
- *What did Commonwealth environmental water contribute to the hydraulic diversity?*

4.4 Methods

Daily discharge data for automated hydrometric gauges (Table 4.2) were obtained from the New South Wales Office of Water website (https://realtimedata.waternsw.com.au/water.stm). Daily discharge data for non-automated sites, such as the Wakool escape from Mulwala Canal, and daily usage of Commonwealth environmental water were obtained from WaterNSW.

Table 4.2 Details of Water NSW hydrometric gauges used to obtain discharge data. Zone codes are as described in Figure 3.1 and Table 3.1.

River	LTIM zone	Gauge number	Name of gauge
Yallakool Creek	1	409020	Yallakool Creek @ Offtake
Wakool River	2	409019	Wakool River Offtake regulator
Wakool River	4	409045	Wakool @ Wakool-Barham Road
Wakool River	5	409062	Wakool River Gee Gee Bridge 2
Wakool River	6	409013	Wakool @ Stoney Crossing
Colligen Creek	8	409024	Colligen Creek B/L regulator

The daily discharge data for sites in the Wakool River zone 2 was estimated by adding the discharge from gauge 409019 Wakool River offtake regulator to the discharge data from the Wakool escape from Mulwala canal.

The daily discharge data for Wakool River zone 3 was estimated by adding daily discharge data from Yallakool Creek offtake (gauge 409020), the Wakool offtake regulator (gauge 409019) and the Wakool Escape from Mulwala Canal with an adjustment during regulated flows to account for travel time (4 days) and estimated 20% losses (V. Kelly, WaterNSW pers. comm.) between the offtakes and the confluence of Yallakool Creek and the Wakool River.

Details of the daily volume of water (ML/d) accounted for as Commonwealth environmental water was provided by WaterNSW and the Commonwealth Environmental Water Office. These data were used to produce hydrographs showing the overall daily discharge and the proportion of that flow that is Commonwealth environmental water for the four hydrological zones. The minimum, maximum, mean, median and coefficient of variation (SD/mean) of the daily discharge was calculated with and without Commonwealth environmental water.

To evaluate to what extent Commonwealth environmental water contributed to longitudinal hydrological connectivity, the hydrographs for the Wakool River at Gee Gee Bridge site 05_02 (gauge 409062) and Stoney Crossing, site 06_01 (gauge 409013) were plotted and visually compared to the shape of the hydrographs upstream that received Commonwealth environmental water.

2D hydraulic models for nineteen reaches and six discharge scenarios were reported in Watts (2015). These results were used to describe the extent of lateral connectivity, as measured by benthic wetted area, in these reaches during watering actions with and without of Commonwealth environmental water in 2017-18.

4.5 Results

Overview of environmental watering over 4 years of LTIM July 2014 to June 2018

The four year hydrograph (1 July 2014 to 30 June 2018) for zones 1-4 in the Edward-Wakool system is dominated by the large unregulated flow in late 2016 (Figure 4.1). The volume of Commonwealth environmental water delivered to the Edward-Wakool system over the four year period is small in comparison to the large unregulated flow in 2016. However, at times when there are no unregulated flow pulses the environmental water has provided small freshes, slowed the recession of operational flows, maintained connectivity by provision of winter base flows, and at times has been delivered from irrigation canal infrastructure during hypoxic events to create refuge habitat (Table 2.3). The continuous winter flow in zones 1, 3 and 4 in 2017 is evident in the 4 year hydrograph (Figure 4.1) and is in contrast to periods of cease to flows during winter in these zones in previous years.

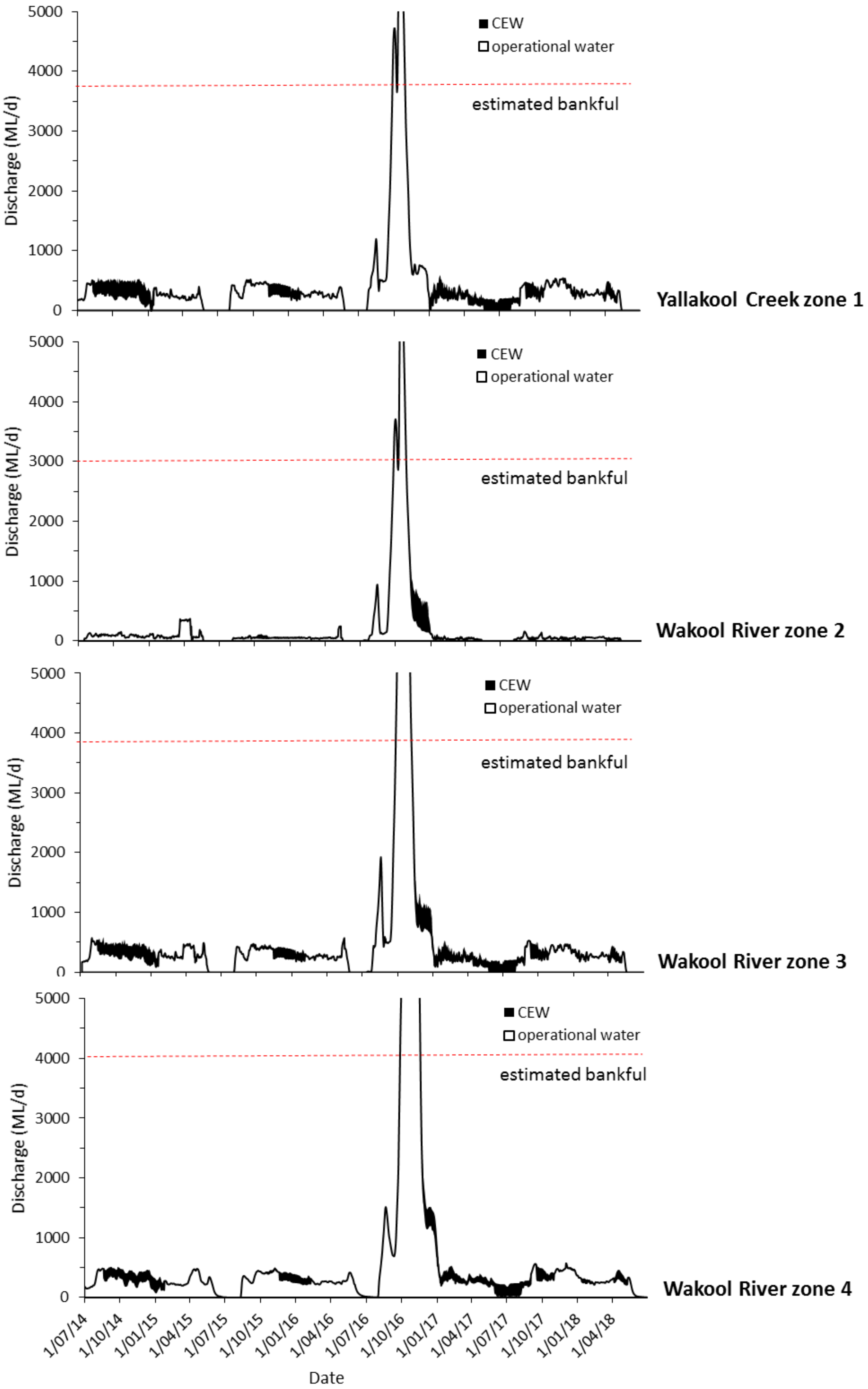


Figure 4.1 Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1 July 2014 to 30 June 2018. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water. Note that the y axis has been truncated at 5,000 $ML.d^{-1}$.

Overview of hydrology in 2017-18

The hydrograph for zones 1 to 4 in 2017-18 was similar to that in 2014-15 and 2015-16 (Figure 4.1). In 2017-18 there were no flow events that exceeded 600 ML/d, which is the operational constraint at the confluence of the Wakool River and Yallakool Creek (Figure 4.2). The maximum discharge (Q_{max}) in 2017-18 was less than 600 ML/d in all zones (Table 4.3) which is considerably less than bankfull in these systems (Figure 4.2).

Zones 1, 3 and 4 received Commonwealth environmental water. The hydrological outcomes of each watering action in these zones are described below.

The Wakool River zone 2 had considerably lower Q_{max} than all other zones (Table 4.3). A small amount of environmental water was delivered to the upper Wakool River (zone 2) (Figure 4.2), and this had minimal effect on the Q_{max}, Q_{min} but increased the mean discharge from 32 to 41 ML/d in spring and the median discharge from 32 to 49 ML/d across the water year (Table 4.3).

Watering action 1 – 2017 winter watering

From 1 May to 23rd August 2017 environmental water was delivered from the regulators on Yallakool Creek and Colligen Creek, whereas the regulator on the Wakool River was closed for the operational shutdown over winter (Figures 4.2, 4.3).

This winter environmental watering action in the Yallakool Creek-Wakool River system achieved the objective of maintaining continuous winter base flows in zones 1, 3, 4 (Table 4.3, Figure 4.2), connecting the river system through to its junction with the Murray River. The effect of the action was evident in the hydrograph of the Wakool River at Gee Gee Bridge and at the most downstream gauge at Stoney Crossing (Figure 4.4). This winter watering action in Colligen Creek-Niemur River system also achieved the objective of maintaining continuous winter base flows in that creek (Figure 4.3). Combined these watering actions created about 530 km of instream overwintering habitat throughout these systems.

Watering action 1 (winter 2017) reduced the coefficient of variation of discharge and increased the minimum, maximum, mean and median discharge in Yallakool Creek (zone 1), the mid and lower Wakool River (zones 3 and 4) and Colligen Creek (Table 4.3).

During this winter flow action the environmental water contributed on average 76.5% in zone 1, 74.5% of water in zone 2 and 49.3% of discharge in zone 4. For a period of time from late May to 28th July the environmental water made up 100% of the discharge in zones 1 and 3 (Figure 4.2, 4.3). Environmental watering action 1 reduced the coefficient of variation of discharge in reaches receiving the environmental water.

In contrast, there was no winter watering in Wakool River zone 2 in 2017 and the minimum discharge (Q_{min}) in winter 2017 was zero in this zone (Table 4.3). This river reach experienced a period of 72 days cease to flow from 23rd May until the 2nd August 2017 (Figure 4.2).

The CEWO's planning for the winter flow actions, as per the proposed hydrographs sent to Edward-Wakool Environmental Water Reference Group members on 8 July 2016, included proposed winter flows via the Wakool offtake regulator (zone 2). However, members of the Reference Group were concerned about the need to ensure that some period of bank drying was provided, particularly for wetland areas around Stevens Weir pool. Following discussions at the August 2016 Reference Group meeting in Deniliquin, the proposed hydrographs were revised so that Stevens Weir would be kept at a lower height to ensure some bank drying in the wetlands around the weir over winter. The lower weir height meant that the weir pool would become disconnected from the Wakool regulator and only enable the provision of winter base flows into the Yallakool Creek and Colligen Creek offtake regulators. In summary, environmental outcomes in the upper Wakool (winter base flows) were traded off against other priority environmental outcomes (allowing some level of bank drying) as identified by the local community.

In July 2017 the CEWO prepared and distributed to the Reference Group the report *2017 Winter flow – Edward-Wakool wetland drying site visit - Informal Report*. That report provided photos of a number of wetland sites impacted by Stevens Weir as well as Yallakool Creek during the period of winter flows.

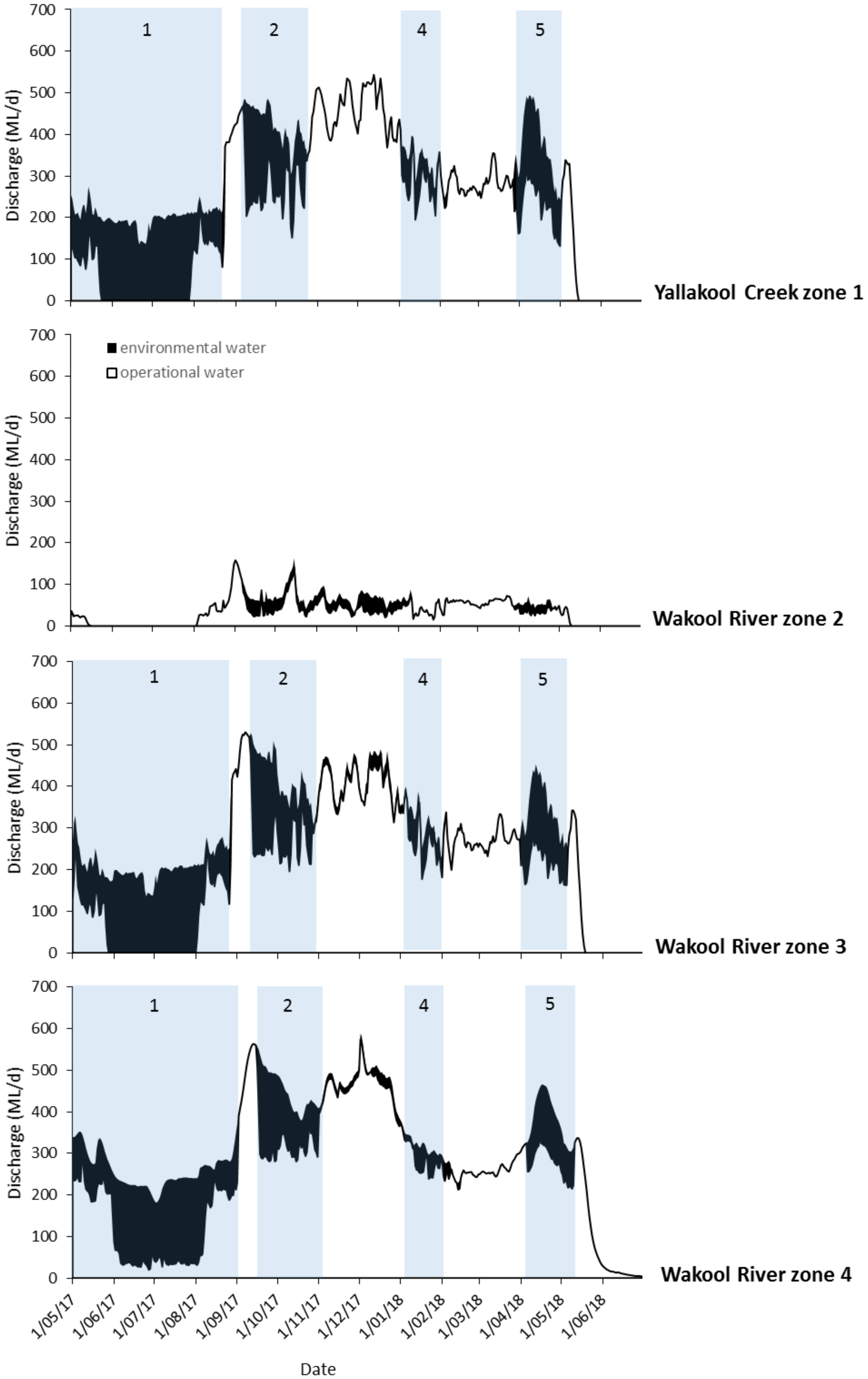


Figure 4.2 Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1 May 2017 to 30 June 2018. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water. Numbered blue shaded sections relate to the environmental watering actions listed in Table 2.4.

Table 4.3 Summary hydrological statistics for four hydrological zones in the Edward-Wakool system for the whole water year (1/5/17 to 30/6/2018) and individual watering actions. Statistics are shown for each zone with and without Commonwealth Environmental Water. The results for winter 2018 only include 1 month from 1 June to 30 June 2018.

Flow variable	Yallakool Creek		Wakool R zone2		Wakool R zone 3		Wakool R zone 4	
	Without CEW	With CEW	Without CEW	With CEW	Without CEW	With CEW	Without CEW	With CEW
Entire 17-18 water year (1 May 2017 – 30 June 2018)								
Q_{min} (ML/d)	0	0	0	0	0	0	4	4
Q_{max} (ML/d)	543	543	158	163	530	530	574	588
mean (Q_{mean}) (ML/d)	215	290	32	41	206	283	244	315
median (Q_{50}) (ML/d)	241	287	32	49	234	277	254	302
Coefficient of variation	0.77	0.51	0.91	0.84	0.73	0.48	0.61	0.43
Watering action 1 - Winter 2017 (1 May 2017 – 23 Aug 2017)								
Q_{min} (ML/d)	0	135	0	0	0	135	20	182
Q_{max} (ML/d)	220	304	61	61	270	329	294	352
mean (Q_{mean}) (ML/d)	52	204	9	9	60	209	111	258
median (Q_{50}) (ML/d)	0	205	0	0	0	204	55	242
Coefficient of variation	1.25	0.12	1.71	1.71	1.28	0.17	0.79	0.16
Watering action 2 (7 Sept – 22 Oct 2017)								
Qmin (ML/d)	152	303	23	56	196	346	280	379
Qmax (ML/d)	448	486	141	163	530	530	563	563
mean (Q_{mean}) (ML/d)	265	427	52	80	292	443	357	477
median (Q50) (ML/d)	252	435	41	69	250	458	312	490
Coefficient of variation	0.21	0.11	0.56	0.32	0.31	0.13	0.28	0.12
Watering action 4 (3 Jan – 29 Jan 2018)								
Qmin (ML/d)	195	271	15	15	177	250	239	295
Qmax (ML/d)	392	397	77	88	382	400	349	362
mean (Q_{mean}) (ML/d)	278	340	39	44	274	324	284	321
median (Q50) (ML/d)	284	342	39	20	265	321	277	320
Coefficient of variation	0.16	0.10	0.38	0.45	0.20	0.13	0.12	0.06
Watering action 5 (28 March – 30 April 2018)								
Qmin (ML/d)	137	241	25	39	164	262	255	292
Qmax (ML/d)	333	494	48	72	295	453	342	466
mean (Q_{mean}) (ML/d)	232	384	37	53	229	354	298	386
median (Q50) (ML/d)	235	371	34	52	226	340	300	388
Coefficient of variation	0.22	0.21	0.19	0.13	0.15	0.17	0.07	0.16
Winter 2018 (1 June – 30 June 2018)								
Qmin (ML/d)	0	0	0	0	0	0	4	4
Qmax (ML/d)	0	0	0	0	0	0	29	29
mean (Q_{mean}) (ML/d)	0	0	0	0	0	0	12	12
median (Q50) ((ML/d)	0	0	0	0	0	0	11	11
Coefficient of variation	-	-	-	-	-	-	0.55	0.55

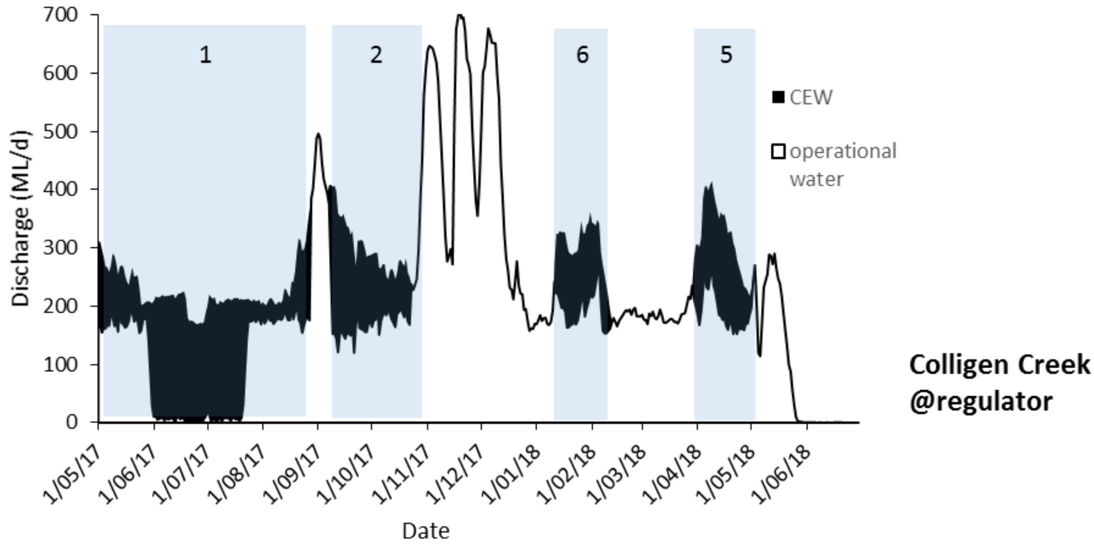


Figure 4.3 Hydrograph for Colligen Creek at the regulator from 1 May 2017 to 30 June 2018. Numbered blue shaded sections relate to the environmental watering actions listed in Table 2.4.

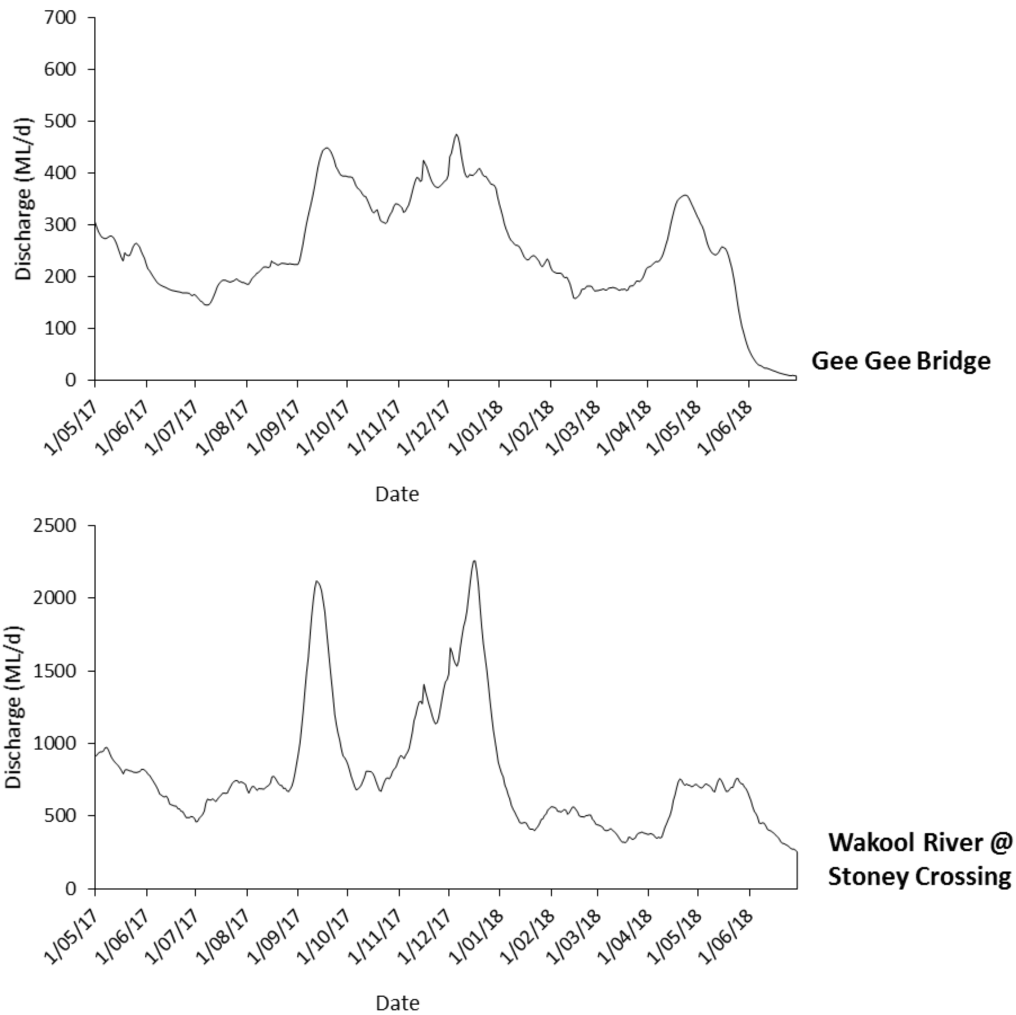


Figure 4.4 Hydrographs for i) the Wakool River at Gee Gee bridge (gauge 409062), and ii) the Wakool River at Stoney Crossing (gauge 409013) from 1 May 2017 to 30 June 2018. Note the different y axis units for Stoney Crossing figure.

Watering action 2 – spring small in-channel fresh with flow recession

There was a small fresh from 24th August until 6th September due to tributary inflows and environmental water accounting was ceased during this period. The fresh was used to trigger the beginning of environmental watering action 2, and the flow was maintain for a few days and then followed by a recession as planned.

Environmental watering action 2 reduced the coefficient of variation of discharge in reaches receiving the environmental water. This watering action did not (or minimally) increased the maximum discharge of the event because the tributary inflows had created the peak of the flow pulse prior to the watering action. However, the action significantly increased the minimum, mean and median discharge in Yallakool Creek (zone 1), the mid and lower Wakool River (zones 3 and 4, Figure 4.2) and Colligen Creek (Figure 4.3).

Watering action 2 achieved the objective of increasing connectivity in the system. The action extended the duration of lateral connectivity in zones 1, 3 and 4 and Colligen Creek compared to operational flows. The duration of the recession was 32 days in Yallakool Creek and other downstream zones compared with what would have been a rapid reduction in discharge from 460 ML/d to 200 ML/d over 3 days under operational flows.

Due to this tributary fresh, there was higher flow variability in Wakool River zone 2 during September than in previous years (Figure 4.2).

Watering action 3 – maintain e-flow at 450 ML/d during cod spawning season

Watering action 3 (Table 2.4) was not delivered as planned due to unregulated flows occurring above channel capacity between 10th October and 24th December. However, the key objective of watering action 3 was largely met by the unregulated flows. Although unregulated flows provided the desired outcomes, this environmental water action played a role in assuring this flow outcome in the absence of these unregulated flows.

The original environmental watering plan was to maintain discharge at approximately 450 ML/d and increase flows by 50 ML/d for 14 days if no variability greater than +/- 50ML/d occurs in the preceding month. The unregulated flows during November and December 2017 resulted in higher variation in discharge in Yallakool Creek zone 1, Wakool River zone 3 and Colligen Creek at this time of year than in 2014-15 and 2015-16 (Watts et al 2015, 2016). In Yallakool Creek there were three freshes during this period varying between approximately 380 ML/d to 530 ML/d (Figure 4.2). For example, between 11 and 23 November 2017 the discharge increased from 385 to 534 ML/day, translates to a range of approximately 28 cm in water level (2.34 to 2.62 m) over 12 days. These freshes were particularly evident in the zone 1 and zone 3 hydrographs but were attenuated by the time the flow reached zone 4.

In Colligen Creek there was high variability of discharge and fast rises and recession of three flow events in November and December 2017 (Figure 4.3). For example, a freshes between 12 and 19 November ranged between approximately 280 ML/d and 715 ML/d. This translates to a rise 50 cm in water level (1.02 to 1.52 m) over 7 days.

Watering action 4 – small summer fresh in zones 1, 3 and 4 with flow recession

This watering action was not delivered as planned as there had already been three small freshes in the system due to unregulated flows during November and December 2017. However, a small volume of environmental water was delivered from the Yallakool Creek regulator during this period to slow the recession of these events in zones 1, 3 and 4.

Watering action 4 resulted in a slightly reduced coefficient of variation of discharge, an increase in the minimum discharge, mean and median discharge in Yallakool Creek (zone 1), the mid and lower Wakool River (zones 3 and 4) (Table 4.3, Figure 4.2). There was only a slight increase in the maximum discharge during this watering action.

Watering action 5 – autumn fresh with flow recession

The autumn fresh was evident in the hydrograph in zones 1, 3 and 4 (Figure 4.2) and Colligen Creek (Figure 4.3). This small fresh did not exceeded 600 ML/d (operational constraint at the confluence of the Wakool River and Yallakool Creek).

Watering action 5 increased the minimum, maximum, mean and median discharge in Yallakool Creek (zone 1), the mid and lower Wakool River (zones 3 and 4) (Table 4.3, Figure 4.2) and Colligen Creek (Figure 4.3). Watering action 5 had no effect on the coefficient of variation of discharge in the reaches receiving environmental water (Table 4.3). This is in contrast watering actions 2 and 4 that reduced the coefficient of variation.

Watering action 5 increased the extent and duration of lateral connectivity in zones 1, 3 and 4 (Figure 4.2) and Colligen Creek (Figure 4.3). Estimates of wetted benthic area from 2D hydraulic models has estimated that there was an increase in wetted benthic area of approximately 10 to 70% under a 500ML/d environmental watering action when compared to operational flows in these systems (Watts et al 2015). The slow recession on this watering action duration would have also increased the duration of lateral connectivity in these reaches.

Watering action 6 – summer fresh in Colligen-Niemur system

A small fresh targeting the Niemur River (gauge 409048) was delivered from the Colligen Creek regulator during the summer months of January and February 2018 (Figure 4.3) to improve water quality as the CEWO had identified that dissolved oxygen levels were dropping in response to heatwave conditions. This small fresh was within normal operational constraints.

Watering action 6 increased the minimum, maximum, mean and median discharge in Colligen Creek during this action (Figure 4.3). The watering action had no effect on the coefficient of variation of discharge (Table 4.3). This is in contrast watering actions 2 and 4 that reduced the coefficient of variation. This action increased the extent of lateral connectivity in this system.

Winter flows 2018

A winter watering action could not be delivered in winter 2018 due to maintenance of Stevens weir. There was an extended cease to flow in Yallakool Creek, Wakool River and Colligen Creek in winter 2018 (Table 4.3, Figures 4.2, 4.3). This winter period will be reported in full in 2018-19 LTIM report.

4.6 Discussion

What was 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?

2017-18 was the first time that a winter watering action has been undertaken in the Edward-Wakool system. From late May to 28th July the environmental water made up 100% of the discharge in zones 1 and 3 and in Colligen Creek. The winter flows addressed one of the expected outcomes of the Basin-wide Environmental Watering Strategy (MDBA 2014) that are relevant to the Mid Murray Region (see section 2.1), that 'base flows are at least 60 per cent of the natural level'.

Watering action 1 (winter 2017) and action 5 (autumn fresh) increased the maximum discharge in Yallakool Creek (zone 1), the mid and lower Wakool River (zones 3 and 4). Action 1, 5 and 6 increased the maximum discharge in Colligen Creek. Actions 1, 2, 4, 5 and 6 increased the minimum, mean and median discharge reaches receiving environmental water compared to operational flows.

Watering action 1 (winter 2017) and action 2 (spring fresh) reduced the coefficient of variation of discharge (CV) in Yallakool Creek and the mid- and lower Wakool River (zones 3 and 4). Actions 5 and 6 had no effect on the CV in Yallakool Creek, the mid and lower Wakool River and Colligen Creek. The unregulated flows during November and December 2017 increased the range of discharge in zones 1, 3 and 4 when compared with spring watering actions in previous years.

What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?

Watering action 1 in winter 2017 maintained longitudinal connectivity in Yallakool Creek, the mid and lower Wakool River and Colligen Creek. In contrast, the upper Wakool River zone 2 (no e-watering) experienced 72 days cease to flow in winter 2017.

The increase in longitudinal connectivity in Yallakool Creek, the mid and lower Wakool River and Colligen Creek created by the winter watering action would provide opportunities for fish movement, dispersal of seeds and vegetation, and maintain critical overwinter habitat for turtles and taxa that have small home ranges. The ongoing presence of water during winter will also prevent potential frost damage to aquatic vegetation rhizomes.

What did Commonwealth environmental water contribute to lateral connectivity?

Environmental watering actions 2, 5 and 6 that increased the maximum discharge and/or the duration of flow recession all contribute to increased lateral connectivity in the system.

Watering action 2 provided a small in-channel fresh that increased the duration of lateral connectivity in zones 1, 3 and 4 compared to operational flows. Watering action 5 provided a small in-channel fresh that increased the extent and duration of lateral connectivity in zones 1, 3 and 4 and Colligen Creek compared to operational flows. Watering action 6 in Colligen Creek increased the extent of lateral connectivity compared to operational flows.

Watering action 2 increased the duration of the recession to 32 days in Yallakool Creek and other downstream zones compared with what would have been a rapid reduction in discharge from 460 ML/d to 200 ML/d over 3 days under operational flows. Action 5 increased the duration of lateral connectivity in zones 1, 3 and 4 and Colligen Creek compared to operational flows.

Increasing the extent and duration of lateral connectivity can play an important role in river productivity, increasing the opportunity for dissolved carbon inputs to the stream from the sediment or organic materials, such as leaves, biofilms, grasses and other inundated vegetation. The slower recession also provides opportunities for growth and increased cover of submerged and amphibious macrophytes which can increase habitat for invertebrates, frogs and fish. Slower recessions can also minimise the stranding of invertebrates, tadpoles and small fish in backwaters.

What did Commonwealth environmental water contribute to the hydraulic diversity?

Based on hydraulic modelling undertaken for each study reach (Watts et al. 2015), environmental watering actions 2, 5 and 6 increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows.

Environmental watering actions that increase the hydraulic diversity create a higher diversity of velocity habitat and enable the system to support a greater diversity of aquatic taxa that have different flow requirements. For example, some fish species require slackwater and slow-water habitats, whereas other fish require faster flowing water to trigger spawning and disperse pelagic eggs (see section 8).

4.7 Evaluation

Table 4.4 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	**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?**
Watering action 1: Winter watering action in Yallakool Creek and Colligen Creek	To contribute to reinstatement of the natural hydrograph and connectivity	*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?*	Reduced coefficient of variation and increased maximum, minimum, mean, median discharge in zones 1, 3, 4 and Colligen Creek compared to operational flows.	Calculation of percent contribution of CEW to total discharge in each zone. Calculations of minimum, maximum, mean, median and coefficient of variation of discharge over the period of the action with and without environmental water	Yes, the flows provided maintained continuous discharge in the target reaches.
		What did Commonwealth environmental water contribute to hydrological connectivity?	Maintained longitudinal connectivity in zones 1, 3, 4 and Colligen Creek and through to the end of the Wakool river system		
		What did Commonwealth environmental water contribute to the in-channel wetted benthic area?	Increased wetted benthic area from what would have been largely dry during winter to wet		
		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	Increased lateral connectivity		
Watering action 2: Early season fresh at beginning of e-flow with flow recession	To contribute to connectivity	*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?*	Reduced coefficient of variation and increased the minimum, mean and median discharge reaches receiving environmental water compared to operational flows.	Calculations of minimum, maximum, mean, median and coefficient of variation of discharge over the period of the action,	Yes

		What did Commonwealth environmental water contribute to hydrological connectivity?	Increased the duration of lateral connectivity in zones 1, 3 and 4 compared to operational flows.	with and without environmental water	
		What did Commonwealth environmental water contribute to the in-channel wetted benthic area?	Watering action 2 increased the duration of the recession to 32 days in Yallakool Creek and other downstream zones compared with what would have been a rapid reduction in discharge from 460 ML/d to 200 ML/d over 3 days under operational flows. This would have increased the duration of wetted bank.		
		What did Commonwealth environmental water contribute to the area of slackwater, slow flowing water and fast water?	Increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows		

5 WATER QUALITY AND CARBON

Key findings	
Dissolved oxygen concentrations	Commonwealth environmental watering action 6 supported dissolved oxygen concentrations in the Colligen-Niemur system during January and February 2018 to by increasing flow to minimise the period where DO concentrations fell below 4 mg/L and prevented DO concentrations falling below 2 mg/L Over the four years of LTIM dissolved oxygen concentration was consistently higher during late summer and early autumn seasons in zones 1, 3 and 4 receiving environmental water than in zone 2 that has received none or minor environmental watering actions
Nutrient concentrations	There was no detectable effect of environmental watering actions on this indicator in 2017-18. Nutrient concentrations remained within the expected range throughout the system during this sampling season. The absence of overbank flows meant that substantial nutrient inputs were not expected in the system, although a general downstream increase in TN and TP were observed in the zones which received the majority of flow (zones 1, 3 and 4).
Temperature Regimes	None of the watering actions targeted temperature. Water temperatures in the system were primarily controlled by the prevailing weather conditions
Type and amount of dissolved Organic Matter	There was no detectable effect of environmental watering actions on this indicator in 2017-18. The watering actions in 2017-18 did not specifically target the transport of dissolved organic matter.

5.1 Background

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). 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 can be observed below 2 mg/L (Gehrke 1988; Gehrke et al. 1993; King et al. 2012; Small et al. 2014).

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, Baldwin 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.

While 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 (Watts et al. 2017), the 2017-18 season was characterised by the in-channel flows more commonly observed in this system.

There were two clear examples during 2017-18 where the CEWO acted in response/regard to Basin Plan water quality targets and requirements (section 2.2). The first example was in January and February 2018 in response to a hypoxic event in the Niemur River when a small summer fresh was provided to improve water quality. Low dissolved oxygen observed in in the Niemur River over this period was not the result of high organic matter inputs but was driven by low water during heatwave conditions and triggered a flow to support DO in that part of the system. The second example was during March 2018 when the CEWO suspended the use of Commonwealth environmental water during a period of red alerts in the Edward-Wakool system. This resulted in the postponing of a planned 800 ML/day flow trial in the Yallakool-Wakool system until spring 2018.

This chapter reports on changes in water quality in response to flows from 1 May 2017 to 30 June 2018.and will consider changes in both the quantity and type of organic matter present in the system.

5.2 Environmental watering actions targeting water quality outcomes

Six commonwealth environmental watering actions were delivered in the Edward-Wakool system in 2017-18 (Tables 2.4, 5.1). Two of these had primary objectives specifically related to water quality.

Table 5.1 Commonwealth environmental watering actions in 2017-18 in the Edward Wakool River system that had objectives targeting water quality.

	Watering action	Type of action	Dates	Rivers	Objectives
2	Early spring fresh at beginning of e-flow with flow recession	small fresh and flow recession	7 Sept - 22 Oct 2017	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to connectivity, water quality, stimulating growth of in-stream aquatic vegetation, pre-spawning condition of native fish, spawning in early spawning native fish
6	Summer fresh	small fresh	11 Jan –11 Feb 2018	Niemur River	To improve water quality (in response to a heatwave driven low DO event)

5.3 Selected Area evaluation 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 actions in 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 2017-18 the key questions relating to the CEW actions were:

- *What did Commonwealth environmental water contribute to:*
  - *dissolved oxygen concentrations*?
  - *nutrient concentrations?*
  - *temperature regimes?*
  - *modification of the type and amount of dissolved organic matter through reconnection with previously dry or disconnected in-channel habitat?*

The remaining question was not addressed as there were no hypoxic blackwater events in the system in 2017-18:

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

5.4 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. 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 1 May 2017 to 31 May 2018. Dissolved oxygen and temperature data is also presented for the Edward River at Toonalook, Wakool River at Gee Gee Bridge and Niemur River at the Barham Moulamein Road and has been sourced from the WaterNSW loggers via the website https://realtimedata.waternsw.com.au/.

From August to April 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. On all sample dates water quality parameters (temperature (°C), 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.

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° 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 5.1. 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.

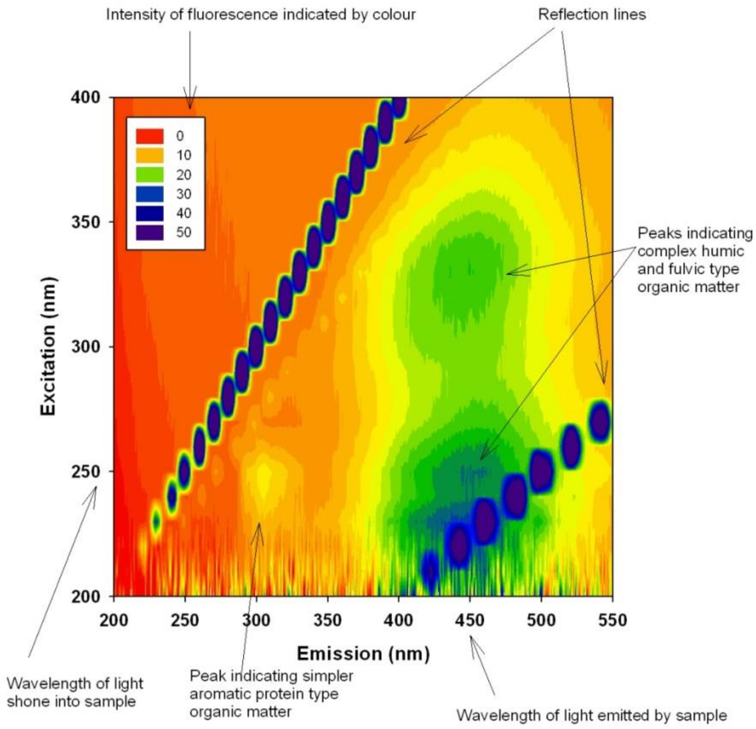


Figure 5.1 Sample excitation emission contour plot indicating key features of the data. (Watts et al. 2013)

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 variations 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.

5.5 Results

Dissolved oxygen and temperature

The Edward River at Toonalook and Wakool River at Gee Gee Bridge are representative of water quality before and after the water passes through the study zones. The temperature range observed in the Edward River (Figure 5.2) is similar to that recorded in the previous sampling year (data not shown). Dissolved oxygen in the source water remained in the acceptable range throughout the study period- no hypoxia was observed in this part of the system (Figure 5.2). Lower, but still acceptable concentrations were recorded at Gee Gee Bridge and the DO concentration did not appear to be strongly influenced by the flow profile at this site but was dominated by seasonal cycles.

Temperature and dissolved oxygen logged within the study sites are shown in Figures 5.3 and 5.4. Daily average temperatures were very consistent between sites with water temperatures exceeding 30 ^{o}C briefly during the summer and staying below 10 ^{o}C for several weeks during the winter. Average daily dissolved oxygen concentrations reflected the expected seasonal variations with higher concentrations in the winter and lower concentrations correlating to the periods of higher water temperature. All sites with the exception of zone 2 had DO concentrations exceeding 5 mg/L throughout the study period. While the logger in zone 2 regularly returned concentrations below 4 mg/L during the daily minimum between November and February, examination of the data in detail showed that no values below 2 mg/L were recorded. It is common for DO to be lower in zone2 Site 4 than the other study sites during summer and flow is much lower at this site.

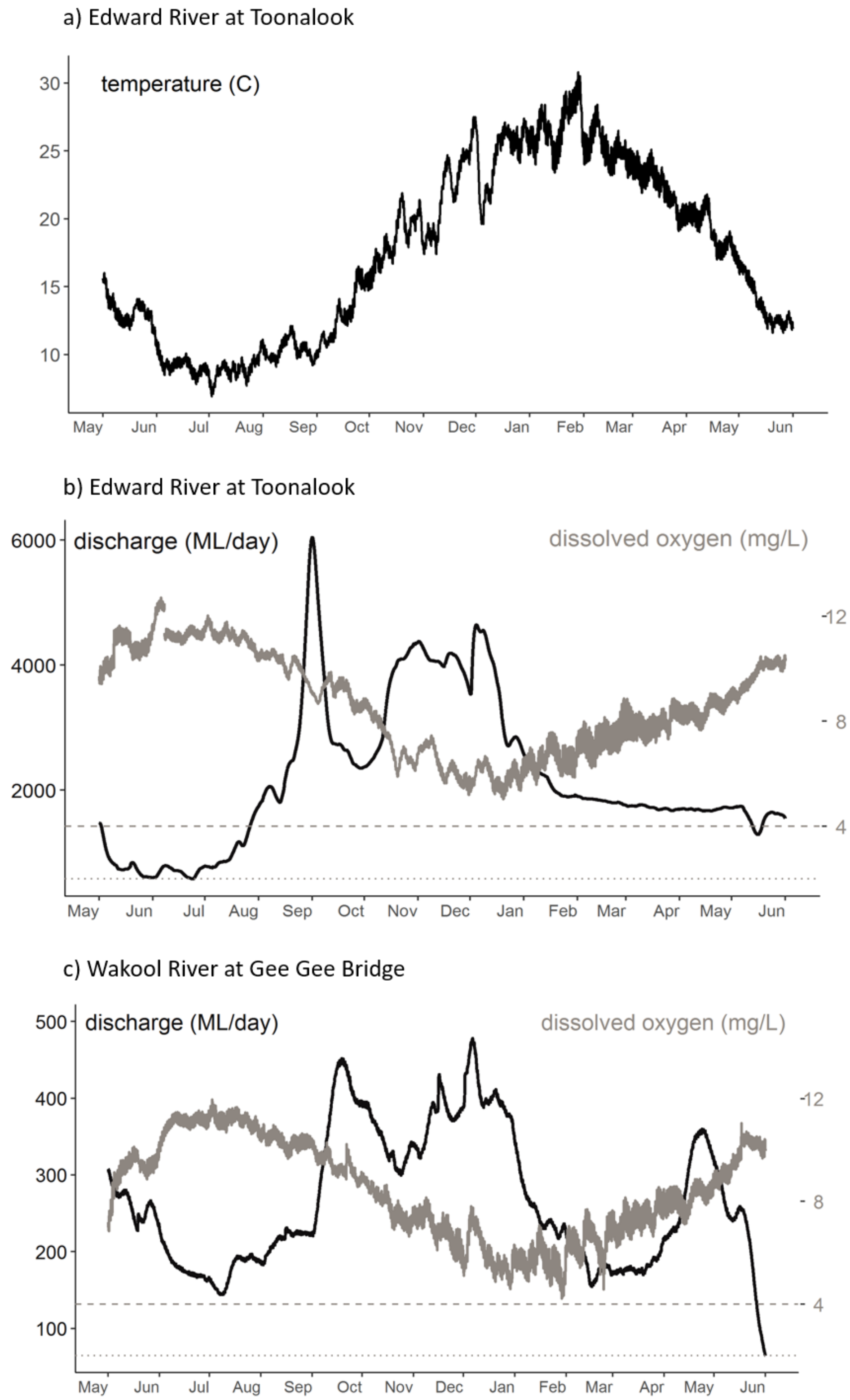


Figure 5.2 Water temperature (a), discharge and dissolved oxygen for the Edward River at Toonalook (b) and Wakool River at Gee Gee Bridge (c). Data: NSW DPI, Waterinfo.gov.au

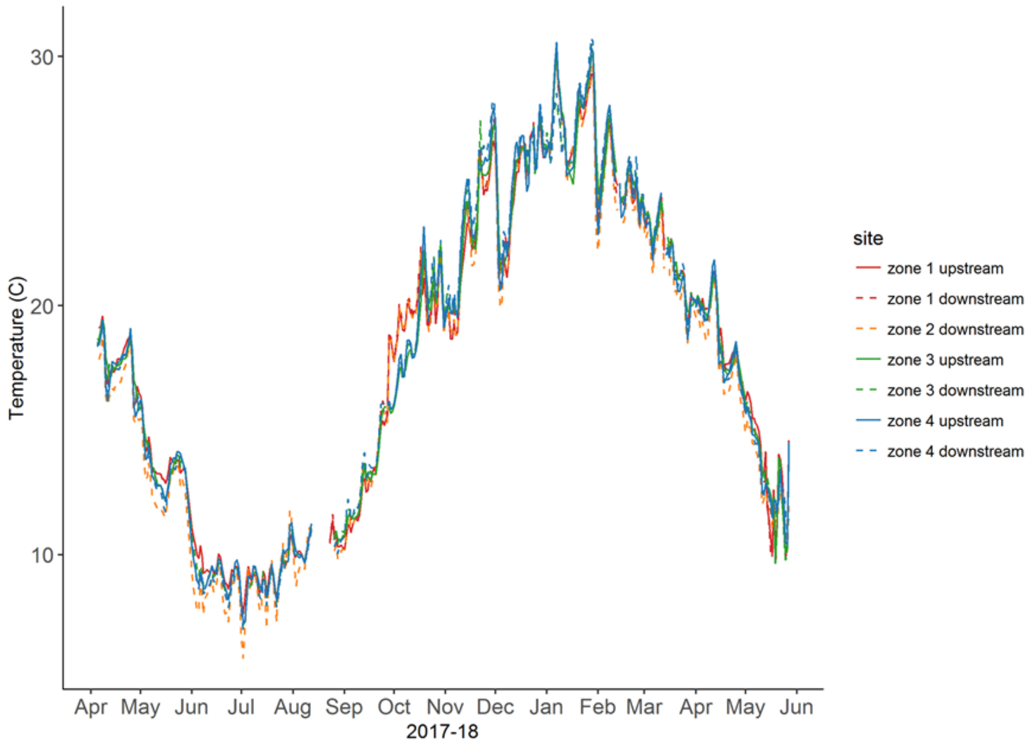


Figure 5.3 Water temperature data from loggers located in each of the study zones

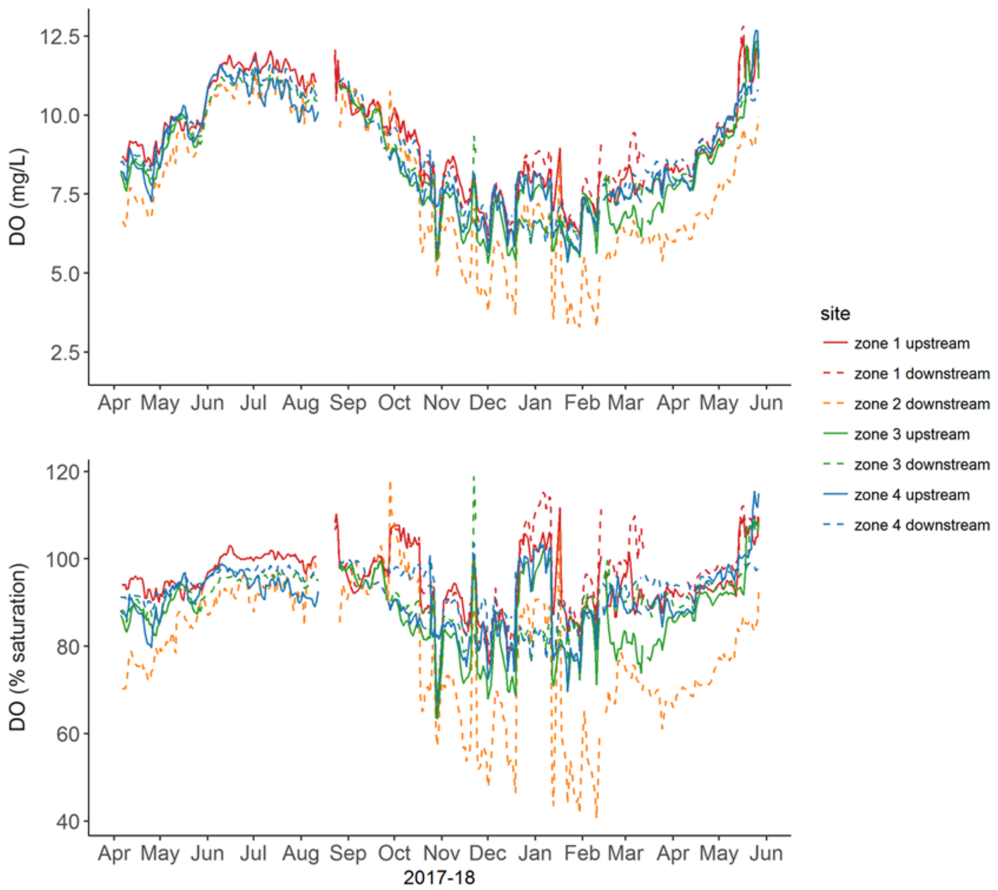


Figure 5.4 Dissolved oxygen (DO) concentration and % saturation at LTIM study sites

Spot water quality parameters

Spot water quality parameters (electrical conductivity, turbidity and pH) were stable and within the normal range for this system throughout the study period and were very similar to the 2014-15 sampling year (Figure 5.5). The increase in EC values sometimes observed in zone 2 during autumn was not observed this season and the relatively stable water levels during this period may have reduced the impact or amount of groundwater seeping into the system which is thought to be the source of this increase in some years. The EC values at all sites were well below the ANZECC (2000) trigger levels on all sampling dates. Turbidity measurements were generally above the ANZECC (2000) trigger level but within the range commonly observed (in the absence of the algal bloom in the second half of the 2015-16 watering year and the blackwater at the start of the 2016-17 watering year). The pH values remained within the acceptable range throughout the sampling season and values were very similar between sites.

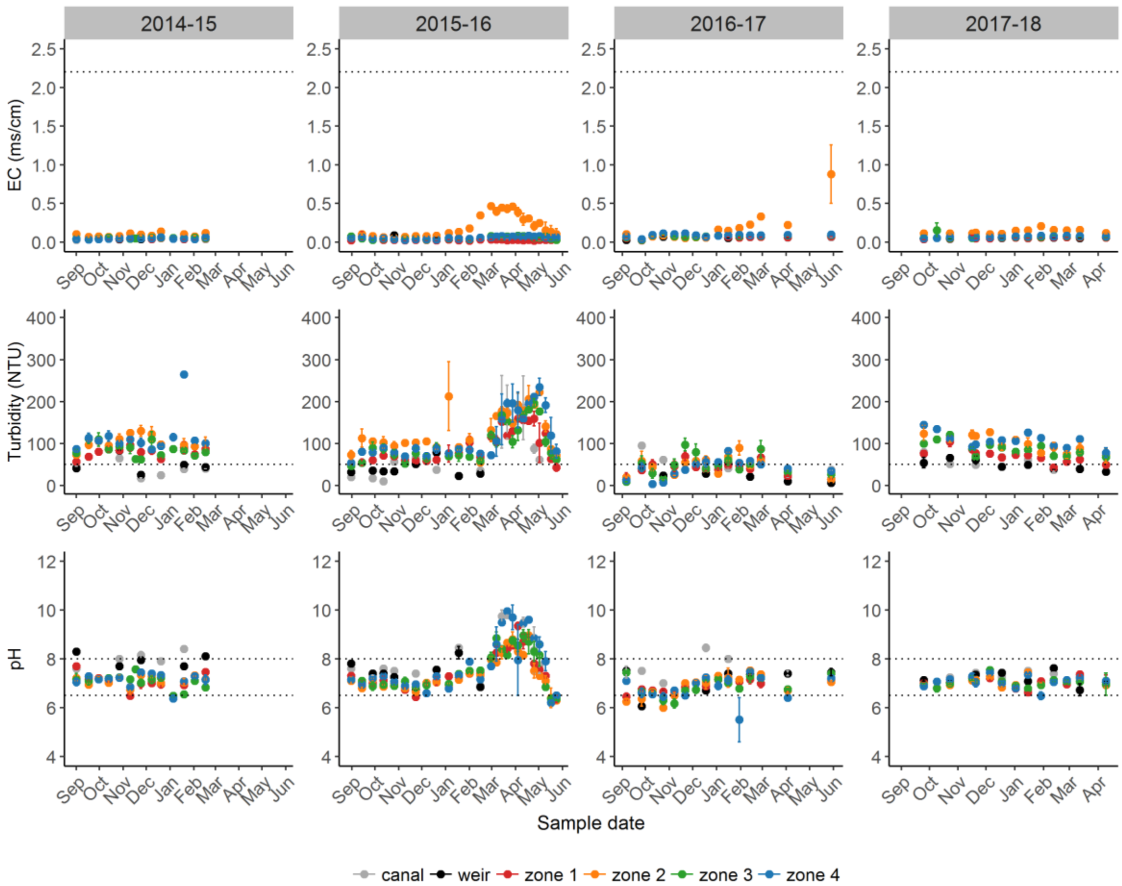


Figure 5.5 Electrical conductivity, turbidity and pH for LTIM sites and source water over the 2014-15, 2015-16, 2016-17 and 2017-18 sampling seasons.

Nutrients

Total nitrogen, NO_x and ammonia concentrations were very consistent throughout the study period with minimal variation between sites or over time and there does not appear to be a measureable effect of the use of Commonwealth Environmental water on these parameters (Figure 5.6, 5.7). Total Nitrogen concentrations fluctuated around the ANZECC (2000) trigger levels and were very similar to the concentrations recorded in previous years, outside the periods of the bloom of nitrogen-fixing cyanobacteria in early 2016 and the flooding in late 2016 (Figure 5.6). Bioavailable forms of nitrogen remained below the trigger levels and were also similar to those observed previously under normal conditions. Figure 5.7 provides detail of the nitrogen concentrations in the 2017-18 watering year and indicates a general increasing trend in total nitrogen as water moves downstream through zone 1 to zone 3 and then zone 4. Zone 2, with much lower flow, does not fit clearly within this pattern.

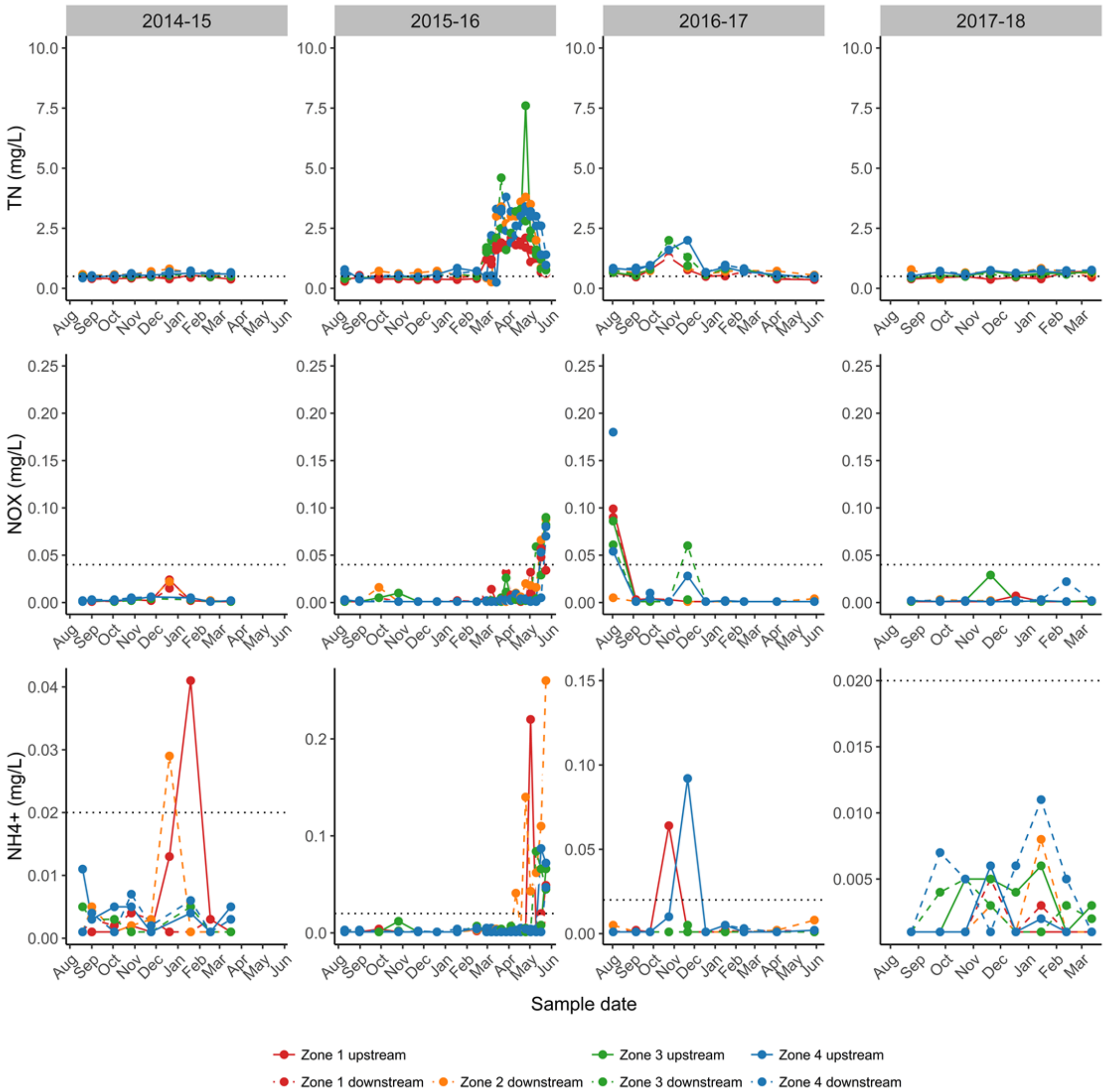


Figure 5.6 Nitrogen concentrations at LTIM sites for the 2014-15, 2015-16, 2016-17 and 2017-18 study periods.

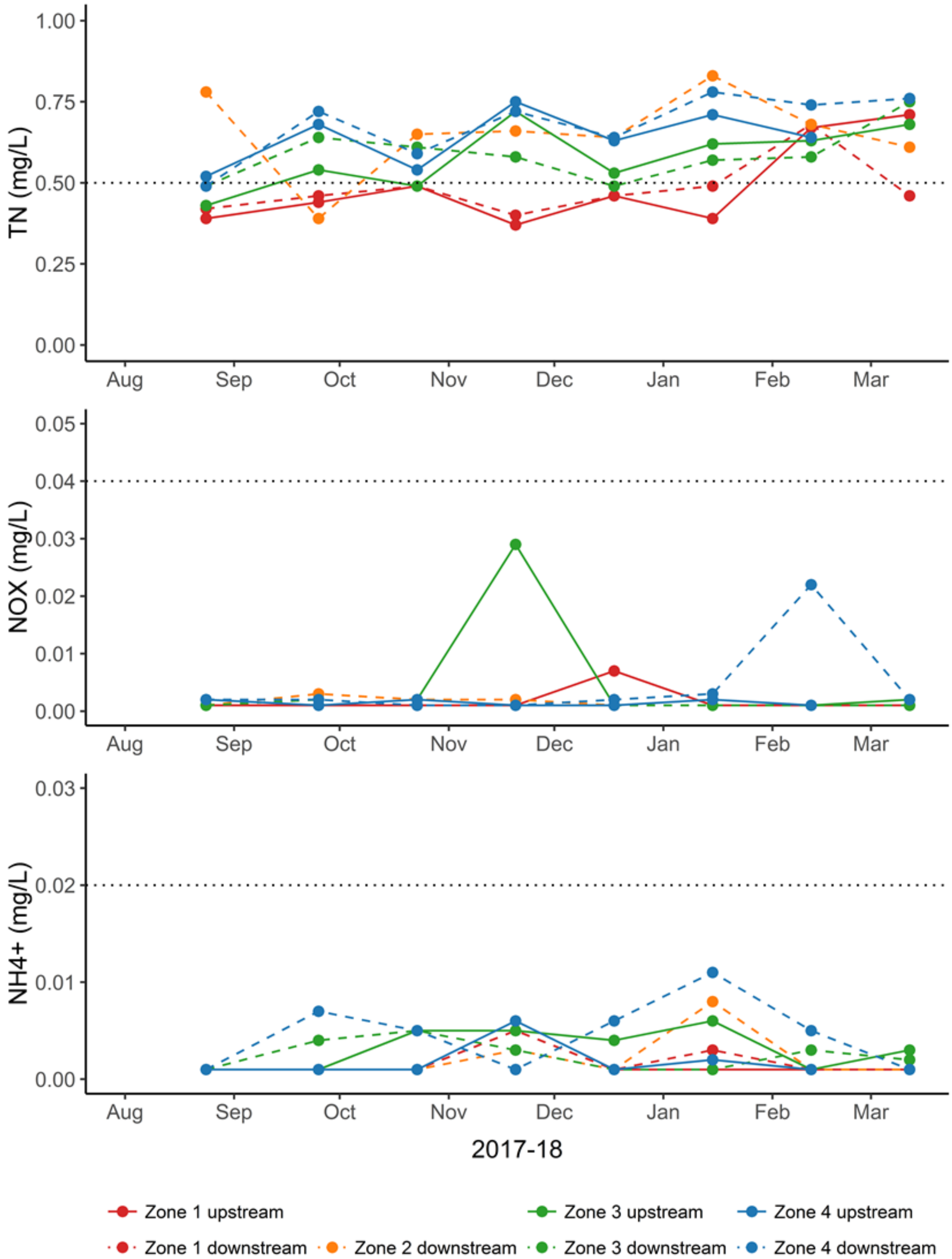


Figure 5.7 Detail of nitrogen concentrations at study sites during the 2017-18 watering year.

Bioavailable phosphorus was at the very low concentrations normally seen in this system except during extensive overbank flooding (Figures 5.8, 5.9). Total P routinely exceeds the ANZECC (2000) trigger level but remained within the normal range observed in this system outside of extreme algal or blackwater water quality events. Total P concentrations generally increased downstream zone 1 <zone 3 <zone 4 and while zone 2 frequently has higher concentrations, the relative contribution to zone 3 is minor in terms of flow (Figure 5.9). This is consistent with the pattern in TN and trends in Chlorophyll –a concentrations (Figure 5.10) broadly follow the pattern in Total P and N. Note that green and amber alerts for cyanobacteria were issued through late spring and early summer but the system was not dominated by a single species at all sites and the cyanobacteria did not have the same influence on nutrient concentrations as was observed during the 2016 event. A red alert for the Edward River at Deniliquin in February 2018 correlates with an increase in chlorophyll a at all sites but there is no clear influence on other water quality parameters.

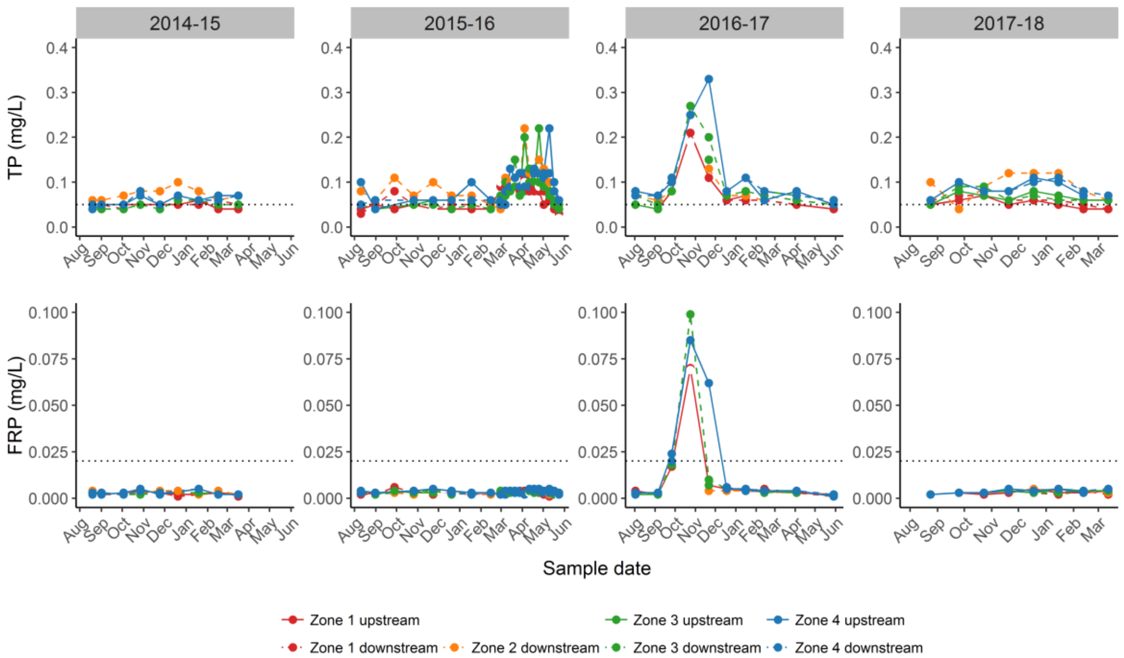


Figure 5.8 Phosphorus concentrations for the LTIM sites in the 2014-15, 2015-16, 2016-17 and 2017-18 study seasons.

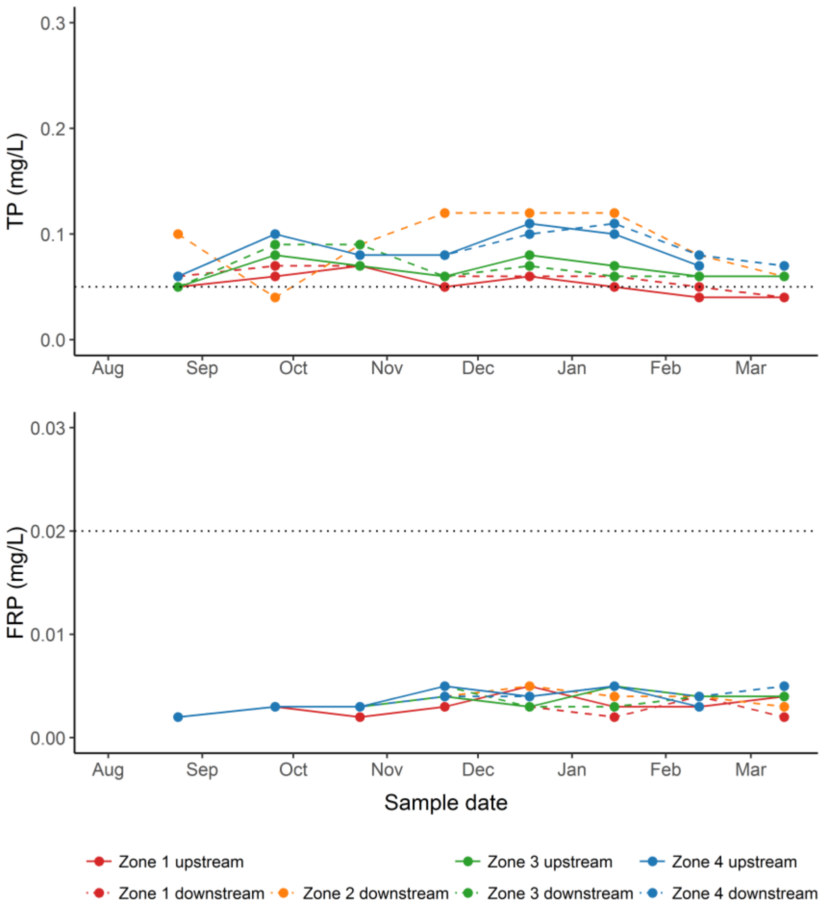


Figure 5.9 Detail of phosphorus concentrations at study sites in the 2017-18 watering year.

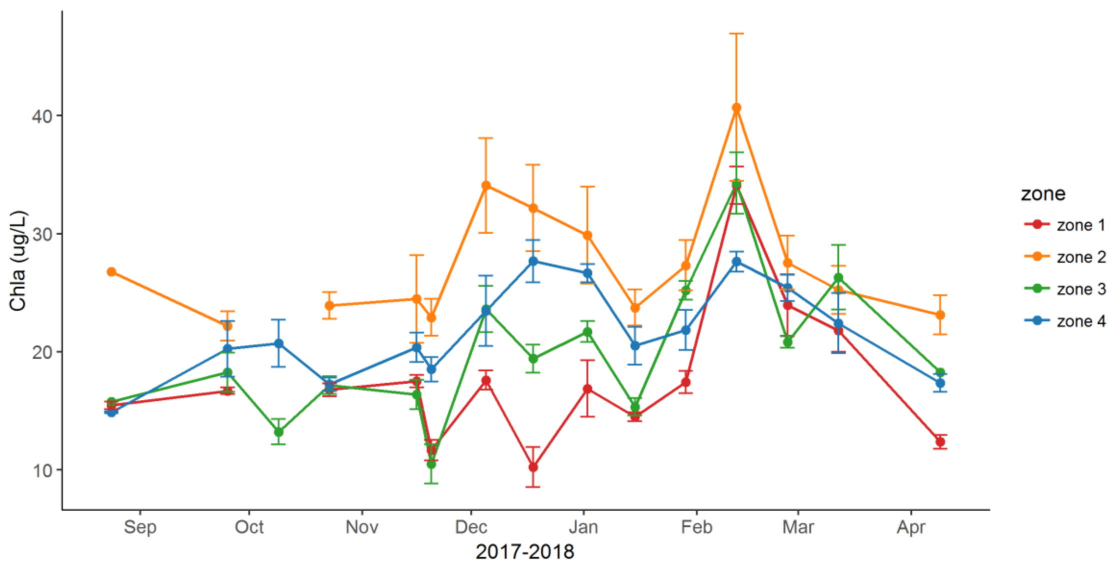


Figure 5.10 Mean (+/- SE) chlorophyll *a* (Chla) concentrations for the LTIM sites in the 2017-18 study seasons.

Dissolved organic carbon and organic matter characterisation

Dissolved organic carbon remained in the range of concentrations normally observed in this system in the absence of overbank flows or excessive algal growth (Figure 5.11). DOC did not enter the range previously associated with hypoxic blackwater. A small peak in DOC was observed in the Edward River samples collected from Stephens Weir around late October/November 2017, and while there is some evidence of this peak transitioning though the system the shape of the peak is much flatter at downstream sites and less readily detected amongst the sample noise. This peak is likely due to water contact with the floodplain upstream (Barmah-Millewa). Increased algal growth over the summer (see chlorophyll data, Figure 5.10) was insufficient to produce a substantial increase in the dissolved fraction of the organic matter in these river systems. DOC concentrations in the canal are shown for comparison with previous years but water was not released into the study sites from the canal in the 2017-18 watering season.

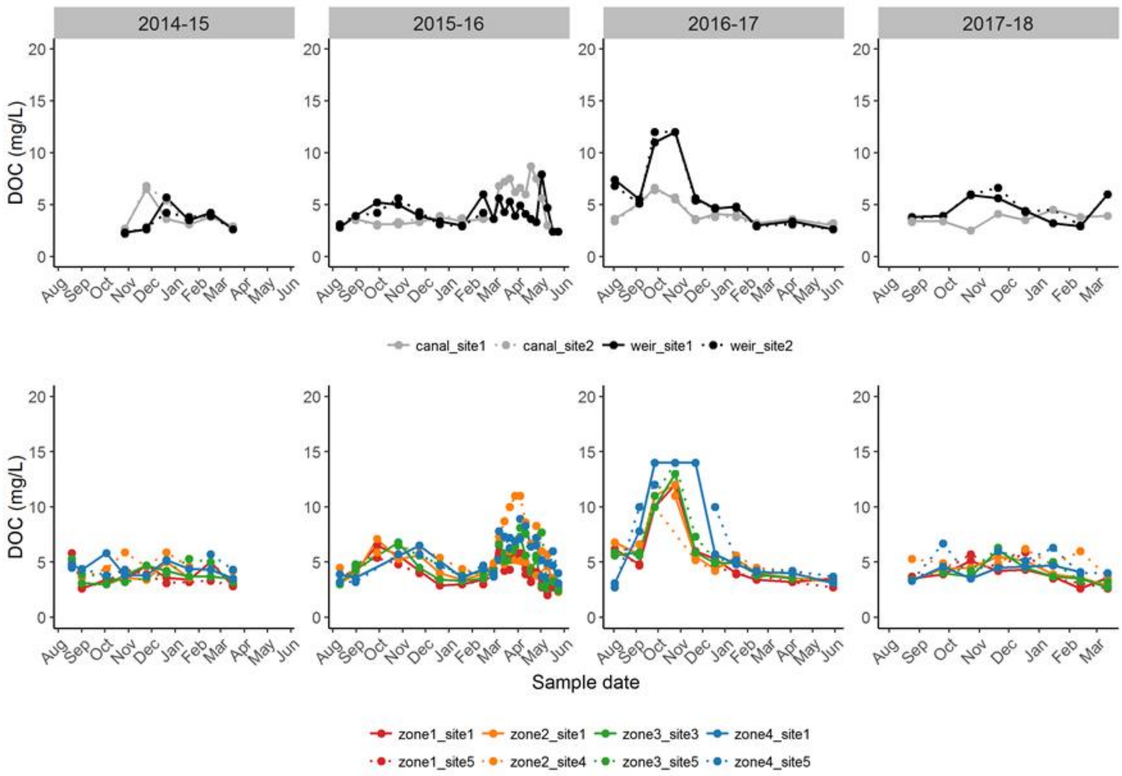


Figure 5.11 DOC concentrations for the LTIM sites in the 2014-15, 2015-16, 2016-17 and 2017-18 study seasons.

Organic matter characterisation - Absorbance

The absorbance spectra for water samples collected at all study sites are shown in Figure 5.12. It is noted that during August 2017 the spectrum for the sample at Weir 1 site has a different shape to the other water samples. This may indicate either a localised water quality difference (algae, run off from the bank etc.) or sample contamination. The absorbance at the downstream site in zone 2 was slightly steeper (more small organic molecules) than at other sites, otherwise study zones are quite similar in organic matter composition. In September 2017 there is a trend towards increasing organic matter absorbance at downstream sites while in October this trend is broadly reversed. This covers the period of the early season pulse and may indicate a transfer of different organic carbon quality downstream. By November 2017 the absorbance spectra for water samples at all sites were very similar and through the summer the sites remain similar, with slightly higher absorbance at the most downstream sampling site. In March 2018 there is some increase in absorbance but the pattern between sites is maintained. The sample from the canal shows signs of interference by particulate matter and this is also the case for the upstream, sample for zone 1 in April (possibly a sample filtering issue).

Organic matter characterisation - Fluorescence

Fluorescence excitation- emission matrices for water samples at all sites through the sampling period are shown in Figure 5.13. As observed in the absorbance scans, the water sample collected from the weir in August 2017 is different from all other sites and the region showing strong fluorescence indicates either organic material of different origin to the rest of the sites is present in the water (run-off or algal material) or sample contamination may be an issue. There were no observations of visible algae noted in the field notes for this sampling date so sample contamination is the most likely explanation for this result. High background fluorescence for zones 1 and 2 is likely instrument variation and DOC fluorescence relative to background is quite low at all sites, although slightly higher at the downstream site in zone 2 relative to the upstream site. In September slightly higher fluorescence was observed at all sites with a very gradual increase downstream, consistent with the absorbance results. The downstream site in zone 4 does separate as being different to the other sites, also consistent with the absorbance results and the decreasing trend downstream in October is also evident here. Broadly similar fluorescence is present across sites in zone 2 in November and in December 2017 clearly has a stronger humic and fulvic signature. Low water levels at this site may concentrate localised leaching of organic matter at this site. Fluorescence is generally low through summer and autumn although in March the upstream site in zone 3 and the downstream site in zone 4 have different fluorescence signatures which may reflect algal carbon present at these sampling sites.

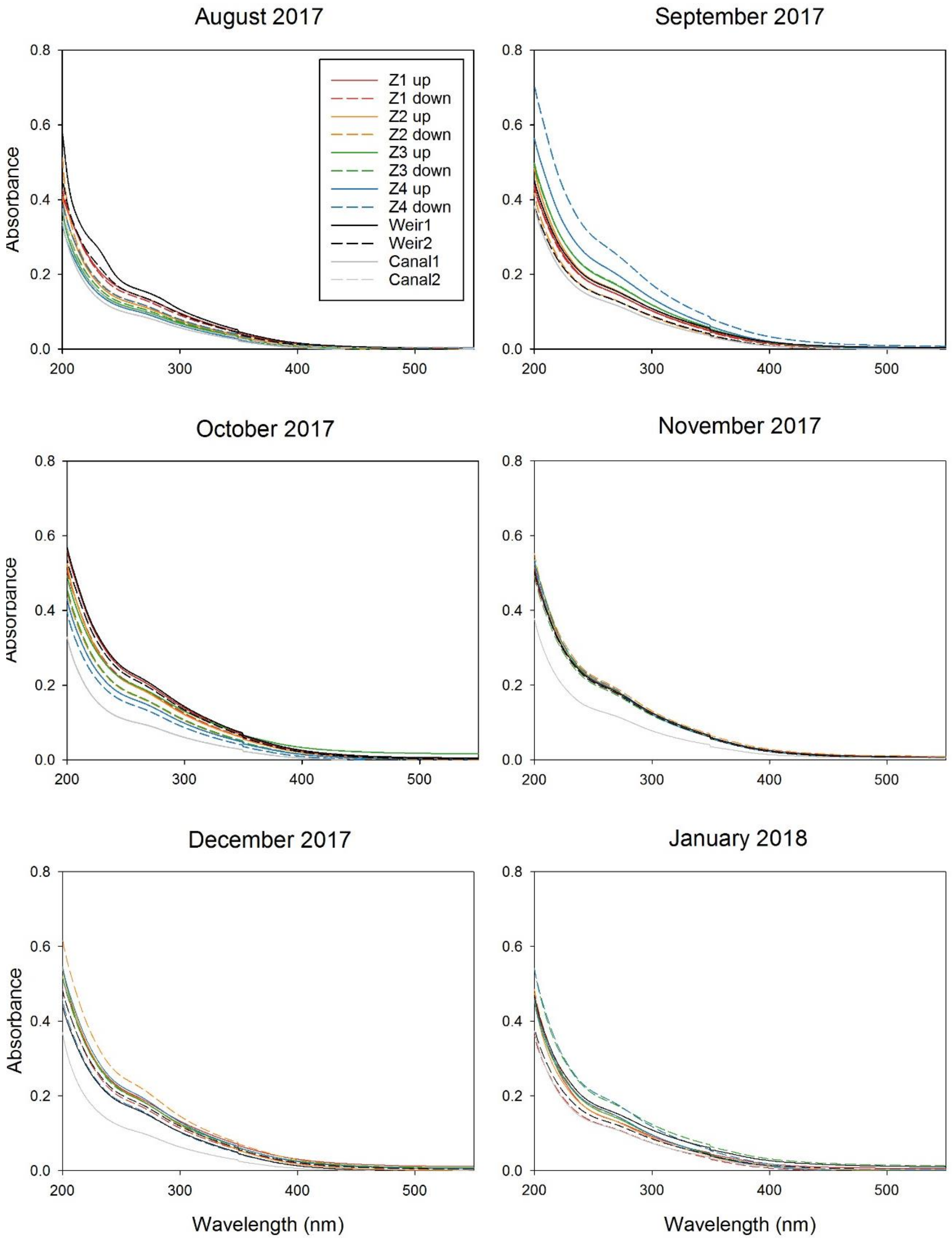


Figure 5.12 Absorbance scans of water samples during the 2017-18 study season (continued).

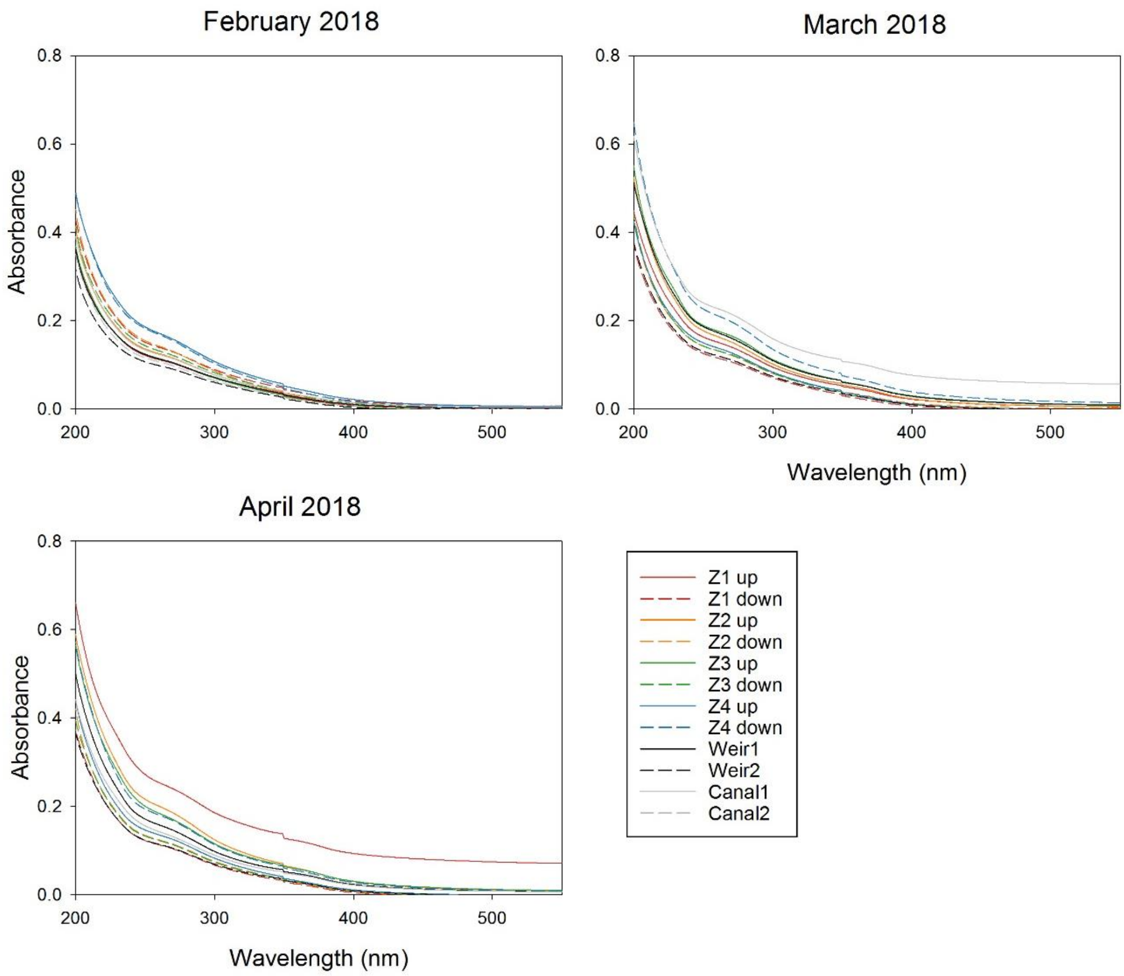


Figure 5.12 (continued).Absorbance scans of water samples during the 2017-18 study season

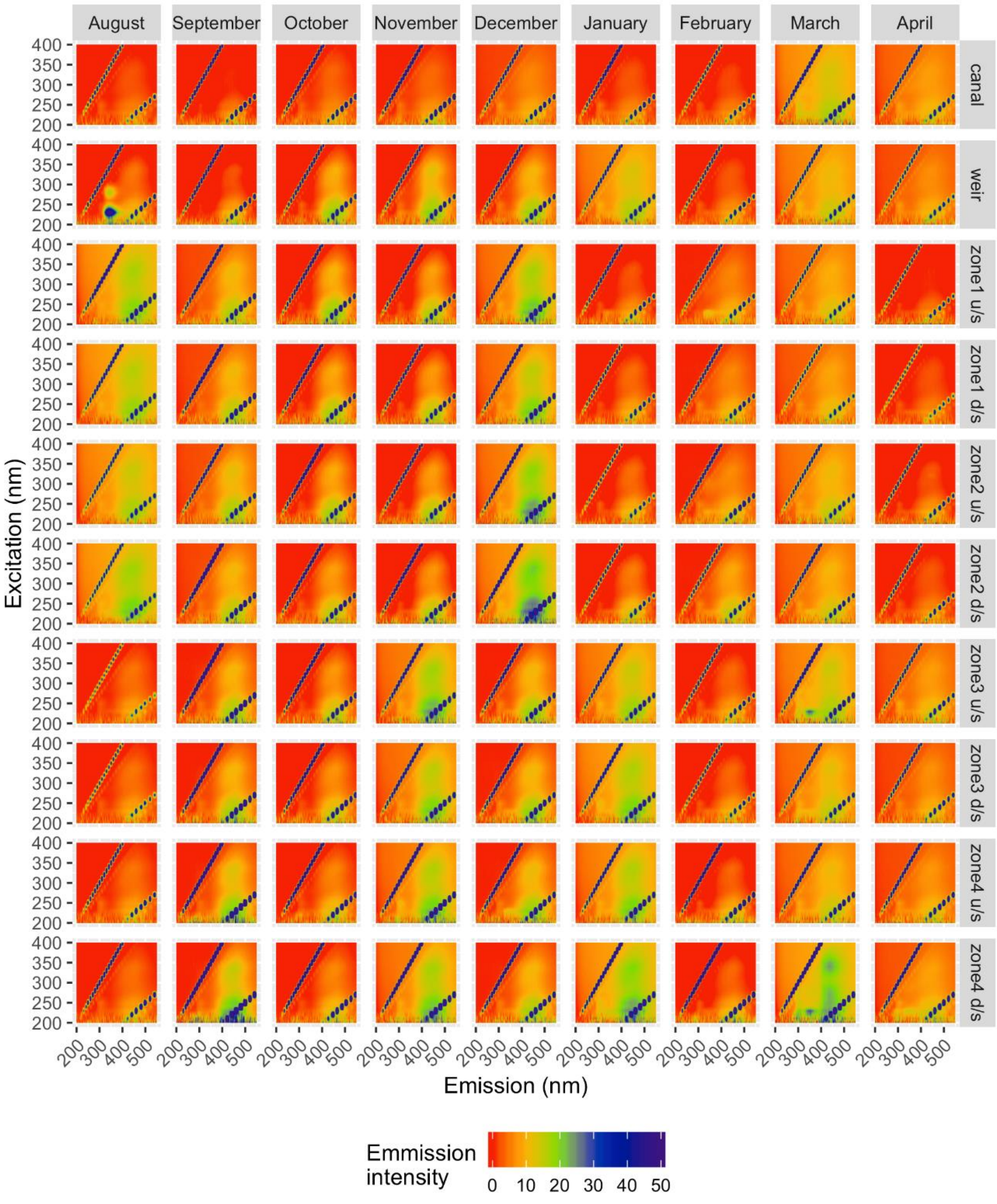


Figure 5.13 Fluorescence excitation-emission spectra for water samples from the 2017-18 watering season.

Colligen Creek environmental watering action

While the Colligen-Niemur system is not included within the sampling zones for this project, environmental water was used in this system during the study period (Figure 4.3) and some data is available from a logger in this system logger via the Waterinfo website. The sole objective for the use of Commonwealth environmental water in this watering action was to avoid a potentially catastrophic event (e.g. a fish kill) in the Niemur River system. The action sought to increase dissolved oxygen levels (preferably to greater than 4.0 mg/L) by increasing the flow rate during the period of high daytime temperatures. This was similar to an action undertaken in the Niemur River system in 2013-14.

Figure 5.14 shows discharge and hourly dissolved oxygen in the Niemur River. The first flow peak in September 2017 (a combination of CEW and unregulated water) had minimal impact on the dissolved oxygen concentration and at this time DO was predominantly impacted by changing seasonal conditions, however each of the peaks later in the season were associated with an increase in the DO concentration (briefly overcoming the seasonal decline in DO concentration). The use of CEW to create a small pulse in late January and February 2018 corresponds to an initial increase in water temperature and drop in DO (this flow corresponds with the start of a period of very hot weather) but then is clearly associated with the DO concentration pushing back over 4 mg/L despite ongoing high air temperatures. As the dissolved oxygen had fallen to almost 2 mg/L at the beginning of this heatwave, it is likely that the use of Commonwealth environmental water prevented the dissolved oxygen falling to lower concentrations during this time. The cessation of this flow is followed by a short period of declining water quality into March 2018. This period of decline does not correspond with high water temperatures (Figure 5.15, 5.16) and demonstrates that the previous flush of CEW had been supporting DO concentrations in this system.

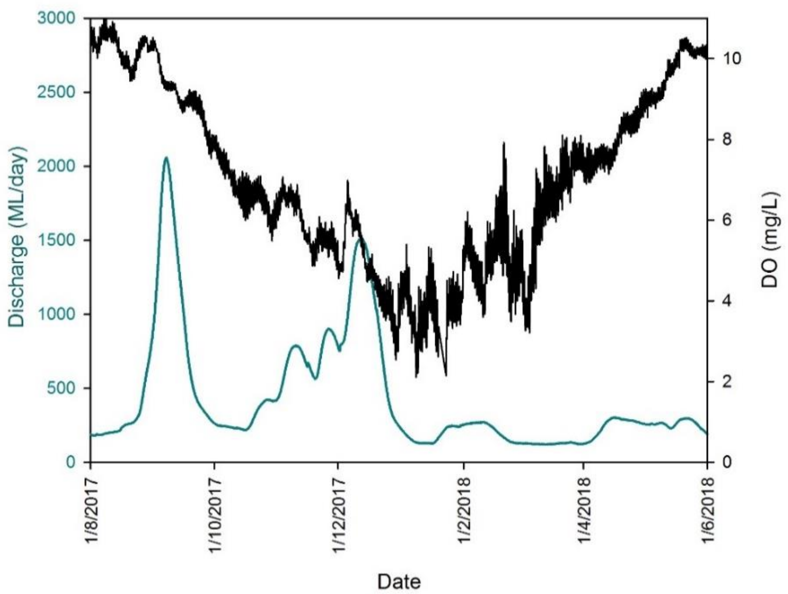


Figure 5.14 Discharge and hourly dissolved oxygen concentration recorded at Niemur River at Barham-Moulamein Rd (409048). Data: NSW DPI, Waterinfo.gov.au

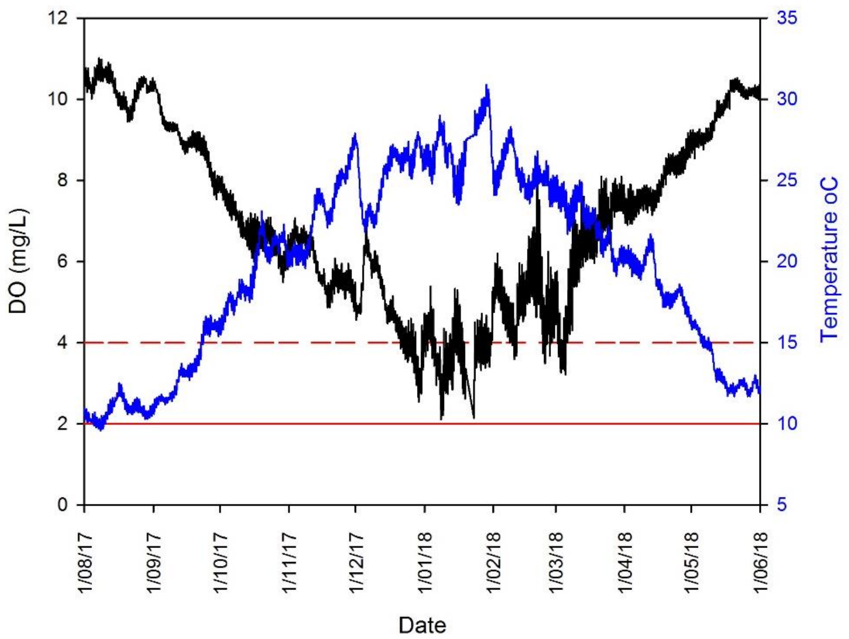


Figure 5.15 Water temperature and hourly dissolved oxygen concentration recorded at Niemur River at Barham-Moulamein Rd (409048). Data: NSW DPI, Waterinfo.gov.au

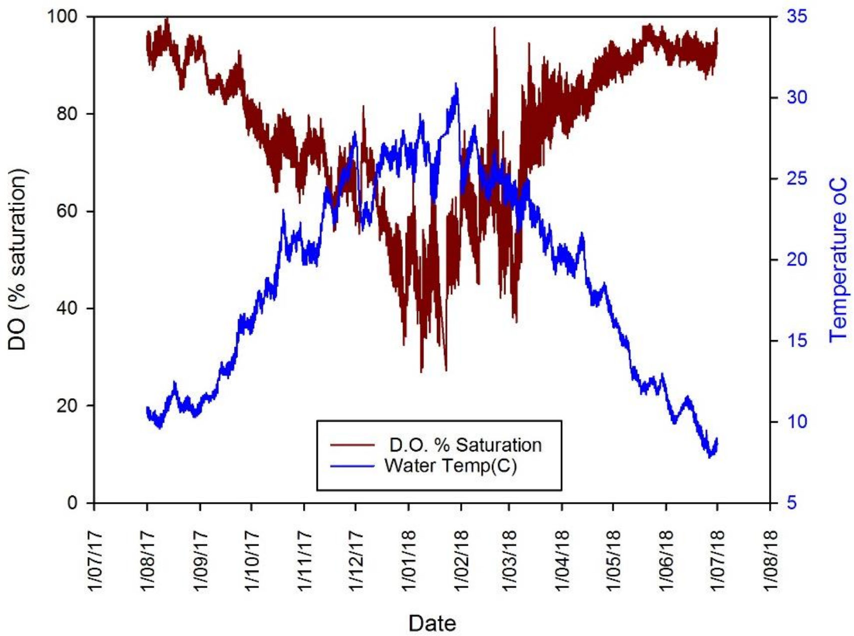


Figure 5.16 Temperature and hourly dissolved oxygen saturation recorded at Niemur River at Barham-Moulamein Rd (409048). Data: NSW DPI, Waterinfo.gov.au

5.6 Discussion

Overall the water quality in the Edward-Wakool selected area during the 2017-18 study season was characterised by a return to normal conditions following two seasons of extreme events (the 2015-16 cyanobacteria bloom and the 2016-17 hypoxic blackwater event).

What did Commonwealth environmental water contribute to dissolved oxygen concentrations?

Commonwealth environmental watering action 6 supported dissolved oxygen concentrations in the Colligen-Niemur system during January and February 2018 by increasing flow to minimise the period where DO concentrations fell below 4 mg/L and prevent DO concentrations falling below 2 mg/L. Hypoxia in the Niemur was developing as a result of slow-moving shallow water during heatwave conditions. This system is not one of the standard LTIM sampling sites, so no DOC data is available but there is no indication that the low DO was the result of hypoxic blackwater or that recent inputs of high DOC would have occurred. Temperature induced hypoxia is likely to result from an increase in the rate of metabolism of the microbial community with normal loadings of DOC and nutrients, combined with lower dissolved oxygen solubility. Increased flow can improve re-aeration to counteract this effect and may also provide some dilution.

Over the four years of LTIM the dissolved oxygen concentration was consistently higher during late summer and early autumn seasons in zones 1, 3 and 4 receiving environmental water than in zone 2 that has received none or minor environmental watering actions. The low-flow conditions in zone 2 result in lower DO concentrations through the same mechanisms as those described for the Niemur, above. The generally lower flow in this zone means the risk of temperature induced hypoxia during heatwaves is greater in this part of the system.

What did Commonwealth environmental water contribute to nutrient concentrations?

There was no detectable effect of environmental watering actions on this indicator in 2017-18. Nutrient concentrations remained within the expected range throughout the system during this sampling season. The absence of overbank flows meant that substantial nutrient inputs were not expected in the system, although a general downstream increase in TN and TP were observed in the zones which received the majority of flow (zones 1, 3 and 4). Nutrient concentrations returned to the range observed during the 2014-15 season with bioavailable forms of both N and P being very low. While cyanobacteria blooms were sufficient to delay a watering action, the blooms were not sufficient to cause a dramatic shift in the nutrient profile as occurred during the much larger bloom event in 2016.

What did Commonwealth environmental water contribute to temperature regimes?

Water temperatures in the system were primarily controlled by the prevailing weather conditions. No specific flow targeted temperature in the system. In general the water temperatures in the Edward Wakool river system was similar across all sites and this trend has been observed in previous years. This suggests that unless a large flow occurs in a previously very shallow part of the system during either extremely hot or cold weather, significant changes in water temperature would not be expected.

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?

There was no detectable effect of environmental watering actions on this indicator in 2017-18. The flows in this season were not specifically targeted to the transport of dissolved organic matter and while small changes were linked to changes in hydrology, they were not clearly linked to the use of Commonwealth environmental water. The type and amount of DOC in the system was similar to previous seasons where blackwater and major algal blooms were not present and no dilution flows or refugia flows were required. Commonwealth environmental water was not delivered with the intention of boosting productivity by connecting with the floodplain during this sampling season.

5.7 Evaluation

Table 5.2 Summary of water quality responses to Commonwealth environmental watering

Water Quality					
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***	***LTIM Question***	***Observed outcomes***	***What information was the evaluation based on?***	***Were appropriate flows provided to achieve the expected outcome?***
Early season fresh at beginning of e-flow (watering action 2)	To contribute to connectivity, water quality, stimulating growth of in-stream aquatic vegetation, pre-spawning condition of native fish, spawning in early spawning native fish	Did Commonwealth environmental water contribute to dissolved oxygen concentrations?	Dissolved oxygen concentrations were dominated by seasonal influences and were in an appropriate range during this period.	Logged DO concentrations	NA
		Did Commonwealth environmental water contribute to nutrient concentrations?	No effect detected	Monthly water samples	Larger flows are required to impact nutrient concentrations but this was not a key outcome for this flow.
		Did Commonwealth environmental water contribute to temperature regimes?	No effect detected	Logged temperature data	Not an objective of this flow
		Did Commonwealth environmental water contribute to modification of the type or amount of dissolved organic matter?	No effect detected	Monthly water samples analyzed for DOC, fluorescence and absorbance	Larger flows are required to impact this parameter.
Summer fresh in Colligen-Niemur system (watering action 6)	Improve water quality	Did Commonwealth environmental water contribute to dissolved oxygen concentrations?	DO increased in response to CEW	Logged DO data from the Niemur River	Yes
		Did Commonwealth environmental water contribute to nutrient concentrations?	Not assessed	NA	NA
		Did Commonwealth environmental water contribute to temperature regimes	Insufficient data available	NA	NA
		Did Commonwealth environmental water contribute to modification of the type or amount of dissolved organic matter?	Not assessed	NA	NA

6 STREAM METABOLISM

Key findings	
Gross Primary Production	Watering actions almost uniformly decreased the rates of gross primary production (mg O_2/L/day) simply through a dilution effect. However, when GPP was calculated as the amount of organic carbon ('fish food') produced per day (kg C/day) then watering actions had a beneficial effect (more 'food' is better), with significant differences between sites. The size of the beneficial impact was largely related to the proportion of total flow that came from the watering action – carbon production was enhanced by between 1% and 218% per day, with a median across all sites and watering actions of 41% more carbon produced during Commonwealth environmental watering actions compared to no Commonwealth environmental water.
Ecosystem Respiration	As with GPP, watering actions almost uniformly decreased the rates of ecosystem respiration (mg O_2/L/day) simply through a dilution effect. However, when ER was calculated as the amount of organic carbon consumed per day (kg C/day), then watering actions had a beneficial effect, with significant differences between sites. A higher amount of organic carbon consumed means more nutrient recycling and hence greater nutrient supply to fuel GPP. At no stage did the environmental watering actions create so much respiration that dissolved oxygen dropped below 'safe' values for aquatic biota.

6.1 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 6.1.

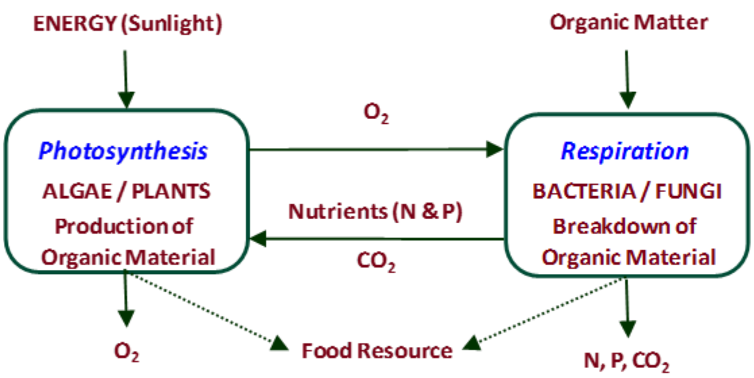


Figure 6.1 Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients

Metabolism is expressed as the increase (through photosynthesis) or decrease (through 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 concern when process rates are too high. Greatly elevated primary production rates usually equate to algal bloom conditions (or excessive growth of plants), which may block sunlight penetration, killing other submerged plants, produce algal toxins and large diel DO swings - overnight elevated respiration rates can decrease 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.

Sustainable 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 the 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 might be extremely low due to heavy shading and low 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.

This chapter reports on changes in stream metabolism in response to flows from 1 May 2017 to 30 June 2018.and will consider changes in gross primary production and ecosystem respiration in the system.

6.2 Environmental watering actions in 2017-18

Six commonwealth environmental watering actions were delivered in the Edward-Wakool system in 2017-18 (section 2). The response of stream metabolism to four of these watering actions (Table 6.1) was evaluated.

Table 6.1 Environmental watering actions in the Edward-Wakool system in 2017-18 indirectly related to stream metabolism

	Planned watering action	Type of action	Dates	Rivers	Objectives
1	Winter watering action	base flow	1 May - 23 Aug 2017	Yallakool Creek, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to reinstatement of the natural hydrograph, connectivity, condition of in-stream aquatic vegetation and fish recruitment
2	Early spring fresh at beginning of e-flow with flow recession	small fresh and flow recession	7 Sept - 22 Oct 2017	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to connectivity, water quality, stimulating growth of in-stream aquatic vegetation, pre-spawning condition of native fish, spawning in early spawning native fish
4	Summer fresh at end of e-flow with flow recession	small fresh and flow recession	3 - 29 Jan 2018	Yallakool Creek, mid and lower Wakool River	To encourage fish movement and assist dispersal of larvae and juveniles of fish species.
5	Autumn fresh with flow recession	small fresh	28 Mar - 1 May 2018	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To encourage fish movement and dispersal of juveniles of a number of fish species.

*Watering action 3 was not implemented due to an unregulated fresh occurring at the time of this planned action

6.3 Selected-area questions

Evaluation of the response of stream metabolism to Commonwealth environmental watering is 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 is evaluated in a separate report. The Edward-Wakool Selected Area reports are evaluating short-term and longer term responses of stream metabolism to Commonwealth environmental water delivery, as per the evaluation question below. This question arises 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.

Q: 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, both at the short term and longer term scales?

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

- 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 (not evaluated in 2017-18)
- Under normal 'base' flow, rates of GPP and ER will be constrained to the low-moderate range, typically 1-3 mg O_2/L/Day.
- 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 (the 'larger flows' did not occur in 2017-18 so this aspect is not evaluated in this report).
- Inundation and reconnection of backwater areas to the main channel during high flows will result in elevated rates of GPP and ER (not evaluated in 2017-18).
- Primary production in the Edward-Wakool system will be limited by low phosphorus concentrations.

In addition to evaluating these hypotheses, this year for the first time we have attempted to examine rates of primary production at a whole of system level, by using the rates estimated from the field measurements of dissolved oxygen dynamics to quantify the total amount of carbon being produced each day. We have also been able to extend these calculations to derive estimates of production likely to have occurred in the absence of Commonwealth Environmental Watering actions. While these calculations rest on a number of important assumptions that will be refined as the project continues, such as deriving improved models for estimates of daily rates of GPP and ER based on antecedent flow, light and temperature.

6.3 Methods

Data collection

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 and all data sets from that time onwards. 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 using 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 5) for each of the zones from June 2017 (to complete a full winter data set encompassing July and August 2017) to early April 2018.

In accord with the LTIM Standard Protocol, water quality parameters (temperature (^{o}C), 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).

Data analysis

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 the equivalent meeting 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%. Data days with reaeration coefficients outside the range 0.1 to 15 Day^{-1} were also excluded as such rates are highly unlikely. 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.

Many data in this report are presented as "boxplots". "Box" (or "Box & Whisker") plots provide a convenient and simple visual means of comparing the spread of data. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. "Whiskers" above and below the box indicate the 90th and 10th percentiles. Values beyond this, called "far outside values" or "outliers" are plotted as single circles.

The mass of oxygen produced per day was calculated by multiplying the GPP or ER in mg O_2/L/Day by the number of Litres discharged that day. Conversion to organic carbon involves a factor of 12/32 (ratio of atomic mass of C and molecular mass of O_2). This factor does not include any physiological efficiency factor for converting oxygen to organic carbon which typically is in the range 0.8-1. Given the exploratory use of this metric, concern over conversion efficiency at this stage is unwarranted.

The estimation of the additional daily carbon production (kg) attributable to Commonwealth environmental watering actions entailed the following steps. This approach addresses issues associated with the fact that higher flows are often associated with lower rates of production per litre.

1. We assigned each day to a season (summer, autumn, winter, spring) and flow quantile (5 groups).
2. For each season and flow quantile we calculated the average rate of production per litre per day (g C/L/day).
3. The total production for each day was then estimated by multiplying the mean rate of production derived for that day based on season and flow quantile (in g C/L/day) by the observed discharge on that day (L).
4. To calculate the discharge predicted to have occurred in the absence of Commonwealth Environmental Water (CEW), we subtracted the volume of-CEW from the total discharge (observed discharge – CEW).
5. We then used the mean rate of production associated with the quantile in which the non-CEW discharge fell, as well as the associated season, to determine the predicted rate of production (g C/L/day) for that day in the absence of CEW.
6. This alternative rate of production was then multiplied by the non-CEW discharge volume to determine the total production predicted to have occurred on that day in the absence of CEW.
7. This above steps produced two time-series of estimated total daily production with and without CEW.
8. The daily estimates of CEW/non-CEW derived production were averaged to determine the average daily additional production during watering actions and total additional production over the entire watering action.

6.4 Results

Stream metabolism 2017-18

Discharge during 2017-18 was characterised by in-channel flows, which are typical in this system. In contrast, in 2016-17 the major feature affecting stream metabolism was the unregulated overbank flooding in spring 2016. Estimates of Gross Primary Production (GPP) and Ecosystem Respiration (ER) for the 7 stream metabolism monitoring sites in 2017-18 were produced using the BASEv2 model (updated from Grace et al., 2015 according to Song et al., 2016). Data loggers were in place from April 2017 until early April 2018. Regular maintenance and occasional problems with some loggers meant that data from some days needed to be discarded. Details of the logger deployments are given in

Two loggers, zone 1 Downstream and zone 3 Upstream, had data sets starting in late August 2017 as they were removed for maintenance during the winter system shutdown (

Table **6.1**).

Using the acceptance criteria for each day's diel DO curve, the acceptance rate ranged from a low of 58% of all days with data available (171 from 294 possible days) for zone 1 Upstream up to a high of 79% (230 of 290 possible days) at zone 3 Upstream. All acceptance data are shown in Table 6.2. A comparison is made with acceptance criteria from 2015-16 and 2016-17. With one very minor exception (zone 1 upstream where acceptance was 1% lower than in 2015-16), % acceptance was the highest for each site in 2017-18. This is predominantly attributed to the absence of large flows and lack of periods of anoxia (low or no DO), both of which frequently preclude data that meets the acceptance criteria.

Table 6.1 Summary of Logger Deployments, September 2016 - May 2017.

Hydrological Zone	Site	First Deployed	Last day Deployed	Periods of Missing Data (> 1 week)
1 Yallakool Ck	Upstream	1/6/2017	8/4/2018	12-22/8
	Downstream	23/8/2017	13/3/2018	-
2 Wakool River	Downstream	1/6/2017	8/4/2018	12-25/8
3 Wakool River upstream Thule Ck	Upstream	26/8/2017	8/4/2018	-
	Downstream	1/6/2017	8/4/2018	13-25/8, 24/11-19/12
4 Wakool River downstream Thule Creek	Upstream	1/6/2017	8/4/2018	13/8-26/9
	Downstream	1/6/2017	8/4/2018	13-25/8

Table 6.2 Summary of data availability for the seven data logger sites, September 2016 - May 2017.

Hydrological Zone	Site	Total Days	Days with Acceptable Data	% Acceptable Days Year 4 (2017-18)	% Acceptable Days Year 3 (2016-17)	% Acceptable Days Year 2 (2015-16)
1 Yallakool Ck	Upstream	294	171	58	42	59
	Downstream	198	129	65	48	62
2 Wakool River	Downstream	291	224	77	30	67
3 Wakool River upstream Thule Creek	Upstream	218	163	75	30	14
	Downstream	264	198	75	37	24
4 Wakool River downstream Thule Ck	Upstream	257	169	66	17	54
	Downstream	290	230	79	35	37

The median GPP values for all seven sites fall within a narrow range of 1.1 to 2.6 mg O_2/L/Day; this range is very similar to that found in 2015-16 (1.4 to 4.1 mg O_2/L/Day) and 2016-17 (1.6 to 3.9 mg O_2/L/Day)(Table 6.4). This closeness in median GPP rates is unsurprising given the similarity in the biogeochemical environments as noted in previous years (Watts et al. 2014, Watts et al. 2015). It is worth noting here that the major events in the previous two years (large flows and anoxia) precluded collection of data meeting acceptance criteria at those times. Hence these comparisons are made using metabolic rates obtained primarily during in-channel flow conditions.

Table 6.3 Summary of primary production (GPP) and ecosystem respiration (ER) rates and P/R ratios for the seven sites in four hydrological zones, June 2017 - April 2018. Each metabolic parameter is expressed as a median and mean with minimum and maximum values also included. 'n' is the number of days for which successful estimates of metabolic parameters were obtained.

	Zone 1 Upstream (n = 171)				Zone 1 Downstream (n = 129)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	1.29	1.87	0.29	7.80	1.13	1.30	0.50	3.2
ER (mg O_2/L/Day)	3.25	3.61	0.27	12.6	3.46	3.76	0.92	11.7
P / R	0.51	0.61	0.14	4.60	0.39	0.41	0.11	1.09

	Zone 2 Downstream (n = 224)			
	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	2.63	2.88	0.97	10.7
ER (mg O_2/L/Day)	8.68	8.77	1.05	23.3
P / R	0.36	0.42	0.11	5.45

	Zone 3 Upstream (n = 163)				Zone 3 Downstream (n = 198)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	1.24	1.35	0.49	3.73	1.83	2.10	0.68	5.15
ER (mg O_2/L/Day)	3.47	3.82	0.85	15.9	3.38	3.32	0.79	8.47
P / R	0.38	0.41	0.12	1.00	0.69	0.66	0.19	1.05

	Zone 4 Upstream (n = 169)				Zone 4 Downstream (n = 230)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	2.25	2.90	0.55	14.8	1.54	1.77	0.48	10.6
ER (mg O_2/L/Day)	4.78	6.49	1.31	27.7	3.41	3.91	1.17	19.7
P / R	0.45	0.47	0.15	1.91	0.45	0.46	0.14	0.76

There was a seasonal increase in GPP from spring into summer in all four zones and then a reduction in GPP in early autumn 2018. This is expected due to the warmer days, and more hours and higher intensity of sunshine during summer. Rates increase during summer beyond the solstice due to increasing plant biomass. Despite the constrained range of median values, there were many days at each site with higher rates of GPP and ER (sometimes exceeding 10 mg O_2/L/day), indicating that elevated rates were possible when conditions were conducive. This was particularly notable in mid-summer in zone 4 for both GPP and ER and from November 2017 onwards, and for ER in zone 2 (Figure 6.2).

Table 6.3). This indicates that for most of the time the system was strongly heterotrophic. This means that much more carbon was being consumed by respiration in the river than being produced by photosynthesis. This organic carbon must have come from either further upstream or from the surrounding catchment including the riparian zones. One of the key roles of rainfall and larger flows is to wash organic carbon into the river channel, often in the form of small particulate matter.

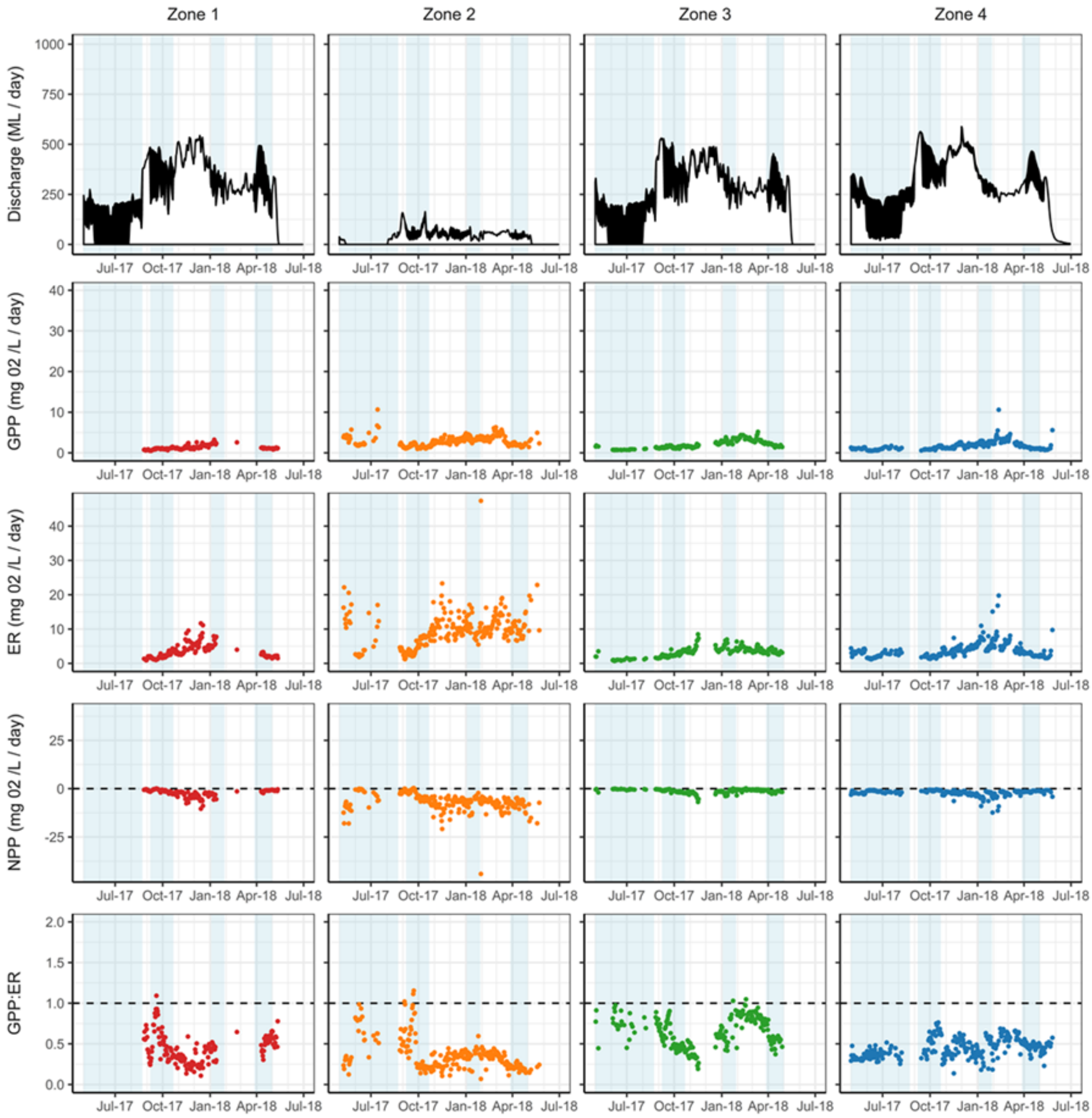


Figure 6.2 Plots of discharge, organic carbon production (GPP), consumption (ER), net production (NPP) and production: consumption ratio (GPP:ER) over all sites in four hydrological zones in 2017-18. Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

Stream metabolism across four years of LTIM (2014-15 to 2017-18)

Figure 6.3 displays the stream metabolism metrics as a function of zone and year. These data show that metabolism in zone 4 is slightly more variable than the other three zones across the four year period. There is a large amount of variability in daily organic carbon loads within a zone each year – carbon production, consumption and net production all vary by up to 2-3 orders of magnitude. This variability is driven by both i) changes in flow (which has varied by several orders of magnitude over the 4 years; and ii) the daily rates of GPP and ER, which can vary over an order of magnitude (e.g. 1 – 10 mg O_2/L/Day) but differences between minimum and maximum rates can be as much as 50 or more (Site 1 Upstream ER 2017-18, Table 6.3**).** The net production, the difference between GPP and ER each day, is almost always negative (also indicated by GPP/ER ratios of less than 1)(Figure 6.3).

Table 6.3

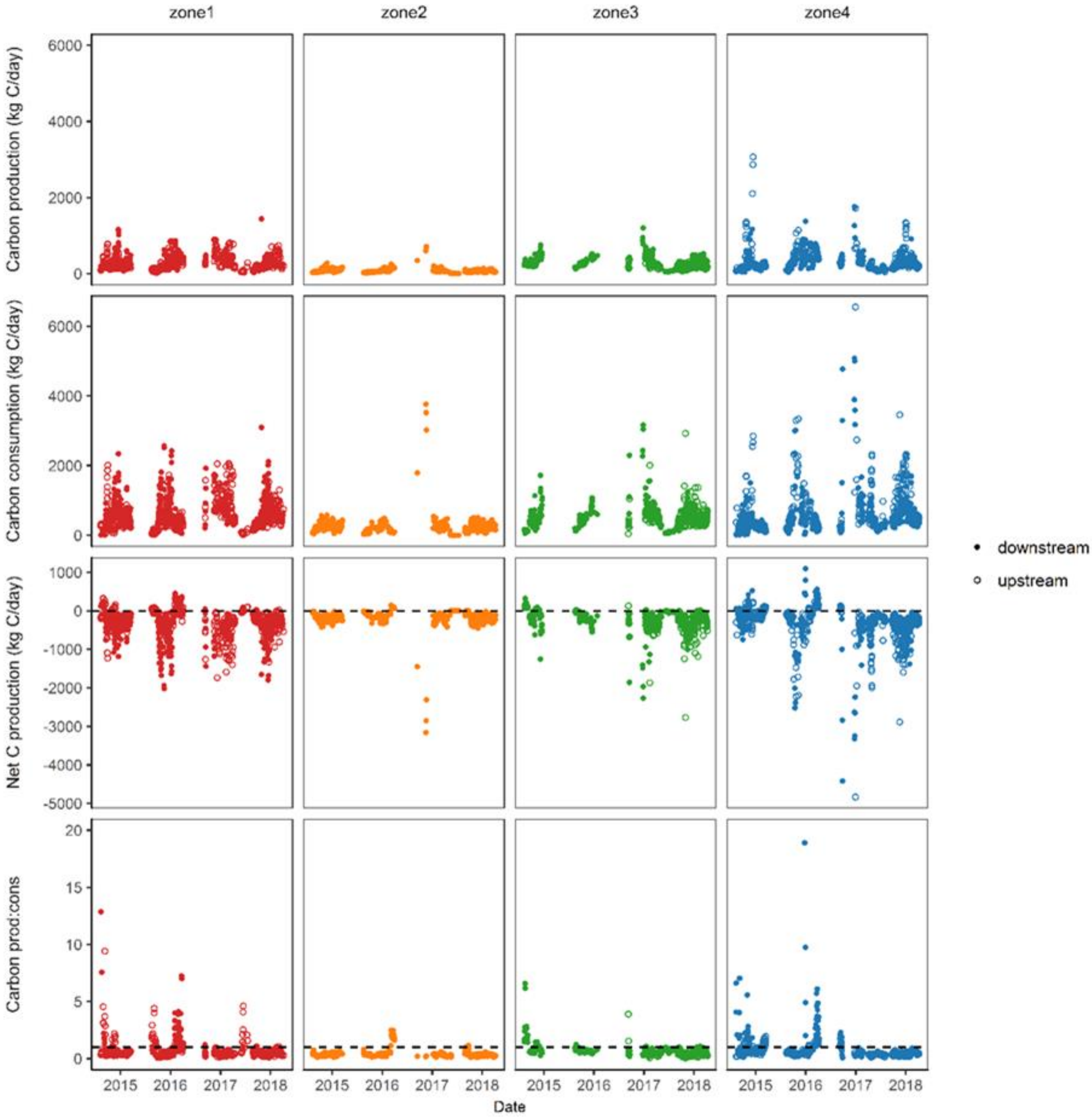


Figure 6.3 Plots of Organic carbon production (GPP), Consumption (ER), Net Production (GPP-ER) and Production: Consumption Ratio (GGP/ER) stratified by zone and year (2014-15 through to 2017-18). Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

Response of stream metabolism to Commonwealth environmental watering actions

Environmental watering action 1 in winter 2017: This action reduced the rate of production of O_2 per litre in zones 3 and 4 through a dilution effect, but overall there was an increased carbon load in these zones compared to zone 2 (no environmental water) (Figure 6.4). Although a logger was not deployed in zone 1 during this action, based on these findings it is likely the action would have increased total carbon load in zone 1. There was a large increase in carbon production (kg C/day) in zones 3 and 4 in response to this watering action (Figure 6.5), due to the environmental water making a large contribution to the overall discharge.

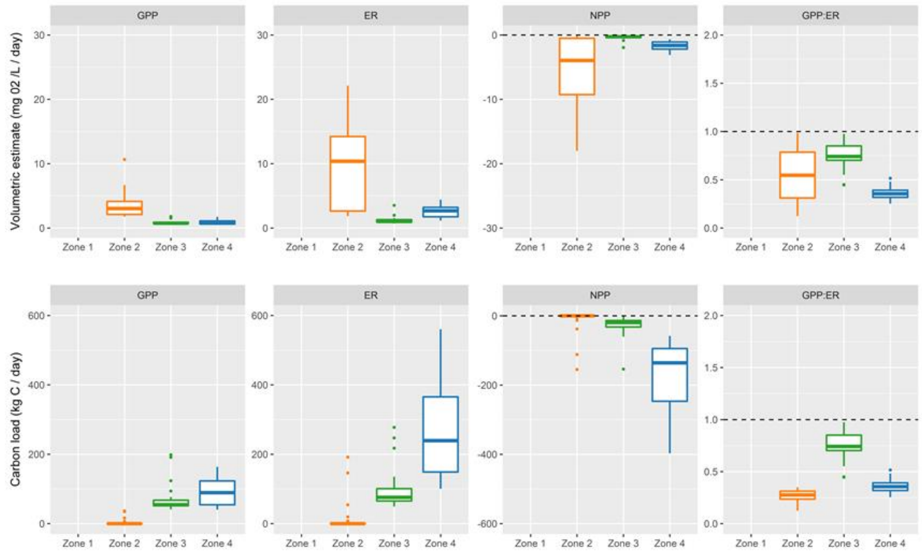


Figure 6.4 Watering action 1 winter 2017. Top panel: Volumetric estimate of carbon (mg O_2/L/day). Bottom panel: total carbon load (kg C/day). Values for organic carbon production (GPP), Consumption (ER), Net Production (GPP-ER) and Production: Consumption Ratio (GGP/ER) are shown. Different coloured box plots represent the four study zones. Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

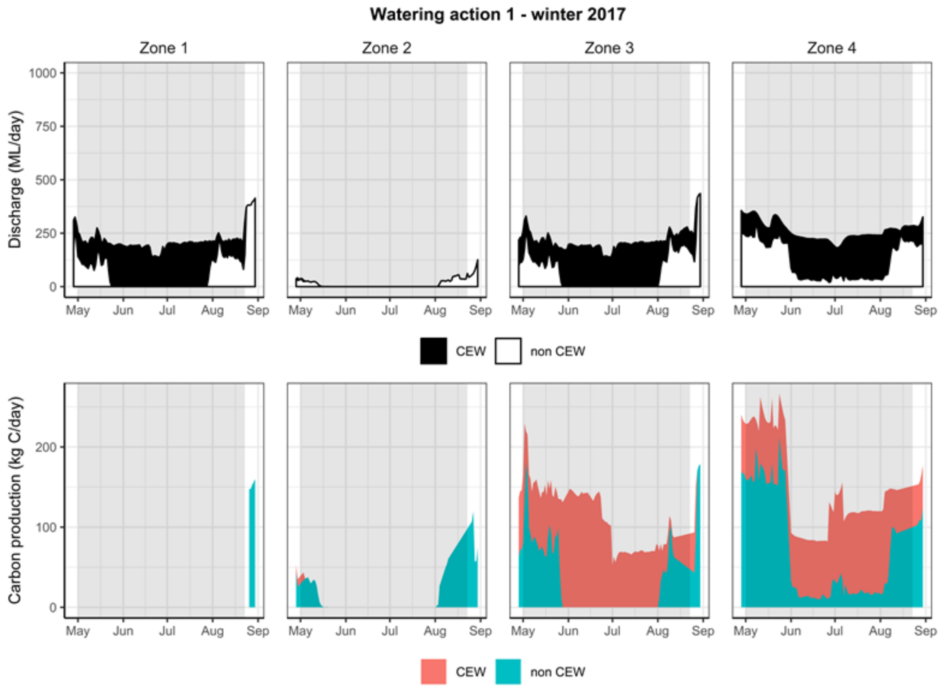


Figure 6.5 Plots of discharge (ML/day) and carbon production (kg C/day) during watering action 1 in winter 2017 showing the component attributed to Commonwealth environmental water.

Environmental watering action 2 small spring fresh: This action reduced the rate of production of O_2 per litre in zones 1, 3 and 4 through a dilution effect, but overall there was a higher carbon load in these zones compared to zone 2 (small environmental water action) (Figure 6.6). There was a large increase in carbon production (kg C/day) in zones 1, 3 and 4 response to the Commonwealth environmental water (Figure 6.7). Even the small volume of environmental water delivered to zone 2 resulted in increased carbon load in that zone.

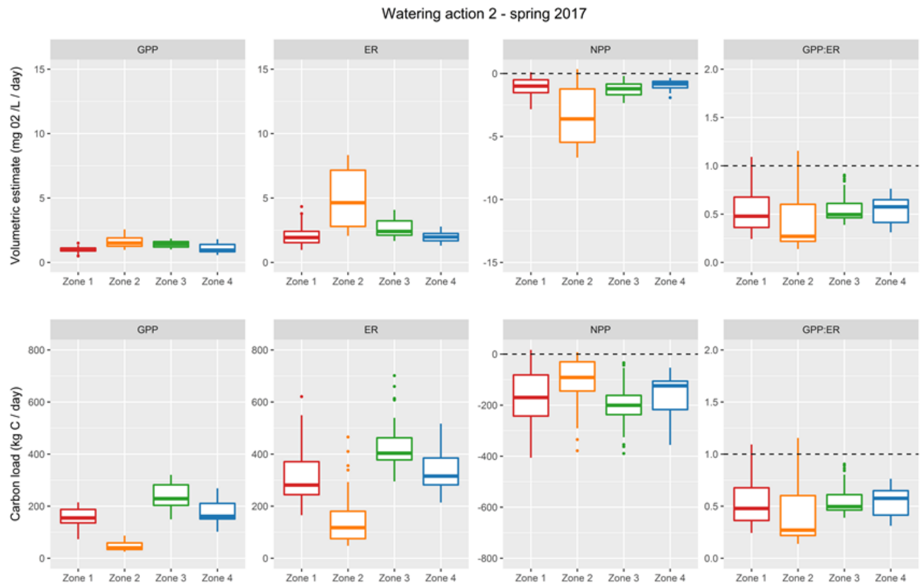


Figure 6.6 Watering action 2 small spring fresh 2017. Top panel: Volumetric estimate of carbon (mg O_2/L/day). Bottom panel: total carbon load (kg C/day). Values for organic carbon production (GPP), Consumption (ER), Net Production (GPP-ER) and Production: Consumption Ratio (GGP/ER) are shown. Different coloured box plots represent the four study zones. Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

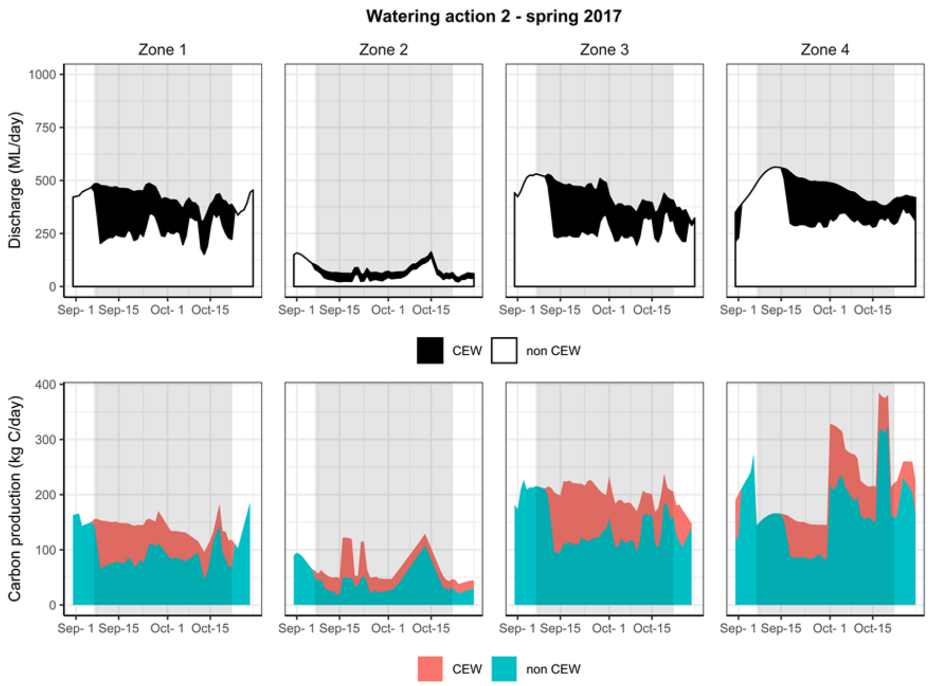


Figure 6.7 Watering action 2 Small spring fresh. Plots of discharge (ML/day) and carbon production (kg C/day) during showing the component attributed to Commonwealth environmental water.

Environmental watering action 4 small summer fresh: Similar to actions 1 and 2, this action reduced the rate of production of O_2 per litre in zones 1, 3 and 4 through a dilution effect. There was a substantial overall carbon load in these zones (~800 kg/day) compared to zone 2 (~250 kg/day) that had lower discharge (Figure 6.8). There was a small increase in overall carbon production (kg C/day) in zones 1, 3 and 4 in response to the Commonwealth environmental water (Figure 6.9).

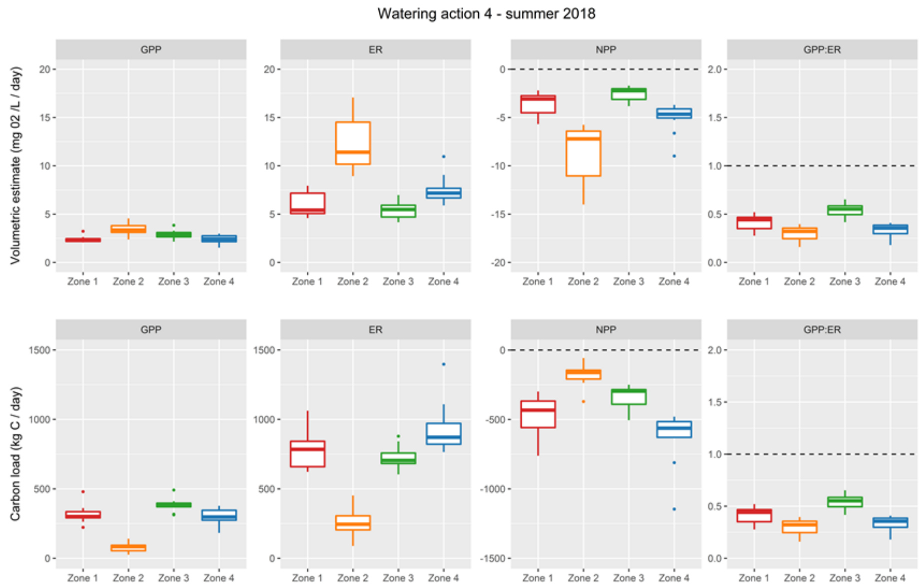


Figure 6.8 Watering action 4 small summer fresh 2017. Top panel: Volumetric estimate of carbon (mg O2/L/day). Bottom panel: total carbon load (kg C/day). Values for organic carbon production (GPP), Consumption (ER), Net Production (GPP-ER) and Production: Consumption Ratio (GGP/ER) are shown. Different coloured box plots represent the four study zones. Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

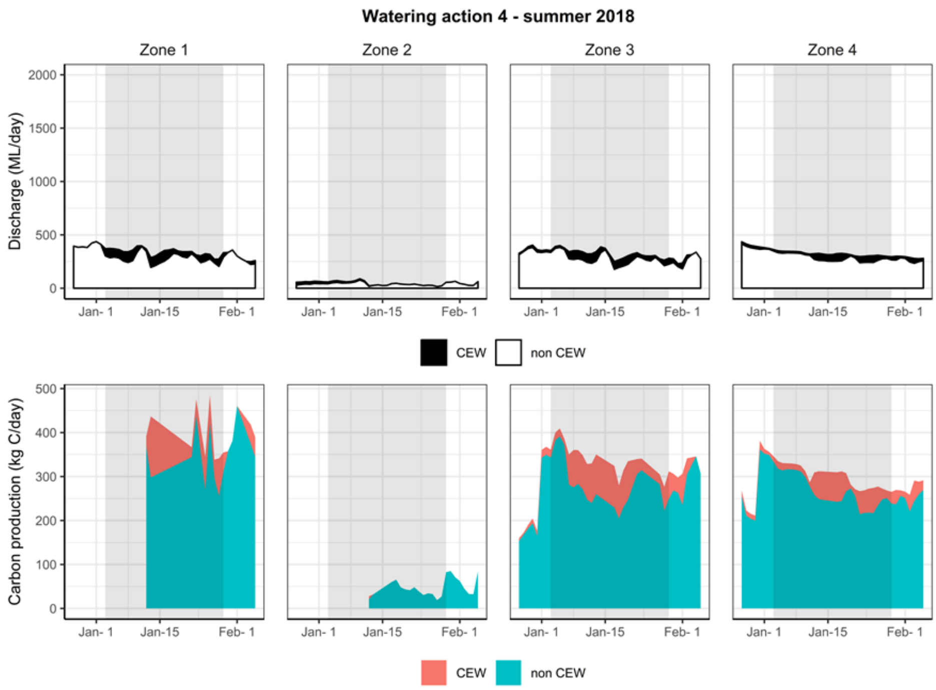


Figure 6.9 Small summer fresh watering action 4. Plots of discharge (ML/day) and carbon production (kg C/day) during showing the component attributed to Commonwealth environmental water.

Environmental watering action 5 small autumn fresh 2018: Similar to actions 1, 2 and 4, this action reduced the rate of production of O_2 per litre in zones 1, 3 and 4 through a dilution effect. Overall there was a higher carbon load in these zones (~250-400 kg/day) compared to zone 2 (~200 kg C/day) that had lower discharge (Figure 6.10). There was a small increase in carbon production (kg C/day) in all zones in response to this watering action (Figure 6.11).

Figure 6.10 Watering action 5 small autumn fresh 2018. Top panel: Volumetric estimate of carbon (mg O2/L/day). Bottom panel: total carbon load (kg C/day). Values for organic carbon production (GPP), Consumption (ER), Net Production (GPP-ER) and Production: Consumption Ratio (GGP/ER) are shown. Different coloured box plots represent the four study zones. Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

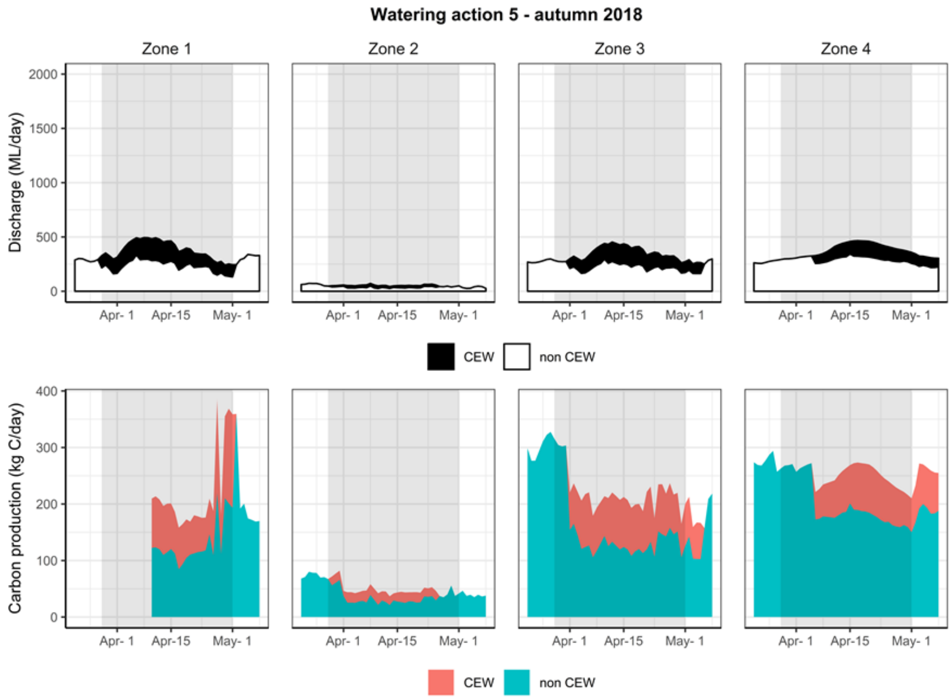


Figure 6.11 Small autumn fresh watering action 5. Plots of discharge (ML/day) and carbon production (kg C/day) during showing the component attributed to Commonwealth environmental water.

Estimated contribution of Commonwealth environmental water to carbon production across all watering actions

The daily estimates of CEW/non-CEW derived production were averaged across the number of days for each watering action to determine the average daily additional production for each watering action and the total additional carbon production over the each watering action.

All of the environmental watering actions resulted in increased production of carbon (Figure 6.12). There was a considerably lower production of carbon in the upper Wakool reach (zone 2) that had an overall lower discharge. However, even the delivery of a very small volume of environmental water for action 2 and 5 resulted in a slight increase in carbon production in zone 2.

During watering action one, more than 50% of the daily carbon production and total carbon production was attributed to Commonwealth environmental water (Figure 6.12). Even though the daily carbon production during this winter action was less than the daily production in the other three actions, the total production was considerable because the watering action extended over a period of 114 days.

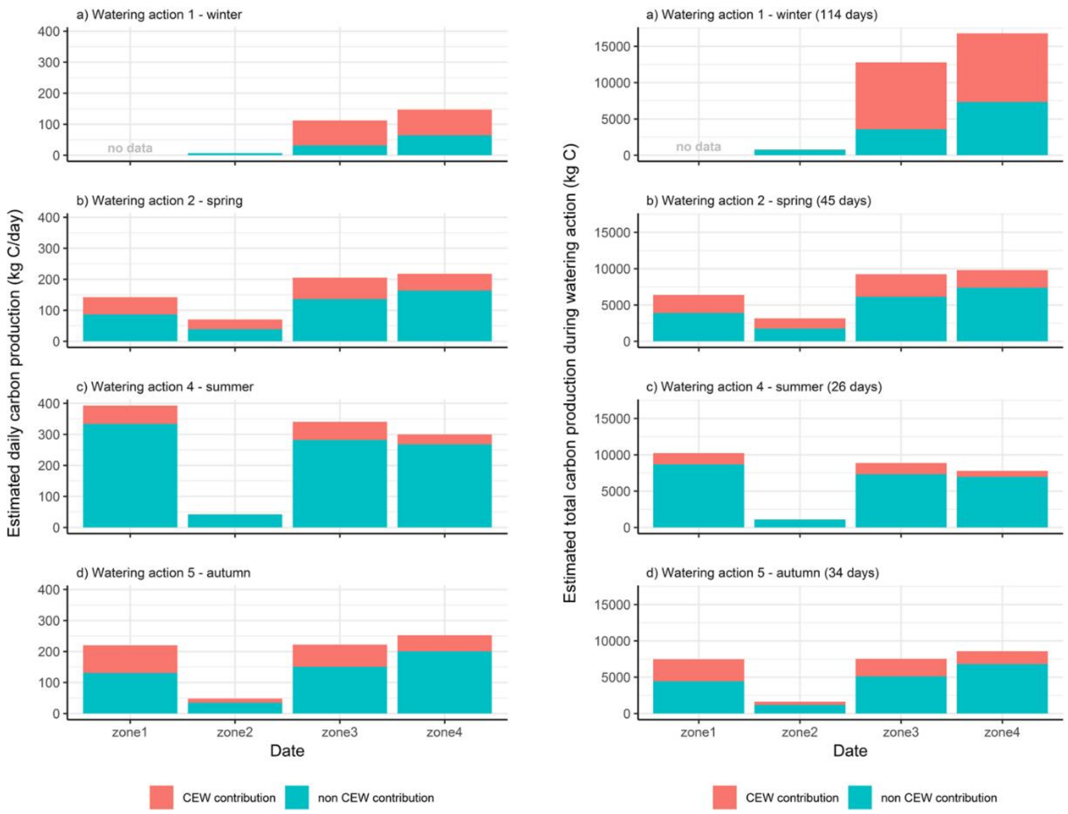


Figure 6.12 Left: The average daily additional production of carbon (kg C/day) during four environmental watering actions. Right: The total additional production of carbon (kg) over the four watering actions. Blue is the production attributed to operational water (non CEW), and orange indicates the production attributed to Commonwealth environmental water.

6.5 Discussion

In past reports (Watts et al. 2016, Watts et al. 2017) it was noted that the immediate effect of a significant flow increase was a substantial decrease in the rates of both GPP and ER. This is simply due to a dilution effect by the large increase in volume of water. Except in conditions of major phytoplankton growth (e.g. an algal bloom), much of the metabolism in the Edward-Wakool system appears to be from biofilms and microbial communities growing on (and in the surface layers) of the sediment and also on hard substrates within the channel, such as logs and plant stems. As the water level rises, the rate at which each photosynthetic or respiring organism is working (amount of oxygen produced or consumed) may not change but the output (change in oxygen concentration) is spread over a larger amount of water. Hence, solely on a volumetric basis, it can appear that GPP and ER have been suppressed by increasing discharge (less oxygen change *per litre of water*).

Effect of Commonwealth environmental watering actions

Overall, Commonwealth environmental water contributed significantly to primary production in reaches where water was delivered. Creating more 'food' at the base of the food web and more nutrients from ecosystem respiration (to generate this 'food') is a positive outcome of these watering actions, even though water remained well within the defined stream channel at all times.

The total additional production varied depending on i) time of year (i.e. with season), ii) the background flow (i.e. without CEW), iii) the volume of CEW being delivered, and iv) the duration of the CEW watering action. In some instances, provision of CEW appears to have had relatively smaller or larger impacts on total production. This may reflect the influence of channel hydraulics and channel shape. At some discharges, small additional water volumes may increase the surface area of the water significantly (this would occur when the additional wetted bank area was broad and shallow). Conversely, if background flows meant that CEW water increased depths, but not water surface area, then there may be negligible increases in production. Elsewhere, wetted area has been used as a simple proxy for the total amount of production, and may also be useful for the Edward-Wakool system, in identifying where the greatest productivity gains may occur. This also highlights the production benefits of expanding wetted habitats by connecting anabranches and low-lying floodplains, both of which may greatly increase the total wetted habitat.

It is still very important to note that although these small watering actions provided a beneficial outcome for the riverine ecosystem, it is highly probable that reconnecting backwaters and the floodplain to the river channel would result in much larger positive outcomes. At this stage there is too much uncertainty in the nominal flow category discharges to extend the analysis done here to the relatively small number of days with higher flows, but this may be achievable for future analyses. It is recommended that, when possible, consideration be given to providing a more variable flow regime in the Edward-Wakool system in future years.

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, both at the short term and longer term scales?

Hypothesis: Under extended 'cease to flow' conditions, 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.

- There were no 'cease to flow' conditions during 2017-18, so this hypothesis was not evaluated.

Hypothesis: Under operational flows, rates of GPP and ER will be constrained to the low-moderate range, typically 1-3 mg O_2/L/Day.

- Results from all four years confirm that GPP is almost always constrained within this range, with ER typically between 3 and 5 mg O_2/L/Day.

With small freshes (operational flows plus Commonwealth environmental water), rates of GPP and ER will increase slightly to 3-5 mg O_2/L/Day. Much larger increases are expected if significant backwater areas are reconnected to the main channel, due to enhanced nutrient delivery.

- There were no large freshes in 2017-18 so this aspect is not evaluated in this report. Results from all four years of LTIM program do not completely support this hypothesis. The most common effect of an increased flow is a decrease in GPP and ER through dilution. As described above, watering actions do increase the amount of organic carbon produced (GPP) and consumed (ER) overall, due to the additional volumes of water increasing total production, even when rates decrease slightly due to dilution effects. Larger increases in production are expected with higher flows, particularly where the additional volumes of water increase the surface area of the river, thereby increasing the area of the photic zone, within which algal growth occurs.

Hypothesis: Inundation and reconnection of backwater areas to the main channel during high flows will result in elevated GPP and ER through the additional habitat created, even if volumetric rates decrease.

- There were no high flow conditions during 2017-18, so this hypothesis was not evaluated.

Hypothesis: Primary production in the Edward-Wakool system will be limited by low phosphorus concentrations.

- It is highly probable that the median rates of GPP and ER observed in the Edward-Wakool are at the lower end of the normal range by world standards due to a combination of very low bioavailable nutrient concentrations and a water column that inhibits photosynthesis by limiting light penetration. Typically, all bioavailable nutrient concentrations in the Edward-Wakool sites are low, the exception being elevated nutrient concentrations in September-November 2016 associated with floods.

Importantly this includes Filterable Reactive Phosphorus (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.

6.6 Evaluation

Table 6.5 Summary of monitoring and evaluation questions for stream metabolism.

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?**
Winter watering action in Yallakool creek 1 May to 23 August 2017	To contribute to reinstatement of the natural hydrograph, improve connectivity, condition of in-stream aquatic vegetation and fish recruitment into 2017-18.	*What did Commonwealth environmental water contribute to patterns and rates of decomposition? (Ecosystem respiration ER)*	Changes in ER (mg O_2/L/Day) were observed but did not correspond to variation in discharge. Changes were associated with changing season and other instream factors. Increasing flows resulted in increases in the amount of organic carbon consumed (hence enhanced nutrient recycling)	Daily estimates of stream metabolism in seven sites within four zones. 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). Calculated organic carbon loads per day – production through GPP and consumption through ER. Estimated flow categories for zone 4.	By using all four years of data enabled assessment of effects of flow increases on the amount of organic carbon ('fish food') created. This approach then facilitates examining impacts of individual flows. This approach relies on flow categorization. Consequently, evidence of the effects of smaller flow increases have been well addressed but there is still insufficient data to quantify the benefits of larger flows (medium freshes and above)
Early spring fresh at beginning of e-flow 7 Sept to 22 Oct 2017	To contribute to connectivity, water quality, stimulating early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish.	*What did Commonwealth environmental water contribute to patterns and rates of primary productivity?* (Gross Primary Productivity, GPP)	Changes in GPP (mg O_2/L/Day) were observed but did not correspond to variation in discharge. Changes were associated with changing season and other instream factors. Increasing flows, as estimated by flow category, resulted in increases in the amount of organic carbon produced (hence more energy, "fish food'")		
Summer fresh at end of e-flow followed by recession 3 Jan to 29 Jan 2018	To encourage fish movement and assist dispersal of larvae and juveniles of fish species.				

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?**
Autumn fresh in Yallakool Creek 28 March to 1 May, 2018	To encourage fish movement and dispersal of juveniles of a number of fish species.	*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 metabolic parameters. Preliminary analysis showed that summertime flow increases resulted in the largest increases in organic carbon loads (produced and consumed) per day, over a flow range from very low to low freshes.		

7 AQUATIC AND RIVERBANK VEGETATION

Key findings	
Total species richness	Riverbank and aquatic vegetation showed some recovery since the flood of 2016, however the total species richness in 2017-18 was lower than in 2015-16 prior to the 2016 flood. Over the 4 years of LTIM there was higher species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that has received none or minor environmental watering actions.
Richness of functional groups	There has been some recovery of the richness of submerged and amphibious taxa in 2017-18 but the richness of submerged and amphibious taxa in 2017-18 was lower than in 2015-16 prior to the 2016 flood. There were more amphibious vegetation taxa in zones 1, 3 and 4 that have received base flows and freshes each year since 2014 and have greater lateral connectivity, than in zone 2 that has received minimal or no environmental water.
Percent cover of functional groups	The percentage cover of submerged and amphibious taxa remains low compared to 2014-15 and 2015-16 prior to the flood There was no difference in vegetation cover among the four hydrological zones.

7.1 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. Many plants, including emergent macrophytes and riparian understorey herbs, often germinate on flood recessions (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 plants that occur within the channel and on the riverbank up to bankfull level can be broadly classified into three functional groups that are defined by wetting and drying patterns. Submerged taxa occupy the wetted river channel, terrestrial taxa typically occupy the upper section of the riverbank, and amphibious taxa occupy both wet and dry parts of the riverbank and respond to, or tolerate, fluctuations in wetting and drying. Different aquatic macrophyte species have different watering requirements. For example, while it is critical that the submerged ribbon weed plants 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 (section 4.1) 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), has had negative impacts on the riverbank and aquatic vegetation in the Edward-Wakool system. Community members and landholders 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, 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 lateral connectivity by increasing 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.

The response of vegetation to environmental watering actions in 2017-18 will be influenced and constrained by the condition and diversity of vegetation at the start of the watering year. In 2015-16 there were more taxa recorded in Yallakool Creek zone 1 (36 taxa), Wakool River zone 3 (30 taxa) and zone 4 (28 taxa) that received the environmental base flow and fresh than in the upper Wakool River zone 2 (22 taxa) that received none or very small volumes of environmental water (Watts et al. 2016). There was also a higher percent cover of riverbank aquatic vegetation growing in zones 3 and 4 that have a history of environmental watering, compared to that in the Wakool River zone 2. However, in late 2016 there was a large unregulated flood event that had negative effects on the riverbank and aquatic vegetation, reducing the cover and richness of vegetation significantly (Watts et al. 2017c).

This chapter reports the on the recovery of riverbank and aquatic vegetation in the Edward-Wakool system in 2017-18 since the flood of late 2016.

7.2 Specific environmental watering actions for vegetation outcomes

Six commonwealth environmental watering actions were delivered in the Edward-Wakool system in 2017-18 (Table 2.4, Table 7.1). Two of these had primary objectives specifically related to riverbank and aquatic vegetation.

Table 7.1 Environmental watering actions in the Edward-Wakool system in 2017-18 indirectly related to riverbank and aquatic vegetation.

	Watering action	Type of action	Dates	Rivers	Objectives
1	Winter watering action	base flow	1 May - 23 Aug 2017	Yallakool Creek, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to reinstatement of the natural hydrograph, connectivity, condition of in-stream aquatic vegetation and fish recruitment
2	Early spring fresh at beginning of e-flow	small fresh and flow recession	7 Sept - 22 Oct 2017	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River	To contribute to connectivity, water quality, stimulating growth of in-stream aquatic vegetation, pre-spawning condition of native fish, spawning in early spawning native fish

7.3 Selected Area 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?*

7.4 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 once per month from August 2017 to May 2018. No monitoring was undertaken in December 2017.

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:

Submerged taxa, being those that have special adaptations for living submerged in water. These plants grow to, but do not emerge from, the surface of the water.

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

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

Total species richness was calculated for each site in each zone for each month. The percent cover was calculated for each transect for each sample date. To compare cover of vegetation across the four years of the LTIM program (2014-15, 2015-16, 2016-17 and 2017-18) the month when the maximum cover occurred across the months of October to May was identified for each taxa. The period from October to May was selected because it is the main growing season for these plants.

7.5 Results

A total of 38 riverbank and aquatic vegetation taxa were recorded across the sixteen sites between November 2017 and April 2018 (Table 7.2). Four of the taxa were submerged, 15 were amphibious and 19 were terrestrial (Table 7.2).

Table 7.2 Number of riverbank and aquatic vegetation taxa recorded at LTIM monitoring sites in the Edward-Wakool system in years 1 to 4 of the LTIM project between 2014 and 2018.

	Number of riverbank and aquatic vegetation taxa			
Year	submerged	amphibious	terrestrial	total
2014-15	3	15	14	32
2015-16	3	20	20	43
2016-17	2	15	34	51
2017-18	4	15	19	38

There was a small reduction in total and mean number submerged taxa after the flood in 2016 (Table 7.2, Figures 7.1 and 7.2). However, in 2017-18 there was a recovery of submerged taxa in all zones (Figure 7.1). However, the percentage cover of submerged taxa remains very low compared to 2014-15 and 2015-16 prior to the flood (Figures 7.3 and 7.4).

When compared to the results from 2016-17, there was a similar number of amphibious taxa in 2017-18 (Table 7.2), but there was fewer taxa and a lower cover of amphibious taxa than in 2015-16 prior to the 2016 flood (Table 7.2, Figures 7.1, 7.2 and 7.3). A number of amphibious taxa (e.g. spiny mud grass and rush) appear to have tolerated the flood in 2016 and persisted into 2017 (Figure 7.4). Other amphibious taxa e.g. floating pondweed and milfoil) were considerably reduced in cover or were killed by the flood in 2016, and there has been minimal recovery of these taxa (Figure 7.4). Over the four years of LTIM there were fewer amphibious taxa in zone 2 that has received very low or no environmental watering actions. This pattern is consistent across years, even in 2016-17 following the 2016 flood (Figure 7.1).

A larger number of terrestrial taxa were recorded in 2016-17 immediately after the large unregulated flood in spring 2016 (Table 7.2, Figure 7.1). There was a considerable decrease in the total number of terrestrial taxa 2017-18 (Table 7.2, Figure 7.1). However, the mean number of terrestrial taxa did not differ between 2016-17 and 2017-18 (Figure 7.2). The change in cover of terrestrial taxa was variable. Some taxa increased in cover after the flood and other taxa decreased or did not show much change (Figure 7.4).

Only six of the taxa were introduced (lippia, arrowhead, medic, yellow cress, clover and sow thistle) and all were in very low abundance, with the exception of lippia in zone 1 (Figure 4.1).

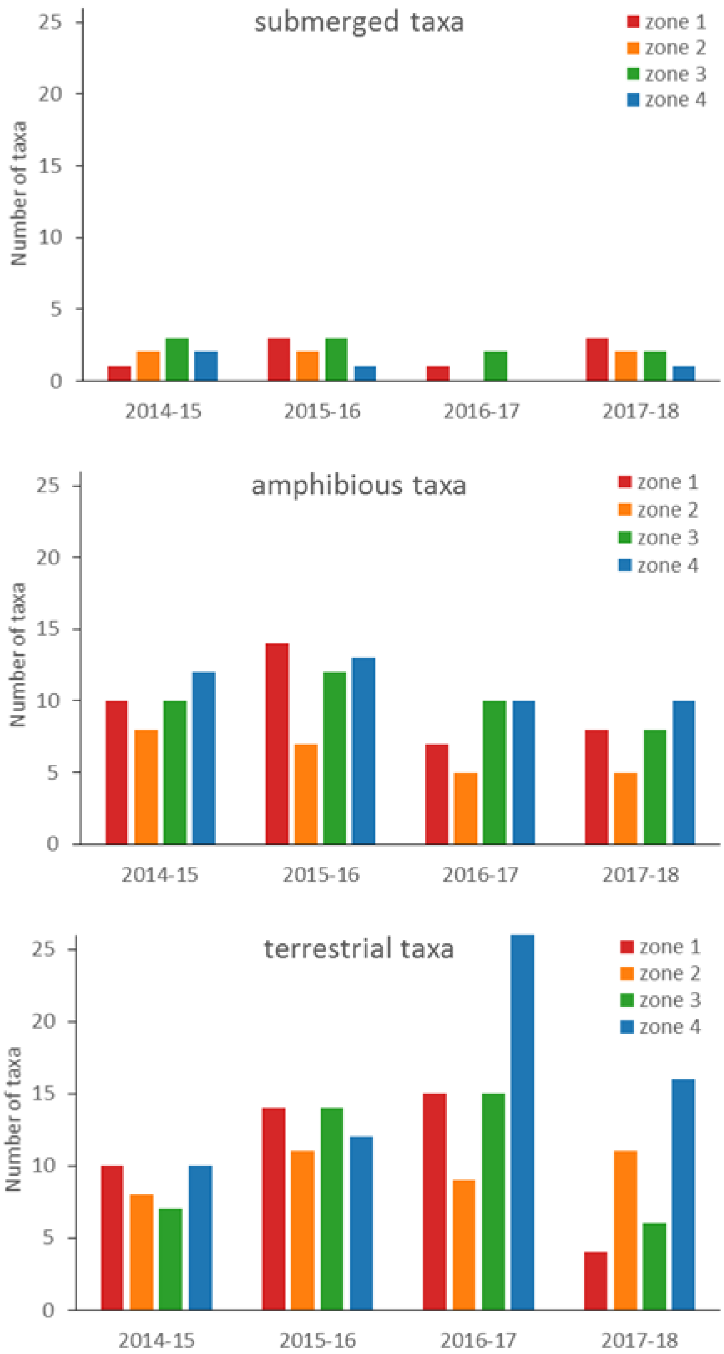


Figure 7.1 Total richness of vegetation taxa monitored monthly across four zones in the Edward-Wakool system between August 2014 and May 2018. Taxa were classified as submerged, amphibious or terrestrial and are represented by zone. Zone 1= Yallakool Creek, zone 2 =upper Wakool River, zone 3 = mid Wakool River upstream of Thule Creek, zone 4=mid Wakool River downstream of Thule Creek.

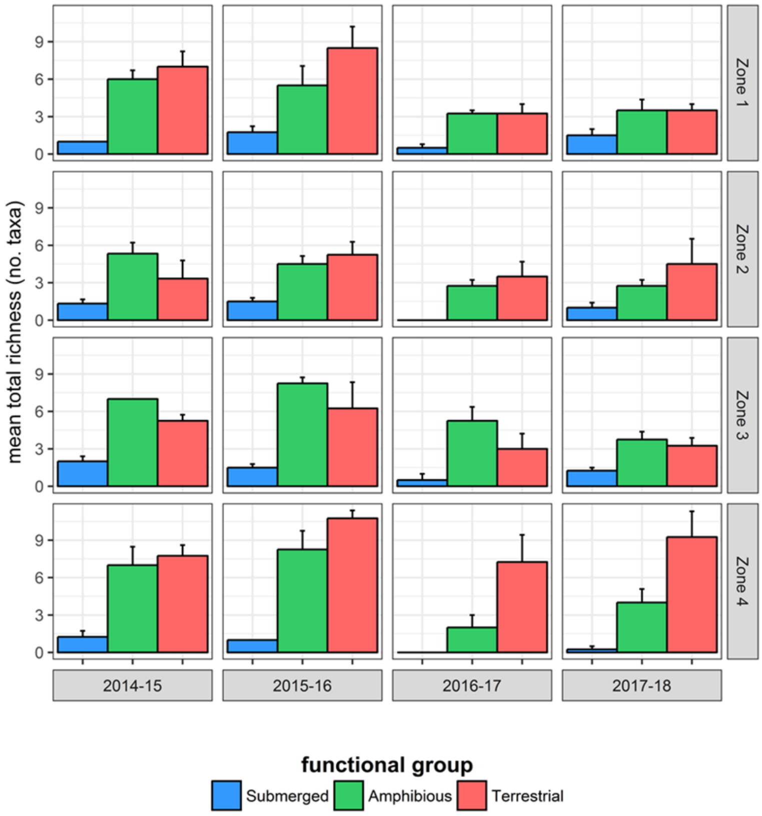


Figure 7.2 Mean total richness of vegetation taxa monitored monthly across four hydrological zones in the Edward-Wakool system between August 2014 and May 2018. Taxa were classified as submerged, amphibious or terrestrial.

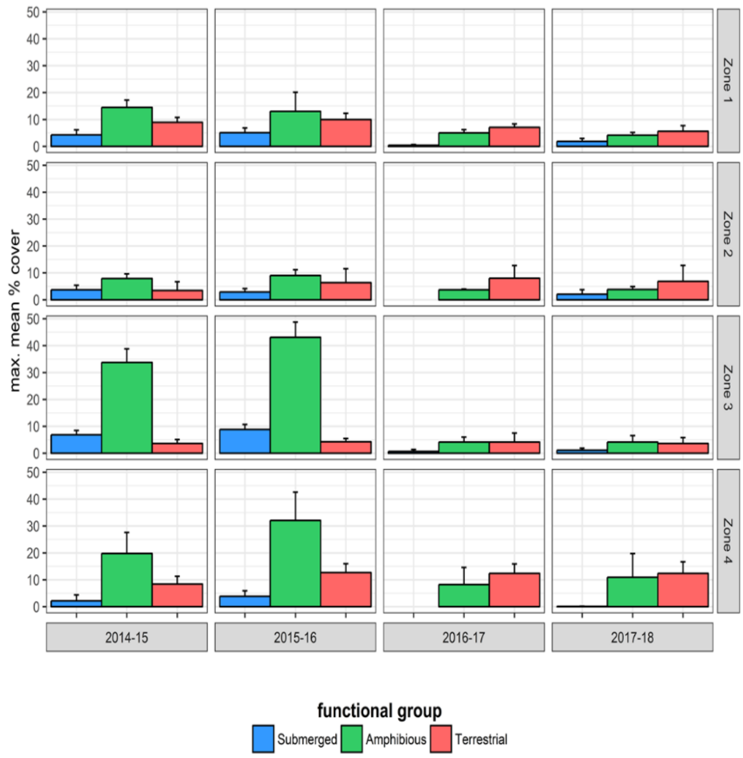


Figure 7.3 Maximum mean percent cover of vegetation taxa monitored monthly across four hydrological zones in the Edward-Wakool system between August 2014 and May 2018. Taxa were classified as submerged, amphibious or terrestrial.

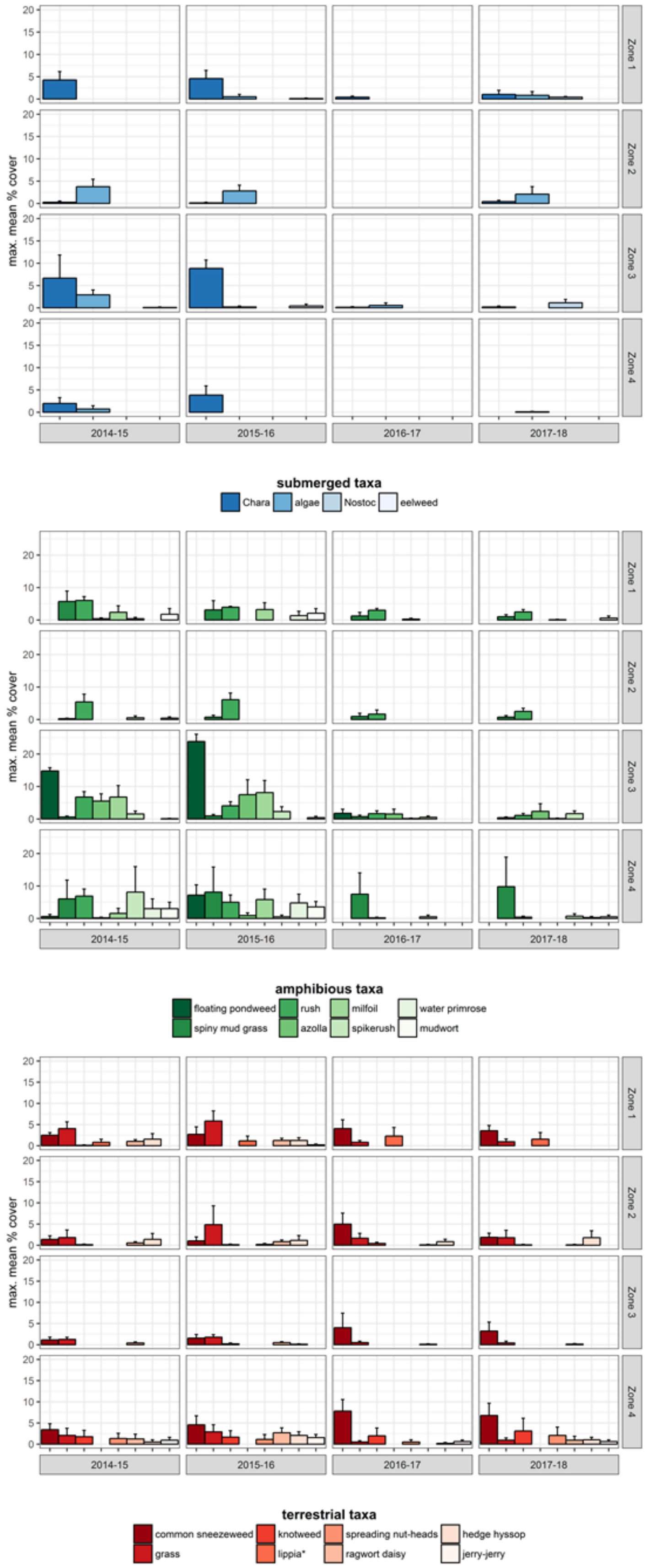


Figure 7.4 Mean percent cover of vegetation taxa monitored monthly across four hydrological zones in the Edward-Wakool system between August 2014 and May 2018. Taxa were classified as submerged, amphibious or terrestrial.

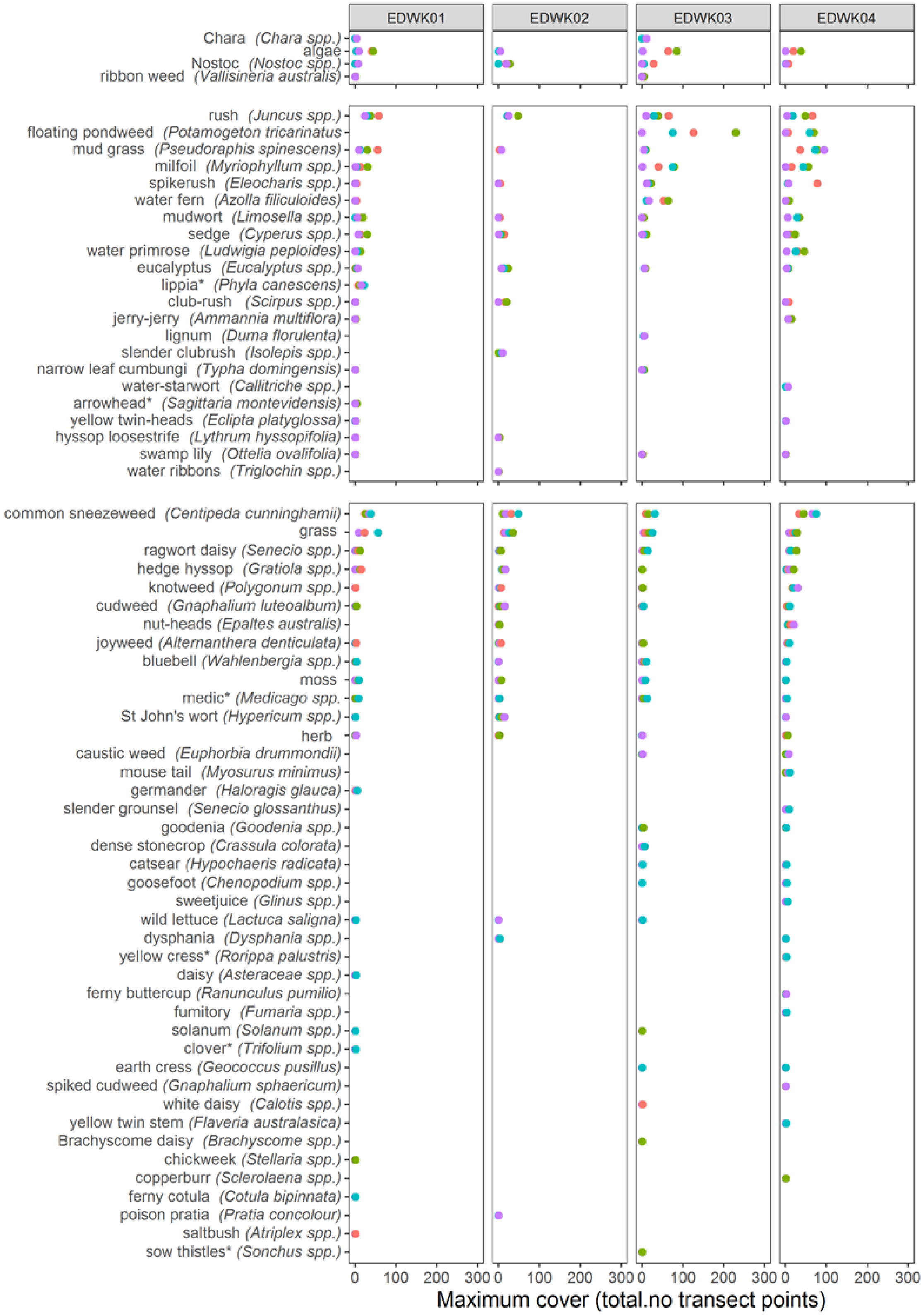


Figure 7.5 Maximum cover of riverbank and aquatic vegetation taxa monitored monthly across four hydrological zones in the Edward-Wakool system between August 2014 and May 2018. Taxa were classified as submerged, amphibious or terrestrial. Red dots indicate maximum cover in 2014-15, green dots indicate maximum cover in 2015-16, blue dots indicate maximum cover in 2016-17, and purple dots indicate maximum cover in 2017-18. 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.

7.6 Discussion

The recovery of riverbank vegetation in 2017-18 was strongly affected by the antecedent conditions from the flood in 2016.

The recovery of submerged and amphibious taxa in 2017-18 has been slow, but there are signs of recovery such as slight increase in the number of submerged taxa and a slight increase in the cover of some taxa. The floods in 2016 decreased the richness and cover of submerged and amphibious taxa throughout the Edward-Wakool system. The reduction in the cover of submerged taxa and amphibious taxa 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 during late 2016 (chapter 4, Fig 4.1) 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 following the 2016 flood, there was an increased cover and number of terrestrial riverbank plant taxa higher up on the river banks following the recession of the flood. Some terrestrial taxa 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). However, in 2017-18 there was a considerable decrease in the total number of terrestrial taxa. The change in cover of terrestrial taxa was variable. Some taxa increased in cover after the flood and other taxa decreased or did not show much change. The cover of terrestrial taxa is influenced by factors other than environmental watering (e.g. rainfall).

These observations from 2017-18 combined with observations in 2014-15 (Watts et al. 2015) and 2015-16 (Watts et al. 2016) suggest that late winter/early spring freshes that inundate low-lying slackwaters, in-channel benches or areas of riverbank within the channel can trigger emergence of river bank vegetation. Following the recession of flows, these damp banks provide ideal conditions for plant growth. Further freshes delivered during spring, summer or autumn that follow the initial event will rewet these areas and provide suitable conditions for amphibious plants to grow and survive the warmer conditions over the summer.

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?

Riverbank and aquatic vegetation in the Edward-Wakool system was considerably impacted by the large unregulated flood in spring 2016. There has been some recovery of riverbank and aquatic vegetation since the flood of 2016, however the total species richness in 2017-18 was lower than in 2015-16 prior to the 2016 flood. There has been some recovery of the richness of submerged and amphibious taxa in 2017-18, but the total number of submerged and amphibious taxa in 2017-18 was lower than in 2015-16 prior to the 2016 flood.

Submerged and amphibious vegetation species have recovered faster in river reaches where Commonwealth environmental watering actions have been implemented. In each of the 4 years of LTIM there has been higher total species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that has received none or insignificant environmental watering actions. There is also more amphibious vegetation taxa in zones 1, 3 and 4 that have received base flows and freshes each year since 2014 and have greater lateral connectivity than in zone 2 that has received minimal or no environmental watering.

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 taxa in Yallakool Creek and the upper and mid Wakool River?

In 2017-18 there was higher species richness in zones 1, 3 and 4 that received base flows and freshes than in zone 2 that received minor environmental watering actions. Similarly, there were more amphibious vegetation taxa in zones 1, 3 and 4 that received base flows and freshes than in zone 2 (no environmental watering).

While there has been some recovery of vegetation following the flood in 2016, the percentage cover of submerged and amphibious taxa remains low compared to 2014-15 and 2015-16 prior to the flood.

7.7 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	**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?**
Winter watering action in Yallakool creek and Colligen Creek Early season fresh at beginning of e-flow	To contribute to condition of in-stream aquatic vegetation To contribute to stimulating growth of in-stream aquatic vegetation	*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?*	yes	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 some recovery since the flood, however the total species richness and cover in 2017-18 was lower than in 2015-16 prior to the 2016 flood.
		How do vegetation responses to Commonwealth environmental water delivery vary among hydrological zones?	There was higher species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that has received none or minor environmental watering actions		
		What did CEW delivered as base flows and freshes contribute to the percent cover of riverbank and aquatic vegetation?	There was no difference in cover among the zones. The percentage cover of submerged and amphibious taxa remains low compared to 2014-15 and 2015-16 prior to the flood		
		What did CEW delivered as base flows and freshes contribute to the taxonomic richness of riverbank and aquatic vegetation taxa?	There is more amphibious vegetation taxa in zones 1, 3 and 4 that received environmental water than in zone 2 that has received minimal or no environmental watering.		

8 FISH

Key findings		
Movement	Movement of golden perch and silver perch	Watering action 1 (winter base flow) facilitated movement of silver perch throughout the system, which is different to previous years when the winter operational shutdown restricted their movements. Watering actions 2 and 4 facilitated connectivity and enabled movement of golden and silver perch. Tagged adult silver perch were present in Yallakool Creek (zone 1) concurrent with the detection of spawning in this system in December 2017.
Spawning	Larval abundance of equilibrium species	Numbers of Murray cod larvae in 2017-18 were similar to numbers collected in 2014-15, and 2015-16. Murray cod larval counts were significantly lower in 2016-17 due to the hypoxic event and associated fish kills during the spawning season for this species. The increase in larval Murray cod counts in 2017-18 suggests that adults have successfully moved back into the Edward-Wakool system to spawn. CEW winter base flows in 2017 may have assisted in facilitating movement of Murray cod back into the system prior to spawning. Freshwater catfish larvae were detected in the Wakool River downstream of Thule Creek (zone 4) for the first time in 2017-18. Winter base flows providing permanency of water throughout river reaches will be important in providing persistence of habitat year round for this species.
	Larval abundance of periodic species	Silver perch were detected to have spawned in Yallakool Creek, the first time spawning has been detected in the study zones since monitoring commenced in 2015. The timing of the presence of silver perch eggs coincided with water temperature >21 °C, peak of a fresh where the change in water height was approximately 23 cm over 4 days, full moon, and a large area of channel in Yallakool Creek having fast water velocities (> 0.3 ms^{-1}).
	Larval abundance of opportunistic species	Watering action 2, an early spring fresh, aimed to enhance the spawning of early spawning fish species. The abundance of Australian smelt larvae was significantly higher in zones that received this watering action (zones 1, 3 and 4) than in zone 2 (almost no environmental water).
Recruitment	Murray cod, silver perch and golden perch recruitment	Murray cod recruits were detected in 2018 throughout the Edward Wakool system, in contrast to the absence of Murray cod recruits in 2017 following the 2016 hypoxic blackwater event. This suggests there has been some recovery of this species in 2018. There were no silver perch YOY or 1+ recruits detected in 2017-18, whereas there was one recruit in 2014-15 and 25 in 2015-16. Golden perch recruits have not been detected by monitoring during any of the four sampling years in the Edward-Wakool Selected Area.
Adults	Adult fish populations	Large-bodied native fish relative abundance, including bony herring, golden perch and Murray cod, increased in comparison to 2016-17. Recruits of Murray cod and bony herring were captured at similar proportions to pre-hypoxia (2016 flooding), indicating successful (albeit reduced) spawning and recruitment in 2017-18.

8.1 Introduction

In this chapter we present results on the monitoring and evaluation of fish movement, spawning, recruitment and adult populations. This chapter includes a combined discussion (section 8.6) where we bring together our results to provide an overview of how the fish community in the Edward-Wakool responded to watering events and Edward-Wakool hydrological conditions in general.

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 8.1), 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 suite of questions and indicators have been selected that all have clear linkages to other components of the monitoring and evaluation plan (see Figure 8.1). The Edward-Wakool Monitoring and Evaluation Plan (Watts et al. 2014a) 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.

Key processes that ultimately shape adult fish populations (movement, spawning, recruitment and growth) have been monitored and evaluated in response to the contribution of Commonwealth environmental water. 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 8.1). The responses measured across these key fish indicators will 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. Each of the fish indicators monitored in the Edward Wakool system is described below.

Table 8.1 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 2014-17
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*	

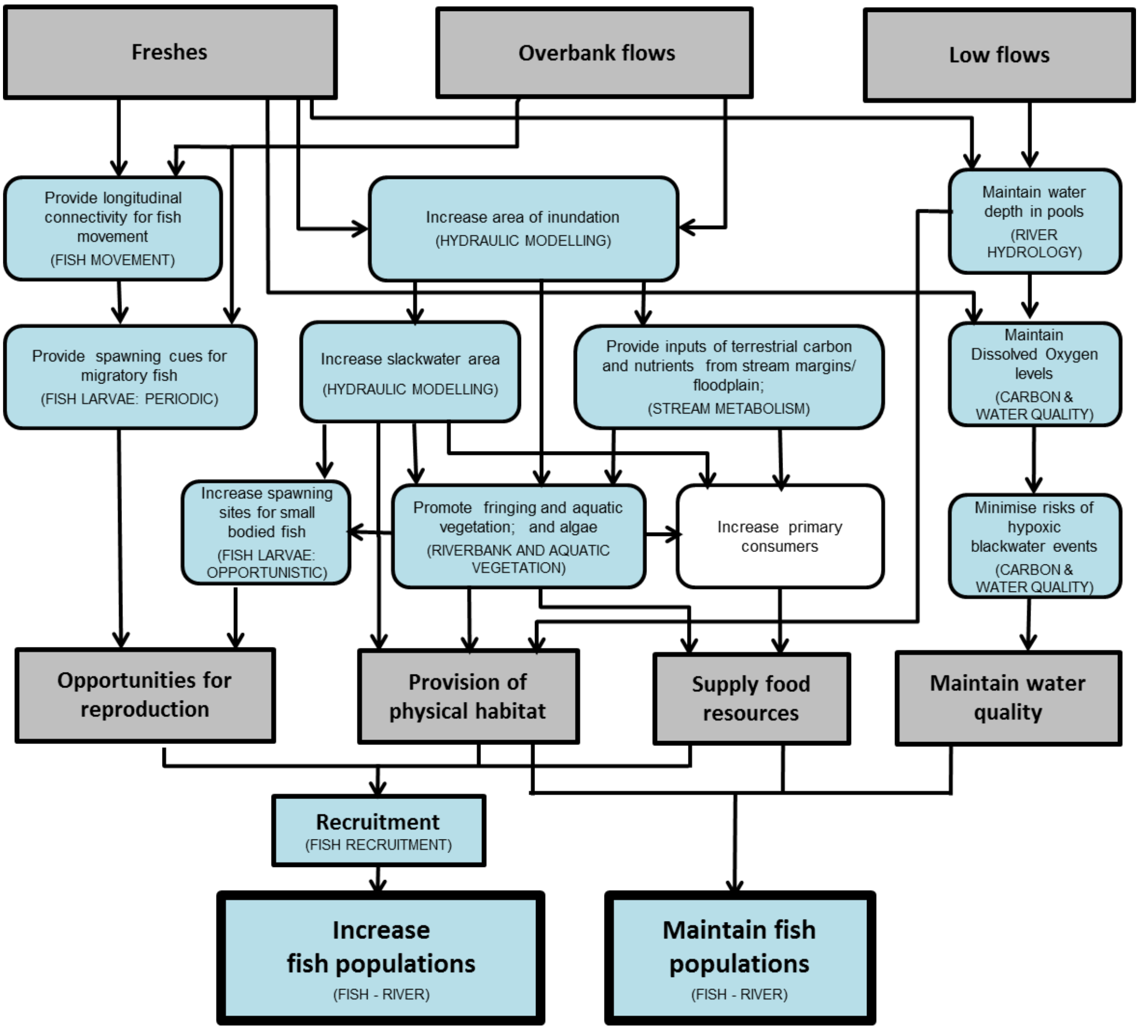


Figure 8.1 Conceptual diagram illustrating the linkages between different types of environmental watering (freshes, overbank flows, low flows) to fish populations via key ecological processes. Key ecological processes that are being monitored as part of the Edward-Wakool M&E Plan are highlighted in blue.

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.

Recruitment of Murray cod, silver perch and golden perch

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 target juvenile Murray cod, silver 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.

8.2 Specific environmental watering actions for fish outcomes

Six Commonwealth environmental watering actions were delivered in the Edward-Wakool system in 2017-18 (Table 2.4). Four of these had primary objectives towards delivering positive outcomes for native fish populations (CEWO 2017):

Table 8.2 Commonwealth environmental watering actions in 2017-18 in the Edward Wakool River system that had objectives targeting native fish.

	Watering action	Type of action	Dates	Rivers	Objectives
1	Winter watering action	base flow	1 May - 23 Aug 2017	Yallakool Creek, mid- and lower Wakool River, Colligen Creek	To contribute to reinstatement of the natural hydrograph, connectivity, condition of in-stream aquatic vegetation and fish recruitment
2	Early spring fresh at beginning of e-flow with flow recession	small fresh and flow recession	7 Sept - 22 Oct 2017	Yallakool Creek, upper, mid- and lower Wakool River, Colligen Creek	To contribute to connectivity, water quality, stimulating growth of in-stream aquatic vegetation, pre-spawning condition of native fish, spawning in early spawning native fish
4	Summer fresh at end of e-flow followed by recession	small fresh and flow recession	3 - 29 Jan 2018	Yallakool Creek, mid- and lower Wakool River	To encourage fish movement and assist dispersal of larvae and juveniles of fish species
5	Autumn fresh	small fresh	28 Mar - 1 May 2018	Yallakool Creek, upper, mid- and lower Wakool River, Colligen Creek	To encourage fish movement and dispersal of juveniles of a number of fish species

8.3 Selected Area evaluation questions

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 fourth 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 8.3. This report will evaluate environmental water against the short-term questions, with long-term evaluation questions to be further assessed in 2019.

Table 8.3 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 CEW delivery? • Did periodic species remain within the target reaches during CEW delivery? • Did CEW stimulate periodic fish species to exhibit movement consistent with reproductive behaviour? • Does CEW enable periodic species to disperse from and return to refuge habitat?
	Fish spawning and reproduction (larval fish sampling)	*Short-term and long term evaluation questions* • What did CEW water contribute to the spawning of 'opportunistic' species? • What did CEW 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 CEW contribute to native fish recruitment to the first year of life? • What did CEW contribute to native fish growth rate during the first year of life?
	Adult fish population demographics (adult fish sampling)	*Short-term evaluation questions* • Does CEW contribute to maintain or enhance fish condition in the Edward-Wakool river system? • Does CEW contribute to the recovery of fish communities following negative conditions within the Edward-Wakool river system? *Long-term evaluation questions* • Does CEW contribute to maintain or enhance existing levels of fish recruitment in the Edward-Wakool river system? • Does CEW contribute to maintain or increase native fish diversity and abundance in the Edward-Wakool river system? • Does CEW contribute to maintain or increase native fish biomass in the Edward-Wakool river system?

8.4 Methods

8.4.1 *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 8.2) 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 additional receivers was specifically supported by the local community and undertaken by funds received by Murray Local Land Services through the National Landcare Programme.

A total of 79 golden perch, 21 Murray cod and 43 silver perch have been fitted with telemetry tags between August 2015 and September 2017. Acoustic tag implantation procedures followed those outlined by Hale et al. (2014). Here we report on overall movement trends following 3 years of data collection as well as specific movements in response to watering events in 2017-18. Sample size varies throughout the study period due to emigration, tag battery life and fish mortality. Sample sizes of Murray cod were inadequate to evaluate any movement responses to watering actions in 2017-18. Further, tagging of additional golden perch was not undertaken in 2017-18 until after watering action 1, and as such evaluation of golden perch movement responses to this action is not reported.

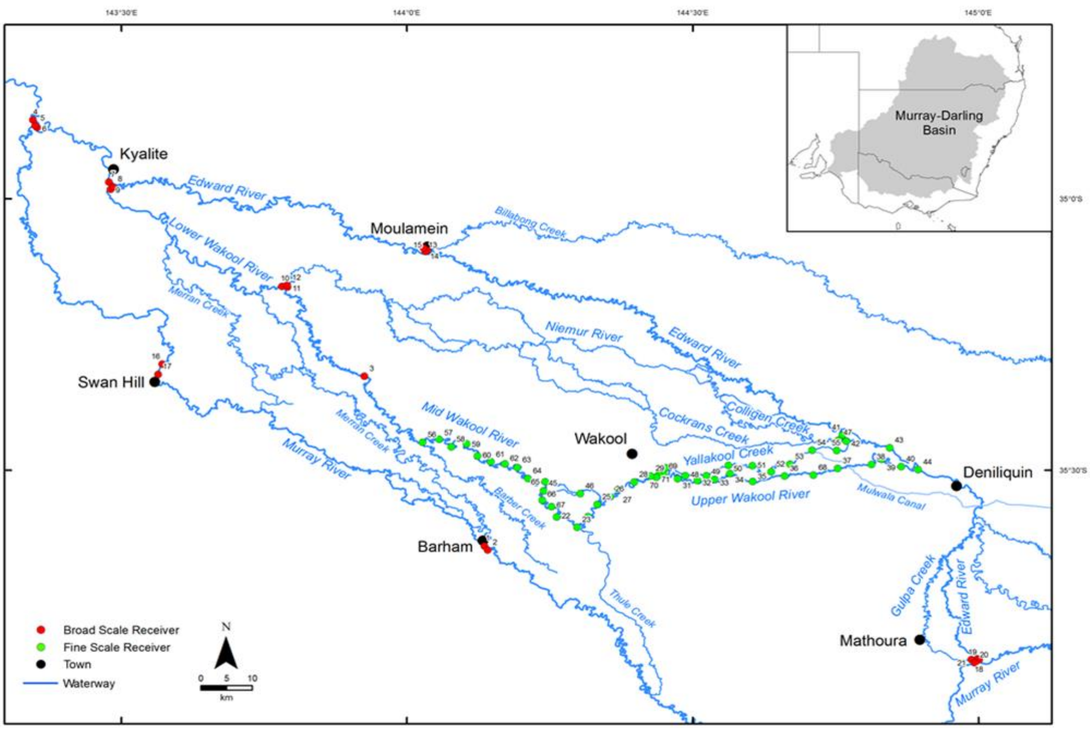


Figure 8.2 Location of acoustic telemetry receivers (green dots) moored in the Edward-Wakool system to determine movements of acoustically tagged golden perch and silver perch. Red dots indicate the 20 additional receivers placed at key entry/exit points and major junctions to monitor any potential emigration 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.

Acoustic receiver downloads are undertaken quarterly (Figure 8.3). Downloaded acoustic tag detection data and meta-data are uploaded into a custom SQL database. Data are 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, tag failure (battery expiration) or mortality.

Figure 8.3 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.

8.4.2 *Fish spawning and reproduction*

Field sampling

Fish larvae were sampled fortnightly within the Edward-Wakool Selected area from the week of 25 September 2017 – 16 March 2018 (n=13 sampling trips). A combination of modified quatrefoil light traps and drift nets were used in all four study zones; Yallakool Creek (zone 1), Upper Wakool River (zone 2), Mid Wakool River upstream of Thule Creek (zone 3), and Mid Wakool River downstream of Thule Creek (zone 4).

As part of the routine fish larval sampling for the Edward-Wakool Selected area (Category 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 a 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 (Category 1 3 methods), albeit over a shorter period of time than that of the light trap surveys. Drift nets are used in addition to the light traps as they are more effective in detecting eggs and early-stage larvae of flow-dependent spawning species, such as golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*). Drift net sampling remained unchanged to that in the 2015-16 and 2016-17 sampling seasons (sensu Watts et al. 2016, Watts et al. 2017c), with drift nets deployed fortnightly for 5 sampling trips from 23 October – 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 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. Drift net samples for Category 1 basin matter drift net samples were also collected fortnightly from the 25 September – 21 December 2017 from zone 3 (n=7 sampling trips), as per the LTIM standard methods, however this data is not reported on here.

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. Genetic analyses undertaken on cod larvae collected from the Selected Area in 2015-16 identified Murray cod only (no trout 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 egg, larvae, or juvenile/adult, according to classifications of Serafini and Humphries (2004). Only the trends in abundances of eggs and larvae are reported.

Larval catch rates from light traps were compared across years and zones; we used generalised linear mixed-effects models to test differences in larval catch between years, where 'year' (2014-15, 2015-16, 2016-17, 2017-18), and 'zone' (zone 1, zone 2, zone 3, zone 4) were treated as fixed effects. The distribution of larval counts were non-Gaussian so Gamma distributions with a log-link were used in the statistical models. Over-dispersion 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 the significance of the fixed effects. P-values of <0.05 were used to determine the significance of each test.

8.4.3 *Fish recruitment*

Four sites were sampled in each of four river zones within the Edward-Wakool system: Yallakool Creek zone 1, 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 four years: 2014-15; 2015-16; 2016-17 and 2017-18.

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 excluding carp which were euthanased.

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. 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.

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).

Recruitment catch per unit effort (CPUE; number of recruits per 10 000 s of sampling) of YOY and 1+ Murray cod and 1+ silver perch were calculated from catch and effort data from backpack electrofishing, set-lines and angling. Generalized Linear Mixed Effects Models (GLMMs) 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 between years.

8.4.4 *Adult fish community*

A system-wide fish community survey was undertaken in year 1 (2014-15), and will be repeated in year 5 (2018-19) (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. Standardised sampling was undertaken in May 2018, 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.

8.5 Results

8.5.1 *Fish movement*

A total of 74 golden perch, 21 Murray cod and 41 silver perch contributed movement data from August 2015 until May 2018. Given the mortality and emigration of all three species associated with the flooding and subsequent hypoxia within the system in late 2016, additional tagging of golden perch and silver perch was undertaken in 2017. From May 2017 to May 2018 a total of 24 golden perch, one Murray cod and 31 silver perch contributed to movement data.

Outside of periods of flooding, movements of golden perch and Murray cod were generally over 10's of kilometres and movements of silver perch over 100's of kilometres (Figures 8.4 and 8.5). Removal of zero data indicated that daily movements were predominantly <10 km for all species, downstream movements were more common for golden perch and silver perch whilst upstream movements were more common for Murray cod (Figure 8.6). Maximum daily movements were 50.7 km for golden perch, 29.4 km for Murray cod and 24.4 km for silver perch. There was a significant difference in mean deviation from modal river position among species ($F_{2,125}$ = 18.40, p <0.001) and between regulated river conditions and flooding ($F_{1,125}$ = 17.30, p <0.001), and this was best explained by the interaction between species and binary river conditions (flood or no flood; $F_{2,125}$ = 21.64, p <0.001). Murray cod moved upstream from their modal river location during flooding, whilst both golden perch and silver perch moved downstream (Figure 8.7). Mean deviation during flooding was significantly different between Murray cod and both golden perch (mean difference 48 km, lower and upper confidence intervals 32–64 km, p<0.001) and silver perch (44 km, 20–70 km, p<0.001), although not between golden perch and silver perch (4 km, -19–26 km, p=0.997).

Silver perch ranged over a substantial distance in 2017-18 and occupied all 4 LTIM zones (Figure 8.8). Golden perch generally moved smaller distances and predominantly occupied zones 3 and 4 (Figure 8.9). Likewise, zones 3 and 4 were predominantly occupied by silver perch, representing the zones individuals were captured and tagged in. However, silver perch entered both the upper Wakool River (zone 2) and Yallakool Creek (zone 1) at various stages throughout the 2017-18 season (Figure 8.8). One silver perch (ID45095) occupied zone 2 of the Wakool River until the end of April 2018, moving as far upstream as 48 km from the junction with Yallakool Creek on 29 September 2017. Four tagged silver perch entered Yallakool Creek (zone 1) from October- December 2017, with one individual (ID1891) exiting Yallakool Creek on 31 October 2017 and entering the Edward River on 1 November 2017 where it subsequently moved downstream past Stevens Weir and was later detected near Moulamein on 14 December 2017. Silver perch moved substantially larger distances in winter 2017 during watering action 1, in contrast to the same period in 2016 (Figure 8.10). While sample sizes were different between the two time periods (n=3/5 silver perch moved in winter 2016 and n=15/18 silver perch moved in 2017), winter flows in 2017 resulted in movements (median: 25^{th}-75^{th} percentiles) of 64 km (15–96 km) in comparison to 25 km (0–42 km) in 2016.

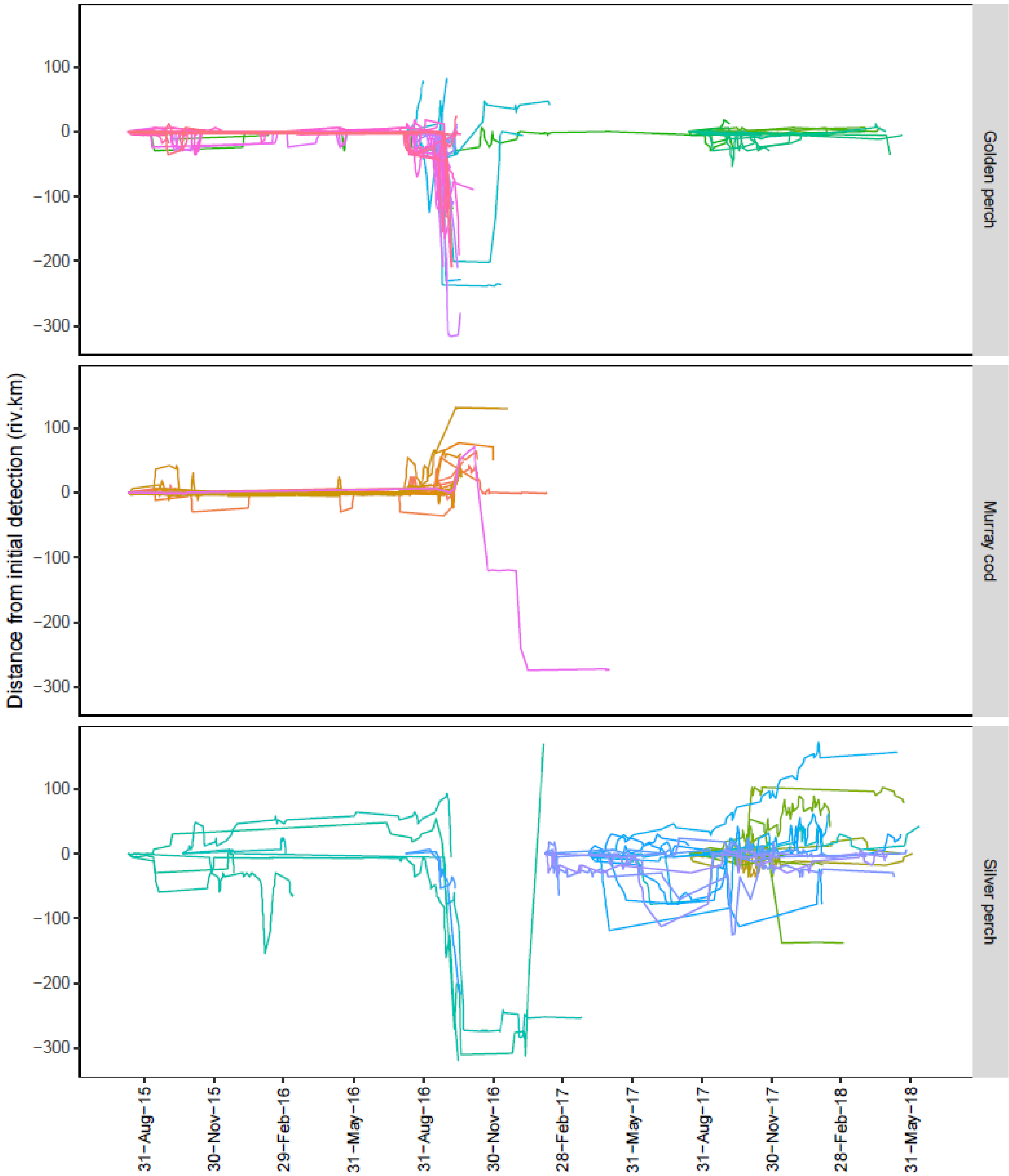


Figure 8.4 Daily locations of acoustically tagged golden perch, Murray cod and silver perch in the Edward-Wakool river system from Aug 2015 to May 2018. Different coloured lines represent different tagged individuals and 0 km represents the initial detection (i.e. first location).

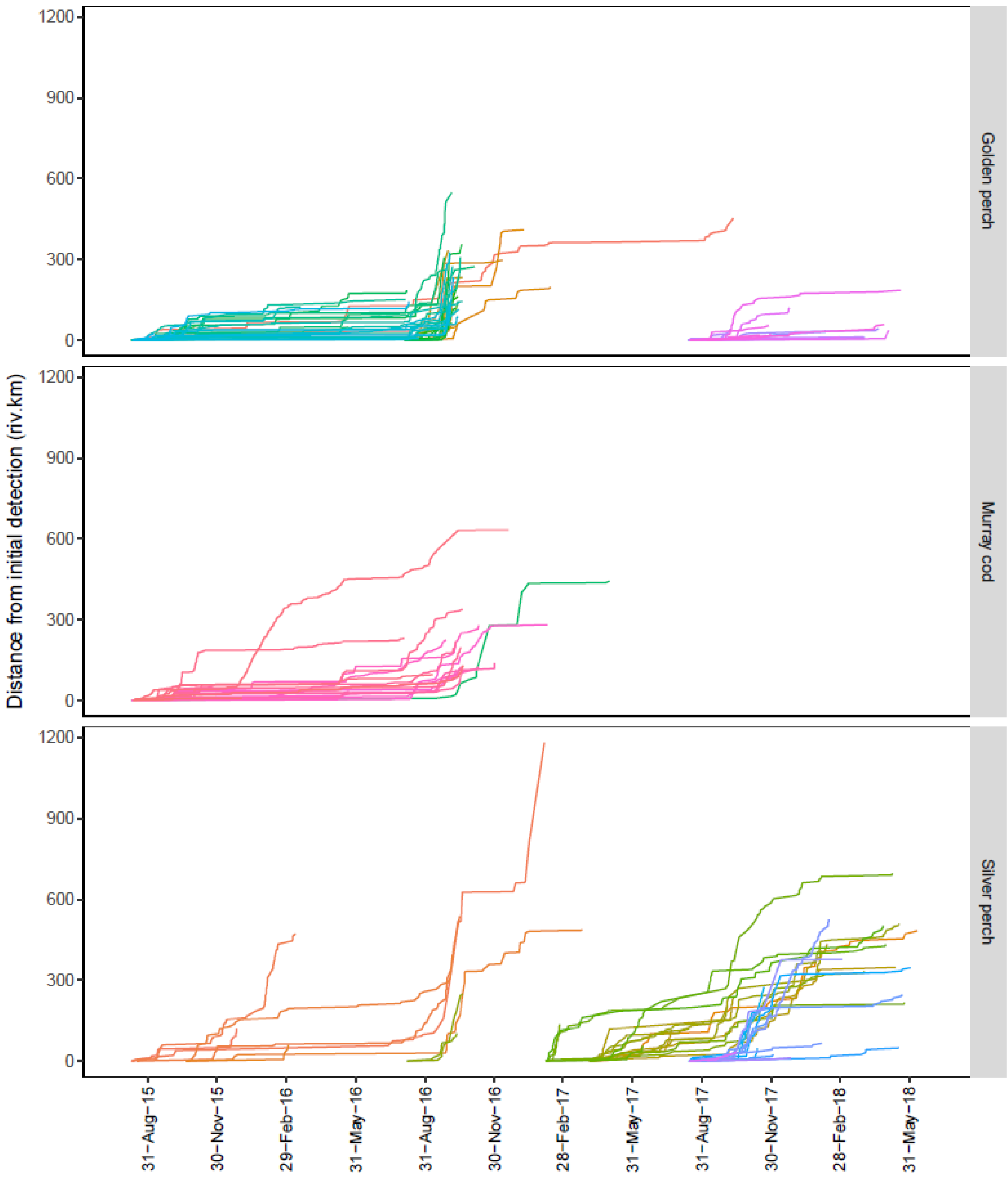


Figure 8.5 Cumulative daily distance moved (irrespective of direction) of acoustically tagged golden perch, Murray cod and silver perch in the Edward-Wakool system between Aug 2015 and May 2018. Different lines represent different tagged individuals and 0 km represents the first detection of an individual fish. Note that when the individual line finishes this represents the last detection of this individual fish within the acoustic array.

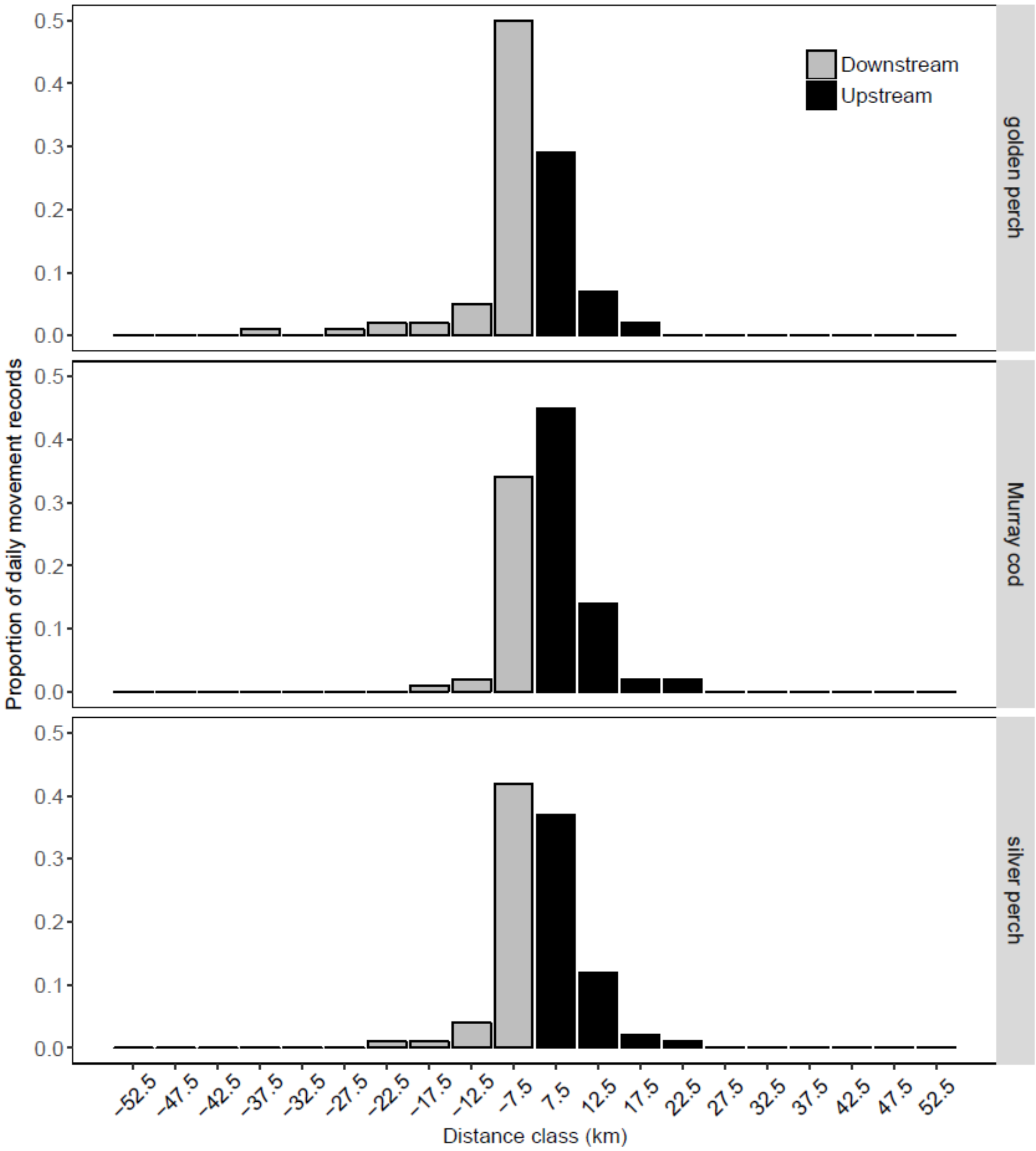


Figure 8.6 Proportionate daily directional distances (5 km bins) moved by golden perch, Murray cod and silver perch over the study period. Black bars indicate upstream movements and grey bar indicate downstream movements. Zero data have been removed for visualisation.

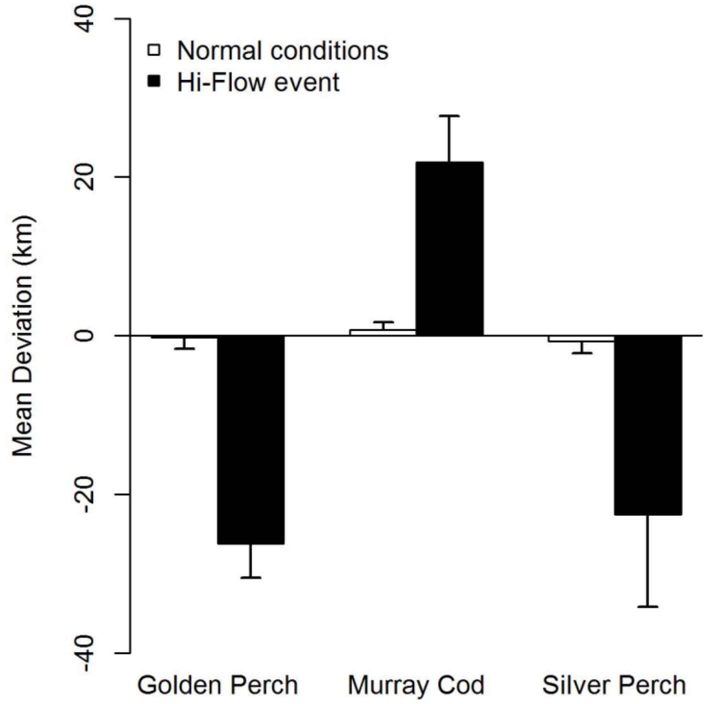


Figure 8.7 Model predictions and 95% confidence intervals of golden perch, Murray cod and silver perch mean deviation from core area during normal operation conditions and the flood event in late 2016.

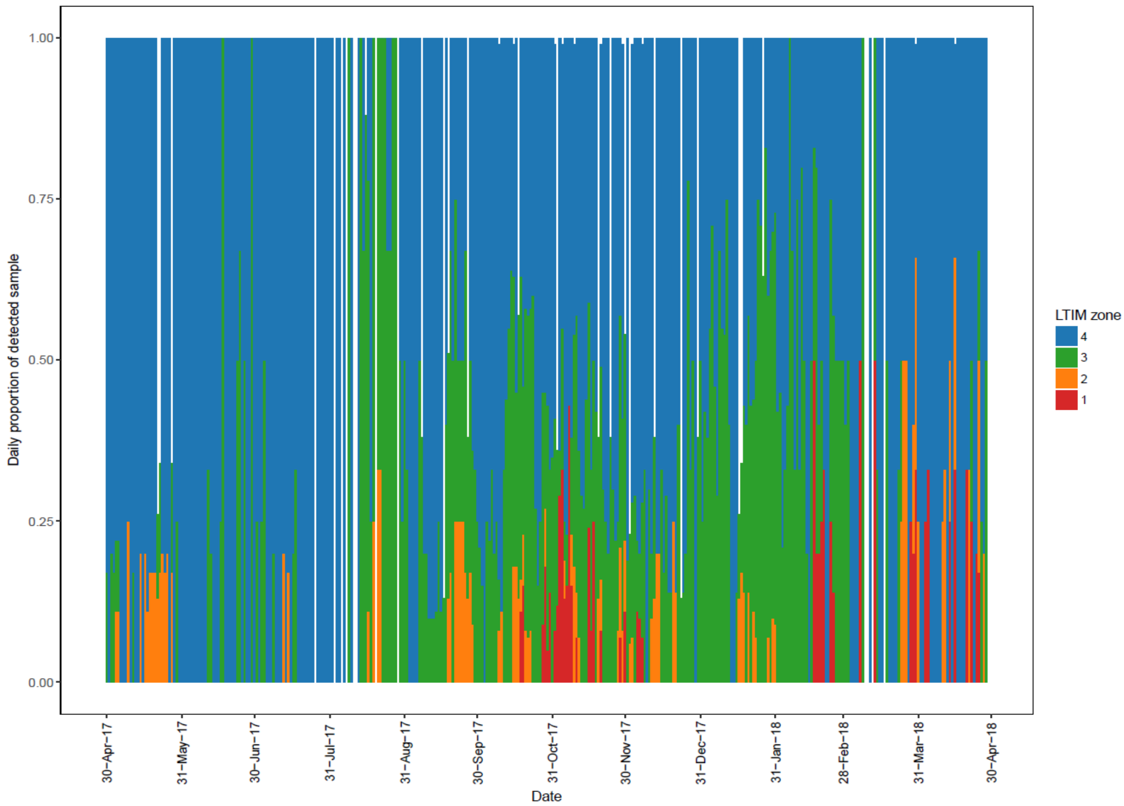


Figure 8.8 Proportionate daily location of acoustically tagged silver perch within each LTIM focal zone in 2017-18.

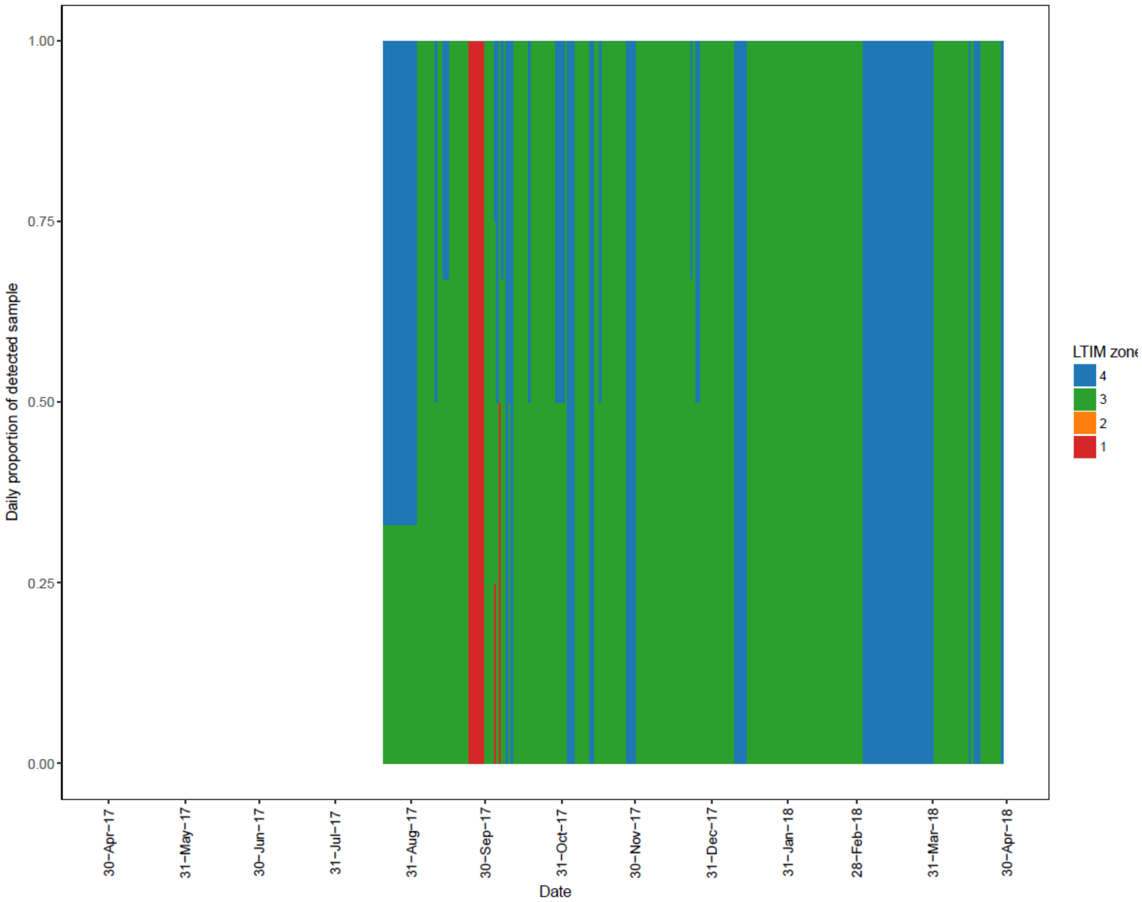


Figure 8.9 Proportionate daily location of acoustically tagged golden perch within each LTIM focal zone in 2017-18. Note sample sizes were insufficient to use prior to August 2017.

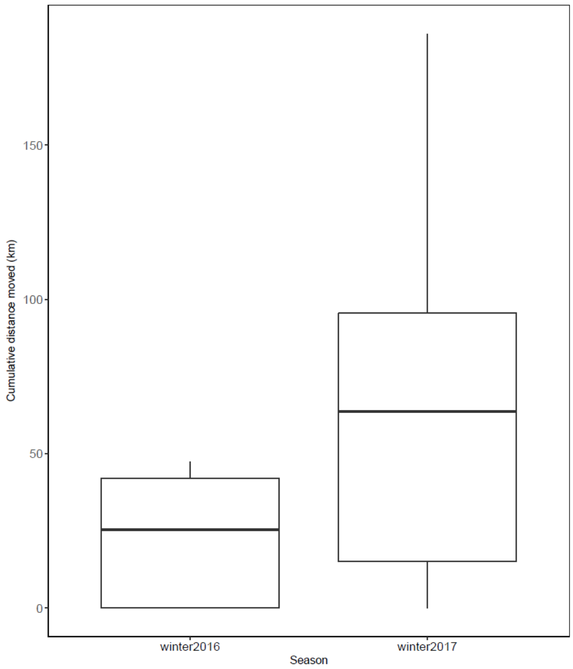


Figure 8.10 Cumulative distances moved by silver perch during watering action 1 (winter 2017) in comparison with the same period in 2016 (winter 2016). Note sample sizes vary considerable between the two sample events (n=5 in 2016 and n=18 in 2017) and that data are represented as box (light bars = 25th and 75th percentiles; dark bar = median value) and whisker (5th and 95th percentiles). .

8.5.2 *Fish spawning and reproduction*

A total of 4,428 fish larvae, representing twelve species, were collected in the 2017-18 study period from light traps (n=3,889) and drift nets (n=538) combined (Table 8.4). Across the four study zones, the greatest number of larvae were collected in Wakool River zone 3 (57%), followed by Wakool River zone 4 (21 %), Wakool River zone 2 (14%) and Yallakool Creek zone 1 (8%) respectively. Compared to previous years, the 2017-18 total larval catch was similar to 2014-15 and 2015-16 which were characterized by within-channel flow events, where 4,249 sampled in 2014-15 and 3,418 larvae in 2015-16. Despite the reduced sampling effort caused by flooding and access issues (Watts et al. 2017c), a magnitude order more larvae were collected in 2016-17 (n= 12, 667).

Ten of the eleven fish species collected as larvae were native, with small-bodied fish species comprising the majority of larvae collected across the four study zones (Table 8.4), Carp gudgeon (*Hypseleotris* spp. n=3,141), were the most numerically abundant larvae caught in light traps, representing 90% of the larvae catch. Australian smelt (*Retropinna semoni* n=231) and flathead gudgeon (*Philypnodon grandiceps*, n=91) larvae were also detected consistently across the four study zones. Other small bodied fish found spawning during 2017-18 unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*, n=4) and Murray River Rainbowfish (*Melanotaenia fluviatilis*, n= 3) and obscure galaxias (*Galaxias oliros*). Gambusia were the only introduced fish species captured as larvae in the 2017-18 spawning period.

2017-18 marked the highest diversity of native large bodied species detected to have spawned across the Edward-Wakool study sites since intervention monitoring of Commonwealth environmental water commenced in 2011 (Table 8.5). Eleven native fish species were detected to have spawned in 2017-18, whereas in previous years only seven or eight species have spawned (Table 8.5). Notably, this is the first year that freshwater catfish larvae (*Tandanus tandanus,* n=8) and silver perch eggs (*Bidyanus bidyanus, n=17*) have been detected, a positive indication of local spawning for these two species in the Selected Area. Freshwater catfish larvae were sampled in the mid reaches of Wakool River downstream Barbers Creek (zone 4), while silver perch eggs where only collected in Yallakool Creek (zone 1). Other large bodied species collected are larvae in 2017-18 were Murray cod *(Maccullochella peelii*), bony herring (*Nematolosa erebi*) and river blackfish (*Gadopsis marmoratus*). Similarly to previous years, we did not detect a golden perch spawning event in the Edward-Wakool River system in 2017-18.

Table 8.4 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 2017-18. The total amount of water filtered across the nets in each study zone; Yallakool Ck, Wakool River zone 2, Wakool River zone 3, and Wakool River zone 4. Fish species listed are those known to occur in the Edward-Wakool river system. Trout cod have been detected in the Edward Wakool Selected Area but not in the four 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	36	1	20	2	140	2	35	8	231	24
carp gudgeon	70	-	105	-	2223	-	743	-	3141	-
flathead gudgeon	1	-	1	-	45	-	44	-	91	-
unspecked hardyhead	-	-	-	-	2	-	2	-	4	-
Murray River rainbowfish	1	-	-	-	2	-	-	-	3	-
obscure galaxias	-	-	-	-	-	-	1	1	1	1
bony herring	-	-	-	-	1	-	6	-	7	-
silver perch (eggs)	-	17	-	-	-	-	-	-	-	17
golden perch	-	-	-	-	-	-	-	-	-	-
freshwater catfish	-	-	-	-	-	-	-	8	-	8
river blackfish	-	-	7	-	-	-	-	-	7	-
trout cod	-	-	-	-	-	-	-	-	-	-
Murray cod	80	159	212	254	104	6	17	69	413	488
Introduced										
gambusia	1	-	-	-	-	-	-	-	1	-
oriental weatherloach	-	-	-	-	-	-	-	-	-	-
redfin perch	-	-	-	-	-	-	-	-	-	-
carp	-	-	-	-	-	-	-	-	-	-
goldfish	-	-	-	-	-	-	-	-	-	-
Other										
tadpoles	-	1	-	--	-	-	-	-	-	1
Grand total	189	177	345	256	2,517	8	848	86	3,889	539

Table 8.5 Number of fish species detected as larvae in each monitoring year from 2014-2018.

Fish species	2014-15	2015-16	2016-17	2017-18
Native species				
Australian smelt	✓	✓	✓	✓
carp gudgeon	✓	✓	✓	✓
flathead gudgeon	✓	✓	✓	✓
Murray cod	✓	✓	✓	✓
Murray River rainbowfish	✓	✓	✓	✓
unspecked hardyhead	✓	✓	✓	✓
river blackfish	✓	✓		✓
obscure galaxias		✓		✓
bony herring			✓	✓
freshwater catfish				✓
silver perch				✓
Total native species	7	8	7	11
Introduced species				
gambusia	✓	✓	✓	✓
carp		✓	✓	
oriental weatherloach			✓	
Total introduced species	1	2	3	1

Comparisons of larval catch across years and study zones

Periodic 'flow-cued' species

Silver perch eggs (Figure 8.11) were detected for the first time in the study zones in 2017-18. Eggs were collected in drift nets on the 5-8th December 2017 at the most downstream site in Yallakool Creek (zone 1).

The maximum discharge in Yallakool Creek during the late spring/early summer was more variable in 2017-18 than it had been in previous years, which was a result of unregulated flows moving through the creek at this time. During November and December 2017 there were three successive unregulated freshes where the discharge ranged from approximately 400 ML/d to 525 ML/day. The timing of the appearance of silver perch eggs coincided with the peak of the third fresh where the change in water height was approximately 23 cm (increase from 2.38 to 2.61 cm) over a period of 4 days (Figure 8.12). The water temperature at this time was above 21°C. At the peak of the second fresh on 23 Nov 2017 there was little or no moon, whereas just prior to the peak of the third fresh there was a full moon on 4th December 2017.

The results of hydraulic modelling of the study sites in the four hydrological zones have been previously reported in Watts et al (2015). Using those results the average area of river channel with fast water velocities (> 0.3 ms^{-1}) were compared among the zones for discharge on 5th December 2017. At the time, the sites in Yallakool Creek had a considerably larger average area with fast water velocities (> 0.3 ms^{-1}); Yallakool Creek 17,195 m^2, upper Wakool River (zone 2) Yallakool Creek 792 m^2, Wakool River (zone 3) Yallakool Creek 3,640 m^2, and Wakool River (zone 4) Yallakool Creek 7,739 m^2.

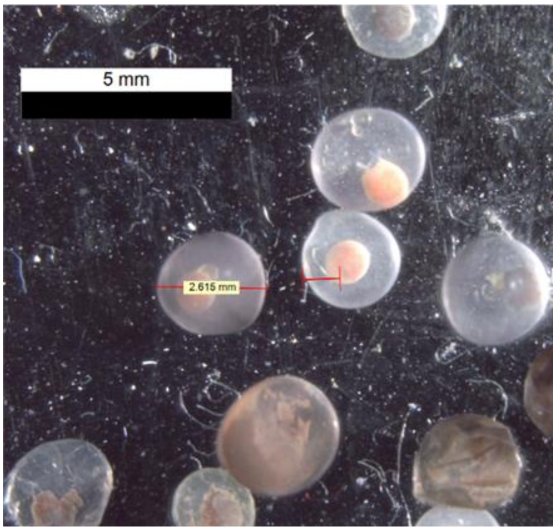


Figure 8.11 Silver perch eggs collected from drift nets deployed in Yallakool Creek, 5-8 December 2017.

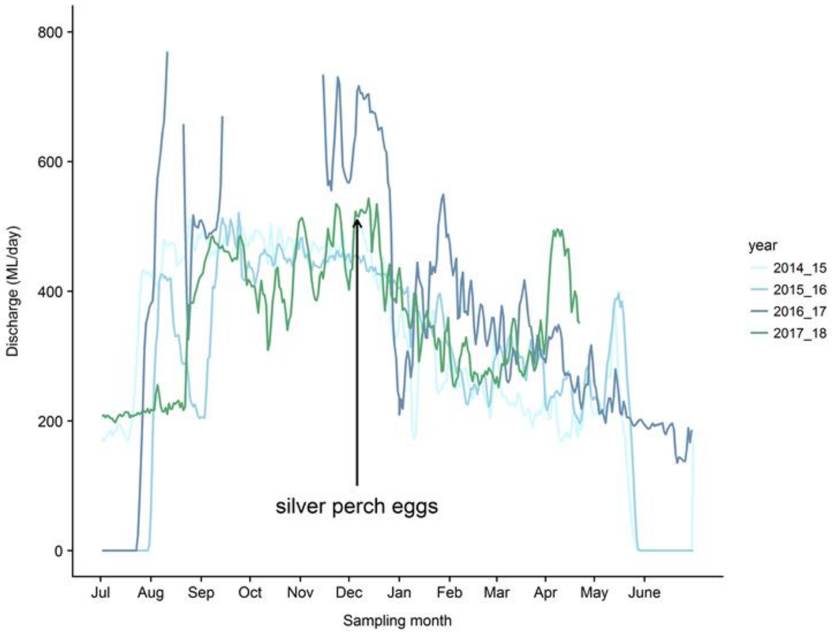
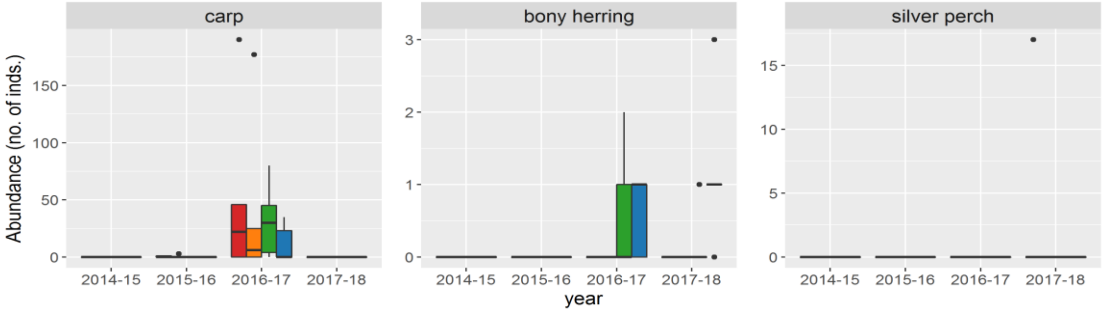


Figure 8.12 Yallakool Creek hydrographs for 2014-15, 205-16, 2016-17 and 2017-18. The detection of silver perch eggs in December 2017 is highlighted.

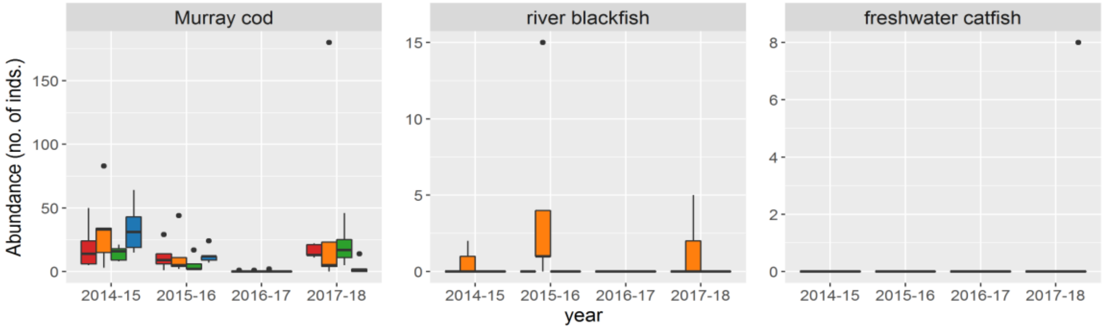
Bony herring larvae were collected for the second consecutive year since long-term monitoring commenced. Similarly to 2016-17, bony herring larvae were detected in the lower Wakool River study zones 3 and 4, between January – March, and were not found in Yallakool Creek (zone 1) or the upper Wakool River (zone 2) (Figure 8.13*a*). Numbers were too low to facilitate formal statistical comparison across years or zones.

Carp larvae were not found in 2017-18 sampling season. This contrasts significantly with the previous year's catch where large numbers of carp larvae were detected in all four study zones in the Edward-Wakool River system during the flood conditions of 2016-17 (Table 8.6, Figure 8.13*a*). The low levels of carp spawning in 2017-18 match those seen in 2014-15 and 2015-16 and when flows remained in channel (Figure 8.13*a*).

a) Periodic species



b) Equilibrium species



c) Opportunistic species

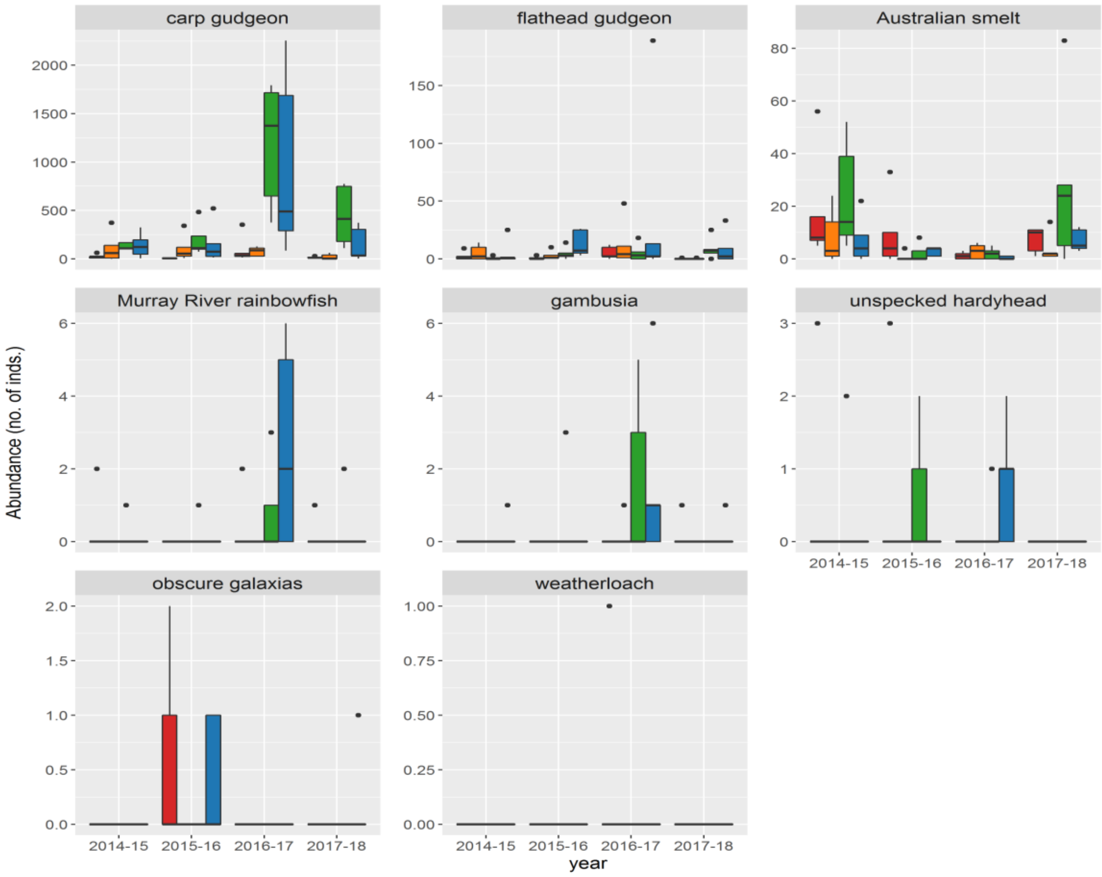


Figure 8.13 Boxplots of the annual total abundance of c) opportunistic fish species collected as larvae for the three years of LTIM to date. Species are grouped according to their life history a*) periodic species* (those expected to spawn in relation to certain flow conditions) b) *equilibrium species* (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. Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

Table 8.6 Results of mixed-models which tested for significance differences in total annual catch of fish larvae across years, for each species. Models where run only on species with n>50, and significance was determined using Wald χ^2. *P* values <0.05 used to determine significance. Significance codes: ***<0.001, **<0.01, *<0.05. ^denotes alien species.

Fish species	n	factor	d.f	χ^2 statistic	*P* value	significance
Periodic species						
common carp^	688	year	3	523.71	<0.0001	***
		zone	3	17.97	0.0004	***
		year x zone	9	11.81	0.2243	NS
Equilibrium species						
Murray cod	1146	year	3	101.69	<0.0001	***
		zone	3	5.08	0.1658	NS
		year x zone	9	15.18	0.0860	NS
river blackfish	31	year	3	17.28	<0.0001	***
		zone	-	-	-	-
		year x zone	-	-	-	-
Opportunistic species						
carp gudgeon	19116	year	3	33.71	<0.0001	***
		zone	3	65.49	<0.0001	***
		year x zone	9	22.80	0.0066	**
flathead gudgeon	593	year	3	13.01	0.0046	**
		zone	3	19.70	0.0002	**
		year x zone	9	20.45	0.0153	*
Australian smelt	629	year	3	34.77	<0.0001	***
		zone	3	11.58	0.0089	**
		year x zone	9	17.71	0.0387	*
Murray river rainbowfish	26	year	3	30.28	<0.0001	***
		zone	3	22.82	<0.0001	***
		year x zone	9	21.29	0.0114	*
gambusia^	23	year	3	32.61	<0.0001	***
		zone	3	24.43	<0.0001	***
		year x zone	9	28.76	0.0007	***

Equilibrium species

Numbers of Murray cod larvae sampled in 2017-18 were similar to those collected in 2014-15, and 2015-16; despite the greater discharge variability experienced in some study zones in 2017-18 (Figure 8.13*b*). Murray cod larval counts were significantly lower in 2016-17 (Table 8.6, Figure 8.13*b*) and this is attributed to the hypoxic event and associated fish kills of adult Murray cod during the spawning season for this species. The increase in larval Murray cod counts in 2017-18 were similar to numbers observed prior to the 2016 hypoxic event, suggesting that adults have been able to successfully move back into the Edward-Wakool to spawn. CEW winter base flows in 2017 may have assisted in facilitating movement of breeding pairs back into the area prior to spawning.

2016-17 was the first year in which we did not detect river blackfish larvae, however in 2017-18 larvae were once again collected in upper Wakool River zone 2 providing promising signs of recovery or resilience of this small population after the hypoxic events of 2016-17 (Figure 8.13*b*). Similarly with Murray cod, there was a significant difference in river black fish across years (Table 8.6), where 2016-17 counts were significantly lower than those in 2014-15, 2015-16 and 2017-18. River blackfish larvae were collected in late October to late November 2017 from 2 sites in zone 2.

Eight freshwater catfish larvae (Figure 8.14) were collected from drift nets in the Wakool River downstream of Thule Creek (zone 4), on two separate sampling trips; 16-19 November and 5-8 December 2017 (Figure 8.13*b*). All catfish larvae were between 12-14 mm TL, and based on published length-age relationships (Burndred et al. 2017), individuals were estimated to be approximately 10-14 days old. At this age, it is likely that the individuals caught would have recently dispersed from their nest (Burndred et al. 2017, Lake et al. 1967) prior to capture, suggesting that spawning is likely to have occurred locally within the lower Wakool River.

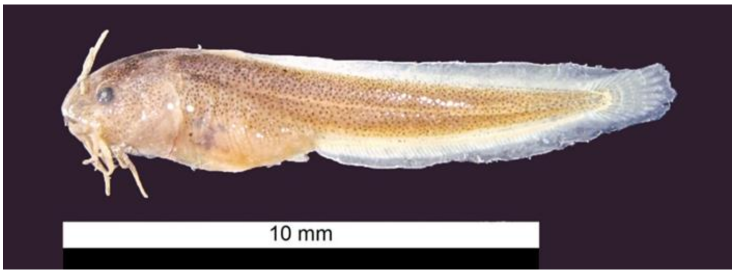


Figure 8.14 Freshwater catfish *(Tandanus Tandanus)* larvae. Photo: John Trethewie

Opportunistic species

Small-bodied opportunistic species numerically dominated the Edward-Wakool larval fish assemblage. Carp gudgeon, flathead gudgeon and Australian smelt spawned at all sites throughout the four study zones (Figure 8.13*c*); carp gudgeons appeared from late September 2017 through to mid-March 2018, Australian smelt late September to early December, and flathead gudgeon from October to February. When comparing larval abundance across years and across zones, carp gudgeon, Murray River rainbowfish and gambusia displayed similar trends with the greatest numbers of larvae occurring during the flood year of 2016-17, but only in zones 3 and 4 (Figure 8.13*c,* Table 8.6). Murray River rainbowfish appeared throughout zone 1 and 3 from November through to the end of February.

Significant interactions between zone and year were also detected for flathead gudgeon, however this pattern is less obvious, but may be due to slighter higher numbers of larvae caught in zone 4 in the past 3 years of sampling (Figure 8.13*c*). Numbers of unspecked hardyhead, obscure galaxias and oriental weatherloach were too low for any statistical comparisons across years or zones to be undertaken. Unspecked hardyhead larvae appeared throughout the Wakool River in zones 3 and 4 from late November to late December; obscure galaxias larvae were collected in zone 4 only in late October and again in early December, and there were no oriental weatherloach sampled at all in 2017-18.

Targeted watering actions for spawning outcomes in 2017-18

One of the watering actions delivered by the CEWO in the Edward Wakool River system was the delivery of small spring fresh and flow recession delivered to Yallakool Creek (zone 1) and Colligen Creek (not monitored) from 7 Sep – 22 October 2017, and with the Wakool Zones 3 and 4 also receiving attenuating downstream benefits of the Yallakool Creek flow. The aim of this flow was to contribute to spawning of early spawning native fish species. Australian smelt and carp gudgeon were observed to spawn during the watering action. We hypothesised there would be a significantly greater number of larvae number of carp gudgeon and Australian smelt in zones receiving the small spring fresh (zone 1, 3 and 4), compared to zone 2 that received only a very small amount of environmental water during this action (Figure 4.2). Just over 50% of all Australian smelt larvae collected were sampled during the timing of the spring action. We found a significant difference in the abundance of Australian smelt larvae across the four study zones (χ^2=11.67, df=3, p=0.008), with more larvae found in zone 1, 3 and 4 than in zone 2, as predicted. We were not able to test for the effects of the spring flow on carp gudgeon spawning, because only 12 of the 3141 carp gudgeon larvae caught during the entire spawning season were collected during the time of the spring action.

8.5.3 *Murray cod, silver perch and golden perch recruitment*

A total of nine native fish species and five alien species were sampled between 2014-15 and 2017-18 as part of the fish recruitment backpack electrofishing monitoring. Adult river blackfish were detected in Yallakool Creek (zone 1) for the first time in 2018 since surveys began, having previously being detected only in the upper Wakool River (zone 2).

The analysis of fish otoliths to evaluate fish recruitment focusses on Murray cod, silver perch and golden perch. Golden perch recruits have not been detected by monitoring during any of the four sampling years in the Edward-Wakool Selected Area. Thus, this following fish recruitment results report on only Murray cod and silver perch recruitment. Growth rates of Murray cod, silver perch or golden perch recruits could not be established in 2017-18 due to the low numbers of individuals captured.

Murray cod

A total of eight YOY and one 1+ Murray cod recruit were detected in February 2018 (Table 8.7), following on from February 2017 when no recruits were detected. All recruits in 2017 were detected in zones 1 and 2, in contrast to 2014-15 and 2015-16 where they were found throughout the system (Figures 8.15 and 8.16). Backpack electrofishing was the most effective gear type for sampling YOY and 1+ recruits. There was a significantly greater number of Murray cod YOY and 1+ recruits captured in 2015-16 compared to other years (Table 8.8).

One of the watering actions in 2017-18 was the delivery of a winter base flow through Yallakool Creek, with Wakool zones 3 and 4 also receiving attenuating downstream benefits of the flow. One of the aims of this watering action was to contribute to fish recruitment. We hypothesised that if the environmental water action was successful there would be a significantly greater number of larvae number of Murray cod young-of-year in zones that received the winter base flow (zones 1, 3 and 4), compared to zone 2 that did not receiving the winter base flow (Figure 4.1). There was no significant difference detected in the number of YOY or 1+ Murray cod across zones (Table 8.8). We were not able to reject the hypotheses, as significantly more Murray cod YOY were captured in zone 2, which did not receive the winter base flows, than zones 3 and 4 (*F*-value=3.99, df=3,12, p=0.034). This result reflects the fact that the total number of Murray cod recruits caught in 2017 was extremely low, and that it takes time to rebuild populations following a major hypoxic event such as that in 2016. It does not suggest that the winter action failed to assist cod recruitment.

Table 8.7 Number of Young-of-Year (YOY), age-class 1 (1+) recruits and older juvenile and adults (JA) of the three target species sampled in recruitment and growth monitoring in the Edward-Wakool system for 2014-15 through 2017-18.

	2014-15			2015-16			2016-17			2017-18		
Zone	YOY recruit	1+ recruit	JA	YOY recruit	1+ recruit	JA	YOY recruit	1+ recruit	JA	YOY recruit	1+ recruit	JA
Murray cod												
Zone 1	5	15	17	20	8	10	0	0	0	2	0	4
Zone 2	5	11	11	9	16	19	0	0	0	6	1	2
Zone 3	3	14	13	8	9	16	0	0	0	0	0	0
Zone 4	7	6	14	5	17	11	0	0	0	0	0	0
Total	20	46	55	42	50	56	0	0	0	8	1	6
Silver perch												
Zone 1	0	0	7	0	1	5	0	0	12	0	0	2
Zone 2	0	0	2	0	0	3	0	0	3	0	0	1
Zone 3	0	0	6	0	4	9	0	0	13	0	0	9
Zone 4	0	1	1	5	15	14	0	0	7	0	0	14
Total	0	1	16	5	20	31	0	0	35	0	0	26
Golden perch												
Zone 1	0	0	0	0	0	0	0	0	0	0	0	0
Zone 2	0	0	0	0	0	0	0	0	0	0	0	0
Zone 3	0	0	1	0	0	3	0	0	0	0	0	0
Zone 4	0	0	2	0	0	1	0	0	0	0	0	0
Total	0	0	3	0	0	4	0	0	0	0	0	0

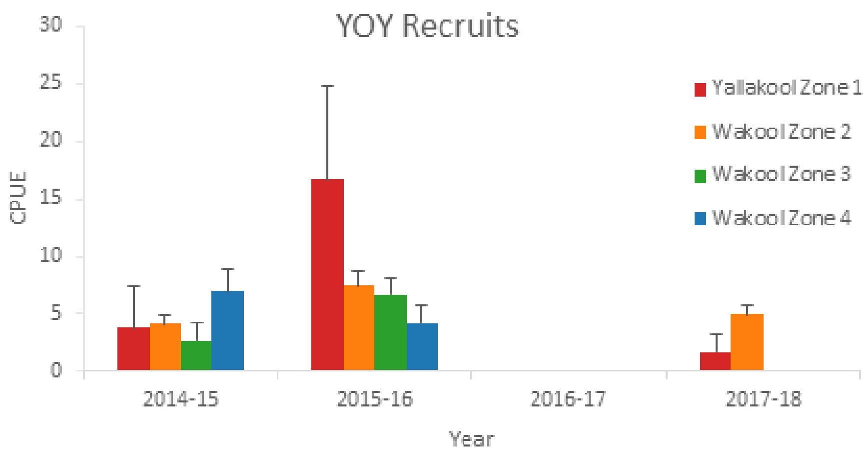


Figure 8.15 Variation in catch per unit effort (CPUE; number per 10,000 sec of backpack electrofishing) of young-of-year (YOY) Murray cod among study zones in the Edward-Wakool river system between 2014-15 and 2017-18. Bars represent mean (+SE) per zone.

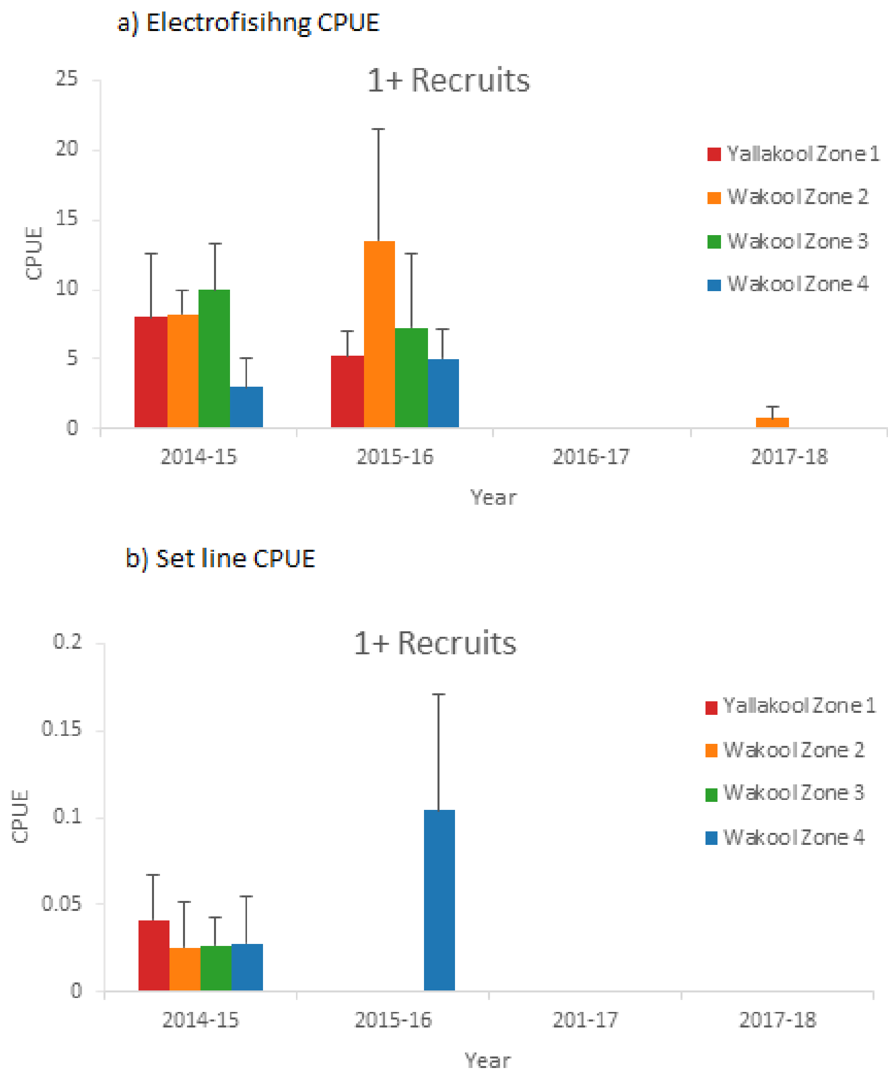


Figure 8.16 Variation in catch per unit effort of 1+ Murray cod among LTIM zones using *a)* backpack electrofishing and *b)* set lines in the Edward-Wakool river system between 2014-15 and 2017-18. Bars represent mean (+SE) per zone.

Table 8.8 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 2017-18. NS = Not significant.

Species	Response variable	Factors	DF	F-value	P value
Murray cod	YOY recruitment	sampling	2	24.9	< 0.0001
		year	3	6.6	0.0003
		zone	3	0.9	NS
		zone x year	9	1.1	NS
	1+ recruitment	sampling	2	21.3	< 0.0001
		year	3	7.0	0.0002
		zone	3	0.8	NS
		zone x	9	0.5	NS
Silver perch	1+ recruitment	sampling	2	2.6	NS
		year	3	6.3	0.0004
		zone	3	3.5	NS
		zone x	9	3.8	0.0002

Silver perch

Adult silver perch were consistently present among all years and zones (Table 8.7). There were no silver perch YOY or 1+ recruits detected in 2017-18, whereas one recruit was sampled in 2014-15 and 25 were sampled in 2015-16 (Table 8.7, Figure 8.17). Comparisons of recruitment across years found there was a significantly greater number of 1+ recruits in 2015-16 compared to all other years (Table 8.8, Figure 8.17). Otoliths from nineteen silver perch collected in 2017-18 were analysed and all were found to be between 2+ and 4+ years old (i.e. no YOY or 1+ recruits). All fish were captured using set lines or angling.

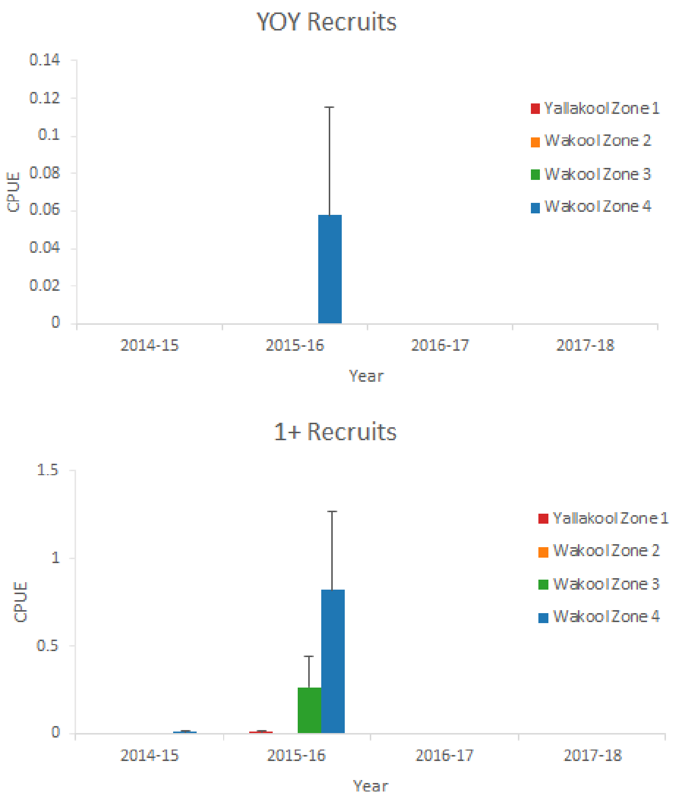


Figure 8.15 Variation in catch per unit effort (number per 10,000 s of sampling) of 1+ Silver perch from the Edward-Wakool river system between 2014-15 and 2017-18. Bars represent mean +SE per zone.

8.5.4 *Adult fish community*

Category 1 fish community sampling (undertaken only in zone 3) identified eight native fish species and three alien species in 2018 (Table 8.9). Overall, standardised catch of Murray cod and golden perch remained substantially lower in both 2017 and 2018 compared with 2015 and 2016 (Table 8.9). Flathead gudgeon were not captured in 2018, although were previously captured at low abundance in both 2016 and 2015 (Table 8.9).

There were significant differences in the abundance of the fish assemblage between sampling years (2018, 2017, 2016 and 2015) in zone 3 (Pseudo-$F_{3,36}$ = 8.428, p<0.001). Pair-wise differences between 2018 and 2017 (t=2.204, p=0.002) were driven by a higher abundance of carp gudgeon in 2018 (contribution to dissimilarity between groups 16.0%) and a lower abundance of unspecked hardyhead and goldfish in 2018 (contribution to dissimilarity between groups 13.0 and 11.0%, respectively).

Length-frequency distributions (Figure 8.16) indicated that bony herring captured in 2018 were significantly smaller than those captured in 2017 (p<0.001), 2016 (p<0.001) and 2015 (p<0.001), and a number of new recruits were captured.

Golden perch captured in 2018 were significantly larger than those captured in 2017 (p=0.025), 2016 (p<0.001) and 2015 (p<0.001) and new recruits of this species have not been captured during four years of sampling (Figure 8.16).

Common carp new recruits were captured in 2018, although common carp were significantly larger in 2018 compared with 2017 (p<0.001) due to a higher proportionate abundance of new recruits in 2017. In contrast, common carp were significantly larger in 2016 (p<0.001) and 2015 (p<0.001) when compared with the size structure in 2018 (Figure 8.16).

A number of Murray cod new recruits were captured in 2018, although the size structure in 2018 was not significantly different to 2017 (p=0.153), 2016 (p=0.053) or 2015 (p=0.123) (Figure 8.16).

Table 8.9 Summary of fish captured during annual Category 1 standardised sampling from 2015–2018 in the Edward-Wakool LTIM project. BE = boat electrofishing, SFN = small fyke net and BT = bait trap.

Fish species	2015				2016				2017				2018			
	BE	SFN	BT	**Total**	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**	301	4	-	**305**
bony herring	31	-	-	**31**	27	-	-	**27**	108	-	-	**108**	148	-	-	**148**
carp gudgeon	47	4302	51	**4400**	68	2367	15	**2450**	165	6814	66	**7045**	52	7804	98	**7954**
flathead gudgeon	-	-	1	**1**	-	-	3	**3**	-	-	-	**0**	-	-	-	**0**
golden perch	107	-	-	**107**	116	-	-	**116**	19	-	-	**19**	38	-	-	**38**
Murray cod	210	-	-	**210**	333	1	-	**334**	12	-	-	**12**	21	-	-	**21**
Murray River rainbowfish	339	168	-	**507**	353	77	5	**435**	650	19	-	**669**	518	19	-	**537**
silver perch	5	-	-	**5**	5	-	-	**5**	3	-	-	**3**	2	-	-	**2**
unspecked hardyhead	86	64	-	**150**	565	35	-	**600**	510	72	-	**582**	82	7	-	**89**
alien species																
common carp	167	-	-	**167**	176	-	-	**176**	735	40	3	**778**	251	1	-	**252**
eastern gambusia	18	175	-	**193**	36	366	1	**403**	31	125	8	**164**	2	53	-	**55**
goldfish	21	-	-	**21**	38	-	-	**38**	73	2	-	**75**	15	-	-	**15**

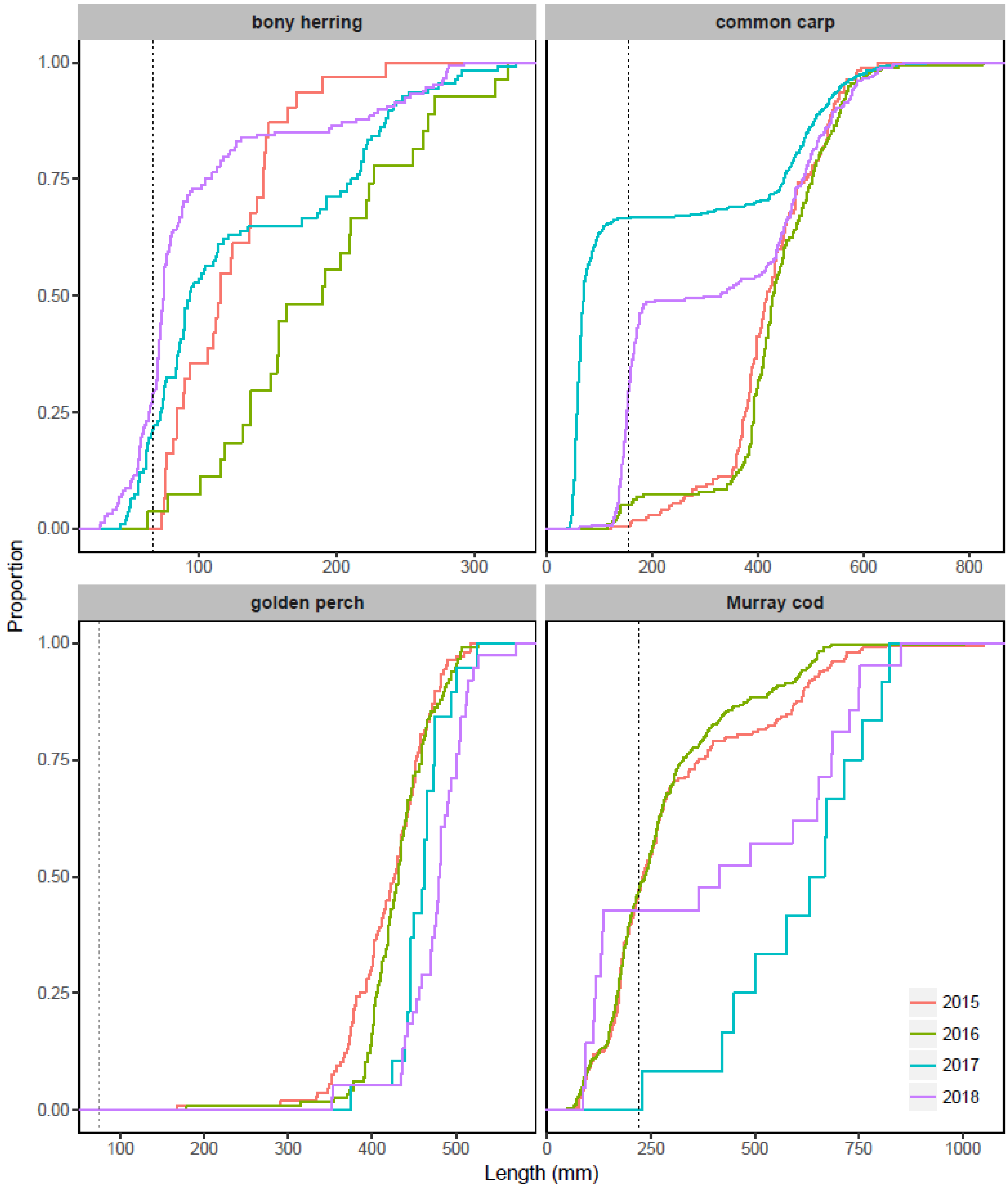


Figure 8.16 Cumulative length-frequency histograms of the four most common large-bodied species captured during Category 1 sampling in the Edward-Wakool LTIM project in 2015, 2016, 2017 and 2018. The dashed line indicates approximate length at one year of age and annual sample sizes are provided in table x for each respective species and sampling year.

8.6 Discussion

Here, we bring together our results from monitoring of movement, spawning, recruitment and adult fish community to provide an overview of how the fish community in the Edward-Wakool responded to watering events and Edward-Wakool hydrological conditions in general. A summary of the species of larvae, recruits and adults present in the system in 2017-18 is presented in Table 8.10.

Table 8.10 Summary of 2017-18 results from fish sampling in the Edward-Wakool River Selected area of species known to occur in the area prior to 2017. For 2017-18 sampling season - ticks denote the presence of larvae (indicating successful spawning), recruits (indicating successful recruitment) and adults. ^ denote introduced species. [1] Indicates species have been recorded in the Edward Wakool system, but outside the LTIM focal study zones.

2014-17	2017-18		
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]			
freshwater catfish[1]	✓		
opportunistic species			
Australian smelt	✓	✓	✓
carp gudgeon	✓	✓	✓
Murray river rainbowfish	✓	✓	✓
flathead gudgeon	✓		
unspecked hardyhead	✓		✓
obscure galaxias	✓		
dwarf flathead gudgeon[1]			
gambusia^	✓		✓
oriental weatherloach^			

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

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, silver perch, golden perch and bony herring 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 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).

Silver perch

The 2017-18 watering year was characterised by moderate regulated flows, with winter base flows, small freshes and gradual recessions supported through targeted delivery of Commonwealth environmental water. Winter base flows supported the movement of silver perch throughout the selected area, and elevated flows in spring and summer enabled silver perch to move among all four LTIM focal zones. Spawning in silver perch was detected in Yallakool Creek (zone 1) in early December 2017, providing the first contemporary evidence of localised spawning in this species in the study focal area. Eggs were captured on the rising limb of the hydrograph, and given the rapid development of eggs (~24–36 hours), the flows immediately prior to capture appear conducive to stimulating spawning in this species. Concurrent with spawning, a small proportion of tagged adult silver perch were recorded to have temporarily occupied Yallakool Creek. Tonkin et al. (2017) recently characterised the environmental conditions during peak silver perch spawning periods (November and December) at Torrumbarry on the Murray River, an area that supports the strongest remnant population of silver perch in the Murray-Darling Basin. In this region, minimum daily water velocities were always greater than 0.45 m s^{-1} and water temperatures ranged from 21.5–24°C during spawning periods (Tonkin et al. 2017). The preference for late season spawning (i.e. water temperatures > 20°C) in this study is consistent with other studies from the Murray (e.g. King et al. 2016) and Murrumbidgee (e.g. Wassens et al. 2017) rivers. The timing of the presence of silver perch spawning in Yallakool Creek also coincided with the full moon, a change in water height of approximately 23 cm over 4 days, and a large area of channel in Yallakool Creek having fast water velocities (> 0.3 ms^{-1}).

Despite successful spawning of silver perch in Yallakool Creek in 2017-18, there was no evidence that this spawning event resulted in successful recruitment in February 2018. Silver perch recruits (0+ or 1+) were also not captured in the Edward-Wakool in February 2017, however this result is unsurprising given the magnitude and extent of hypoxic blackwater fish kills within the Murray region in late 2016. In contrast, a number of juvenile and adult silver perch were captured during recruitment sampling and fish community surveys in 2017 and 2018. Telemetry data indicates that silver perch regularly move 100's of kilometres, and the presence of these individuals within the Edward-Wakool system may reflect rapid re-colonisation following the hypoxic blackwater event in late 2016, or alternatively survival during the hypoxic event. Commonwealth environmental water actions in 2017-18 contributed to the recolonization of silver perch in The Edward-Wakool system following the hypoxic blackwater event in 2016. Watering action 1 (winter base flow) facilitated movement of silver perch throughout the system, which is different to previous years when the winter operational shutdown restricted their movements. Watering actions 2 and 4 facilitated connectivity and movement of silver perch.

The Edward-Wakool is part of the mid-Murray region that supports the strongest remnant population of silver perch in the Murray-Darling Basin. Indeed, this reach of the Murray River represents the longest stretch of free-flowing (lotic) habitat in the Murray River (Mallen-Cooper and Zampatti 2018), a necessary requirement for this obligate riverine species to complete all aspects of its lifecycle. 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. Further work is required to examine silver perch movement and spawning in other parts of the Edward-Wakool system outside the current focal study area.

Golden perch

Consistent with previous sampling conducted in 2014-15, 2015-16 and 2016-17, there was no evidence of spawning or recruitment of golden perch in the Edward-Wakool LTIM focal zones. Relative abundance of adult golden perch in the system appears to be low as a result of emigration and/or mortality from hypoxia following widespread flooding in 2016. The tagged adult sample demonstrated minimal movement during 2017-18 and no emigration from the system. Length-frequency data are indicative of a growing (ageing) population with no recruitment in the past four years. 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).

Previous work by Sharpe (2011) and Mallen-Cooper et al. (2014) have recorded strong recruitment of golden perch in floodplain lakes, and suggest that connection of the main river channel to floodplain lake habitats is a critical element to successful spawning and recruitment. They propose that life cycle of golden perch involves adults spawning in the main channel on high flows, enabling larvae to drift from the main river channel into recently inundated lake habitats whey they grow as juveniles over the spring-summer-winter period. Following the over winter period, re-connection of these off-channel habitats to the main channel environment becomes important by facilitating dispersal of juveniles back into the main riverine habitat, where they have been observed to disperse over large spatial scales (e.g. over 1000’s km). Hence, flow conditions that not only help to initiate spawning, but also provide suitable connection and provision of off-channel nursery habitats are hypothesised to be important flow features required for golden perch, as is equally flow conditions to provide reconnection of these nursery habitats back to main channel environments the following winter/spring (Sharpe 2011). Identification of off-channel floodplain lakes or oxbows in the Edward-Wakool Selected area where Commonwealth environmental watering actions could be targeted to provide these kinds of flow environments and connections at the right time of year, could be a worthy priority to be considered by the CEWO. For example, the oxbow lakes adjacent to the Edward River downstream of Stevens Weir may be a location where this could be tested in the Edward-Wakool system. These areas may contribute to local golden perch spawning and recruitment outcomes and contribute to the local golden perch population, in addition to immigration of juveniles in the system during higher flow events.

Regardless of whether golden perch spawn in the system, it is likely that flows have a role to play in supporting the survival and growth of golden perch individuals in the system. Recent multiyear analyses of adult golden perch condition and growth under a range of hydrological conditions across the Murray Darling Basin has found that high winter flows can have subtle, but significantly positive effects on adult golden perch condition (Stoffels et al. 2017). Further, Stoffels et al. (2017) found a positive relationship between condition of adult golden perch and seasonal flow patterns of the year observed, as well as the discharge of the year prior. In the Edward-Wakool system, winter flows are often absent from the rivers entirely, and therefore potentially impacting on the condition and subsequent on fecundity and spawning likelihood of adult fish. This could be one explanation for the lack of spawning and recruitment occurring in the region. Stoffels et al. (2017) hypotheses that appropriately timed higher flows, over multiple years, may have cumulative benefits for golden perch condition. As such, we suggest that future use of CEW in the Edward-Wakool system to provide winter base flows could have a positive influence on the condition, and therefore subsequent spawning and recruitment for golden perch. In addition, recommendations from Stoffels et al. (2017) that priority be given to delivering water actions for golden perch in the year following a high flow year are worth considering for the Edward-Wakool selected area. Future use of CEW could also target connectivity to promote immigration of juveniles and adults into the system from the Murray River.

Bony herring

Bony herring larvae were captured in the downstream reaches (zones 3 and 4) of the Edward-Wakool system, indicating that localised spawning of this species occurred for the second consecutive year. New recruits were also captured in May 2017 and 2018, indicating that spawning is translating to positive recruitment outcomes within the Edward-Wakool system. Bony herring have a flexible life history, with Balcombe et al. (2006) identifying recruitment under both flood conditions and no-flow conditions in the Warrego River. However, body condition is generally greater during high flow events, translating into improved recruitment outcomes (Balcombe et al. 2012).

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

Equilibrium species are characterised by medium-late maturation, low fecundity and 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 Murray cod, trout cod, river blackfish and freshwater catfish. 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 four species occur within the broader Edward-Wakool system, although Murray cod are the only species considered abundant and regularly captured as larvae, juveniles and adults in the system. In 2017-18 three equilibrium species, Murray cod, river blackfish and freshwater catfish, were captured as larvae, indicating localised spawning within the LTIM focal zones.

Murray cod

While adult populations of Murray cod have not recovered to pre-2016 levels within the system, the presence of a low abundance of adults appears to be translating to successful spawning and recruitment. Murray cod 0+ and 1+ recruits were not captured during recruitment sampling in February 2017, however a number of small Murray cod (not aged) were captured during the community surveys undertaken in zone 3 in May 2017, with the overall size structure indicative of a similar proportion of YOY as 2014-15 and 2015-16 (i.e. ~40% YOY). The lack of Murray cod 0 and 1+ recruits in February 2017 reflects the fact that the total number of Murray cod recruits caught in 2017 was extremely low and that it takes time to rebuild populations following a major hypoxic event such as that in 2016. It does not suggest that the winter action failed to assist cod recruitment.

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 continued evidence of a number of adult Murray cod in the system, 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 flowing water habitats that maximise nest site inundation and support productivity and provision of habitat 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.

River blackfish

Larval river blackfish were captured in zone 2 of the Wakool River in 2017-18, and have been captured in this zone in all years except 2016-17 following the hypoxic blackwater event. It is hypothesised that the adult population in this zone may have established from the Mulwala Canal population and entered the system through the Wakool Escape. In 2017-18, adult river blackfish were captured in Yallakool Creek (zone 1) for the first time. River blackfish typically occupy discrete home-ranges (10’s of metres), are most active at night and may range over 100’s of metres (Koster and Crook 2008). It is possible that range expansion occurred during one of the recent flooding events, as the upper Wakool River (zone 2) and Yallakool Creek (zone 1) regularly connect during these periods through creeks and floodrunners such as Blackdog Creek, and fish movement between these waterways has previously been documented using telemetry. Environmental watering actions that target connectivity and enable this species to maintain their home range during winter could promote further range expansion of this species.

Freshwater catfish

Freshwater catfish are typically associated with submerged macrophyte beds such as *Vallisneria australis* in the Murray River (Bice et al. 2014). The species exhibits typical movements an order of magnitude greater than river blackfish, for example Koster et al. (2014) identified catfish moving up to 1.5 km between river and off-channel habitats. While movements of this scale are infrequent, unregulated flooding events can promote increased immigration and emigration (Stoffels 2016). It is possible that the presence of freshwater catfish in zone 4, where they haven't previously been detected during the LTIM program, is a result of flood-induced immigration. Environmental watering actions that target connectivity, support the development of aquatic macrophyte beds, and enable this species to maintain their home range during winter could promote further range expansion of this species in the Edward-Wakool system.

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

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 expected to result in an increase larval production and subsequent adult abundance (Humphries et al. 1999, Lyon et al. 2010).

Using the category 1 adult survey data (surveys conducted in zone 3 only) to indicate annual patterns in adult populations of opportunistic species, the number of Australian smelt and carp gudgeon adults captured was highest in 2016-17 and 2017-18, whereas for unspecked hardyheads we observed the lowest catch in 2017-18; and for Murray River rainbowfish numbers have remained relatively consistent across the time. A number of factors may be influencing these results, including timing of food resources, temperature during the spawning season, and availability of suitable habitat at critical times of the life cycle.

Spawning was detected in 2017-18 for seven small bodied opportunistic species known to the Edward Wakool Selected Area study zones (Table 8.10). Comparisons in larval abundance across years revealed that carp gudgeon, Murray River rainbowfish and gambusia spawning was greatest under the 2016-17 flood conditions – with larval abundances in 2017-18 typical of previous non flood years.

The hypoxic blackwater event in 2016 did not appear to adversely affect spawning for the majority of opportunistic species in the Edward Wakool River system. The spawning of only two species, Australian smelt and obscure galaxias appeared to have been impacted by the hypoxia, and in 2017-18, we observed a significant increase in the number Australian smelt captured compared to the results from the 2016-17 monitoring (Watts et al. 2017). Unlike in 2016-17 when the spawning period of Australian smelt coincided with arrival of hypoxic blackwater, in 2017-18 it coincided with the small spring fresh delivered by the CEWO (watering action 2), which flowed through Yallakool Creek and downstream into the mid and lower Wakool River. We observed significantly more Australian smelt larvae in the study zones that received environmental water compared to the upper Wakool River (zone 2) that received a minimal amount of environmental water. Australian smelt are a pelagic spawning species, and therefore it may be that the increase in water moving through the Edward Wakool system as a result of the early spring watering action would have been advantageous for spawning in this species.

8.6 Evaluation

Table 8.11 Summary of fish movement responses to Commonwealth environmental watering. N/A = Not applicable to this watering action.

Fish movement					
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?*
Winter base flow in Yallakool creek	To contribute to reinstatement of the natural hydrograph, connectivity, condition of in-stream aquatic vegetation and fish recruitment	Were periodic species (golden and silver perch) present in the target reaches during Commonwealth environmental water delivery?	Only tagged silver perch were present during the winter water action	Occupation of specific zones, scales of movements observed of silver perch	Silver perch moved substantially larger distances in winter 2017 during watering action 1, in contrast to the same period in 2016 (winter shutdown)
		Did periodic species remain within the target reaches during Commonwealth environmental water delivery?	Silver perch remained within zones 1-4		
		Did Commonwealth environmental water stimulate periodic fish species to exhibit movement consistent with reproductive behaviour?	The winter action occurred outside the spawning season		
		Does Commonwealth environmental water enable periodic species to disperse from and return to refuge habitat?	Yes, silver perch moved to and from refuge habitat during this action		
Summer fresh at end of e-flow followed by recession	To encourage fish movement and assist dispersal of larvae and juveniles of fish species	Were periodic species (golden and silver perch) present in the target reaches during Commonwealth environmental water delivery?	Periodic species movements occurred throughout delivery	Occupation of specific zones, scales of movements observed	The delivered flows likely had little impact on fish movements in zones 3 and 4. Movement impacting flows are likely to result from full or partial disconnection of habitats, large freshes or overbank flooding.
		Did periodic species remain within the target reaches during Commonwealth environmental water delivery?	Periodic species remained within zones 1-4		
		Did Commonwealth environmental water stimulate periodic fish species to	This was outside the scope of expected outcomes		NA

		exhibit movement consistent with reproductive behaviour?			
		Does Commonwealth environmental water enable periodic species to disperse from and return to refuge habitat?	Refuge habitats were not required at this time		NA
Autumn fresh in Yallakool Creek	To encourage fish movement and dispersal of juveniles of a number of fish species	Were periodic species (golden and silver perch) present in the target reaches during Commonwealth environmental water delivery?	Periodic species movements occurred throughout delivery	Occupation of specific zones, scales of movements observed	The delivered flows likely had little impact on fish movements in zones 3 and 4. Movement impacting flows are likely to result from full or partial disconnection of habitats, large freshes or overbank flooding. Additionally, flows were delivered during a time when large-scale movements are unlikely to occur due to falling water temperatures
		Did periodic species remain within the target reaches during Commonwealth environmental water delivery?	Periodic species remained within zones 1-4		As above
		Did Commonwealth environmental water stimulate periodic fish species to exhibit movement consistent with reproductive behaviour?	This was outside the scope of expected outcomes		
		Does Commonwealth environmental water enable periodic species to disperse from and return to refuge habitat?	Refuge habitats were not required at this time		

Table 8.12 Summary of fish spawning responses to Commonwealth environmental watering. N/A = Not applicable to this watering action.

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?*
Winter base flow in Yallakool creek	To contribute to fish recruitment	What did Commonwealth environmental water contribute to increased spawning activity of equilibrium species (e.g. Murray cod?)	*Not assessed through larval monitoring*		
		What did Commonwealth environmental water contribute to 'periodic' flow dependent spawning species (e.g. silver perch?)	*Not assessed through larval monitoring*		
		What did Commonwealth environmental water contribute to the spawning of 'opportunistic species' (e.g. small bodied fish)?	*Not assessed through larval monitoring*		
Early spring fresh in Yallakool Creek	To contribute to pre-spawning condition of native fish, and spawning in early spawning native fish	What did commonwealth environmental water contribute to increased spawning activity of equilibrium species (e.g. Murray cod?)	The early spring fresh flow did not appear to have a significant effect on the spawning magnitude of Murray cod.	The abundance of Murray cod larvae did not significantly differ across study zones that did and did not receive the spring fresh.	The environmental watering action had no measurable effect on spawning of Murray cod in the Edward Wakool.
		What did Commonwealth environmental water contribute to 'periodic' flow dependent spawning species (e.g. silver perch?)	Silver perch spawned in Yallakool Ck in early December,	Eggs found in drift nets set in Yallakool Creek. Drift nets are set fortnightly across the four study zones from early October – late December 2017.	The silver perch spawning event was likely to be associated with the greater instream flow variability in spring 2017-18 compared to previous years. These flows were unregulated, but could be mimicked in future years by environmental water delivery.
		What did Commonwealth environmental water contribute to the spawning of 'opportunistic species' (e.g. small bodied fish)?	There were significantly more Australian smelt larvae caught in zones receiving spring fresh	Fortnightly light trap sampling from Sep-Mar, across the 4 study zones.	Yes. Australian smelt are a pelagic spawner, therefore an increase in the volume of water in reaches during their spawning period is likely to be advantageous.

Table 8.13 Summary of fish recruitment responses to Commonwealth environmental watering. N/A = Not applicable to this watering action.

Fish recruitment					
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?*
Winter watering action in Yallakool creek	To contribute to fish recruitment	Did Commonwealth Environmental Water affect the growth rate of Murray cod, silver perch and golden perch during the first year of life?	*Not assessed*	Growth rates of Murray cod, silver perch or golden perch recruits could not be established in 2017-18 due to the low numbers of individuals captured.	NA
		Did Commonwealth environmental water contribute to the recruitment of Murray cod, golden perch and silver perch?	No effect detected.	Relative abundance of Young-of-year fish determined from otolith analysis.	Yes, however, the lack of response detected is likely to be due to the system still recovering from the hypoxic blackwater event in 2016.

RECOMMENDATIONS

Summary of recommendations from previous reports and progress made to date

Recommendations were outlined in the 2014-15, 2015-16 and 2016-17 Edward-Wakool LTIM annual reports (Watts et al. 2015, 2016, 2017c) to improve the planning and delivery of Commonwealth environmental water. A list of these recommendations and the extent to which they have been implemented (as of October 2018) in the Edward-Wakool system is summarised in Table 9.1.

Table 9.1 Summary of recommendations from Edward-Wakool 2014-15, 2015-16 and 2016-17 LTIM annual reports, showing year implemented and details of actions undertaken. EWEWRG = Edward-Wakool Environmental Water Reference Group, EWSC=Edward-Wakool Stakeholder Committee, EWOAG= Edward-Wakool Operations Advisory Group. R = recommendation number

Recommendation	Year(s) recommended	Year(s) implemented	Details of actions undertaken
1. Increase the duration of the recession of environmental watering actions relative to the Yallakool Creek environmental watering actions in 2012-13 and 2013-14	2014-15 (R1) 2015-16 (R8)	2015-16 2016-17 2017-18	Environmental water has consistently been used to increase the duration of recession of small in-channel freshes in the Edward-Wakool system
2. Avoid long periods of constant flows by introducing flow variability into environmental watering actions.	2014-15 (R2) 2015-16 (R5)	2015-16 2016-17 2018-19	**2015-16** was provided the river operator with an 'operational range'. **2016-17 and 2017-18** this has been applied by including variability in the watering plan.
3. Consider a trial to increase the delivery of environmental water to the upper Wakool River	2014-15 (R3) 2015-16 (R6) 2016-17 (R5)	Not implemented	In most years a small volume of environmental water has been delivered to the upper Wakool River. However the regulator limits the delivery of larger volumes of environmental water to this zone. Water can be delivered to part of this zone from the Wakool escape.
4. Consider the delivery of continuous base environmental flows during autumn and winter to promote the temporal availability and continuity of instream habitat	2014-15 (R4) 2015-16 (R2) 2016-17 (R3)	Winter 2017	**2016-17:** CEWO held discussions with stakeholder groups and management agencies **2017-18:** A continuous winter flow was implemented in Yallakool Creek,-Mid & Lower Wakool River and the Colligen - Niemur system. **2018-19:** Winter watering was discussed during planning for 2018-19 but could not be delivered in 2018 due to maintenance of Stevens weir.
5. Continue to include a water use option in water planning that enables environmental water to be used to mitigate adverse water quality events	2014-15 (R5) 2015-16 (R7)	2014-15 2015-16 2016-17 2017-18	Contingency flows have been made available to contribute to responses to hypoxic blackwater events or other poor water quality events should they occur. This allowance has been used on several occasions to deliver flows.
6. Set watering action objectives that identify the temporal and spatial scale at which the response is expected and are realistic given the magnitude of watering actions proposed	2014-15 (R6)	ongoing	Water managers have improved objective setting in their water planning.

7. Consider the implementation of a short duration environmental flow trial in late winter/spring 2016 at a higher discharge than the current constraint of 600 ML/d. This would facilitate a test of the hypothesis that larger in-channel environmental watering action will result in increased river productivity.	2014-15 (R7) 2015-16 (R3)	2018-19	**2016-17:** CEWO and Wakool River Association facilitated discussions with stakeholders to trial flows above current operational constraints, up to ~ 800 ML/d at the Wakool/Yallakool confluence. **2017-18:** Discussions continued and flow trial proposal was planned to proceed in Autumn 2018. However, due to poor water quality in the system the Autumn flow trial was postponed until 2018-19. **2018-19:** A flow trial up to 800 ML/d is being implemented in Spring 2018.
8. Consider the implementation of an environmental watering action in the Edward River to target golden perch and silver perch spawning.	2014-15 (R8) 2015-16 (R4) 2016-17 (R4)	Not yet implemented	This recommendation has not yet been implemented nor is there monitoring in place to detect a spawning response if it occurred.
9. Undertake a comprehensive flows assessment for the tributaries of the Edward-Wakool system to better inform future decisions on environmental watering in this system.	2014-15 (R9) 2015-16 (R1)	Partly undertaken	Some flow assessments have been undertaken by MDBA and NSW OEH but there are still limitations of models in parts of the Edward-Wakool system. These assessments contribute management decisions and long-term water planning by OEH.
10. Collaborate with other management agencies and the community to maximise the benefits of Commonwealth environmental watering actions	2014-15 (R10)	ongoing	**2014-16:** Engagement through the Edward-Wakool Stakeholder Group (chair Murray LLS). **2016 - ongoing**: EWEWRG established **2014 - ongoing**: Edward-Wakool Operations Advisory Group.
11. If there is an imminent hypoxic blackwater event during an unregulated flow and the quality of source water is suitable, water managers 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}.	2016-17 (R1)	Not yet implemented	The opportunity to action this recommendation has not yet arisen.
12. The installation of a dissolved oxygen logger on a gauge downstream of Yarrawonga and upstream of Barmah-Millewa Forest should be considered a priority. Consideration should also be given to installing dissolved oxygen loggers, both upstream and downstream of other forested areas that influence water quality in the Edward-Wakool system	2016-17 (R2)	Not yet implemented	
13. Undertake in-channel habitat mapping for key reaches of the Edward-Wakool system, which could then be combined with existing hydraulic modelling to facilitate learning about this system	2016-17 (R6)	Not yet implemented	
14. 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	2016-17 (R7)	2017	A review was undertaken in 2017

Recommendations from 2017-18 watering actions

We continue to endorse the five recommendations that have not yet been implemented (R3, R8, R11, R12, R13), one recommendation that has been partially implemented (R9), and other recommendations that are ongoing from the previous Edward-Wakool LTIM annual reports (Table 9.1). In addition, we outline five new recommendations to improve the planning and delivery of Commonwealth environmental water in the Edward-Wakool system. These recommendations are underpinned by the 2017-18 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 2018) in the planning or use of Commonwealth environmental water in the Edward-Wakool system.

Recommendation 1: Implement environmental watering actions for freshes in spring and early summer (October to December) that include flow variability up to a magnitude of + 125 to 150 ML/d. Undertake trials to improve understanding of the magnitude of variability that provides beneficial ecosystem outcomes.

Watering actions in the Wakool-Yallakool system in spring 2014-15 and 2015-16 aimed to provide a period of relatively constant flows during the Murray cod spawning season (October to December) to avoid disturbance of nesting sites. In 2017-18 the planned watering action during the cod breeding season was “Maintain flow at 450ML/d over the peak cod breeding period. Increase flows by 50 ML/d for 14 days if no variability greater than +/- 50ML/d occurs in the preceding month. Reduce flow by 25ML/d every 14 days returning to 450ML/d. Maintain flow until Cod larvae detection in Yallakool/Wakool ceases“(Appendix 1). However, in spring 2017 the system experienced unregulated flows with variation of discharge of approximately 125 ML/d (up to 23 cm change water level) over 4 days. This flow variability did not have a detrimental effect on cod spawning and was associated with spawning of silver perch in Yallakool Creek. This suggests it is possible to deliver future environmental watering actions that include higher variability in discharge (e.g. up to at least + 125 to 150 ML/d in Yallakool Creek) that will benefit other ecosystem outcomes and not be detrimental to Murray cod.

Late winter/early spring freshes that inundate low-lying slackwaters, in-channel benches and riverbanks can trigger emergence of river bank vegetation. Following the recession of flows the damp banks provide ideal conditions for plant growth. Further freshes that follow the initial event will re-wet these areas and provide suitable conditions for riverbank plants to grow and survive the warmer conditions over the summer. We hypothesise that the proposed increased flow variability would provide a number of beneficial outcomes, including increased cover of riverbank vegetation and flow-on benefits for other taxa (e.g. invertebrates, frogs, larval fish) that use this vegetation as habitat. Monitoring of future watering actions will help improve understanding of the magnitude of variability that provides beneficial ecosystem outcomes.

Adaptive management: Watering actions are currently planned for spring 2018 that include multiple pulses in Yallakool Creek with discharge ranging from 430 to 550 ML/d, over a range of approximately 20 cm change in water level.

Recommendation 2: Implement a second trial of continuous base winter environmental flow (no winter 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.

Under normal operational flows there is a period of no flow during winter (operational shutdown) when the Yallakool Creek Offtake, Wakool Offtake, and Colligen Creek Offtake regulators are closed and Stevens Weir pool is lowered. This may potentially have a negative impact on the condition and subsequent fecundity and spawning of adult fish, and negatively impact on other aquatic animals (e.g. turtles) that have small home ranges or those that take refuge in pools over winter. Winter shutdown can also have a detrimental effect on aquatic vegetation that is exposed to frost or feral animal disturbance.

In 2017 an environmental watering action delivered continuous winter base flows to Yallakool Creek, the mid and lower Wakool River and Colligen Creek. This winter flow action increased longitudinal connectivity and facilitated the movement of fish in the system.

Future delivery of winter base flows could have a positive influence on the condition and subsequent spawning and recruitment of golden perch. Stoffels et al. (2017) found a positive relationship between condition of adult golden perch and seasonal flow patterns of the year observed, as well as with the discharge of the previous year. This could be one explanation for the lack of spawning and recruitment in the region. Stoffels et al. (2017) hypotheses that appropriately timed flows, over multiple years, may have cumulative benefits for golden perch condition. Delivery of winter flows could also promote immigration of juveniles and adults perch into the system from the Murray River and maintain habitat for taxa that have small home ranges. Winter flows also have the potential to assist the recovery of submerged aquatic plants by preventing the exposure of rhizomes to frost and feral animal disturbance when exposed during winter. Winter flows that continue into early spring may also promote early germination of some riverbank plants.

The delivery of continuous winter flows should be explored in systems in addition to Yallakool Creek and Colligen Creek, such as the Niemur River and Merran Creek. Alternative delivery options may be required in years when Stevens Weir requires maintenance and winter flows to Yallakool Creek, Wakool River and Colligen Creek cannot be achieved.

Adaptive management: Following the successful implementation of the winter flow trial in winter 2017, a winter flow could not be delivered in 2018 due to maintenance of Stevens Weir. CEWO have undertaken the discussions with various stakeholder groups regarding the implementation of a winter base flow in 2019, 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 3: 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 previous reports (Recommendation 8, Table 9.1).

Golden perch spawning and recruitment are thought to be associated with flow pulses (Mallen-Cooper and Stuart 2003; Roberts et al. 2008; Zampatti and Leigh 2013). Flow conditions that help to initiate spawning and also provide suitable connection and provision of off-channel nursery habitats are hypothesised to be important successful spawning and recruitment of golden perch. Sharpe (2011) and Mallen-Cooper et al. (2014) propose that the life cycle of golden perch involves adults spawning in the main channel on high flows, enabling larvae to drift from the channel into recently inundated off-channel habitats where they grow as juveniles over the spring-summer-winter period. Re-connection of these off-channel habitats to the main channel in winter/spring facilitates dispersal of juveniles back into the river, where they have been observed to disperse over large distances. Flow pulses are also considered important for silver perch spawning. Tonkin et al. (2017) documented the environmental conditions during peak silver perch spawning periods at Torrumbarry on the Murray River, where minimum daily water velocities were always greater than 0.45 m s^{-1} and water temperatures ranged from 21.5–24°C during spawning periods.

The Edward-Wakool system is known to support juveniles and adults of both golden perch and silver perch (Watts et al. 2014, 2015, 2016, 2017c). The current operational rules in the Wakool-Yallakool system limit regulated flows to a maximum of 600 $ML.d^{-1}$ at the confluence of the Wakool River and Yallakool Creek. Under this rule there are limited opportunities for environmental watering actions to create the conditions required for successful spawning of golden perch or silver perch in the Wakool-Yallakool system. Although spawning of silver perch was recorded for the first time in Yallakool Creek December 2017, it was localised to just one reach that has been shown (through 2D hydraulic modelling) to have a considerably larger area of fast water velocities (> 0.3 ms^{-1}) than other reaches in the Wakool-Yallakool system.

The Edward River is similar to other large river systems (e.g. Goulburn River) where golden perch have been observed to spawn in recent years (Koster et al. 2014). Under regulated conditions the Edward River does not have the same operational constraints as the tributaries. In addition, there are some low lying wetlands along the Edward River that are known to connect during regulated flows. We propose a trial environmental watering action (including a fresh and connection of low lying wetlands) be implemented downstream of Stevens Weir targeting perch spawning and recruitment. Results from other river systems and hydrological modelling for the Edward River could help guide the development of a proposed hydrograph during an environmental flow planning workshop. Delivery of these freshes may also facilitate immigration of juveniles and adults into the system from the Murray River.

The current M&E Plan for the Edward-Wakool system does not include monitoring of fish reproduction in the Edward River. Additional monitoring in the Edward River would be required to evaluate the effectiveness of this proposed watering action and help contribute to better understanding of conditions required for spawning of perch.

Recommendation 4: In collaboration with stakeholders explore options to implement environmental watering actions that include a short duration flow peak that is higher than the current constraint of 600 ML/d at the Wakool-Yallakool confluence. This would facilitate a test of the hypothesis that a higher discharge in-channel environmental watering action will result in increased river productivity.

This recommendation has been carried over from previous reports (Recommendation 7, Table 9.1).

Studies of unregulated flows in the Edward-Wakool system and several studies in other systems in the Murray-Darling Basin support the hypothesis that in-channel flows that inundate low-lying slackwaters, in-channel benches and riverbanks will result in increased river productivity.

The current operational rules in the Wakool-Yallakool system limit regulated flows to a maximum of 600 ML.d-1 at the confluence of the Wakool River and Yallakool Creek. Under this rule there are limited opportunities for environmental watering actions in the Wakool-Yallakool system to create conditions to increase river productivity.

We recommend that environmental watering actions that include a short duration flow peak that is higher than the current constraint of 600 ML/d at the Wakool-Yallakool confluence be implemented to test of the hypothesis that higher in-channel flows that inundate low-lying slackwaters, in-channel benches and riverbanks will result in increased river productivity. The opportunity to trial flows above the current operational constraint has been discussed in a number of forums over several years. In 2016-17 the CEWO and Wakool River Association facilitated discussions with stakeholders to trial flows above current operational constraints, up to ~ 800 ML/d at the Wakool/Yallakool confluence. In 2017-18 discussions continued and a flow trial proposal was planned to proceed in Autumn 2018. However, due to poor water quality in the system the Autumn flow trial was postponed until 2018-19.

Adaptive management: A flow trial with discharge of 800 ML/d at the Wakool-Yallakool confluence was implemented in spring 2018 (to be reported in 2018-19 Edward-Wakool LTIM report). The outcomes of the 2018 flow trial will be included on the agenda for future meetings of the Edward-Wakool Environmental Water Reference Group and will underpin discussions of future flow actions. Social research on the communities' perceptions, concerns and understanding of the flow trial and environmental watering is being undertaken to assist discussions about future watering actions.

Recommendation 5: Trial a carefully managed environmental watering action through Koondrook-Perricoota Forest via Barbers Creek to improve the productivity of the mid and lower Wakool River system.

Monitoring of stream metabolism in the Edward-Wakool system has consistently shown that gross primary productivity (GPP) in this system is low. The current operational rule in the Wakool-Yallakool system restricts the magnitude of environmental watering actions that can be implemented in this system. This limits the extent to which low lying in-channel geomorphic features (such as benches and backwaters) can be inundated, which in turn limits the productivity of the system.

Infrastructure deployed in Koondrook-Perricoota Forest could facilitate the delivery of environmental water from the Murray River to the Wakool River. This type of watering action would need to be carefully timed and planned to ensure productivity benefits and avoid adverse water quality outcomes. An environmental watering action via Barbers Creek could be coincided with an environmental watering action via Yallakool Creek to achieve beneficial outcomes in terms of productivity and fish movement through the system. Existing background data from four years of LTIM monitoring in the Wakool River at Gee Gee Bridge and results from Koondrook-Perricoota floodplain runoff study (Watts et al 2017b) could be used to assist planning of a trial watering action.

ACKNOWLEDGEMENTS

The authors of this report as well as the Commonwealth Environmental Water Office respectfully acknowledge the traditional owners of the Murray-Darling Basin, their Elders past and present, their Nations, and their cultural, social, environmental, spiritual and economic connection to their lands and waters.

We extend our thanks to the Edward-Wakool Environmental Water Reference Group, Wakool River Association, the Colligen and Niemur Group, Edward-Wakool Angling Association, Yarkuwa Indigenous Knowledge Centre Aboriginal Corporation, and landholders in the Edward-Wakool river system for their keen interest in this project and for providing access to monitoring sites on their properties. Fieldwork and/or laboratory work was led by John Trethewie, Chris Smith, Sascha Healy and Xiaoying Liu, with assistance from Shayne Bell, Tom Butterfield, Jonathon Doyle, Ben Edwards, Roseanna Farrant, Tim McGarry, Matt Linn, Nathan McGrath, Jarryd McGowan, Nick O'Brien, Deena Paris, Rohan Rehwinkel, Sam Ryan, Dale Wood and Ian Wooden.

Maps were prepared by Simon McDonald and Deanna Duffy (Charles Sturt University Spatial Analysis Unit), Rod Martin (NSW DPI) and Ian Wooden (NSW DPI). Tina Hines at the Monash University Water Studies Centre processed carbon and nutrient samples. Larval and juvenile fish sampling was carried out under NSW Fisheries license (P14/0004-1.3) and approved by the CSU Animal Care and Ethics Committee (larval fish surveys: A16080, recruitment surveys: A16098). Sampling in the Murray Valley National Park was permitted under the National Parks and Wildlife Act 1974 (Scientific License: SL101403). Adult fish surveys were conducted by DPI Fisheries under Fisheries NSW Animal Care and Ethics permit 14/10. This project was funded by the Commonwealth Environmental Water Office with in-kind contributions from Charles Sturt University, NSW Department of Primary Industries, Monash University, NSW Office of Environment and Heritage, and Murray Local Land Services.

REFERENCES

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

Balcombe S.R., Arthington A.H., Foster N.D., Thoms M.C., Wilson G.A. and Bunn S.E. (2006) Fish assemblages of an Australian dryland river: abundance, assemblage structure and recruitment patterns in the Warrego River, Murray–Darling Basin. *Marine and Freshwater Research* **57**, 619–633.

Balcombe S.R. and Arthington A.H. (2009) Temporal changes in fish abundance in response to hydrological variability in a dryland floodplain river. *Marine and Freshwater Research* **60**, 146–159.

Balcombe S.R, Lobegeiger J.S., Marshall S.M., Ly D. and Jones, D.N (2012) Fish body condition and recruitment success reflect antecedent flows in an Australian dryland river. *Fisheries Science* **78**, 841-847.

Baldwin D.S. (1999) Dissolved organic matter and phosphorus leached from fresh and 'terrestrially' aged river red gum leaves: implications for assessing river-floodplain interactions. *Freshwater Biology* **41**, 675-685.

Baldwin D.S., Colloff M.J., Mitrovic S.M., Bond N.R. and Wolfenden B. (2016) Restoring dissolved organic carbon subsidies from floodplains to lowland river food webs: a role for environmental flows? *Marine and Freshwater Research* **67**, 1387-1399.

Baldwin D.S. and Mitchell A.M. (2000) The effects of drying and re-flooding on the sediment and soil nutrient dynamics of lowland river-floodplain systems: a synthesis. *Regulated Rivers: Research & Management* **16**, 457-467.

Bertilsson S. and Bergh S. (1999) Photochemical reactivity of XAD-4 and XAD-8 adsorbable dissolved organic compounds from humic waters. *Chemosphere* **39**, 2289-2300.

Bice C.M., Gehrig S.L., Zampatti B.P., Nicol J.M., Wilson P., Leight S.L. and Narsland K. (2014) Flow-induced alterations to fish assemblages, habitat and fish-habitat associations in a regulated lowland river. *Hydrobiologia* **722**, 205-222.

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

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

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

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

Burndred K.R., Cockayne B.J. and Lou D.C (2017) Early development of eel-tailed catfish, *Tandanus tandanus*, with validation of daily otolith increment formation. *Australian Journal of Zoology* **65**, 12-20.

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

Chiew F.H., Potter N.J., Vaze J. and others. (2014) Observed hydrologic non-stationarity in far south-eastern Australia: implications for modelling and prediction. *Stochastic Environmental Research Risk Assessment* **28**, 3-15.

Choudhry G.G. (1984) Humic Substances-Structural, Photophysical, Photochemical and Free Radical Aspects and Interactions with Environmental Chemicals. (Gordon and Breach Science Publishers: New York) 185pp

Commonwealth Environmental Water Office (2015) Integrated planning for the use, carryover and trade of Commonwealth environmental water: Mid-Murray region 2015-16. Commonwealth Environmental Water Office.

Commonwealth Environmental Water Office (2018) Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Edward-Wakool system. Addendum of 31 July 2018 to the Monitoring and Evaluation Plan.

Crook D.A., O'Mahony D.J. and Sanger A.C. (2011) *Quantitative measurement of calcein fluorescence for non-lethal, field based discrimination of hatchery and wild fish*. American Fisheries Society Symposium, pp.1-8.

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

Gawne B, Brooks S, Butcher R, Cottingham P, Everingham P and Hale J (2013) Long-term Intervention Monitoring Project Monitoring and Evaluation Requirements Edward-Wakool river system for Commonwealth environmental water. Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre, MDFRC Publication 01.2/2013, May, 32pp.

Gehrke P.C. (1988) Response surface analysis of teleost cardio-respiratory responses to temperature and dissolved oxygen. *Comparative Biochemistry and Physiology,* **89A**, 587-592.

Gehrke P.C., Revell M.B. and Philbey A.W. (1993) Effects of river red gum, *Eucalyptus camaldulensis*, litter on golden perch, *Macquaria ambigua*. *Journal of Fish Biology* **43**, 265-279.

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

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

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

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

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

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

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

King A.J., Crook D.A., Koster W.M., Mahoney J. and Tonkin Z. (2005) Comparison of larval fish drift in the Lower Goulburn and mid-Murray Rivers. *Ecological Management and Restoration* **6**, 136-139.

King A.J., Tonkin Z., and Lieshcke J. (2012) Short-term effects of a prolonged blackwater event on aquatic fauna in the Murray River, Australia: considerations for future events. *Marine and Freshwater Research* **63**, 576-586.

King A., Humphries P. and McCasker N. (2013) Reproduction and early life history. In (Eds Humphries P. & Walker K.) *Ecology of Australian Freshwater Fishes. Melbourne: CSIRO Publishing*, 159-193.

King A, Gwinn, D.C., Tonkin Z., Mahoney J., Raymond S. and Beesley L (2016) Using abiotic drivers of fish spawning to inform environmental flow management. *Journal of Applied Ecology* **53**, 34-43.

Koster W.M. and Crook D.A. (2008) Diurnal and notcturnal movements of river blackfish (*Gadopsis marmoratus*) in a south-eastern Australian upland stream. *Ecology of Freshwater Fish* **17**,146-154.

Koster W.M., Dawson D.R., O'Mahony D.J., Moloney P. and Crook D.A. (2014) Timing, Frequency and Environmental Conditions Associated with Mainstem–Tributary Movement by a Lowland River Fish, Golden Perch (Macquaria ambigua*). PLoS ONE* **9**, e96044.

Lintermans M. (2007) *Fishes of the Murray-Darling Basin: an introductory guide*. Murray-Darling Basin Commission, Canberra.

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

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

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

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

Mallen-Cooper, M., Sturt I. and Sharpe C. (2014). *Gunbower Island Native Fish Recovery Management Plan*. Report prepared for the North Central Catchment Management Authority by Fishway Consulting Services.

Mallen-Cooper, M. and Zampatti B.P (2018) History, hydrology and hyraulics: Rethinking the ecological management of large rivers. *Ecohydrology* **11**, e1965.

Moran M.A. and Hodson R.E. (1990) Bacterial production on humic and nonhumic components of dissolved organic carbon. *Limnology and Oceanography* **35**, 1744-1756.

Moran M.A. and Zepp R.G. (1997) Role of photoreactions in the formation of biologically labile compounds from dissolved organic matter. *Limnology and Oceanography* **42**, 1307-1316.

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

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

Office of Environment and heritage (2017) Murray and Lower Darling Catchment: Annual environmental watering priorities 2017-18. NSW Office of Environment and Heritage.

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

Nielsen D.L., Cook R.A., Ning N., Gawne B. and Petrie R. (2016) Carbon and nutrient subsidies to a lowland river following floodplain inundation. *Marine and Freshwater Research* **67**, 1302-1312.

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

Pepin P., Robert D., Bouchard C., Dower J.F., Falardeau M., Fortier L., Jenkins G.P., Leclerc V., Levesque K. and Llopiz J.K. (2015) Once upon a larva: revisiting the relationship between feeding success and growth in fish larvae. *ICES Journal of Marine Science: Journal du Conseil* **72**, 359-373.

R Core Team (2016) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

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

Robertson A., Burns A. and Hillman T. (2016) Scale dependent lateral exchanges of organic carbon in a dryland river during a high flow experiment. *Marine and Freshwater Research* **67**, 1293-1301.

Rowland S.J. (1983) Spawning of the Australian freshwater fish Murray cod, *Maccullochella peelii* (Mitchell), in earthen ponds. *Journal of Fish Biology* **23**, 525–534.

Serafini, L.G and Humphries, P. (2004) Preliminary guide to the identification of larvae of fish, with a bibliography of their studies, from the Murray-Darling Basin. Technical Series, Report no. 48. Cooperative Research Centre Fresh Water Ecology, Albury.

Sharp, C (2011) *Spawning and recruitment ecology of golden perch (Macquaria ambigua Richardson 1845) in the Murray and Darling Rivers.* PhD Thesis, Griffith University.

Small K., Kopf R.K., Watts R.J. and Howitt J. (2014) Hypoxia, Blackwater and Fish Kills: Experimental Lethal Oxygen Thresholds in Juvenile Predatory Lowland River Fishes. *Plos One* **9**, e94524.

Stoffels R.J., Clarke K.R., Rehwinkel R.A. and McCarthy B.J. (2014) Response of a floodplain fish community to river-floodplain connectivity: natural versus managed reconnection. *Canadian Journal of Fisheries and Aquatic Sciences* **71(2),** 236-245.

Stoffels R.J., Bond N.R., Weatherman K. and Gawne B. (2016) *2014–15 Basin-scale evaluation of Commonwealth environmental water — Fish Report.* Draft Report prepared for the Commonwealth Environmental Water Office by The Murray–Darling Freshwater Research Centre, MDFRC Publication 108/2016, August, 54 pp.

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

Thiem J.D., Wooden I.J., Baumgartner L.J., Butler G.L., Forbes J.P. and Conallin J. (2017) Recovery from a fish kill in a semi-arid Australian river: Can stocking augment natural recruitment processes? *Austral Ecology* **42**, 218-226.

Tonkin Z., Stuart I., Kitchingman A., Jones M., Thiem J., Zampatti B., Hackett G., Koster W. and Koehn J. (2017) *The effects of flow on silver perch population dynamics in the Murray River*. Unpublished Client Report for the Murray Darling Basin Authority March 2017. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

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

van Dijk A.I., Beck H.E., Crosbie .R.S, de Jeu R.A., Liu Y.Y., Podger G.M., Timbal B. and Viney N.R. (2013) The Millennium Drought in southeast Australia (2001–2009): Natural and human causes and implications for water resources, ecosystems, economy, and society. *Water Resources Research,* **49**, doi:10.1002/wrcr.20123.

Wehr J.D., Peterson J. and Findlay S. (1999) Influence of three contrasting detrital carbon sources on planktonic bacterial metabolism in a mesotrophic lake. *Microbial Ecology* **37**, 23-35.

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

Wassens S., Spencer J., Wolfenden B., Thiem J., Thomas R., Jenkins K., Brandis K., Lenon E., Hall A., Ocock J., Kobayashi T, Bino G., Heath J. and Callaghan D. (2017) Commonwealth Environmental Water Office Long-Term Intervention Monitoring project Murrumbidgee River System Selected Area evaluation report, 2014-17. Report prepared for the Commonwealth Environmental Water Office

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

Watts R., McCasker N., Thiem J., Howitt J., Grace M., Kopf R., Healy S. and Bond N. (2015) *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool Selected Area Technical Report, 2014-15*. Prepared for Commonwealth Environmental Water Office.

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

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

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

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

Watts R.J., McCasker N.G., Howitt J.A., Thiem J.D., Grace M.R., Trethewie J.A., Healy S., Bond N.R. (2018b). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Edward-Wakool River System Selected Area Summary Report, 2017-18. Report prepared for Commonwealth Environmental Water Office. Commonwealth of Australia.

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

Winemiller K.O. and Rose K.A. (1992) Patterns of life-history diversification in North American fishes: implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences* **49**, 2196-2218.

Wolfenden B.J., Wassens S.M., Jenkins K.M., Baldwin D.S., Kobayashi T. and Maguire J. (2017) Adaptive Management of Return Flows: Lessons from a Case Study in Environmental Water Delivery to a Floodplain River. *Environmental management*. Early online, DOI: 10.1007/s00267-017-0861-0.

Zampatti B.P., Wilson P.J., Baumgartner L., Koster W., Livore J.P., McCasker N., Thiem J., Tonkin Z. and Ye Q. (2014) *Reproduction and recruitment of golden perch (Macquaria ambigua ambigua) in the southern Murray–Darling Basin in 2013–2014: an exploration of river-scale response, connectivity and population dynamics*. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

APPENDICES

Appendix 1

Table A1: Planned environmental watering actions in the Edward-Wakool system in 2017-18 as described in planning documents and the Water Use Minute.

	Watering action	Dates	Flow strategy	Objectives
1	Winter watering action in Yallakool Creek and Colligen Creek	1 May to 23 August 2017	Maintain 200 ML/d	To provide low winter base flows to contribute to reinstatement of the natural hydrograph, improve connectivity, condition of in-stream aquatic vegetation and fish recruitment into 2017-18.
2	Early season pulse at beginning of e-flow	7 Sept to 22 Oct 2017	Increase flows by approximately 50 ML/d (~10cm rise) every 4 days until 600 ML/d Maintain for 7 days Recess by 25 ML/d (~5cm/d fall) every 5 days until cod flows of 450ML/d are met.	To provide an early season rise in river level to contribute to connectivity, water quality, stimulating early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish.
3	Maintain e-flow	N/A (not delivered)	Maintain flow at 450ML/d over the peak Cod breeding period. Increase flows by 50 ML/d for 14 days if no variability greater than +/- 50ML/d occurs in the preceding month. Reduce flow by 25ML/d every 14 days returning to 450ML/d. Maintain flow until Cod larvae detection in Yallakool/Wakool ceases	To maintain nesting habitat for Murray Cod and inundation for aquatic vegetation growth.
4	Summer pulse at end of e-flow followed by recession	3 Jan to 29 Jan	Increase flows by approximately 50 ML/d(~10cm rise) every 4 days until 550 ML/d . Maintain for 7 days. Recess by 25 ML/d (~5cm/d fall) every 5 days until flows of 250ML/d are met (if practicable depending on other flows and timing of Autumn pulse). Begin when Cod larvae detection in Yallakool/Wakool ceases	Summer pulse to influence/encourage fish movement, may be coordinated with wider river Murray actions to maximise benefit. May also assist with dispersal of larvae and juveniles of a number of fish species.
5	Autumn pulse in Yallakool Creek	28 March to 1 May	Increase flows by approximately 50 ML/d(~10cm rise) every 4 days until 450 ML/d. Maintain for 7 days Recess by 25 ML/d (~5cm/d fall) every 5 days until flows of 200ML/d are met.	Autumn pulse to influence/encourage fish movement, may be coordinated with wider river Murray actions to maximise benefit. May also assist with dispersal of juveniles of a number of fish species.
6	Small fresh in Colligen-Niemur system	11 January to 11 February 2018	Operational base flows through this regulator were ~ 170 ML/day. Proposed use of CEW would increase the total flow rate up to 300 ML/day. The flow would last for 40 days initially and then be reviewed to determine if a continuation was required. During the delivery period refuge flows would cease if DO's recovered to 5.0 mg/L or if they could be replaced with other system flows (such as a rain rejections passed into the Colligen system, or increased irrigation demand).	To improve water quality (in response to a heatwave driven low DO event). Refuge flows providing hypoxic water refuge for fish and other aquatic biota