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

2018-19

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Cover photos:

Left –Inundated backwater on Bookit Island during the peak of flow trial watering action. (Photo: R. Watts)

Middle – Young of year Murray cod (*Maccullochella peelii*) from Yallakool Creek (zone 1). (Photo: J Trethewie)

Right – Riverbank vegetation in the mid Wakool River, December 2018 (Photo: R. Watts)

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EXECUTIVE SUMMARY

This report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward/Kolety-Wakool River Selected Area in 2018-19. It also provides a summary of the key findings across the five years 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 Department of Planning, Industry and Environment (DPIE), and La Trobe University. Field monitoring for the project was undertaken by staff from CSU, NSW Fisheries and DPIE.

This report documents the monitoring and evaluation of environmental watering actions and watering regimes the Edward/Kolety-Wakool Selected Area 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

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.

Environmental watering in the Edward/Kolety-Wakool system 2018-19

This report focusses on Commonwealth environmental watering actions in the Edward/Kolety-Wakool Selected Area from 1 July 2018 until 30 June 2019. In 2018-18 five environmental watering actions were planned (Table i). Watering action number 1 (spring fresh, 800 ML/day flow trial) is the focus of this report. Watering action 2, 3 and 4 were not implemented because environmental water was suspended between 2 October 2018 and mid-May 2019 due to increased demand in the Murray system and lack of operational capacity to accommodate environmental water in the river due to channel constraints. The winter watering action (number 5) commenced on 16 May 2019. This action will continue into the 2019-20 water year and will be evaluated in the 2019-20 Monitoring Evaluation and Research (MER) project report.

The Edward/Kolety-Wakool MER project (2019-2022) is an extension of the existing LTIM monitoring and evaluation that began in 2014 and concluded in 2019 with this report.

Table i Planned Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2018-19 in the Edward/Kolety Wakool River system. This report focusses on watering action 1 (highlighted). Planned actions 2, 3 and 4 were not implemented. The winter flow action number 5 commenced on 16th May 2019 and continued into the 2019-20 water year. This action will be evaluated in the MER project report in 2020.

	Watering action	Action	Dates	Rivers	Objective
1	Early spring fresh	small fresh	22 August to 25 September 2018	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To provide early season rise in river level to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish
2	Late spring action	Higher base flow and small fresh	Planned for late Oct and early Nov 2018. Not implemented	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To maintain nesting habitat for Murray cod and inundation for aquatic vegetation growth. The variability flow was to prevent a flat river
3	Summer pulse	small fresh	Planned for late Nov 2018 to early Jan 2019 Not implemented	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To influence and encourage fish movement. May be coordinated with wider Murray River actions to maximise benefit. May also assist with dispersal of larvae and juveniles of a number of fish species. Slow recession for instream plants.
4	Autumn pulse	Small fresh	Planned for mid Feb to early May 2019 Not implemented	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To influence/encourage fish movement. May be coordinated with wider Murray River actions to maximise benefit. May also assist with the dispersal of juveniles of a number of fish species.
5	2019 winter flow	base flow	Commenced 16 May 2019 (Ongoing)	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To contribute to reinstatement of the natural hydrograph, improve connectivity, condition of in-stream aquatic vegetation and fish recruitment into 2019-20.

Outcomes of environmental watering in 2018-19

Key results from environmental watering action 1 (referred to as the 800 ML/day flow trial) in the Edward/Kolety-Wakool system in 2018-19 are presented in Table ii. Watering action 1 was an early spring fresh undertaken from 22 August to 25 September 2018 (Table i) in Yallakool Creek and the Wakool River. The flow trial involved changes to operating rules and practices, the aim being to exceed the maximum daily discharge of 600 ML/day at the confluence of Yallakool Creek and the Wakool River under regulated operating rules, with the target maximum discharge being 800 ML/day. Planning for the action was undertaken over a period of more than one year, with the Wakool River Association, the Edward/Kolety-Wakool Environmental Water Reference Group and landholders engaged and involved in the planning and water delivery. There were some operational limitations to deliver the environmental water via the Yallakool Creek regulator when Steven's weir pool was low, so some of the environmental water was delivered via the Wakool escape from Mulwala canal.

Table ii Key results for each indicator in response to environmental watering action 1 (the 800 ML/day flow trial) in the Edward/Kolety-Wakool system in 2018-19.

Theme	Indicator	Key result
Hydrology	Maximum and minimum discharge	Watering action 1 increased the maximum discharge in all zones compared to operational flows. From a water accounting perspective the total discharge of water delivery reached a maximum of 870 ML/day on 13 September. However, the discharge did not exceed 800 ML/day at any site because water was delivered from different regulators. The maximum daily discharge was 488 ML/day in Yallakool Creek (15 September), 398 ML/day at Wakool River zone 2 site 4 (13 September), 696 ML/day in Wakool River zone 3 (17 September), 652 ML/d in Wakool River zone 4 (19 September). The maximum daily operating discharge of 600 ML/day was exceeded in zones 3 and 4. The discharge in zone 2 downstream of the Wakool escape was higher than normal operational flows in this zone (40-80 ML/d).
	Flow variability	Watering action 1 increased the coefficient of variation of discharge in zones 2 and 3 compared to operational flows.
	Longitudinal connectivity	Watering action 1 maintained longitudinal connectivity in Yallakool Creek and the Wakool River. The higher flows in the upper Wakool River (zone 2) initiated flow in Black Dog Creek, linking the Wakool River near 'Widgee' (zone 2 site 4) with Yallakool Creek to 'Windra Vale' near zone 1 site 5.
	Lateral connectivity	Watering action 1 increased lateral connectivity in Yallakool Creek and the Wakool River. The wetted area increased by an average of 10.2%, ranging from an increase of 3.7% in zone 2 site3 to 30.3% in zone 2 site 4.
	Hydraulic diversity	Watering action 1 increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows.
Water quality and carbon	Dissolved oxygen concentration	Watering action 1 did not result in any adverse water quality outcomes. This action was deliberately timed for when water temperatures would be low and hence the risk of creating low DO conditions was reduced. DO concentrations remained normal for the time of year.
	Nutrient concentrations	There was no detectable effect of environmental watering on this indicator and there were no adverse water quality outcomes. Total Phosphorus and Total Nitrogen were slightly elevated, likely due to greater turbidity (particles suspended in the water column) but bioavailable nutrient remained low.
	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 on this indicator in 2018-19 and there were no adverse water quality outcomes. Dissolved organic carbon was not elevated outside the normal range.
Stream metabolism	Gross Primary Production (GPP)	Watering action 1 had a beneficial effect on the total amount of primary production. Commonwealth environmental water increased organic carbon production in zones 1 to 4 by 36%, 134%, 71% and 38% respectively compared to operational flows. By calculating rates of primary production that would have occurred at lower flows we estimate CEW added an additional 7.27 tonnes of organic carbon to the 13.9 tonnes generated by GPP without the CEW; an overall increase of 52%. This translates to a significant increase in energy available to support aquatic foodwebs.
	Ecosystem Respiration (ER)	As with GPP, watering actions decreased the rates of ER (mg O_2/L/day) 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. 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 DO dropped below safe values for aquatic biota.

Table ii (continued) Key results for each indicator in response to environmental watering action 1 (the 800 ML/day flow trial) in the Edward/Kolety-Wakool system in 2018-19.

Theme	Indicator	Key result
Riverbank and aquatic vegetation	Total species richness	Riverbank and aquatic vegetation continued to recover following the flood of 2016. 65 riverbank and aquatic plant taxa were recorded across sixteen sites. This was the highest number of taxa recorded over the five years of the LTIM project. Between 2014 and 2018 there was higher species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that received minimal or no environmental water. However, in 2018-19 the combined effects of environmental water and higher operational flows in zone 2 increased the total and mean richness of plant taxa, so this zone had a similar average species richness as the other zones.
	Richness of functional groups	The total species richness of submerged, amphibious and terrestrial taxa has increased since the 2016 flood. In 2018-19 there were overall more amphibious taxa than in the years preceding the 2016 flood.
	Percent cover of functional groups	The maximum mean percentage cover of submerged taxa and some amphibious taxa increased in 2018-19 and was similar to that in 2014-15 and 2015-16 prior to the flood. However there has been minimal recovery of some amphibious taxa, such as floating pondweed and milfoil since the 2016 flood. Small plants of these species were observed outside the survey transects, suggesting there is the possibility of the recovery of these species can be supported by future environmental watering actions.
Fish movement	Movement of golden perch and silver perch	Watering action 1 in spring 2018 facilitated silver perch and golden perch movements of 57 and 12.2 km (median) respectively. Watering action 1 was followed by reduced zone coverage by tagged silver perch (occurring in zone 3 and 4 only), but increased LTIM zone coverage by golden perch.
Fish spawning	Larval abundance of equilibrium species	Murray cod larvae were detected in greatest numbers in 2018-19 compared to the four previous years of LTIM, with the majority of Murray cod larvae collected from upper Wakool River (Zone 2). The greater number of larvae detected in drift nets compared to light traps, suggests that dispersal of larvae downstream may have exceeded local retention, and may contribute to further re-establishment of Murray cod within the wider Selected Area.
	Larval abundance of periodic species	Silver perch eggs were collected in Yallakool Creek (zone 1) and Wakool River (zone 4) in November and December 2018. This is the second year that silver perch spawning has been detected in the study zones since monitoring commenced in 2015.
	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 greater in 2018-19 compared to previous years.
Fish recruitment	Murray cod, silver perch and golden perch recruitment	Murray cod 1+ recruits were detected in highest numbers since the hypoxic blackwater event in 2015-16. Silver perch 1+ recruits were detected for the first time since the hypoxic blackwater event in 2015-16. Golden perch recruits appear to remain absent from system, having been not recorded since the start of the LTIM program in 2015.
Fish populations	Adult fish populations	In 2018-19 nine native fish species, including silver perch and trout cod, were captured at sites across the Edward/Kolety-Wakool system. New recruits were detected for 6 of the 9 native species, with the exception of golden perch, silver perch and trout cod.
Other	Other observations	During watering action 1 there was increased frog calling, waterbird activity and invertebrate activity observed in inundated areas around Bookit Island.

Outcomes of environmental water delivery in the Edward/Kolety-Wakool system over five years of LTIM project from 2014 to 2019

The volume of Commonwealth environmental water delivered to the Edward/Kolety-Wakool system over the four year period was small in comparison to the large unregulated flow in 2016. However, environmental water provided a number of small freshes, slowed the recession of operational flows, and maintained connectivity by provision of winter base flows. A summary of key outcomes from environmental watering actions across the five years of the Long Term Intervention Monitoring Program 2014 to 2019 is presented in Table iii.

Table iii Key outcomes of five years of Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2014-19.

Theme	Indicator	Key result
Hydrology	Maximum and minimum discharge	All Commonwealth watering actions delivered between 2014 and 2019 increased the maximum discharge compared to operational flows. The majority of watering actions over the five years were delivered within normal operating ranges as advised by river operators to avoid third party impacts. However, following consultation with landholders, a flow trial in the Wakool-Yallakool system in 2018-19 exceeded the maximum daily operating discharge of 600 ML/day in the Wakool River; discharge peaked at 696 ML/d in zone 3 and 652 ML/d in zone 4. Two flow trials undertaken in the winter of 2017 and 2019 maintained winter base flows
	Longitudinal connectivity	Some of the watering actions between 2014 and 2019 increased the longitudinal connectivity in the river system. For example, the winter watering in 2017 maintained longitudinal connectivity in over 500 km of river channels in Yallakool Creek, the Wakool River and the Colligen-Niemur River. This provided opportunities for fish movement, seed dispersal and maintained critical overwinter habitat for turtles and taxa that have small home ranges. Under normal operations these systems usually experience extended periods of cease to flow during winter. The higher flows in the upper Wakool River (zone 2) in 2018-19 initiated flow in Black Dog Creek, instigating connectivity between the Wakool River and Yallakool Creek.
	Lateral connectivity	Hydraulic modelling showed that watering actions increased lateral connectivity and increased wetted area by as much as 30% at some sites.
	Flow recession	Some watering actions increased the duration of the flow recession. For example, in 2017-18 watering action 1 increased the recession over 32 days in Yallakool Creek compared to what would have been a rapid recession from 460 ML/d to 200 ML/d over 3 days under operational flows.
	Hydraulic diversity	Based on hydraulic modelling of study reaches, Commonwealth watering actions increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows
Water quality and carbon	Dissolved oxygen concentration	None of the watering actions between 2014 and 2018 resulted in adverse DO outcomes. Several watering actions were specifically targeted to improve DO during poor water quality events; DO concentrations were consistently higher in zones receiving environmental water than in zones receiving none or minimal environmental water.
	Nutrient concentrations	Nutrient concentrations during watering actions remained within the expected range throughout 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	None of the watering actions undertaken between 2014 and 2018 had adverse organic matter outcomes. Some freshes resulted in small increases in organic carbon that had positive outcomes on river productivity.

Table iii (continued) Key outcomes of five years of Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2014-19.

Theme	Indicator	Key result
Stream metabolism	Gross Primary Production (GPP)	Commonwealth environmental watering increased the amount of GPP occurring in the river over the five year period. This increase in GPP translates to greater amounts of energy being created by plants and algae, which in turn are available to support aquatic food webs. Across all watering actions from 2014 to 2019, the size of the beneficial impact was largely related to the proportion of total flow that came from the watering action rather than the source of water. Carbon production was enhanced by between 0% and 330% over the ten watering actions assessed between 2014 and 2019, with a sum over all zones and watering actions of 52% more carbon produced compared to no Commonwealth environmental water being delivered. This is an important outcome given that competition for food resources can be a significant factor limiting the growth and survival of fish and other aquatic animals.
	Ecosystem Respiration (ER)	As with GPP, watering actions almost uniformly decreased the rates of ER (mg O_2/L/day) 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 DO dropped below safe values for aquatic biota.
Riverbank and aquatic vegetation	Total species richness and cover	Between 2014 and 2016 riverbank and aquatic plant richness and cover was increasing and recovering in response to the millennium drought. However a large unregulated flood in late 2016 considerably reduced the richness and cover and some previously abundant taxa were absent in 2017. Between 2017 and 2019 there was a slow recovery, and in 2019 the highest number of taxa were recorded over the five years since the LTIM project commenced. Environmental watering played an important role in the richness and health of riverbank and aquatic vegetation. Between 2014 and 2018 there was consistently higher species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that received no or minimal environmental water. However, in 2018-19 the combined effects of environmental water and the period of higher operational flows in the upper Wakool River zone 2 increased the total and mean richness of plant taxa, such that this zone now has similar average species richness as the other zones. The delivery of environmental water in winter maintains aquatic taxa and can prevent potential frost damage to aquatic vegetation rhizomes.
	Richness and cover of functional groups	The total species richness of submerged, amphibious and terrestrial taxa decreased in 2016 following the unregulated flood. Between 2017 and 2019 there was a slow recovery, and in 2018-19 there were overall more amphibious taxa than prior to the flood. The cover of submerged and amphibious taxa was particularly negatively impacted by the unregulated flow. In 2018-19 the maximum mean percentage cover of submerged taxa and some amphibious taxa increased and was similar to that in 2015-16 prior to the flood. However there has been minimal recovery of some amphibious taxa, such as floating pondweed and milfoil. Small plants of these species have been observed outside survey transects, suggesting there is the possibility that these species can recover with support from environmental watering.

Table iii (continued) Key outcomes of five years of Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2014-19.

Theme	Indicator	Key result
Fish movement	Movement of golden perch and silver perch	Watering actions undertaken during the LTIM project supported fish movement. The winter watering in 2017 greatly increased river connectivity and fish moved longer distances than in previous periods of operational shutdown during winter. Spring watering actions facilitated movements of silver perch, golden perch and Murray cod.
Fish spawning	Larval abundance of equilibrium, periodic and opportunistic species	Over the 5 years of LTIM of 16 fish species (including 4 introduced species) were detected as larvae or eggs in the monitored zones of the Edward/Kolety-Wakool system. Murray cod larvae were detected in greatest numbers in 2018-19 compared to the four previous years of LTIM, with the majority of Murray cod larvae collected from upper Wakool River that for the first time in 2018 received substantial environmental water followed by higher operational flows. The abundance of Australian smelt larvae was significantly greater in 2018-19 compared to previous years, possibly due to increased water velocities during the higher spring fresh. Between 2016-2019 eggs or larvae of silver perch, catfish and obscure galaxias were detected for the first time in this system. It is difficult to confirm to what extent environmental watering contributed to this. However, the spawning of catfish may have been due to increased connectivity, and the spawning of silver perch may have been due to increased velocities or increased variability in some reaches during environmental watering actions.
Fish recruitment	Murray cod, silver perch and golden perch recruitment	In 2018-19 Murray cod YOY and 1+ fish were detected in highest numbers since LTIM monitoring commenced in 2015. Along with the presence of 1+ silver perch in the system, this suggests that the Edward Wakool fish assemblage is showing positive signs of recovery post the 2016-17 hypoxic blackwater event that resulted in large scale fish kills in the southern Murray-Darling Basin.
Fish populations	Adult fish populations	This project demonstrates the value of the Edward/Kolety-Wakool river system in supporting populations of native freshwater fish, nested within the broader Murray catchment. Throughout this five year study, and utilising a range of sampling techniques, we captured 15 species of native fish representing various life-stages. System-specific trends, indicated through the use of SRA fish 'health' indicators, suggest that the health of the Edward/Kolety-Wakool fish community decreased from 2015 to 2019, although we argue that the fish assemblage is in a state of recovery following adverse water quality and associate fish deaths in 2016. A number of flow-related mechanisms may contribute to the recovery of these populations at a local scale. These include 1) the persistence of refuge habitat at low flows or during adverse water quality events, 2) the presence of diverse in-channel and off-channel habitats, and 3) opportunities for movement that enable the re-distribution of individuals and promote emigration and immigration.
Other	Other observations	The watering actions in the Edward River, Wakool River and Niemur River 2016-17 during the unregulated flood aimed to create small refuges with higher levels of DO. The local community also installed aerators to create DO refuges. Fish were observed congregating in these refuges, suggesting these actions supported the survival of some fish and other aquatic animals. During watering action 1 in 2018-19 there was increased frog calling, waterbird activity and invertebrate activity observed in inundated areas around Bookit Island. Similar observations were made throughout the LTIM program during other watering actions that inundated backwaters.

Recommendations for future management of environmental water

A summary of recommendations from the 2014-15, 2015-16, 2016-17 and 2017-18 Edward/Kolety-Wakool LTIM annual reports (Watts et al. 2015, 2016, 2017b, 2018) and the extent to which they have been implemented to improve the planning and delivery of Commonwealth environmental water are summarised in Table iv.

Table iv Summary of recommendations from Edward/Kolety-Wakool LTIM annual reports 2014-15, 2015-16, 2016-17 and 2017-18, showing year implemented. R = recommendation number.

Recommendation	Year(s) recommended	Year(s) implemented
Small in-channel freshes (within normal river operating rules)		
1. Consider a trial to increase the delivery of environmental water to the upper Wakool River	2014-15 (R3) 2015-16 (R6) 2016-17 (R5)	2018-19
2. 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) 2017-18 (R3)	Not yet implemented
In-channel freshes (higher than current normal operating rules to connect additional in-channel habitats)		
3. In collaboration with stakeholders explore options to implement a short duration environmental flow trial in late winter/spring 2016 at a higher discharge than the current constraint of 600 ML/d at the Wakool-Yallakool confluence. 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) 2017-18 (R4)	2018-19
Flows that contribute to flow recession		
4. Increase the duration of the recession of environmental watering actions relative to the Yallakool Creek environmental watering actions in 2012-14	2014-15 (R1) 2015-16 (R8)	2015-16 2016-17, 2017-18
Winter flows		
5. 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
6. Implement a second trial of continuous base winter environmental flow (no winter cease to flow) in the tributaries of the Edward/Kolety-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.	2017-18 (R2)	Winter 2019
Flow variability		
7. 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
8. 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.	2017-18 (R1)	
Flows to mitigate poor water quality events		
9. 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 2018-19
10. 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 DO concentrations falling below 2 mgL^{-1}.	2016-17 (R1)	Not yet implemented
Flows through forests and/or floodplains		
11. 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.	2017-18 (R5)	Not yet implemented via Barbers Creek

Other flow related recommendations		
12. 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
13. Undertake a comprehensive flows assessment for the tributaries of the Edward/Kolety-Wakool system to better inform future decisions on environmental watering in this system.	2014-15 (R9) 2015-16 (R1)	Partly undertaken
14. Collaborate with other management agencies and the community to maximise the benefits of Commonwealth environmental watering actions	2014-15 (R10)	ongoing
15. The installation of a DO 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 DO loggers, both upstream and downstream of other forested areas that influence water quality in the Edward/Kolety-Wakool system	2016-17 (R2)	Not yet implemented
16. Undertake in-channel habitat mapping for key reaches of the Edward/Kolety-Wakool system, which could then be combined with existing hydraulic modelling to facilitate learning about this system	2016-17 (R6)	Not yet implemented
17. 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

Recommendations from 2018-19 watering actions

We continue to endorse the five recommendations that have not yet been implemented (R2, R10, R11, R15, R16), one recommendation that has been partially implemented (R13), and other recommendations that are ongoing from the previous Edward/Kolety-Wakool LTIM annual reports (Table iv). In addition, we present five new recommendations to improve the planning and delivery of Commonwealth environmental water in the Edward/Kolety-Wakool system. These recommendations are underpinned by monitoring and evaluation results.

Recommendation 1: Each year plan to deliver at least one flow event with higher than normal operating discharge to the upper Wakool River. This may include delivery of water through the Wakool offtake regulator or via the Wakool escape from Mulwala Canal.

Recommendation 2: Include variation in the timing of environmental watering actions among water years 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.

Recommendation 3: Implement a second flow trial in-channel fresh in late winter or early spring that briefly exceeds the current normal operating rules**,** to increase the lateral connection of in-channel habitats and increase river productivity. The earlier timing of flows would help to prime the system and thus increase the outcomes of subsequent watering actions delivered later in spring or early summer.

Recommendation 4: Explore options to implement in-channel pulses at any time of the year to connect additional in-channel habitats and increase river productivity.

Recommendation 5: Explore and develop a range of options for the delivery of environmental water during times of drought to ensure connectivity of habitat and avoid damage to key environmental assets. Inform the community of the factors limiting water delivery in extreme drought.

1 INTRODUCTION

1.1 Purpose of this report

The Commonwealth Environmental Water Office (CEWO) has funded a Long-Term Intervention Monitoring (LTIM) Project in seven Selected Areas to evaluate the ecological outcomes of Commonwealth environmental water use throughout the Murray-Darling Basin (MDB). The LTIM Project was 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 report documents the monitoring and evaluation of ecosystem responses to Commonwealth environmental watering in the Edward/Kolety-Wakool system during the 2018-19 watering year from 1 July 2018 until 30 June 2019 at the end of the watering year. As it is the fifth and final annual report of the Long Term Intervention Monitoring (LTIM) Project funded by the Commonwealth Environmental Watering Office we also present long-term trends across the five years of the project. This project was undertaken as a collaboration among Charles Sturt University, NSW DPI (Fisheries), Monash University, NSW Department of Planning, Industry and Environment (DPIE), and La Trobe University. Field sampling for this project was undertaken by staff from Charles Sturt University, NSW DPI (Fisheries) and DPIE.

This report has eleven sections. This introduction (section 1) is followed by a description of the Commonwealth environmental water use objectives and watering actions for this system for 2018-19 (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 2018-19 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). Section 9 reports on additional monitoring undertaken to evaluate the 800 ML/d flow trial undertaken in the Yallakool-Wakool system from 22 August to 26 September 2018. Key outcomes of environmental water delivery from 2014-2019 are summarised in section 10. Recommendations to help inform adaptive management of environmental water in this system in the future is presented in section 11. A summary report (Watts et al. 2019) provides an overview of the monitoring and key findings of the ecosystem responses to environmental watering actions in the Edward/Kolety-Wakool system in 2018-19 and across the five years of the LTIM program.

1.2 Edward/Kolety-Wakool Selected Area

The Edward/Kolety-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).

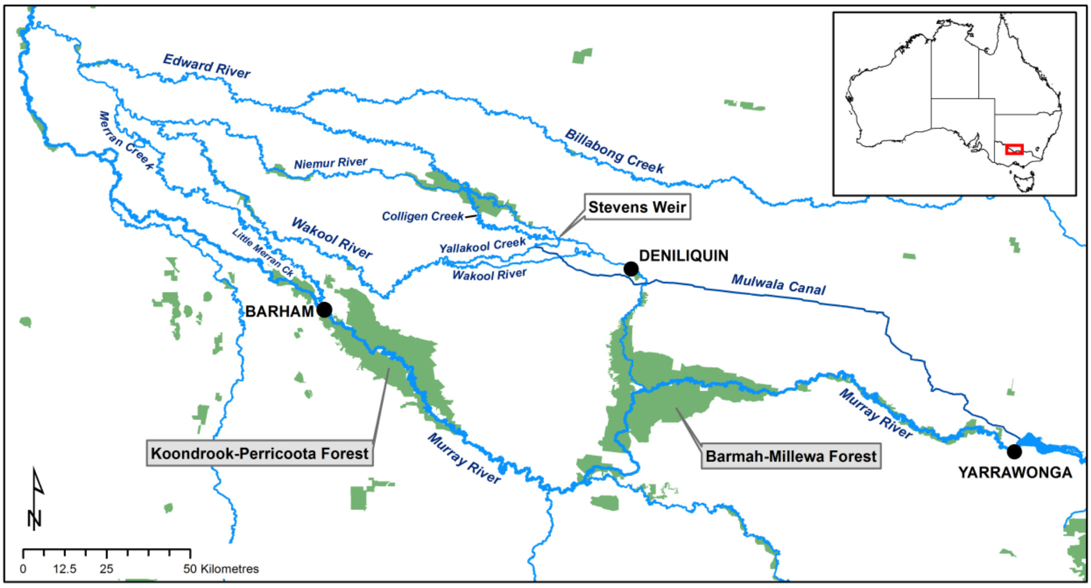


Figure 1.1 Map showing the main rivers in the Edward/Kolety-Wakool system. (Source: Watts et al. 2013)

The Edward/Kolety-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/Kolety-Wakool system to avoid breaching operational constraints in the mid-Murray River. The Edward/Kolety-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/Kolety-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/Kolety-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 2018-19

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 Table 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 to 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 Significance	Key site of hydrodynamic diversity	Threatened species	Dry period / drought refuge	In-scope for Commonwealth 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 Commonwealth 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 River 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 DO in the Plan is to maintain DO 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 DO 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/Kolety-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.

2.5 Commonwealth environmental watering actions 2009-2018

Commonwealth environmental watering actions have occurred in the Edward/Kolety-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/Kolety-Wakool forests (Table 2.3).

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 2.1).

It has not been possible to deliver large within channel freshes or overbank flows due to operational constraints in this system (e.g. operational constraint of 600 ML/d at confluence of the Wakool River and Yallakool Creek).

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

Table 2.3 Summary of Commonwealth environmental watering actions and unregulated overbank flows in the Edward/Kolety-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).
[2] Some of the watering actions in ephemeral creeks done jointly with NSW Office of Environment and Heritage

2.3 Environmental Watering Priorities for 2018-19

OEH watering priorities statement for the Murray – Lower Darling catchments

The Murray – Lower Darling Environmental Watering Priorities Statement 2018–19 (OEH 2018) states that "availability of planned and licenced water is expected to be limited in the Murray catchment early in the 2018-19 water year due to a lack of inflows into the major storages during Autumn and winter". Under a dry to moderate resource availability scenario, in 2018-19 "managed water will be used to target a range of outcomes, including the maintenance of habitat for colonial nesting waterbirds, improving conditions for small-bodied native fish, providing dispersal flows for large-bodied native fish, supporting wetland plants and enhancing connectivity in waterways for native fish" (OEH 2018).

Planned actions for 2018-19 in the Edward/Kolety-Wakool system as outlined by OEH (2018) were:

- "Fish flows (60 gigalitres) in the Edward/Kolety-Wakool river system will provide benefits for native fisheries, instream vegetation and food-webs. Water (110 gigalitres) will be delivered via the Murray irrigation system to provide refuge habitat for native fish (especially Murray cod) if an oxygen depleted blackwater event occurs".
- "Should a natural rainfall event occur, flows (6 gigalitres) will be released to enhance the health of vegetation along the Jimaringle, Cockran and Gwynnes creeks, aiming to improve water quality in highly saline sections, provide wildlife corridors across a modified landscape, and maintain habitats for iconic species, such as the threatened southern bell frog.
- "Flows (6 gigalitres) will provide connectivity between Tuppal Creek and the Edward River for native fish and carbon exchange".

CEWO Portfolio management Plan for the Mid-Murray in 2018–19

CEWO (2018a) states that "The overall 'purpose' for managing the Commonwealth's water portfolio in the Mid-Murray Region for 2018–19 is to maintain and/or improve the ecological health and resilience of environmental assets."

The 2018–19 Basin annual environmental watering priorities for the Mid Murray Region as outlined by the CEWO (2018a) were listed as i) rolling multiyear priorities and ii) 2018-19 annual priorities.

Rolling, multi-year priorities (CEWO 2018a):

- Support lateral and longitudinal connectivity;
- Maintain and improve the condition and promote recruitment of forests and woodlands;
- Improve the condition and extent of lignum shrublands;
- Improve the condition and extent of Moira grass in Barmah-Millewa Forest;
- Improve the abundance and maintain the diversity of the Basin's waterbird population;
- Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales in the southern connected Basin;
- Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations.

2018–19 Annual Priorities (CEWO 2018a)

- Support opportunities for lateral connectivity between the river and adjacent low-lying floodplains and wetlands to reinstate natural nutrient and carbon cycling processes
- Enable growth and maintain the condition of lignum shrublands;
- Provide flows to improve habitat and support waterbird breeding;
- Support Basin-scale population recovery of native fish by reinstating flows that promote key ecological processes across local, regional and system scales in the southern connected Basin;
- Support viable populations of threatened native fish, maximise opportunities for range expansion and establish new populations.

CEWO Portfolio management plan for the Edward/Kolety-Wakool in 2018–19

The 2018–19 demands for environmental water outlined by the CEWO (2018a) in the mid-Murray region Portfolio Plan that were specific for the Edward/Kolety-Wakool system were:

> "There is a moderate to high demand for environmental water in the Edward/Kolety-Wakool system. Flows would seek to support the recovery of large bodied native fish and instream aquatic plants after the 2016 flood and hypoxic blackwater event. Where possible, this includes providing winter base flows and preventing cease-to-flow conditions in the Yallakool-Wakool and Colligen-Niemur systems, and also the maintenance of breeding habitat and unobstructed movement pathways between interconnected streams and channels."

Delivery options for the Edward/Kolety-Wakool system were listed by CEWO (2018a) as follows:

> *Permanent Waterways:* Environmental water will contribute to year-round variable base flows and freshes to support the recovery of in-stream habitat, particularly aquatic vegetation and areas supporting the various life stages of native fish. Watering actions will be scalable depending on catchment conditions and water availability during the year. Environmental water use may also 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 these annual watering events would be to maintain ephemeral instream and wetland habitat, particularly water quality, aquatic vegetation and areas supporting the various life stages of native frogs, birds and aquatic invertebrates.
>
> *Edward/Kolety-Wakool forests:* The purpose of watering events may include the protection or maintenance of floodplain vegetation health, the provision of localised habitat for aquatic native plants and animals, contributing to hydrological connectivity and nutrient/carbon cycling processes. Environmental flows, including pumping, could be considered subject to stakeholder support, operational delivery infrastructure, third party impacts and accounting being addressed.

CEWO planned watering actions for the Edward/Kolety-Wakool in 2018–19

Five watering actions were planned by the Commonwealth Environmental Water Office for the 2018-19 water year in the Wakool-Yallakool system (Table 2.4) and the Colligen-Niemur system (Figure 2.1 and 2.2):

1. An early spring fresh in Yallakool Creek was planned from August to September 2018. This action will be referred to elsewhere in this report as the 800 ML/d flow trial. The flow trial in early spring 2018-19 is the first time that an environmental watering action was planned to exceed the 600 ML/d operational constraint at the confluence of the Wakool River and Yallakool Creek.
2. A late spring action incorporating higher base flows and a small fresh planned for late October to early November
3. A small summer fresh with managed recession planned for late November to early January
4. Two small freshes in autumn 2019 planned for mid-February to early May
5. A winter base flow in 2019 for Yallakool Creek and the Colligen-Niemur system. 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. This second planned winter watering action will continue into the 2019-20 water year and will be evaluated in the 2019-20 MER project report.

As per Water Use Minute WUM 10083, the 2018-19 Commonwealth environmental water use in the Edward/Kolety-Wakool system was expected to contribute to achieving the following outcomes:

- support the recovery of instream aquatic vegetation and large bodied native fish for three years following the 2016 hypoxic blackwater event
- maintain the diversity and condition of native fish and other native species through maintaining suitable habitat and providing/supporting opportunities to move, breed and recruit
- maintain habitat quality in ephemeral watercourses
- support mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter) through longitudinal and lateral hydrological connectivity
- support inundation of low-lying wetlands/floodplains habitats within the system
- maintain health of riparian and in-channel aquatic native vegetation communities
- maintain/improve water quality within the system, particularly DO, salinity and pH
- maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.

Table 2.4 Planned Commonwealth environmental watering actions in 2018-19 in the Edward/Kolety-Wakool River system. Planned actions 2, 3 and 4 were not implemented. The winter flow action (action number 5) commenced on 16th May2019 and continued into the 2019-20 water year. This action will be evaluated in the MER project report.

	Watering action	Action	Dates	Rivers	Objective
1	Early spring fresh	small fresh	22 August to 25 September 2018	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To provide early season rise in river level to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish
2	Late spring action	Higher base flow and small fresh	Planned for late Oct and early Nov 2018. Not implemented	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To maintain nesting habitat for Murray cod and inundation for aquatic vegetation growth. The variability flow was to prevent a flat river
3	Summer pulse	small fresh	Planned for late Nov 2018 to early Jan 2019 Not implemented	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To influence and encourage fish movement. May be coordinated with wider Murray River actions to maximise benefit. May also assist with dispersal of larvae and juveniles of a number of fish species. Slow recession for instream plants.
4	Autumn pulse	Small fresh	Planned for mid Fe to early May 2019 Not implemented	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To influence/encourage fish movement. May be coordinated with wider Murray River actions to maximise benefit. May also assist with the dispersal of juveniles of a number of fish species.
5	2019 winter flow	base flow	Commenced 16 May 2019 (Ongoing)	Yallakool Creek, upper, mid- and lower Wakool R, Colligen-Niemur	To contribute to reinstatement of the natural hydrograph, improve connectivity, condition of in-stream aquatic vegetation and fish recruitment into 2019-20.

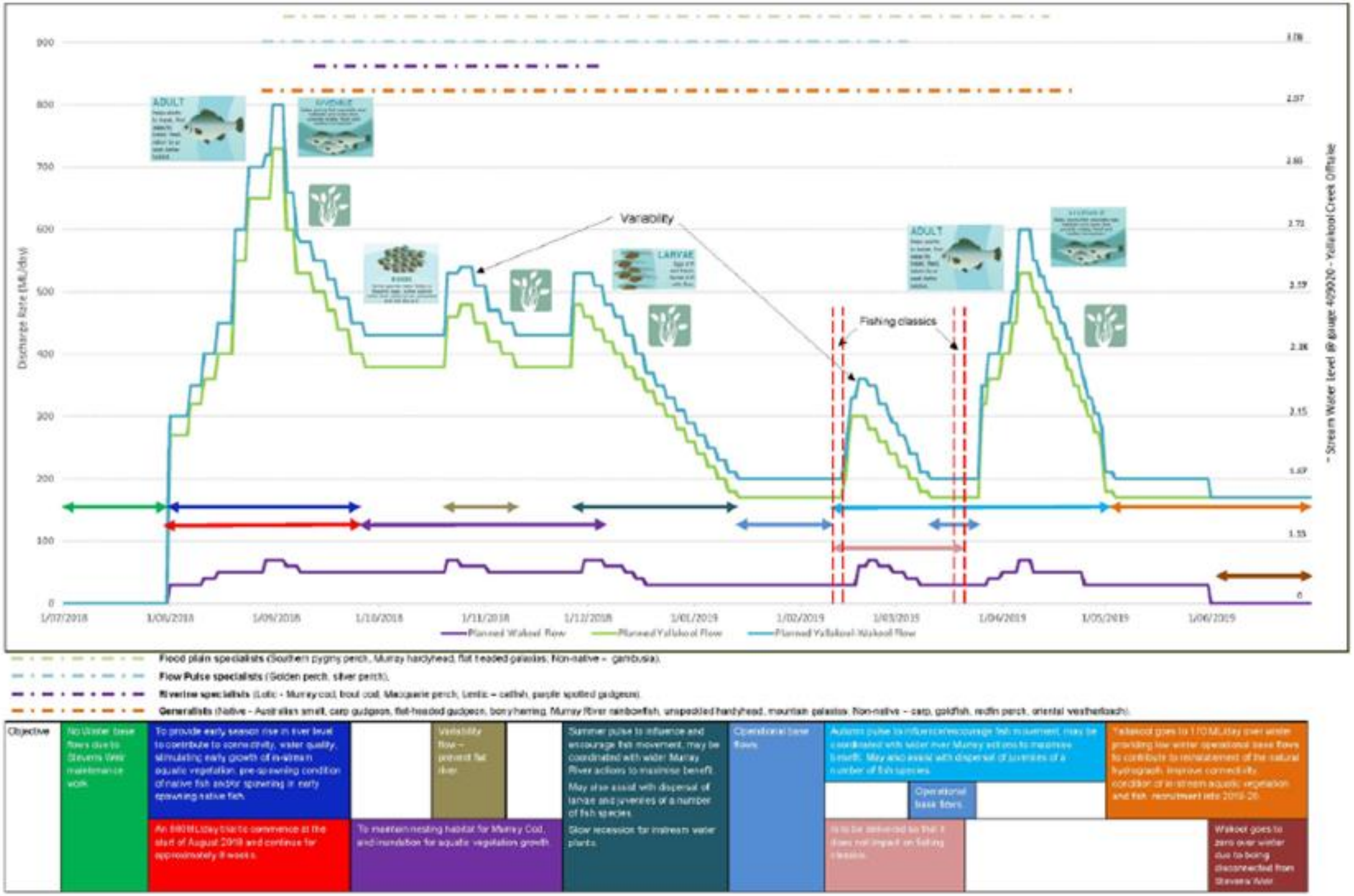


Figure 2.1. Planned Commonwealth environmental watering actions for Yallakool Creek and Wakool River for the 2018-19 water year.

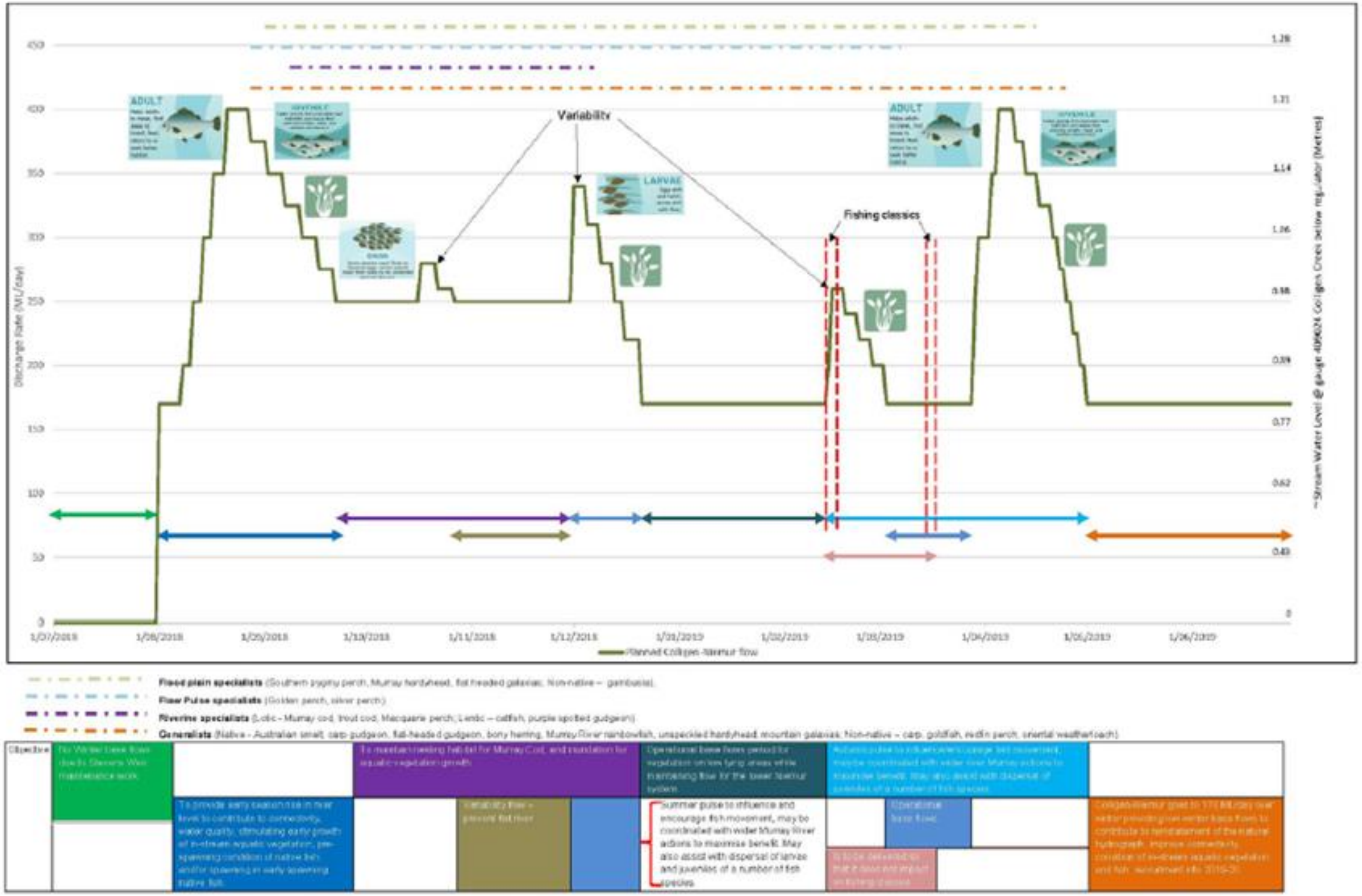


Figure 2.2. Planned Commonwealth environmental watering actions for the Colligen-Niemur system for the 2018-19 water year.

2.4 Practicalities of environmental watering in the Edward/Kolety-Wakool system

The main source of Commonwealth environmental water for the Edward/Kolety-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/Kolety-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/Kolety-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 the 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 also 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. 2017b).

The ability to deliver environmental water to the Edward/Kolety-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-Niemur system 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 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. Environmental watering may also be constrained due to limitations on how much water can be delivered under regulated conditions. At times of high irrigation demand channel capacity will be shared among 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 watering actions in Edward/Kolety-Wakool River system 2018-19

Infrastructure maintenance at Stevens Weir over the winter of 2018 resulted in no environmental watering actions being delivered over the winter of 2018. In 2018-19 there were five planned watering actions in the Edward/Kolety-Wakool system (Table 2.4).

The first Commonwealth environmental watering action delivered in 2018-19 was an early spring fresh undertaken from 22 August to 25 September 2018 (Table 2.5) in Yallakool Creek and the Wakool River. This will be referred to in this report as the 800 ML/day flow trial in Yallakool-Wakool system. Planning for the action was undertaken over a period of more than one year, with the Wakool River Association, the Edward/Kolety-Wakool Environmental Water Reference Group and landholders engaged and involved in the planning and water delivery. The flow trial involved changes to operating rules and practices, the aim being to exceed the maximum daily discharge of 600 ML/day at the confluence of Yallakool Creek and the Wakool River under regulated operating rules by up to 200 ML/day, with the maximum discharge being 800 ML/day. The plan was for environmental water to be largely delivered to the Yallakool-Wakool system via the Yallakool Offtake regulator. The outcomes of this flow trial will be evaluated throughout this report, with section nine focussing specifically on the flow trial.

Planned actions 2, 3 and 4 in the Wakool-Yallakool system (Figure 2.1) and the Colligen-Niemur system (Figure 2.2) during spring, summer and autumn were not implemented because environmental water was suspended between 2 October 2018 and mid-May 2019 due to increased operational demand in the Murray system and lack of capacity to accommodate environmental water in the river due to channel constraints. Due to this suspension only two of the planned Commonwealth environmental watering actions (actions 1 and 5) were delivered in the Edward/Kolety-Wakool system in 2018-19 (Table 2.5).

Commonwealth environmental watering action number 5 in the 2018-19 water year was a winter watering action commencing on 16 May 2019. This winter action will continue into the 2019-20 water year and will be evaluated in the 2019-20 MER project report.

Table 2.5 Commonwealth environmental watering actions delivered in 2018-19 in the Edward Wakool River system. Planned actions 2, 3 and 4 were not implemented. The winter flow action (action number 5) commenced on 16th May2019 and continued into the 2019-20 water year. This action will be evaluated in the MER project report.

	Watering action	Action	Dates	Rivers	Objective
1	Early spring fresh	small fresh	22 August to 25 September 2018	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur	To provide early season rise in river level to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish
5	2019 winter flow	base flow	Commenced 16 May 2019 (Ongoing)	Yallakool Creek, upper, mid- and lower Wakool River, Colligen Niemur	To contribute to reinstatement of the natural hydrograph, improve connectivity, condition of in-stream aquatic vegetation and fish recruitment into 2019-20.

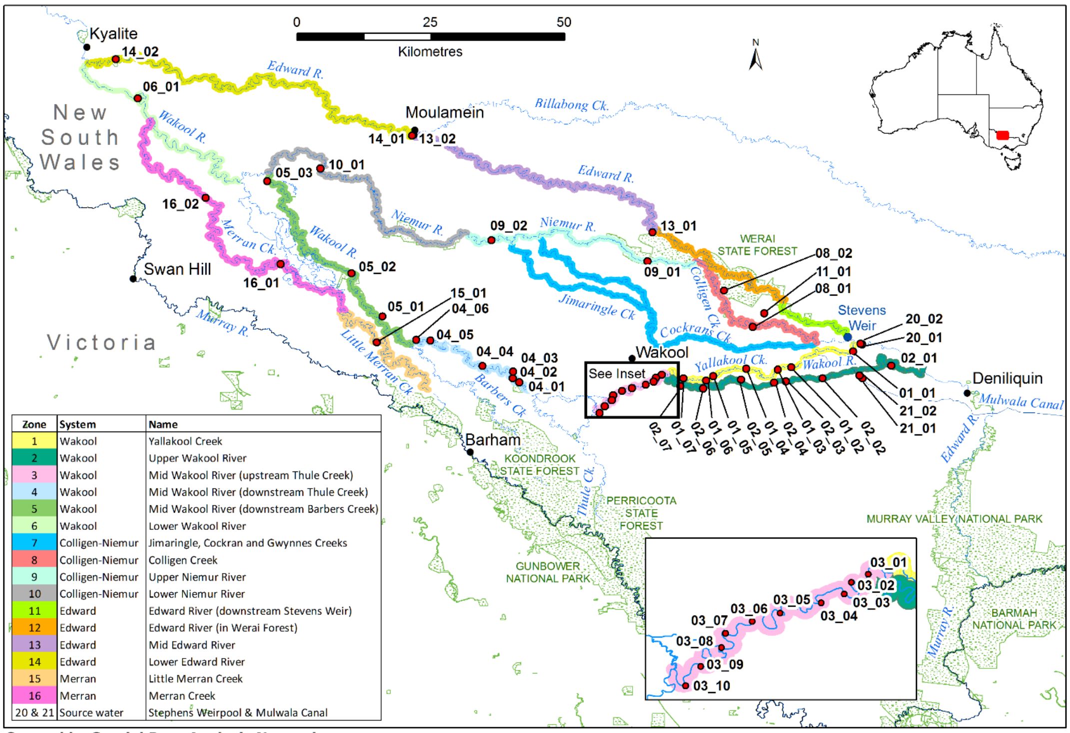
3 Monitoring and Evaluation

3.1 Monitoring zones and sites

The monitoring of ecosystem responses to Commonwealth environmental watering in the Edward/Kolety-Wakool system in 2018-19 was undertaken following the Edward/Kolety-Wakool Long-Term Intervention Monitoring and Evaluation Plan (Watts et al. 2014a) and Monitoring and Evaluation Plan Addendum (CEWO 2018b).

The majority of the LTIM monitoring in the Edward/Kolety-Wakool Selected Area was focussed on four hydrological zones: Yallakool Creek (zone 1), upper Wakool River (zone 2) and mid reaches of the Wakool River (zones 3 and 4) (Figure 3.1, Table 3.1). Most reaches in zones 1 and 2 are more constrained, have steeper riverbanks and fewer in-channel geomorphic features (e.g. benches) than reaches in zones 3 and 4 (Figure 3.2). Additional sites throughout the 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.

In 2018-19 additional sites were selected to facilitate the evaluation of responses to the 800 ML/day flow trial in the Wakool-Yallakool system. The focus of the monitoring was in the area around Bookit Island and Merrabit Creek, where there were potential issues associated with inundation of low level bridges (Table 3.2, Figure 3.4).



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/Kolety-Wakool Selected Area for the Long-Term Intervention Monitoring (LTIM) Project. Zones 1-4 are referred to as the focal zone for the Edward/Kolety-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/Kolety-Wakool Selected Area.

Zone Name	Zone	Site Code	Site Name
Yallakool Creek	01	EDWK01_01	Yallakool/Back Creek 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 Creek
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 Creek
Lower Edward River	14	EDWK14_01	Moulamien DS Billabong Creek
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

August 2018 prior to e-water	Sept 2018 during e-watering action 1	Feb 2019, after e-water during operational flows

Yallakool Creek 370 ML.d^{-1} 23/8/18 | 18/09/18, 460ML.d^{-1} (e-flow) | 20/02/19, 401 ML.d^{-1}

Wakool R (zone 2) 157 ML.d^{-1}23/8/18 | 18/09/18, 76 ML.d^{-1} | 20/02/19, 51 ML.d^{-1}

Wakool R (zone 3) 371 ML.d^{-1-}23/08/18 | 17/09/18, 696 ML.d^{-1} (e-flow) | 21/02/19, 468 ML.d^{-1}

Wakool R (zone 4) 320 ML.d^{-1-} 22/08/17 | 17/109/18, 623 ML.d^{-1} (e-flow) | 21/02/19, 517 ML.d^{-1}

Figure 3.2 Photos of study sites in the four hydrological zones i) left: August 2018 before environmental watering action 1, ii) middle: September 2018 during watering action 1, and iii) right: February 2019 after watering action 1 and during the operations flows (Photos Nathan McGrath).

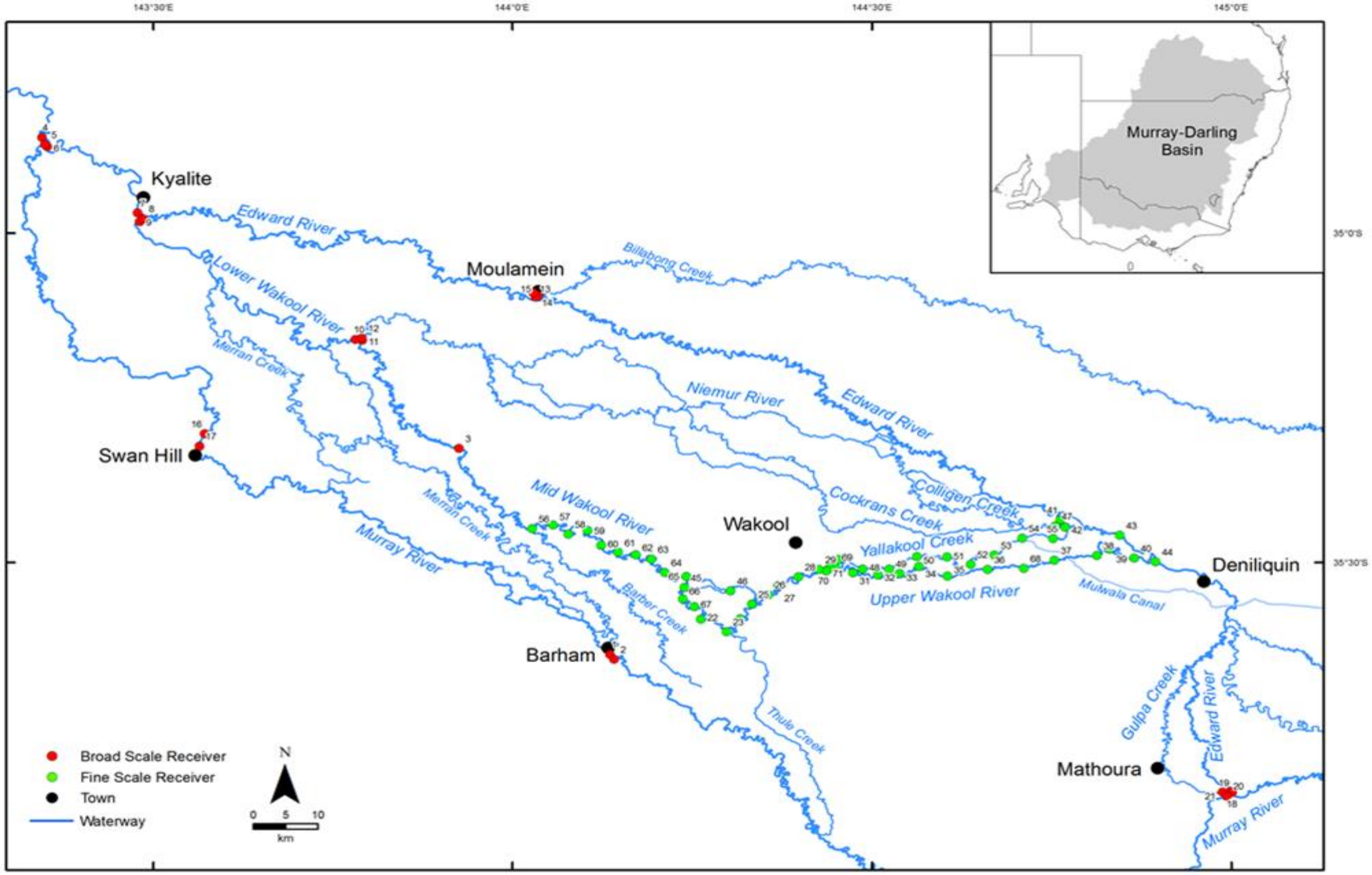


Figure 3.3 Location of acoustic telemetry receivers moored in the Edward/Kolety-Wakool system to determine movements of acoustically tagged golden perch and silver perch. Green dots indicate the fine-scale acoustic receiver array of ~6 km receiver spacing in the focal study zones. An additional 20 receivers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

Table 3.2. Monitored sites during the 800 ML/day flow trial. The presence of gauge boards, monitoring cameras, and water pressure loggers are indicated for each site.

Monitoring sites	River	LTIM site	Site Name	Gauge Board#	Camera	Water logger#
Sites with gauge boards	Yallakool Creek	zone1site1	Hopwood	29	yes	20
	Yallakool Creek	zone1site3	Cumnock	28	yes	
	Yallakool Creek	zone1site5	Windra Vale	30	yes	21
	Wakool River	zone2site1	Brassi Bridge	yes		
	Wakool River	zone2site4	Widgee	26	yes	22
	Wakool River	zone3site1	Wakool R -Deni Wakool Rd	62/34		07
	Wakool River	zone3site3	Cummins	23	yes	
	Wakool River	zone3site5	Llanos Park	25	yes	23
	Griminal Creek		Griminal Creek	65/ 08	yes	19
	Merrabit Creek		McLays Lane	64/ 10	yes	
	Merrabit Creek		Merrabit Creek – Lolicato Bridge	37	yes	12
	Bookit Creek		Bookit Creek	31	yes	01
	Bookit island		Wakool R - Bookit Island Bridge	38	yes	15
	Wakool River	Zone4site1	Wakool R - Barham Rd	63		
Infrastructure (bridges, weirs and crossings)	Yallakool Creek		Mascot bridge		yes	
	Yallakool Creek		Windra Vale bridge		yes	
	Wakool River		Bookit Island bridge #1		yes	
	Wakool River		Bookit Island bridge #2		yes	
	Bookit Creek		Bookit creek Ford		yes	
	Bookit Creek		Bookit Creek Weir		yes	
	Merrabit Creek		Merrabit Creek Weir		yes	
	Wakool River		Tilga bridge		yes	

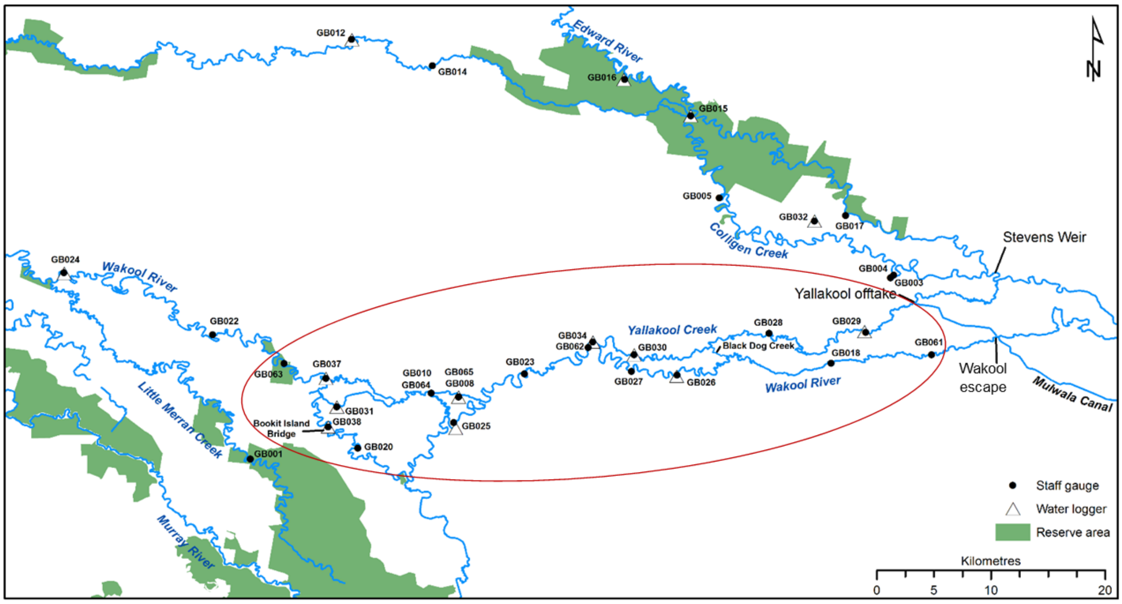


Figure 3.4 Monitored sites (within red circle) during the 800 ML/day flow trial in Yallakool-Wakool system.

3.2 Indicators

The rationale regarding the selection of indicators is outlined in the Edward/Kolety-Wakool Long Term Intervention Monitoring and Evaluation Plan (Watts et al. 2014a) and Monitoring and Evaluation Plan Addendum (CEWO 2018b). Indicators are monitored to contribute to the Edward/Kolety-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 2014-19 is presented in Table 3.3.

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/Kolety-Wakool system (Table 3.3) 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/Kolety-Wakool system.
- **Category 3** – Selected Area specific monitoring protocols to answer Selected Area questions. Category 3 indicators monitored in the Edward/Kolety-Wakool system (Table 3.3) 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 3.3 Summary of indicators to be monitored in the Edward/Kolety-Wakool system for the Long Term Intervention Monitoring Project from 2014-2019.

Indicator	Method	Zone	Edward/Kolety-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)	DO 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 2018-19

The monitoring undertaken in 2018-19 is summarized in Table 3.4. 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 2014-18 (Watts et al. 2015, 2016, 2017b, 2018).

Table 3.4 Schedule of monitoring activities For Edward/Kolety-Wakool Long-Term Intervention Monitoring project for 2018-19 (grey shading). The three categories of indicators are described in section 3.2.

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

3.4 Evaluation of outcomes

Evaluations of the outcomes of Commonwealth environmental watering undertaken in 2018-19 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 (section 8)

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 increased the maximum discharge in all zones compared to operational flows. From a water accounting perspective the total discharge of water delivery reached a maximum of 870 ML/day on 13 September. However, the discharge did not exceed 800 ML/day at any site because water was delivered from different regulators. The maximum daily discharge was 488 ML/day in Yallakool Creek (15 September), 398 ML/day at Wakool River zone 2 site 4 (13 September), 696 ML/day in Wakool River zone 3 (17 September), 652 ML/d in Wakool River zone 4 (19 September). The maximum daily operating discharge of 600 ML/day was exceeded in zones 3 and 4. The discharge in zone 2 downstream of the Wakool escape was higher than normal operational flows in this zone (40-80 ML/d). A winter environmental watering action commenced in Yallakool Creek on 16 May 2019 and also influenced flows in zones 3 and 4. This action will continue into the 2019-20 water year and will be evaluated in the 2019-20 Monitoring, Evaluation and Research (MER) report.
Flow variability	Watering action 1 increased the coefficient of variation of discharge in zones 2 and 3 compared to operational flows. Between October 2018 and February 2019 there was an extended period of low variability operational flows in the system. Some of the operational water was delivered from the Wakool escape from Mulwala canal, resulting in higher discharge in Wakool River zone 2 (approx. 160 ML/day) than previous years in this zone (approx. 40-80 ML/d).
Longitudinal connectivity	Watering action 1 (800 ML/day flow trial) maintained longitudinal connectivity in Yallakool Creek and the Wakool River. The higher flows in the Wakool River (zone 2) during the watering action initiated flow in Black Dog Creek, connecting the upper Wakool River near 'Widgee' (zone 2 site 4) with Yallakool Creek to 'Windra Vale' near zone 1 site 5.
Lateral connectivity	Watering action 1 (800 ML/day flow trial) increased lateral connectivity in Yallakool Creek and the Wakool River. There was considerable variation in wetted area among reaches, with some of the variability due to the local geomorphology of the reaches. This watering action increased the wetted area by an average of 10.2%, ranging from an increase of 3.7% in zone 2 site3 to 30.3% in zone 2 site 4.
Hydraulic diversity	Based on hydraulic modelling undertaken for each study reach (Watts et al. 2015), the 800 ML/day watering action 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/Kolety-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/Kolety-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; Watts et al. 2017a).

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/Kolety-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/Kolety-Wakool system.

The 2018-19 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/Kolety-Wakool system from 1 July 2018 to 30 June 2019. Specifically, this work will be addressing the questions in section 4.3. This report also summarises the 5 years of hydrological data from the Long Term Intervention Monitoring (LTIM) Project keeping in mind that this period has included both drought, unregulated flooding and operational flows that have influenced hydrology in addition to the availability of Commonwealth environmental water.

4.2 Environmental watering actions targeting hydrology outcomes

Two Commonwealth environmental watering actions were delivered in the Edward/Kolety-Wakool system in 2018-19 (Table 4.1). A spring freshwater delivered in the Yallakool Creek and the Wakool River from August to September 2018. This will be referred to in this report as the 800 ML/day flow trial.

A winter watering action commenced on 16 May 2019. This action will continue into the 2019-20 water year and will be evaluated in the 2019-20 annual report. All other planned flow actions in the Wakool system during spring, summer and autumn were suspended between 2 October 2018 and mid-May 2019 due to lack of operational capacity to accommodate environmental water in the river in addition to operational water that was required to be delivered through the system.

Table 4.1 Commonwealth environmental watering actions in 2018-19 in the Edward Wakool River system. The winter flow action continued into the 2019-20 water year and will be evaluated in the 2019-20 MER report.

	Watering action	Action	Dates	Rivers
1	Spring fresh	small fresh	22 August to 25 September 2018	Yallakool Creek, mid- and lower Wakool River
5	2019 winter flow	base flow	Commenced 16 May 2019 (Ongoing)	Yallakool Creek, upper, mid- and lower Wakool River, Colligen-Niemur River

4.3 Selected Area evaluation questions

- *What was the effect of Commonwealth environmental water on the hydrology of the four zones in the Edward/Kolety-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. 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.

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
Niemur River	10	409086	Niemur at Mallan School
Edward River		409008	Edward River Offtake
Edward River	11	409023	Edward River DS Stevens weir
Edward River	14	409035	Edward River at Liewah

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.

Additional hydrological information and results of 2D hydraulic models of the 800 ML/d flow trial is presented in section 9.

The extent of riverbank inundation under operational flows and the Commonwealth environmental watering actions was estimated using 2-dimensional hydraulic modelling as described in Watts (2015). A 2D hydraulic model was created for nineteen river reaches each 4 km in length; five reaches in Yallakool Creek, five in the Wakool River (zone 2), four in Wakool River upstream of Thule Creek (zone 3) and five in the Wakool River downstream of Thule Creek (zone 4). Between ten and twelve discharge scenarios were modelled for each reach, with the majority of the discharge scenarios being in the range of 30 ML/day to 1200 ML/day and one discharge scenario in each reach being just less than bankfull. The models were used to estimate the extent of wetted benthic surface area. The relationship between discharge and wetted benthic area for each study reach was determined using cubic smoothing spline regression modelling. The modelled curve for each reach (examples provided in Figure 4.1) was used to estimate the daily wetted area due to operational discharge and discharge including Commonwealth environmental water.

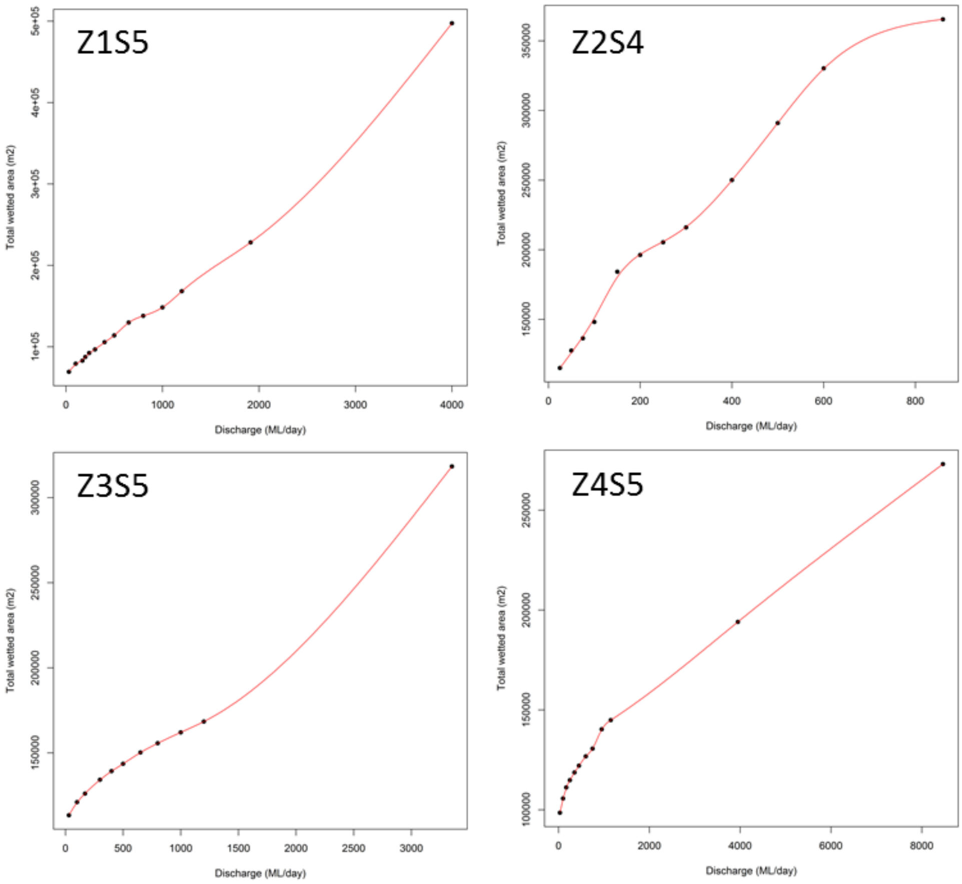


Figure 4.1 Examples of relationship between discharge (ML/d) and total wetted benthic area (m^2) for three of the nineteen 4 km reaches in the Yallakool-Wakool system. Estimates of wetted area were calculated from 2D hydraulic models. Curves were modelled using cubic smoothing spline regression approach, and were used to estimate the daily wetted area in each reach for each daily discharge during the flow trial.

4.5 Results

Overview of hydrology over 5 years of LTIM from July 2014 to June 2019

The five year hydrograph (1 July 2014 to 30 June 2019) in the Edward/Kolety-Wakool system is dominated by the large unregulated flow in late 2016 (Figure 4.2). The volume of Commonwealth environmental water delivered to the Edward/Kolety-Wakool system over the five year period is small in comparison to the large unregulated flow in 2016. However, at the 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 5 year hydrograph (Figure 4.2) and is in contrast to periods of cease to flows during winter in these zones in previous years.

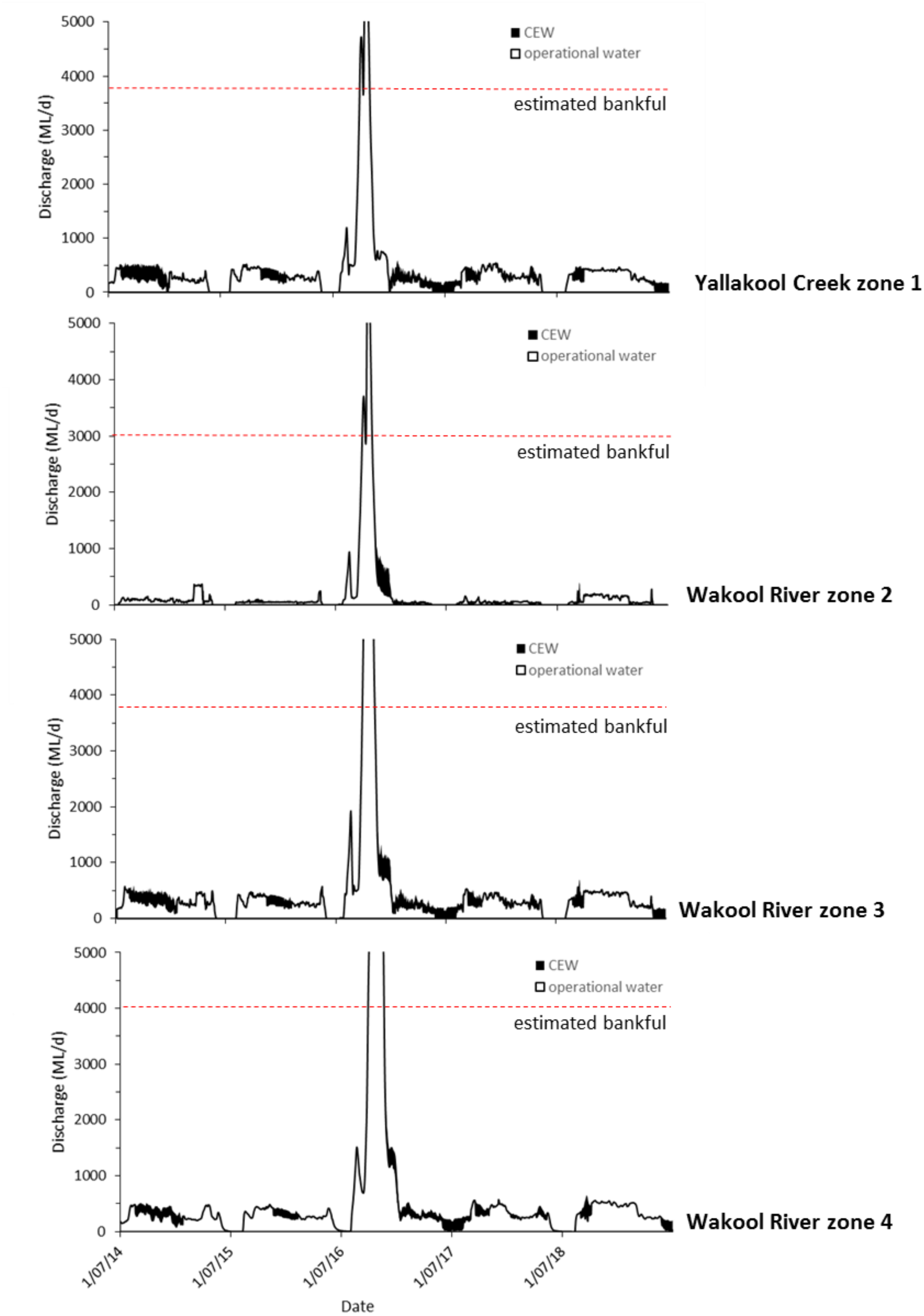


Figure 4.2 Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1 July 2014 to 30 June 2019. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water. Note that the y axis has been truncated at 5,000 ML.d^{-1}.

Under regulated flow conditions the discharge in the upper Wakool River is consistently lower than in Yallakool Creek and the mid Wakool River (zones 3 and 4) (Figure 4.2, Table 4.3). When compared to the annual median discharge without CEW, the delivery of Commonwealth environmental water increased the annual median discharge in zones 1, 3 and 4 zones in all years, with an increase of between 11.4% (zone 4 2015-16) and 63% increase (zone 3, 2016-17). In most years the delivery of CEW did not increase the maximum annual discharge as the delivery of environmental water is constrained by operational regulations (see section 2.4). However in 2018-19 the maximum discharge across the year was increased by 5.2% in Yallakool Creek, 42% in the Wakool River zone 2, 35% in zone 3 and 16% in zone 4 (Table 4.3).

Table 4.3 Summary hydrological statistics for the entire water year (1 July to 30 June the following year) over the five years of the LTIM program for four hydrological zones in the Edward/Kolety-Wakool system. Statistics are shown for each zone with and without Commonwealth Environmental Water.

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 2018-19 water year (1 July 2018 – 30 June 2019)								
Q_{min} (ML/d)	0	0	0	0	0	0	0	0
Q_{max} (ML/d)	464	488	280	398	517	696	561	652
mean (Q_{mean}) (ML/d)	265	307	81	90	281	324	313	351
median (Q_{50}) (ML/d)	271	383	49	61	262	387	302	397
Coefficient of variation	2.28	1.93	6.42	5.90	3.10	2.68	8.63	7.68
Entire 2017-18 water year (1 July 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)	244	305	36	47	231	297	262	322
median (Q_{50}) (ML/d)	264	328	36	54	250	304	270	314
Coefficient of variation	0.66	0.50	0.79	0.71	0.63	0.48	0.56	0.44
Entire 2016-17 water year (1 July 2016 – 30 June 2017)								
Q_{min} (ML/d)	0	0	0	0	0	0	4	4
Q_{max} (ML/d)	5043	5043	4825	4825	7441	7441	23984	23984
mean (Q_{mean}) (ML/d)	668	744	446	520	883	1006	2276	2374
median (Q_{50}) (ML/d)	258	382	41	72	237	385	304	426
Coefficient of variation	1.62	1.41	2.13	1.83	1.79	1.54	2.14	2.04
Entire 2015-16 water year (1 July 2015 – 30 June 2016)								
Q_{min} (ML/d)	0	0	0	0	0	0	0	0
Q_{max} (ML/d)	520	520	247	247	572	572	477	506
mean (Q_{mean}) (ML/d)	249	287	43	52	239	276	252	281
median (Q_{50}) (ML/d)	256	309	48	52	251	295	263	293
Coefficient of variation	0.59	0.56	0.80	0.76	0.58	0.56	0.52	0.52
Entire 2014-15 water year (1 July 2014 – 30 June 2015)								
Q_{min} (ML/d)	0	0	0	0	0	0	5	4
Q_{max} (ML/d)	509	547	370	370	573	584	486	514
mean (Q_{mean}) (ML/d)	219	324	91	91	261	345	256	324
median (Q_{50}) (ML/d)	236	325	78	78	265	391	247	334
Coefficient of variation	0.49	0.51	0.91	0.91	0.48	0.45	0.44	0.43

Hydrology in 2018-19

In 2018-19 there was increased demand in the Murray system and the requirement for the MDBA to deliver operational water through the system. Consequently, there was a lack of operational capacity to accommodate environmental water in the river due to channel constraints and Commonwealth environmental watering actions were suspended between 2 October 2018 and mid-May 2019.

The hydrology of the rivers in the Edward/Kolety-Wakool system in 2018-19 was dominated by extended periods of relatively stable regulated operational flows. Long periods of low variability in discharge due to regulated operational flows was most evident at upstream reaches of each of the major river systems; in the Edward/Kolety River at the offtake (Figure 4.3), Wakool River at offtake (Figure 4.4) and in the Colligen-Niemur system below the regulator (Figure 4.5).

In the Edward/Kolety River downstream of the Edward offtake the discharge was held steady at approximately 1550 ML/day for nine months between August 2018 and the end of April 2019 (Figure 4.3). In the Edward/Kolety River downstream of Stevens Weir the discharge was more variable, however there was a period of 3 months between December 2018 and February 2019 where the discharge was held steady at around 2600 ML/day. However, further downstream at Liewah the discharge was more variable (Figure 4.3).

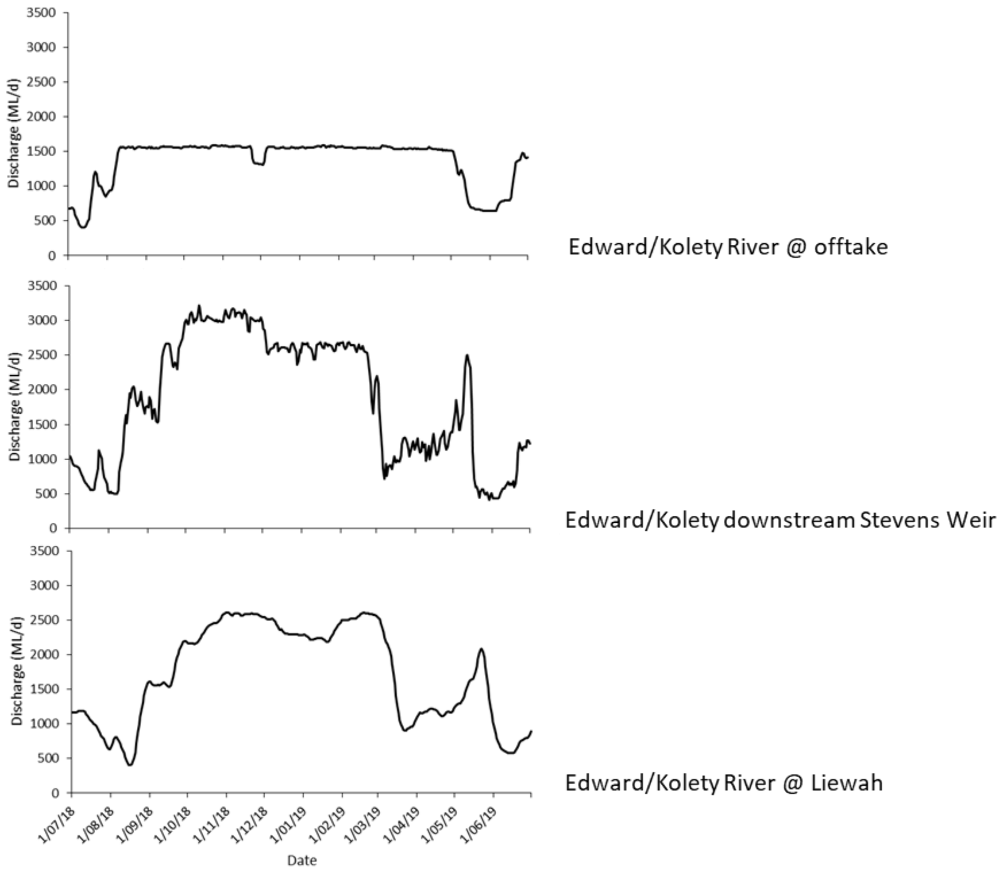


Figure 4.3 Hydrographs for the Edward River at the Edward River offtake (gauge 409008), downstream of Stevens Weir (gauge 409023) and at Liewah (gauge 409035) from 1 July 2018 to 30 June 2019.

A similar pattern was evident in the Wakool River. The discharge was less variable at the offtake and in the mid reaches and more variable in the lower reaches of the Wakool at Stoney Crossing (Figure 4.4) after inputs of flows from the Murray system. Similarly, in the Colligen Niemur system the most upstream hydrological gauge below the regulator shows there was almost 5 months where flows were held at approximately 400 ML/day from October 2018 to February 2019 (Figure 4.5). Whereas further downstream in the Niemur River at Mallan School gauge the influence of other inflows has resulted in a more variable hydrograph (Figure 4.5).

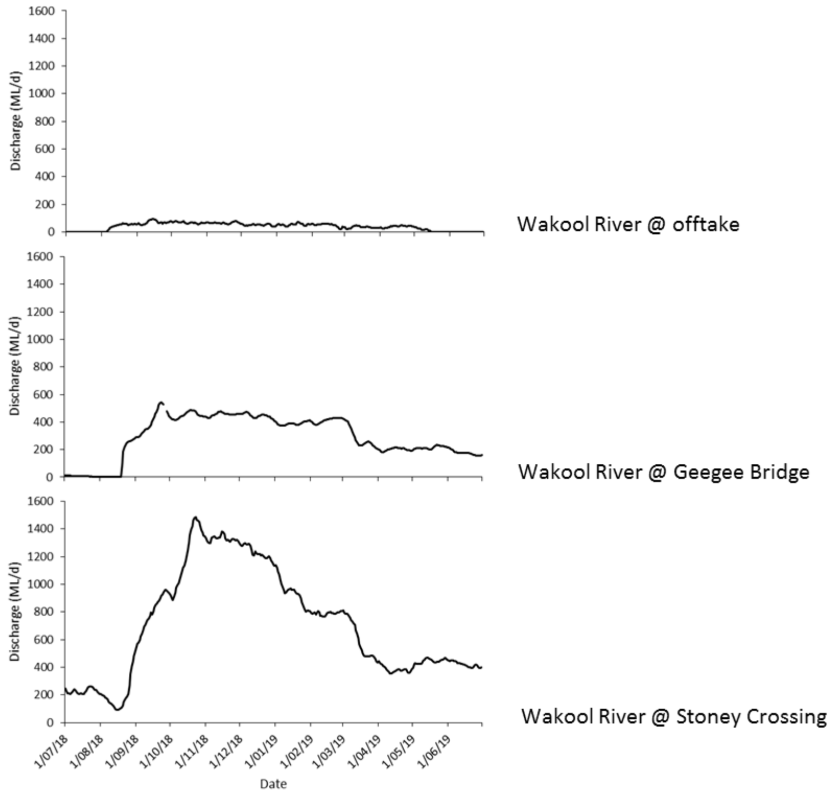


Figure 4.4 Hydrographs for the Wakool River at offtake (gauge 409019), Gee Gee Bridge (gauge 409062), and at Stoney Crossing (gauge 409013) from 1 July 2018 to 30 June 2019.

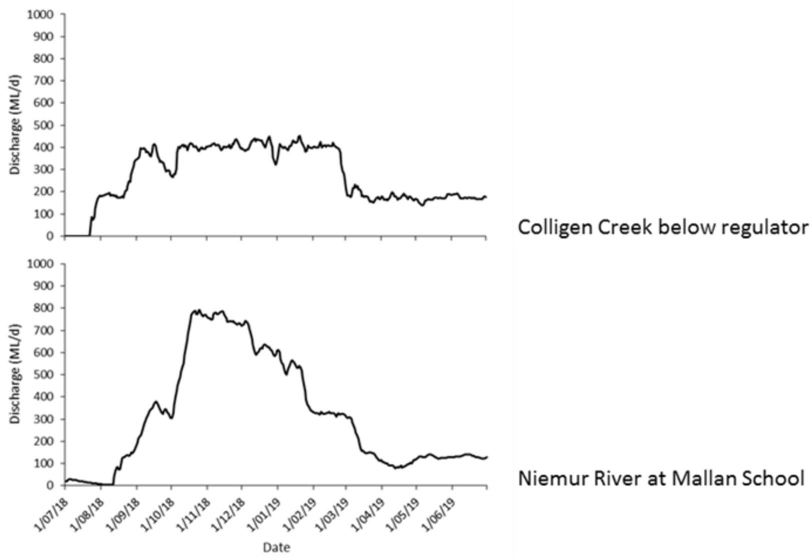


Figure 4.5 Hydrographs for the Colligen-Niemur system at Colligen Creek below regulator (gauge 409024), and in the Niemur River at Mallan School (gauge 409086) from 1 July 2018 to 30 June 2019.

Overview of hydrology in zones 1 to 4 in 2018-19

One of the main features of the hydrograph in zones one to four in 2018-19 was due to the spring environmental watering action (Watering action #1, Table 4.1), referred to in this report as the 800 ML/day flow trial. This action occurred from 22 August to 25 September 2018 and the peak of this event is clearly evident in the hydrograph prior to the period of operational flows (Figure 4.6).

Another feature of the 2019-19 hydrographs for zones one to four is the extended period of operational flows between October 2018 and February 2019. Some of the operational flows were delivered from the Wakool escape from Mulwala canal, resulting in higher operational discharge in Wakool River zone 2 (approx. 160 ML/day) than in this zone in previous years (approx. 40-80 ML/d). This water transfer end abruptly in late February 2019, with a sharp recession in discharge (Figure 4.6).

Another feature of the hydrograph is a distinct sharp rise and fall in discharge in zones 2 and 3 in early May 2019 due to MIL operations emptying Mulwala Canal at the end of the irrigation season (Figure 4.6). This spike in discharge due to the emptying of the canal was also evident in 2015, 2016 and 2018.

A winter environmental watering action (watering action #5, Table 4.1) commenced in Yallakool Creek on 16 May 2019 and also influenced flows in zones 3 and 4. This action will continue into the 2019-20 water year and will be evaluated in the 2019-20 MER report.

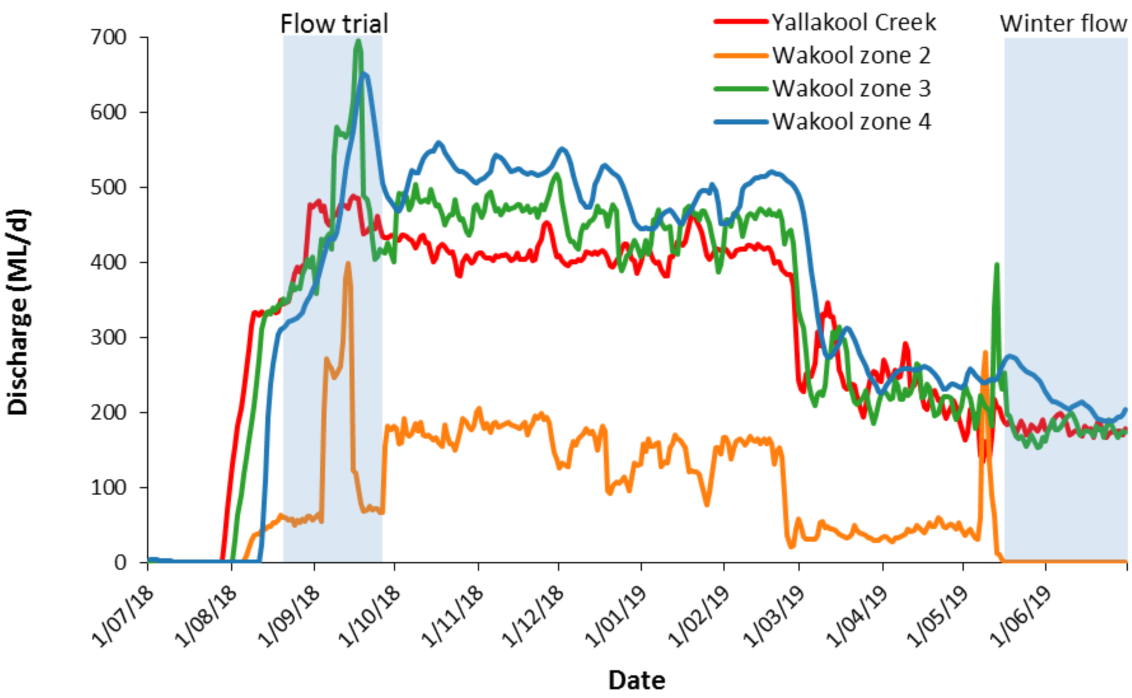


Figure 4.6 Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1 July 2018 to 30 June 2019. The blue shaded sections relate to the environmental watering actions listed in Table 4.1. Action 1: 800 ML/day flow trial, Action 2: 2019 winter watering action.

Environmental watering action 1 – 800 ML/d flow trial in Yallakool-Wakool system

The initial plan for 2018-19 was for environmental water for the 800 ML/d flow trial to be delivered via the Yallakool Creek offtake and Wakool River offtake regulator. However, it was not possible for WaterNSW to maintain the height of Stevens Weir to deliver the required discharge through those regulators, so the Wakool escape from Mulwala canal was used from 4th to 17th September 2018 to contribute to the watering action (Figure 4.7).

From a water accounting perspective, the water delivery reached a maximum of 870 ML/day on 13th September when water delivered from Yallakool Creek offtake, the Wakool offtake regulator and the Wakool Escape from Mulwala Canal were summed on each date.

As the water was delivered from different regulators and had different travel times, the flows in from the three offtakes translated to less than 800ML/day in individual tributaries, and discharge did not exceed 800 ML/day at any location in the river system. The peak discharge in different zones was as follows, as is describe in more detail in section 9 of this report:

- The discharge peaked at 488 ML/day on 15th September in Yallakool Creek zone 1 (Figure 4.7), which is a lower peak than previous environmental water actions in spring in this system (Watts et al 2015, 2016, 2018).
- The combined discharge from the Wakool offtake regulator and the Wakool Escape resulted in a peak of approximately 398 ML/day at zone 2 site 4 on 13th September (Figure 4.7). This resulted in a considerably higher discharge in zone 2 compared to previous operational flows in this zone (40-80 ML/d). The higher flows in zone 2 initiated flow in Black Dog Creek, that exits the upper Wakool River near 'Widgee' (zone 2 site 4) and flows across to Yallakool Creek to 'Windra Vale' near zone 1 site 5. The creek was observed to be flowing inundated on 13th September and on 17th September 2018 the flow was continuing, but the water level was slightly lower.
- In zone 3 at the confluence of Yallakool Creek and the Wakool River the peak was 696 ML/day on 17th September (Figure 4.7). This peak flow was higher than had been previously achieved at this site during an environmental watering action.
- In zone 4 at the Wakool - Barham Rd gauge the peak was 652 ML/d on 19th September (Figure 4.7). This peak flow was higher than had been previously achieved at this site during an environmental watering action.

The coefficient of variation of discharge during the environmental watering action was considerably higher in zones 2 and 3 than under operational flows without the CEW (Table 4.4).

The Commonwealth environmental water delivered to the Yallakool-Wakool system via the Yallakool Offtake regulator, Wakool Offtake regulator and Wakool escape from Mulwala Canal increased lateral connectivity within the river system. There was considerable variation in wetted area among the study reaches (Figure 4.8), with some of this variability due to the local geomorphology of the reaches. The Commonwealth environmental water increased the wetted area by an average of 10.2%, ranging from an increase of 3.7% in zone 2 site3 and as high as 30.3% in zone 2 site 4.

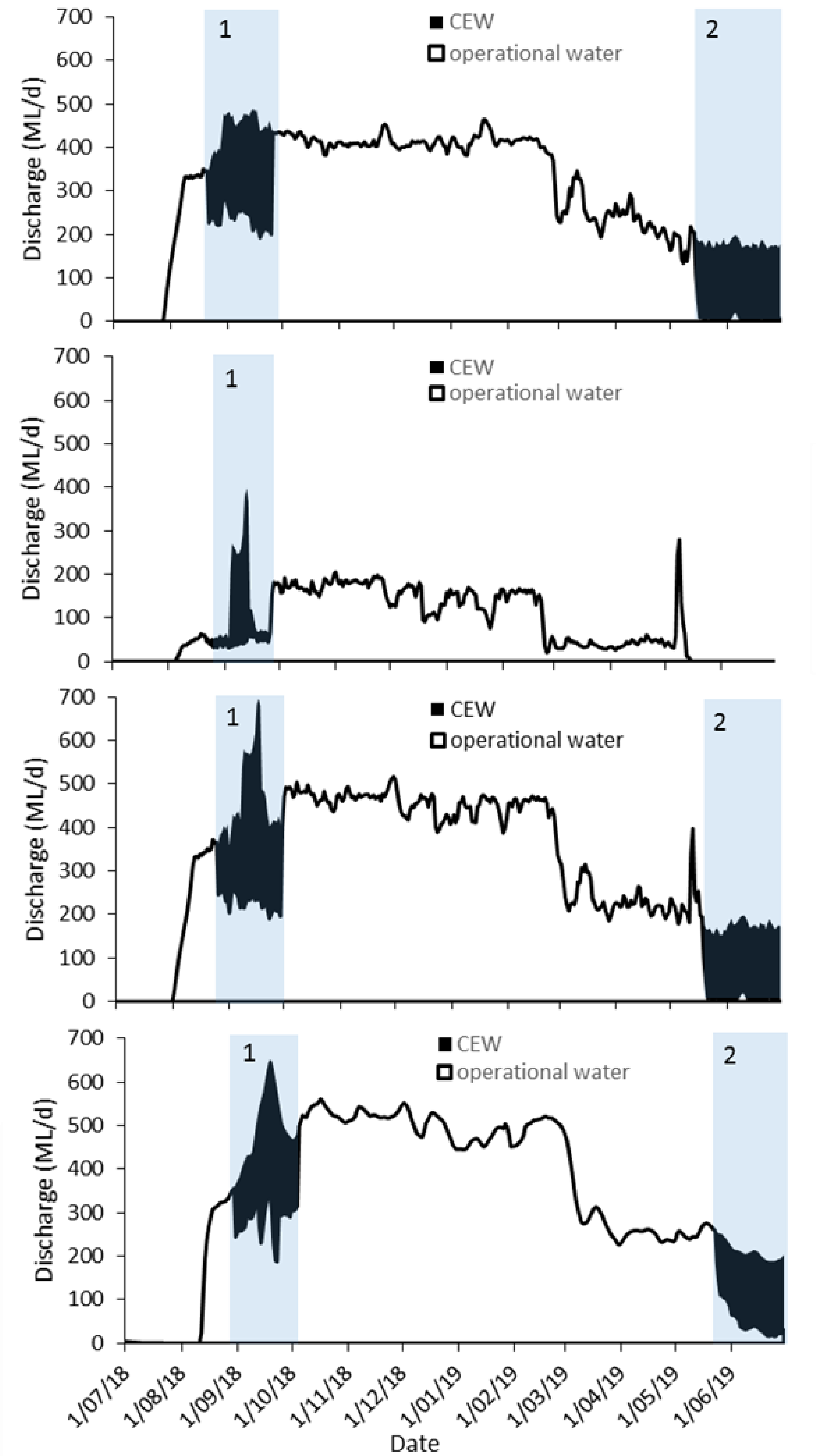


Figure 4.7 Hydrographs of zones 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1st July 2018 to 30th June 2019. The portion of the hydrographs coloured black is attributed to the delivery of Commonwealth Environmental Water. The blue shaded sections relate to the environmental watering actions listed in Table 4.1. 1: 800 ML/day flow trial and 2: 2019 winter watering action.

Table 4.4 Summary hydrological statistics for the 800 ML/d flow trial (watering action 1) in August and September 2018 in four hydrological zones in the Edward/Kolety-Wakool system. Statistics are shown for each zone with and without Commonwealth Environmental Water.

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
	22 Aug to 25 Sep		4 Sep to 16 Sep		26 Aug to 29 Sep		31 Aug to 4 Oct	
Q_{min} (ML/d)	192	348	33	119	190	359	187	364
Q_{max} (ML/d)	298	488	61	398	270	696	344	652
mean (Q_{mean}) (ML/d)	238	448	45	264	230	476	284	504
median (Q_{50}) (ML/d)	238	460	42	262	233	430	293	487
Coefficient of variation	0.10	0.08	0.21	0.32	0.08	0.20	0.13	0.17

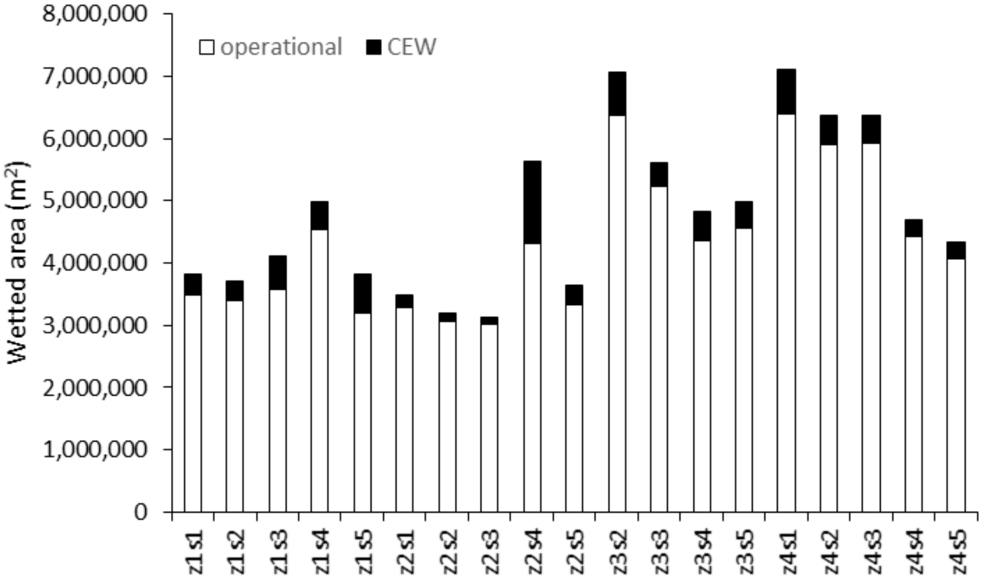


Figure 4.8 Total wetted benthic area (m^2) modelled for 19 reaches in the Edward/Kolety-Wakool system under operational flows and Commonwealth environmental watering action from 22 August to 25 September 2018. Total wetted area was calculated by adding the total area for each day of the watering action. Zone 1 = Yallakool Creek, zone 2 = upper Wakool River, zone 3 = Wakool River upstream of Thule Creek and zone 4 = Wakool River downstream of Thule Creek. Discharge levels for operational and environmental flows are in Figure 9.4.

4.6 Discussion

What was the effect of Commonwealth environmental water on the hydrology of the four zones in the Edward/Kolety-Wakool system that were monitored for the LTIM project?

Watering action 1 (800 ML/day flow trial) increased the maximum discharge in all zones compared to operational flows. From a water accounting perspective the water delivery reached a maximum of 870 ML/day on 13th September when water delivered from Yallakool Creek offtake, the Wakool offtake regulator and the Wakool Escape from Mulwala Canal were summed on each date. As the water was delivered from different regulators and had different travel times, the discharge did not exceed 800 ML/day at any location in the river system. Watering action 1 reached a maximum daily discharge of 488 ML/day in Yallakool Creek zone 1 (15 September) which did not exceed the maximum operation discharge in that zone. The combined discharge from the escape and the Wakool offtake resulted in a peak of approximately 398 ML/day at zone 2 site 4 (13 September). This was considerably higher discharge in zone 2 compared to previous operational flows in this zone (40-80 ML/d). The flow peak was 696 ML/day in zone 3 (17 September) at the confluence of Yallakool Creek and the Wakool River which exceeded the operating maximum daily discharge of 600 ML/day in this zone. The flow peak was 652 ML/d in zone 4 at the Wakool - Barham Rd gauge on 19 September.

What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?

Watering action 1 (800 ML/day flow trial) maintained longitudinal connectivity in Yallakool Creek and the mid and lower Wakool River.

Due to the delivery of environmental water from the Wakool escape from Mulwala canal, the flows in the Wakool River (zone 2) were higher than originally planned, initiating flow in Black Dog Creek, that exits the Wakool River near 'Widgee' (zone 2 site 4) and flows across to Yallakool Creek to 'Windra Vale' near zone 1 site 5. This example of increased longitudinal connectivity resulting from the flow trial would provide increased opportunities for fish movement, dispersal of seeds and vegetation.

What did Commonwealth environmental water contribute to lateral connectivity?

The 800 ML/day flow trial increased lateral connectivity within the river system. There was considerable variation in wetted area among the study reaches, with some of this variability due to the local geomorphology of the reaches. The Commonwealth environmental water increased the wetted area by an average of 10.2%, ranging from an increase of 3.7% in zone 2 site3 and as high as 30.3% in zone 2 site 4.

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), the 800 ML/day watering action would have 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 in the velocities among habitat patches 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?**
Early spring watering action (small fresh) in Yallakool Creek, and mid and lower Wakool River from 22nd August 2018 to 25th September 2018	To provide early season rise in river level to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish	*What is the effect of Commonwealth environmental water on the hydrology of the four zones in the Edward/Kolety-Wakool system that were monitored for the LTIM project?*	Increased the maximum discharge in all zones compared to operational flows. Increased the coefficient of variation of discharge in zones 2 and 3 compared to operational flows. The maximum daily operating discharge in zones 3 and 4 was exceeded; discharge peaked at 696 ML/d in zone 3 and 652 ML/d in zone 4.	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, however the discharge did not exceed 800 ML/day at any site because the water was delivered from different regulators. From a water accounting perspective the total discharge of water delivery reached a maximum of 870 ML/day on 13 September. The maximum daily discharge was 488 ML/day in Yallakool Creek (15 September), 398 ML/day at Wakool River zone 2 site 4 on 13 September, 696 ML/day in Wakool River zone 3 (17 September), 652 ML/d in Wakool River zone 4 on 19 September. The maximum daily operating discharge of 600 ML/day was exceeded in zones 3 and 4.
		What did Commonwealth environmental water contribute to longitudinal hydrological connectivity?	Maintained longitudinal connectivity in zones 1, 2, 3, and 4 and Colligen Creek. Initiated flow in Black Dog Creek, connecting the upper Wakool River and Yallakool Creek.		
		What did Commonwealth environmental water contribute to lateral connectivity?	Increased the wetted area by an average of 10.2%, ranging from an increase of 3.7% in zone 2 site3 to 30.3% in zone 2 site 4.		
		What did Commonwealth environmental water contribute to hydraulic diversity?	Increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows.		

5 Water quality and carbon

Key findings	
Dissolved oxygen concentrations	The 800 ML/day flow trial in 2018-19 did not result in any adverse water quality outcomes. This action was deliberately timed for when water temperatures would be low and hence the risk of creating low DO conditions was reduced. DO concentrations remained normal for the time of year. Between 2014 and 2018 DO concentration was consistently higher during late summer and early autumn in zones 1, 3 and 4. Zones 1, 3 and 4 received more environmental water than zone 2. Zone 2 received minor to no amount environmental water. Higher than usual flows in zone 2 over the summer of 2018-19 demonstrated the potential to reduce the period over which this part of the Wakool River usually experiences low DO concentrations during hot weather.
Nutrient concentrations	The flow trial did not result in any adverse water quality outcomes. Total Phosphorus and Total Nitrogen were slightly elevated, likely due to greater turbidity (particles suspended in the water column) but bioavailable nutrient remained low. 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	The 800 ML/day flow trial in 2018-19 did not result in any adverse water quality outcomes. This action was deliberately timed for when water temperatures would be low and hence the risk of creating low DO conditions was reduced. Dissolved organic carbon was not elevated outside the normal range.

5.1 Background

Water quality is a key indicator of aquatic ecosystem health, and flow plays an important role in the maintenance of water quality in lowland rivers. Changes in flow in a river system can influence water quality both positively and negatively with the outcome dependent on the source of the water, magnitude and duration of the flow, time of the year and other catchment conditions. High flow events can result in exchange of nutrients and carbon between the river and the adjacent floodplain, and/or previously disconnected in-channel areas (Baldwin 1999; Baldwin and Mitchell 2000; Robertson et al. 2016) and environmental flows play a key role in restoring carbon exchange that has been lost due to extensive river regulation and modification of channel and bank features (Baldwin et al. 2016).

A range of parameters can be measured as indicators of water quality in river systems and many of these parameters are directly or indirectly influenced by alterations in flow. For example, dissolved oxygen (DO) can be influenced by flow through changes in water volume and turbulence, and through indirect processes such as alterations in rates of bacterial metabolism and photosynthesis. This, in turn, will directly influence the suitability of the water quality for aquatic organisms, such as fish. Nutrients and organic matter concentrations may be influenced by flow, either by dilution or through inputs associated with water contacting parts of the channel or floodplain which were previously dry and which have stores of nutrients and carbon in both plant materials and the soil (Baldwin 1999; Baldwin and Mitchell 2000).

Australian riverine ecosystems can be heavily reliant on both algal and terrestrial dissolved organic matter for microbial productivity and can be limited by dissolved organic carbon concentrations (Hadwen et al. 2010). Aquatic environments naturally have quite variable dissolved organic matter concentrations and there are no optimal concentrations or trigger values provided for organic matter (ANZECC 2000).

This chapter reports on changes in water quality in response to flows from 1 July 2018 to 30 June 2019 and will consider changes in both the quantity and type of organic matter present in the system. Specifically, this work will be addressing the questions in section 5.3.

The Commonwealth Environmental Water Office (CEWO) Long Term Intervention Monitoring (LTIM) Project concluded in June 2019 after 5 years. Therefore this report also brings the 5 years of water quality data together keeping in mind that this period has included both drought and flooding events that have influenced water quality in addition to the availability of Commonwealth environmental water.

5.2 Environmental watering actions targeting water quality outcomes

Two Commonwealth environmental watering actions were delivered in the Edward/Kolety-Wakool system in 2018-2019 (Table 5.1) to contribute to water quality. This report will consider water quality data up to April 2019. Water quality associated with the 2019 winter flow (commencing in May 2019) will be reported in the 2020 MER report.

Table 5.1 Commonwealth environmental watering actions in 2018-19 in the Edward Wakool River system that had objectives targeting water quality.

Watering action	Type of action	Dates	Rivers
Spring fresh	small fresh	22 Aug to 25 Sep 2018	Yallakool Creek, mid and lower Wakool River
2019 winter flow	base flow	Commenced 16 May 2019 (Ongoing)	Yallakool Creek, upper, mid and lower Wakool River, Colligen Creek-Niemur River

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 deliveries to the Edward/Kolety-Wakool River system on the water quality in the Wakool River and Yallakool Creek, we monitor a number of parameters at 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 2018-19 the key questions relating to the CEW actions were:

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

The remaining question was not addressed as these conditions were not present in the system:

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

5.4 Methods

Water temperature and DO 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 sites. 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 DO concentrations for each of the rivers from 1 July 2018 to 30 April 2019.

From July 2018 to April 2019 water quality parameters (temperature (°C), electrical conductivity (mS/cm), DO (%), pH, and turbidity (NTU)) were measured as spot recordings fortnightly at two sites within each river reach, and from Stevens Weir on the Edward River and the Mulwala Canal. Water samples were collected once per month from two sites within each zone, and from Stevens Weir on the Edward River, and the Mulwala Canal.

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

- Dissolved Organic Carbon (DOC)
- Nutrients (Ammonium (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.

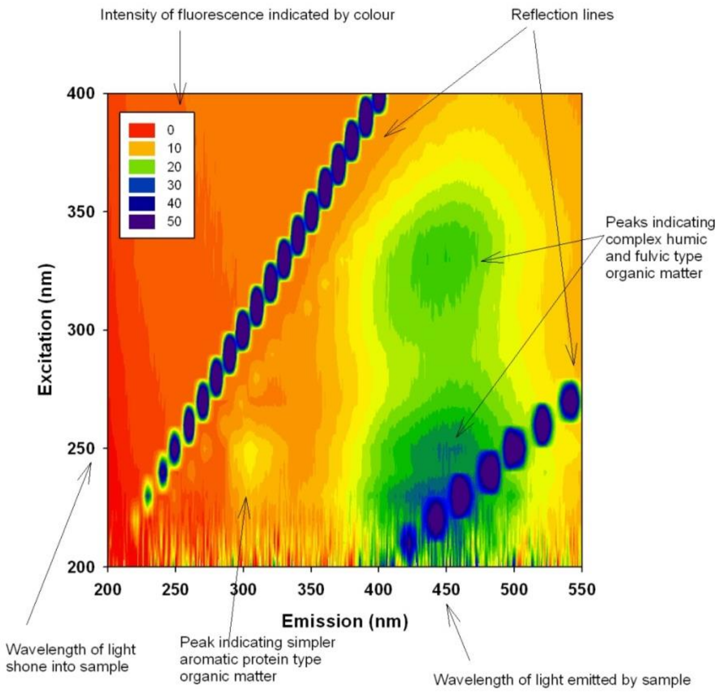


Figure 5.1 Sample excitation emission contour plot indicating key features of the data. (Watts et al. 2013)

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 variation in the 'normal' concentrations of organic carbon between ecosystems and also in the chemical and biological reactivity of the mixture of organic compounds making up the DOC and TOC at a particular site. Given the variable make-up of organic carbon, and the possible range of ecological responses to this mixture, a trigger level for this parameter would not be appropriate. However, trigger levels are provided for a number of nutrients and these are discussed below.

5.5 Results

Temperature and dissolved oxygen

The data collected by the loggers was used to calculate daily average temperature results and DO concentrations (Figure 5.2) for each site of the rivers from June 2018 to April 2019. Water temperature was very consistent across all sites with water temperatures exceeding 25 °C briefly during the summer and staying below 10 °C for several weeks during winter 2018. The results indicate that water temperature is influenced predominantly by seasonal rather than site-specific factors. There was no discernible effect of Commonwealth environmental watering action on water temperature, with all sites displaying the same seasonal variation and influence of weather patterns. This was consistent with the trend observed in previous years.

The plot of average daily DO concentrations in each hydrological zone (Figure 5.2) shows the expected seasonal variations with higher concentrations in the winter and lower concentrations correlating to the periods of higher water temperature.

Yallakool Creek (zone 1) and the Wakool River in zones 3 and 4 (all receiving base flows and small freshes of in-channel Commonwealth environmental water) were similar to each other throughout most of the study period, with slightly more variability observed during January and February. The Wakool River in zone 2 (shown in orange) had slightly lower DO than the other sites throughout the study period, which is common for this reach. In all cases a decline in DO was observed during the hotter months, as expected with the increased water temperature (which decreases oxygen solubility and increases the rate of many microbial processes).

The difference in DO concentration between zones does not reflect water temperature differences and likely reflects differences in input of oxygenated water from upstream and different rates of re-aeration and oxygen consumption associated with flow. Concentrations of DO in the Wakool River zone 2 briefly dropped into the range of concern to fish populations (below 4 mg/L) during mid to late January 2019. While this reach regularly has daily minimum concentrations that drop briefly below 4 mg/L between November and February, no values below 2 mg/L were recorded. It is common for DO to be lower in zone 2 Site 4 than the other study sites during summer when discharge is much lower at this reach. The difference between zone 2 and the other study zones was less in 2018-19 than was commonly observed in other years (Figure 5.3) and the period where DO was close to 4 mg/L was shorter, likely due to the higher discharge in this zone than in previous years. Typically flow is extremely low in this zone over the summer, and while Commonwealth environmental water was not the source of the additional flow in the 2018-19 summer, the higher than usual flow conditions demonstrate that there is potential to use Commonwealth environmental water to improve water quality in this part of the system in the future.

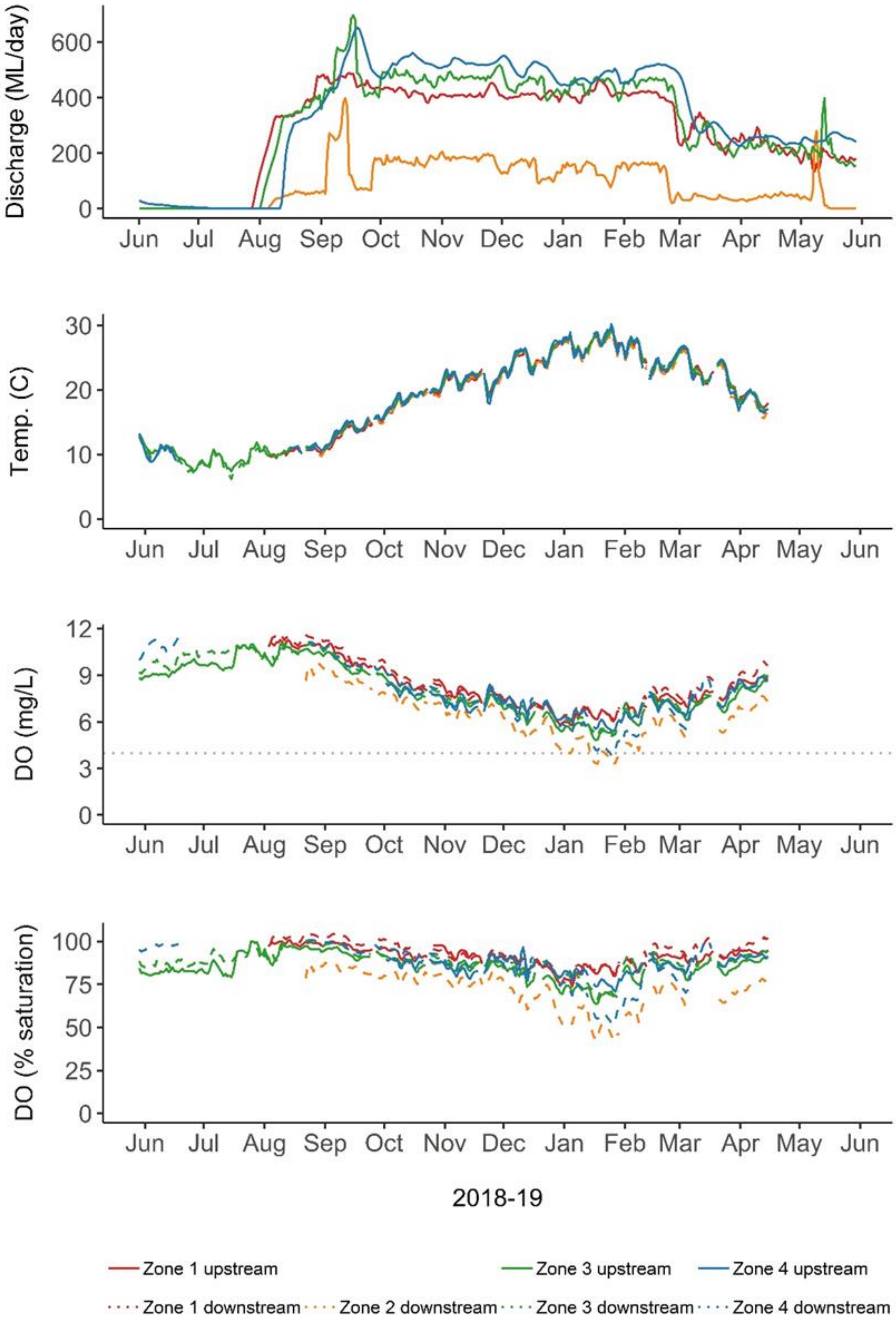


Figure 5.2 Daily average temperature results and daily average DO concentrations in four hydrological zones of the Edward/Kolety-Wakool River system in the 2018-19 watering year.

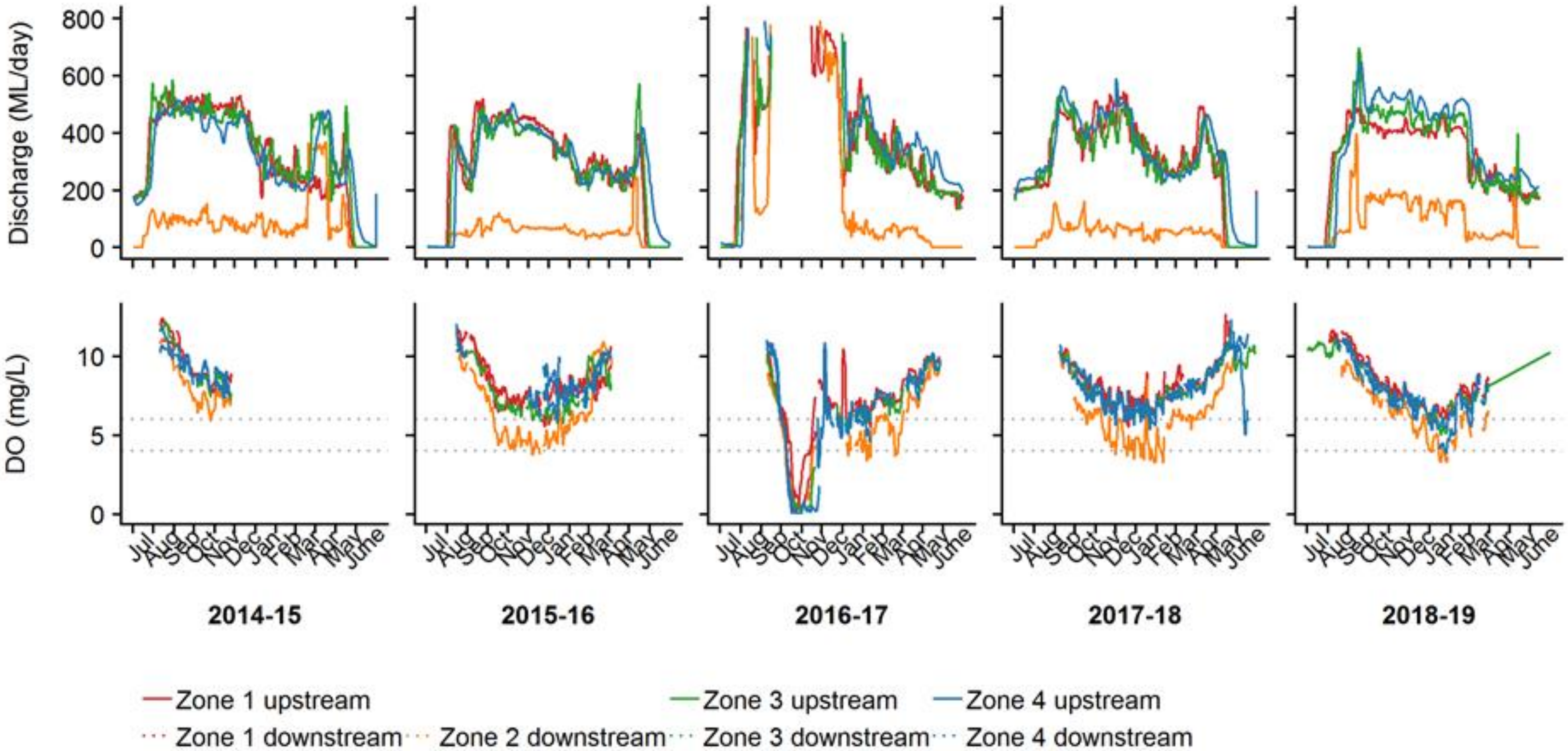


Figure 5.3 DO concentrations across study sites from July 2014 to June 2019.

Spot water quality parameters

Spot water quality parameters (electrical conductivity (EC), turbidity and pH) remained stable and within the normal range for this system throughout the study period and were very similar to results from the 2014-15 and 2017-2018 sampling years (Figure 5.4).

The EC values at all sites were well below the ANZECC (2000) trigger levels on all sampling dates. The increase in EC values sometimes observed in the upper Wakool River zone 2 during autumn was not observed in the 2018-19 water year and the relatively stable water levels during this period may have reduced the impact or amount of groundwater seeping into the system which was hypothesised to be the source of this increase in some years. A slightly higher EC value was recorded in spring 2018, when flow in zone 2 was recommencing and water levels were low.

Turbidity measurements were generally above the ANZECC (2000) trigger level but within the range commonly observed in the 2014-15 and 2017-2018 sampling years.

Most pH values were within the acceptable range throughout the year and values were very similar between sites. The greater range of pH results observed towards the end of the water year may reflect declining instrument performance and are not of concern.

Nutrients

Total Nitrogen (TN) concentrations during 2018-19 were similar to the concentrations recorded in previous years, with the exception of the periods of the cyanobacteria bloom in 2015-16 and the unregulated overbank flooding in 2016-17 (Figure 5.5). In 2015-16 an increase in TN was observed following the onset of bloom conditions because the dominant species of cyanobacteria (*Chrysosporum ovalisporum*) can fix nitrogen from the atmosphere. The 2016-17 flood also resulted in a considerable increase in TN above the baseline concentrations, but not as high as during the cyanobacteria bloom. During 2018-19 Yallakool Creek zone 1 had its highest TN in July 2018 and the TN pulse in the Wakool River zones 2, 3 and 4 occurred in August 2018 and then reduced. After the watering action, TN concentrations fluctuated above and below the ANZECC trigger value of 0.5 mg/L. There was generally lower concentrations in Yallakool Creek zone 1 than in Wakool River zones 2, 3 and 4, suggesting a slight increase in TN as the water progresses through the system.

The NO_x forms of bioavailable nitrogen remained below the trigger levels and was similar to previous observations under normal conditions. The high ammonia values in the Wakool River system on two occasions were only in zone 4 and could possibly be due to ammonia introduced from a disturbance upstream or disturbance of the sediments while sampling.

There were some small water pulses at the end of the water year, and both TN and TP were increased in zone 4 during that period which might have been associated with higher turbidity (suspended particles keeping adsorbed nutrients in the water column).

Bioavailable phosphorus remained at the very low concentrations normally seen in this system in the absence of extensive overbank flooding (Figure 5.6). Total phosphorus (TP) routinely exceeds the ANZECC (2000) trigger level but remained within the normal range observed in this system with the exception being the periods of algal bloom and hypoxic blackwater water. The dominant species of cyanobacteria (*Chrysosporum ovalisporum*) is known to be an efficient scavenger of phosphorus, and TP was observed to increase slightly in the water column during the algal bloom in 2015-16. The largest input of phosphorus, especially the bioavailable form FRP, into the system occurred during the flood in 2016-17. The pattern observed for TP was similar to TN. Yallakool Creek zone 1 had its highest TP in July 2018 and the higher input of TP in the Wakool River zones 2, 3 and 4 occurred in August and then reduced. The TP pulse in the Wakool River zones 2, 3 and 4 was possibly caused by in-stream processes during the watering action keeping particles suspended. TP concentrations generally increased downstream zone 1 <zone 3 <zone 4. Zone 2 had higher concentrations over the watering action period and after the watering action the TP concentrations dropped (Figure 5.6). This is consistent with the pattern in TN.

Dissolved organic carbon and organic matter characterisation

In 2018-19 dissolved organic carbon (DOC) concentrations remained in the range of concentrations normally observed in this system in the absence of overbank flows or excessive algal growth (Figure 5.7). The overbank flood in 2016-17 introduced considerable quantities of DOC into the river system, resulting in concentrations well above those measured during the algal bloom in 2015-16.

During 2018-19 DOC did not enter the range previously associated with hypoxic blackwater, although a pulse of dark coloured water was observed in the system in late January (See images of zone 2, Figure 5.8). This corresponds with a slight increase in DOC concentrations but these remained within the normal range. The timing of this pulse corresponds with the lowest DO concentrations observed over the water year, although these were within the range normally measured at that time of year (Figure 5.2). It is noted that the upstream site in the Yallakool Creek (zone 1) has lower DOC than the downstream site in this zone, however the results remain within the scatter of concentrations observed for the other sampling sites. This likely indicates that the pulse was of very brief duration and had already begun to clear from the top of the system at the time of sampling. Small inputs of DOC to the river can help with supporting microbial productivity which become available food for aquatic organisms such as fish. Increased algal growth over the summer was insufficient to produce a substantial increase in the dissolved fraction of the organic matter in these river systems. Note that DOC increases in zones do not all occur at the same time. This suggests there may be local sources of DOC at times during this study period, possibly due to water that was in backwaters or on low lying benches during the higher summer flows draining back into the river system.

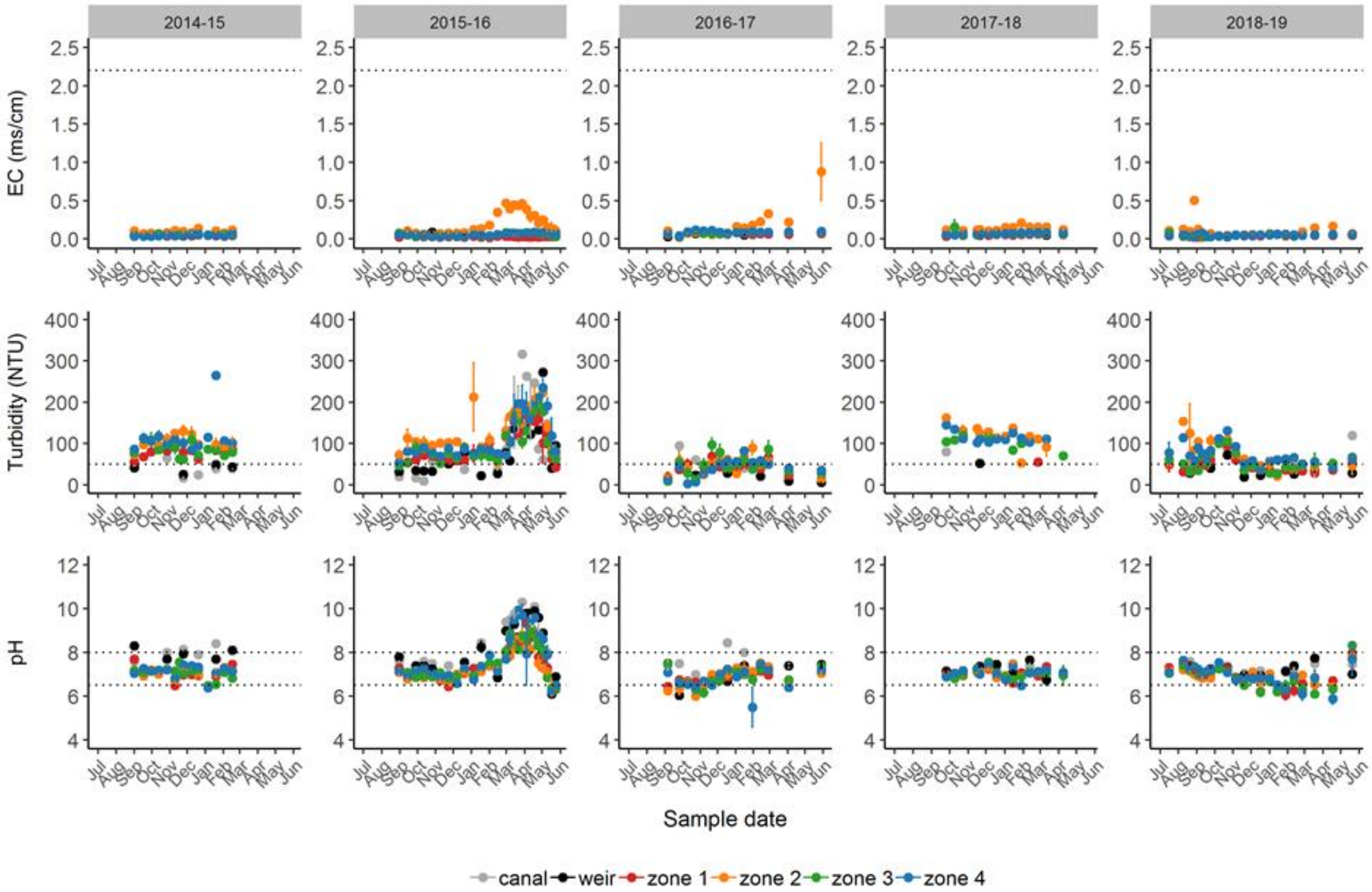


Figure 5.4 Electrical conductivity (EC), turbidity and pH for LTIM sites and source water over the 2014-15, 2015-16, 2016-17, 2017-18 and 2018-19 water years in the Edward Wakool system.

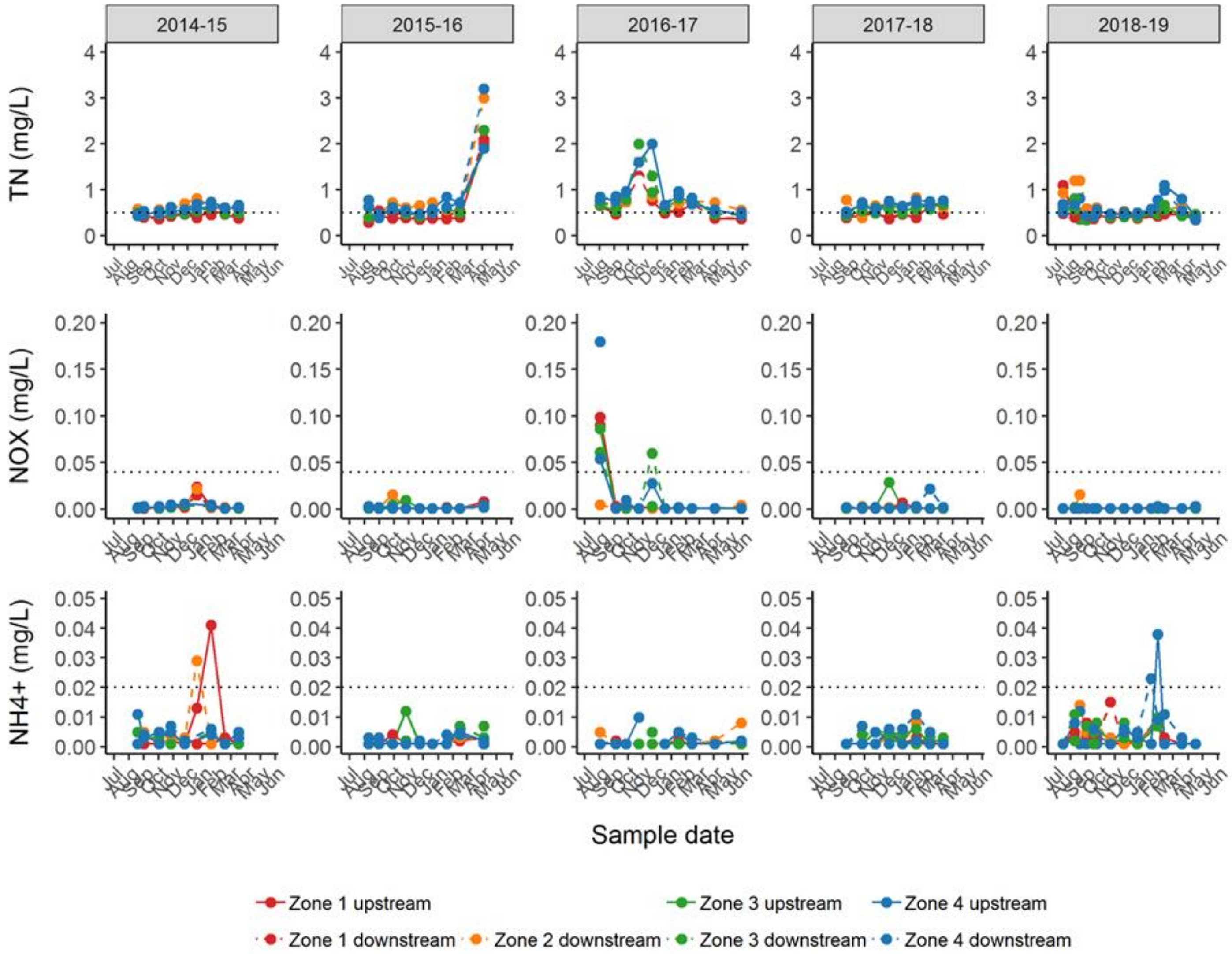


Figure 5.5 Nitrogen concentrations at LTIM study zones for the 2014-15, 2015-16, 2016-17, 2017-18 and 2018-19 study periods in the Edward/Kolety-Wakool system.

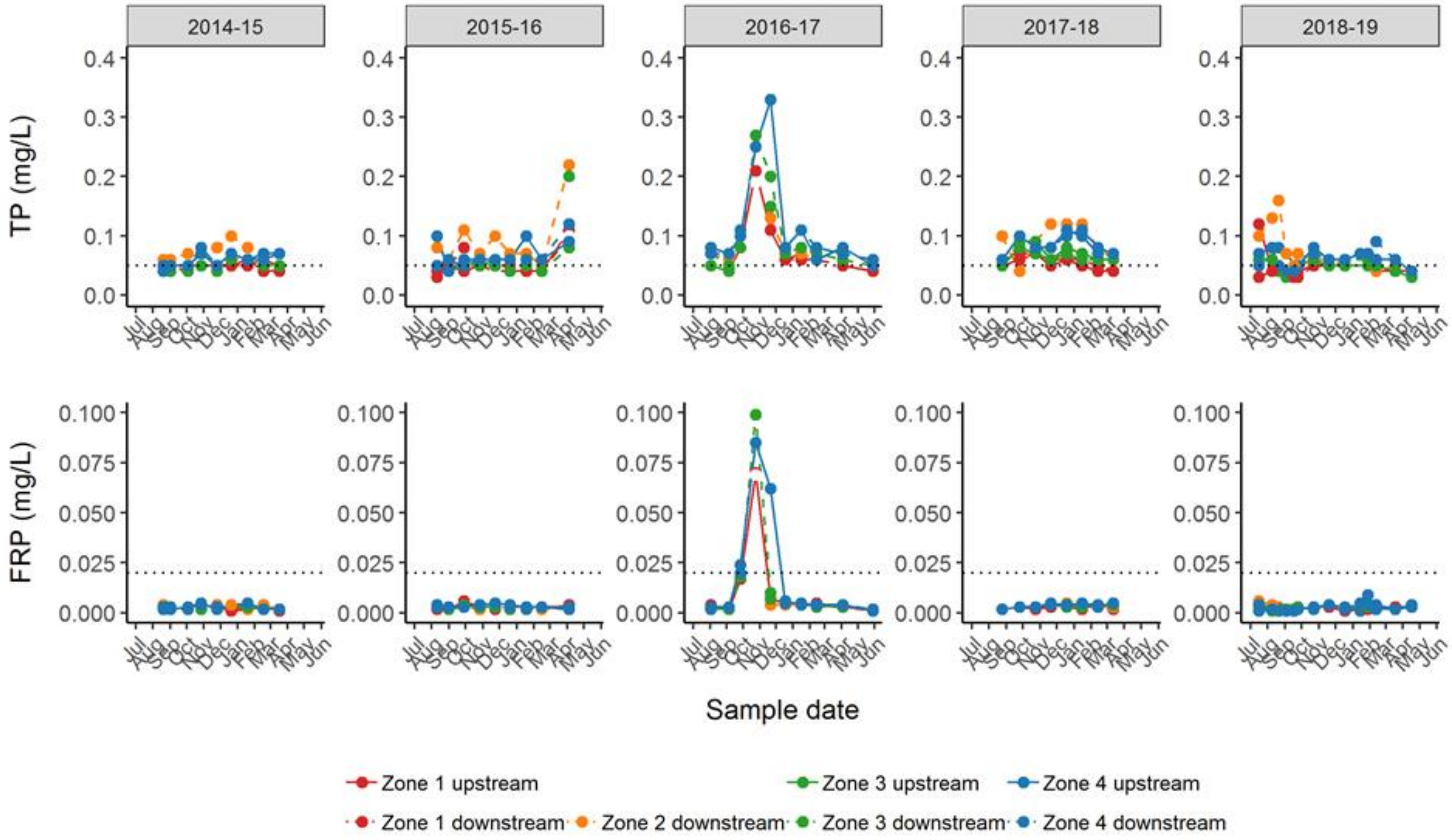


Figure 5.6 Phosphorus concentrations for the LTIM sites in 2014-15, 2015-16, 2016-17, 2017-18 and 2018-19 study periods in the Edward/Kolety-Wakool system.

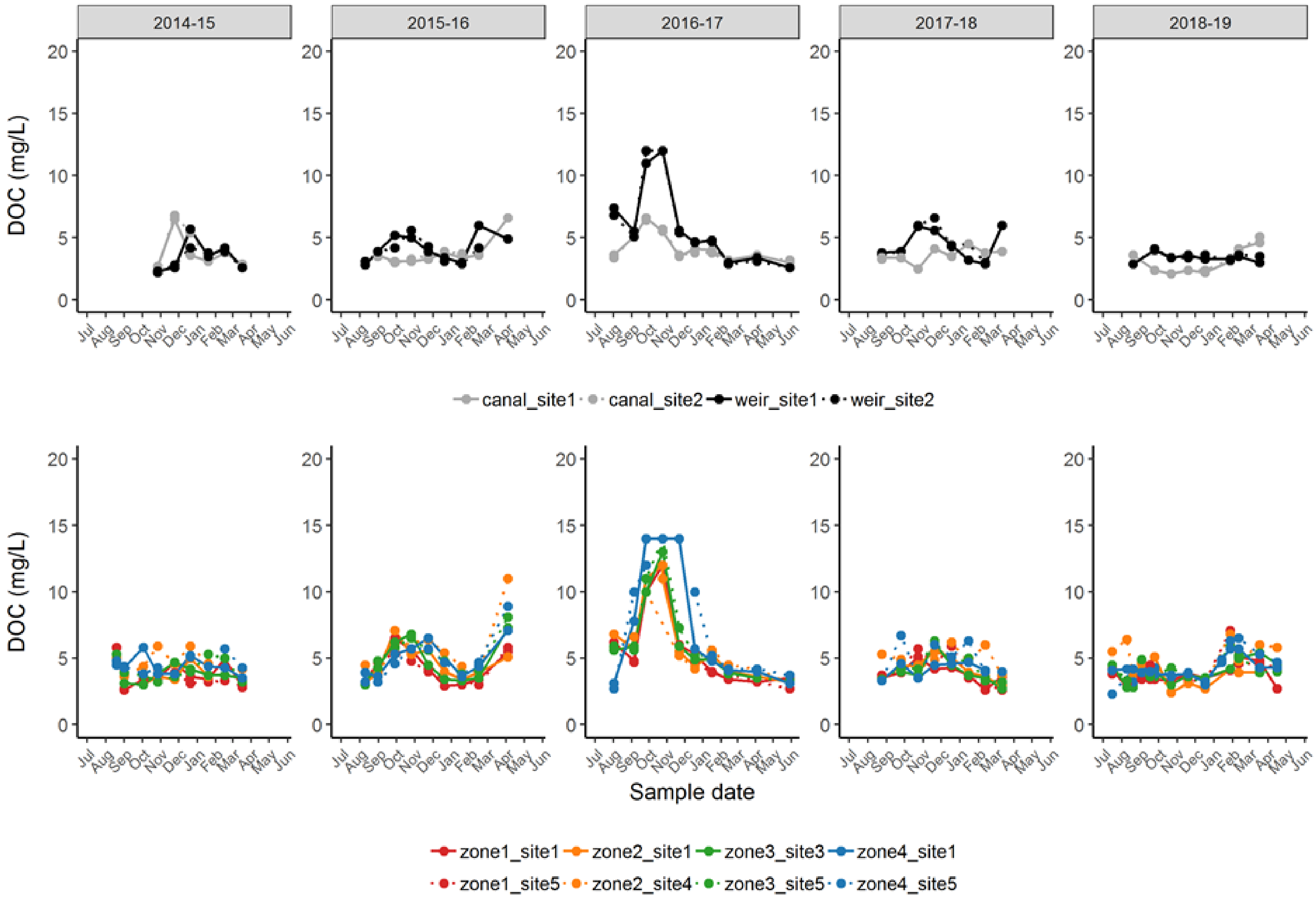


Figure 5.7 DOC concentrations for the Edward/Kolety-Wakool LTIM sites in 2014-15, 2015-16, 2016-17, 2017-18 and 2018-19.

Figure 5.8 Dark water passing through the upper Wakool River zone 2 Site 2 and zone 2 Site 5 on 31/1/2019

Organic matter characterisation - Absorbance

Absorbance scans (Figure 5.9) indicate that throughout most of the 2018-19 water year the mixture of organic compounds making up the DOC was fairly consistent across sites with no clear upstream/downstream trends in variation between the scans. In September 2018 during the flow trial all sites were extremely similar to the source water. In November 2018 the upper Wakool River zone 2 most closely resembled the organic matter profile of the canal and the other zones were more similar to the Edward River, although the differences were minimal. Over the summer slightly more variation between sites was observed particularly for zones 2, 3 and 4. In January the absorbance scans show the elevated organic matter in both zones 2 and 4, with the downstream site in zone 3 also more similar in profile to these sites than zone 1 and the upstream site in zone 3. In February the downstream sites in zone 2 and 3 group with the zone 4 sites while the other sites all group with the source water but by March absorbance has decreased and all sites are similar.

Organic matter characterisation - Fluorescence

Fluorescence excitation- emission matrices for water samples at all sites through the sampling period (Figure 5.10) indicate that the organic matter mix was similar across zones across the 2018-19 water year. In September 2018 the higher discharge during the flow trial did not result in a change in water quality.

Variation among zones was evident in January 2019, especially for zones 2, 3 and 4. This is consistent with the observations for other water quality parameters. Comparison between the zone 2 site 4 (downstream) site and the zone 3 site 5 and zone 4 sites suggest that there are differences in the organic matter mixture at these sites. In zone 2, where the dark water was observed, the fluorescence is present as a number of broad peaks distributed across the region between the two blue scatter lines. This is suggestive of a mixture of humic and fulvic substances and smaller fluorescent molecules, possibly a combination of aged organic matter and very fresh leachates or algal organic matter. Zone 3 has a similar distribution of peaks, but is stronger at the downstream site. Zone 4 has fluorescence more heavily dominated by aged organic matter, possibly suggesting floodplain organic matter inputs (e.g. reconnection of a billabong or low lying floodplain). Fluorescence gradually decreases from late summer through to autumn 2019 (Figure 5.10).

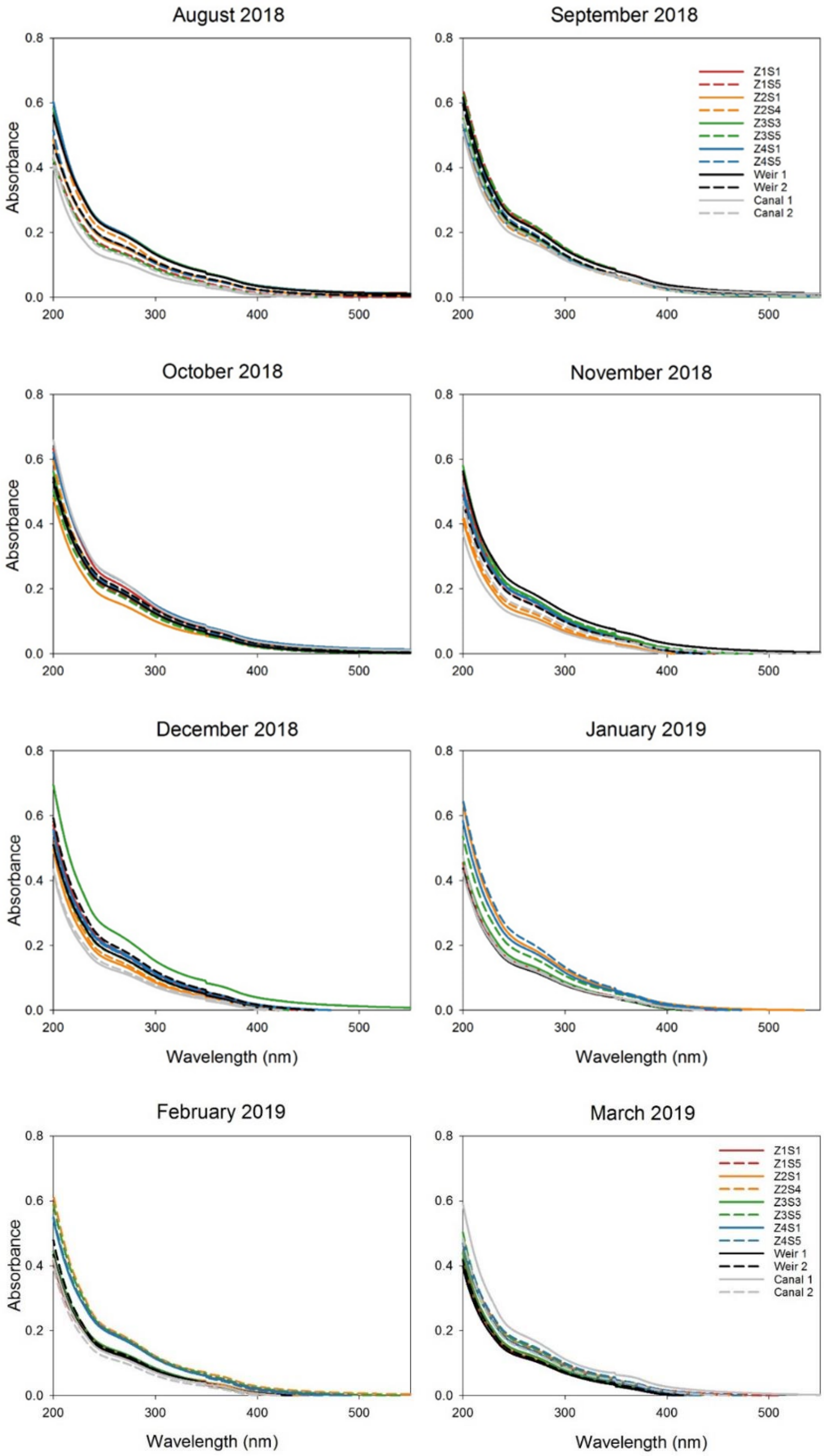


Figure 5.9 Absorbance of water samples at LTIM sites in 2018-19.

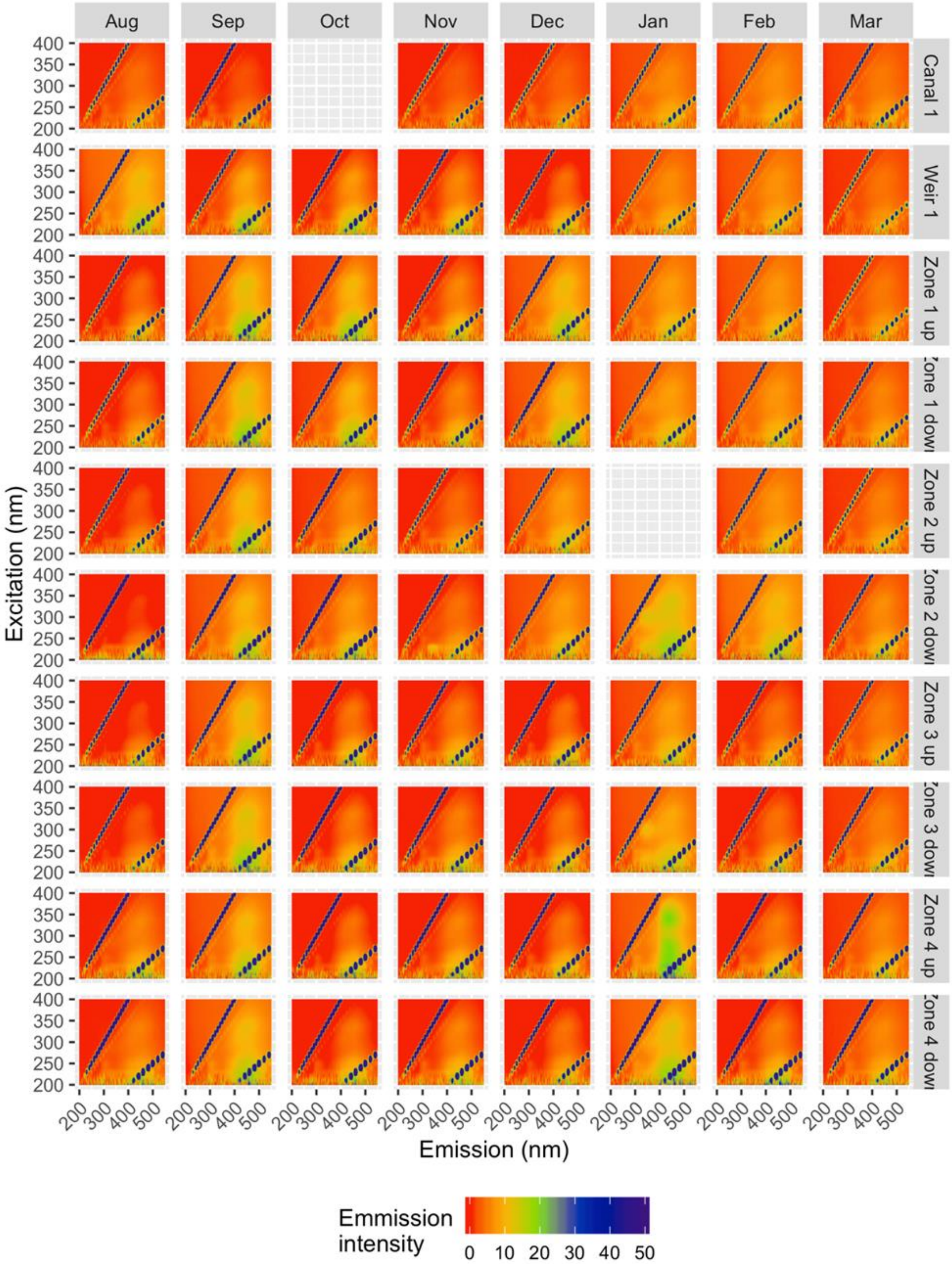


Figure 5.10 Fluorescence scans of water samples from LTIM sites in 2018-19 study season.

Broader system observations

Additional water quality data is available for the broader Edward/Kolety-Wakool system through the WaterNSW hydrographic stations. The DO logger in the Niemur River on the Barham Moulamein Rd shows that DO declined to below 5 mg/L during a period of very high temperature in late January 2019, and this trend reversed as water temperatures cooled with a change in the weather conditions (Figure 5.11). A logger at the Niemur Mallan School gauge shows a similar DO/temperature relationship (Figure 5.12), although the DO concentrations were not quite as low at this downstream site as at the gauge in the Niemur River at Barham Moulamein Rd. Corresponding DOC data is not available to match with these DO observations, however an additional fluorescence sample collected in the Niemur in late January indicates that DOC was within the range found at the other sampling sites (data not shown).

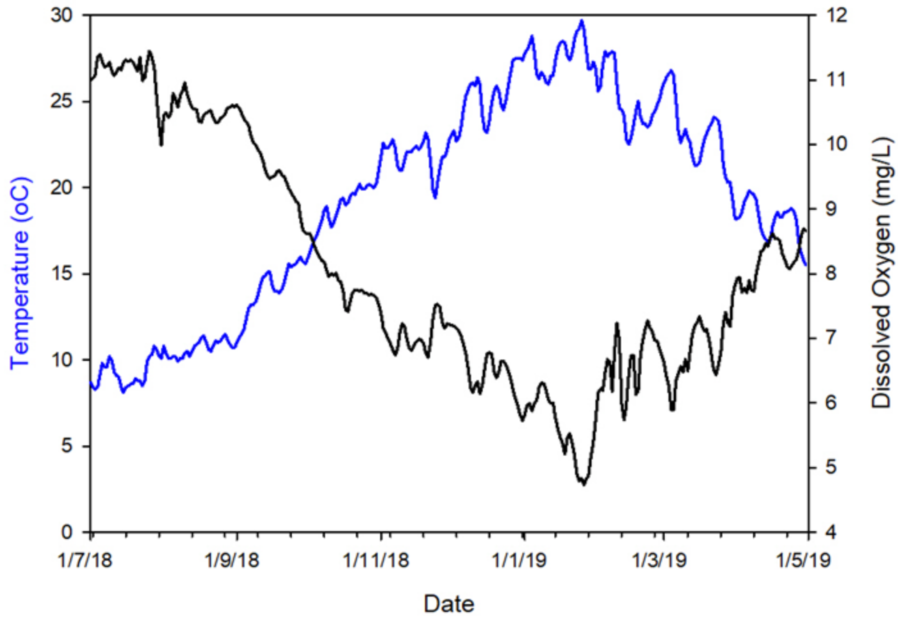


Figure 5.11 Dissolved oxygen concentration (mg/L) and temperature (°C) in the Niemur River at the Barham Moulamein Rd (Data: Water NSW).

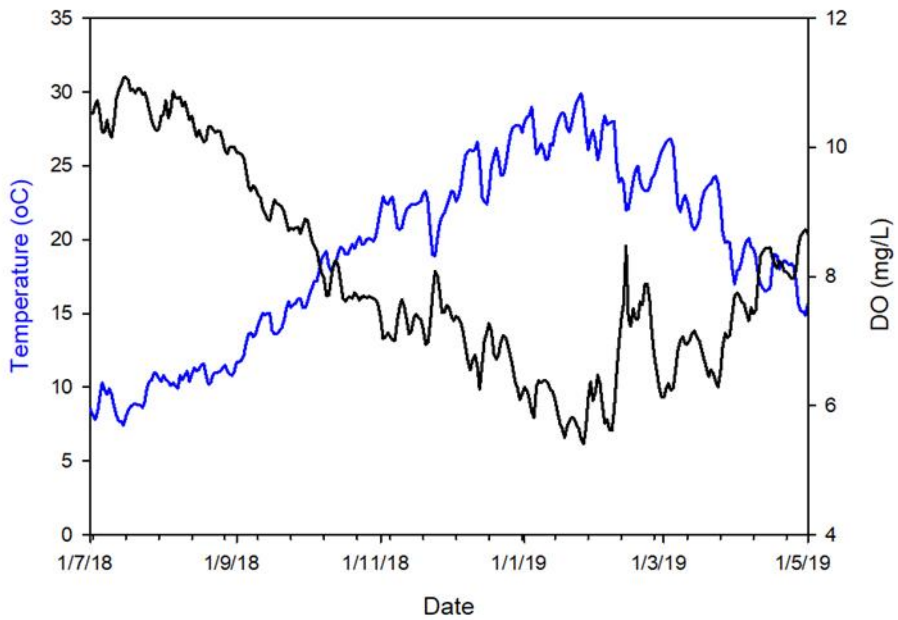


Figure 5.12 Dissolved oxygen concentration (mg/L) and temperature (°C) in the Niemur River at Mallan School (data: Water NSW).

During the summer Thule Creek was not flowing and a period of high temperature resulted in a decline in DO in the pooled water (Figure 5.13), but from a relatively high starting point, suggesting the presence of an algal bloom in the still water. DO declined to below 4 mg/L in this part of the system in autumn 2019.

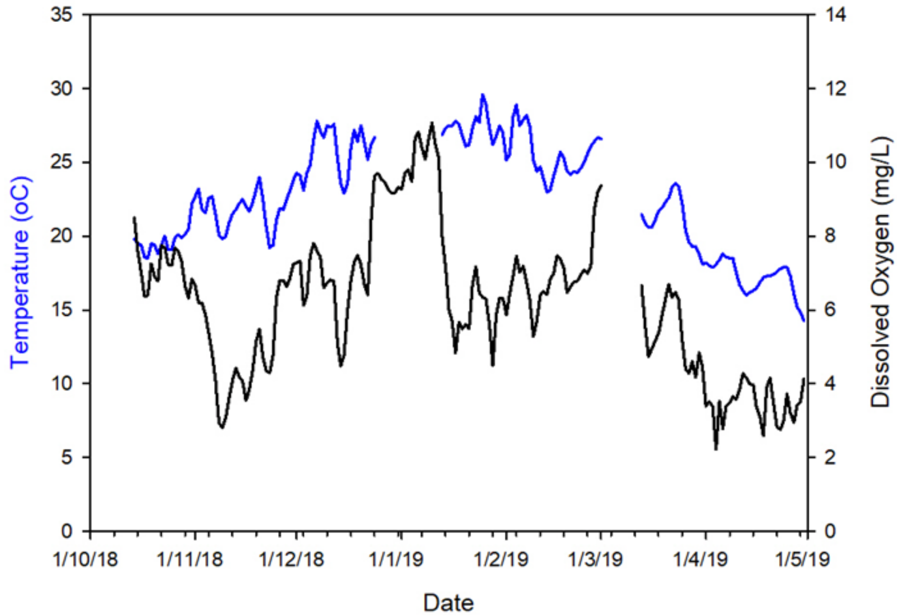


Figure 5.13 Dissolved oxygen concentration (mg/L) and temperature (°C) in Thule Creek. (Data: NSW DPI, Waterinfo.gov.au)

5.6 Discussion

Short-term evaluation questions

Overall the water quality in the Edward/Kolety-Wakool Selected Area during the 2018-19 water year was characterised by normal conditions (similar to 2014-15 and 2017-18) following two extreme events (the 2015-16 cyanobacteria bloom and the 2016-17 hypoxic blackwater event). Returning to the questions associated with the impact of the 800 ML/day flow trial environmental watering action on the Edward/Kolety-Wakool system, it is clear that the impact on water quality parameters of this action was variable and in most cases very small.

In 2018-19 the key questions relating to the CEW actions were:

- *What did Commonwealth environmental water contribute to DO concentrations?*

  The 800 ML/day flow trial watering action commenced from August to September 2018 in Yallakool Creek, and the mid- and lower Wakool River. Dissolved oxygen in all zones was well within the normal range throughout this flow, as was anticipated with a flow of this size during cooler months. The DO concentrations in the Wakool River zone 2 were slightly lower than the concentrations at all other study sites throughout the flow trial watering action, however this is commonly observed in this zone. This difference persisted beyond the end of the watering action. The DO concentration was consistently higher during late summer and early autumn in zones 1, 3 and 4 than in zone 2. The low-flow (less discharge) conditions in zone 2 result in lower DO concentrations, however this was less prolonged than in previous years. The generally lower flow in zone 2 means the risk of temperature induced hypoxia during heatwaves is greater in this part of the system. This finding corresponds to the notably higher rates of ER in this zone (see section 6), which results in DO drawdown, especially overnight. As discussed in section 6, the higher rates of ER in Zone 2 are not driven by higher DOC concentrations, but are influenced instead by the shallower water depth, and respiration on and within the organic carbon rich surface sediments.

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

  Nutrient concentrations remained within the expected range throughout the Edward/Kolety-Wakool River system during the 2018-19 water year. 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 800 ML/day flow trial watering action. The Yallakool Creek zone 1 had its highest TN and TP in July 2018 and the higher concentration of TN and TP in the Wakool River zones 2, 3 and 4 occurred in August 2018 and then reduced. The TN and TP pulses in zones 2, 3 and 4 were possibly caused by higher turbidity and in-stream processes during the watering action. TN and TP were generally higher in the Wakool River zone 2 during the 800 ML/day flow trial, suggesting either dilution of these nutrients by Commonwealth environmental water at the other study zones, or that conditions in zone 2 favoured the retention of nutrients associated with organic matter or particulates (e.g. algal cells) within the water column. Bioavailable nutrients were similar across study sites and do not appear to have been influenced by Commonwealth environmental water.

- *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 2018-19. The type and amount of DOC in the system was similar to previous years where blackwater and major algal blooms were not present. It is noted that the downstream site in the Wakool River zone 2 had higher DOC between July and August 2018.

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

  Commonwealth environmental water was not observed to affect temperature regimes within the system, with all study zones having very similar water temperatures. Water temperatures in the system were primarily controlled by the prevailing weather conditions. No specific flow targeted was designed to change water temperature, although the timing of some watering actions was heavily influenced by the need to target particular water temperatures, for example to avoid periods of high temperature which can reduce oxygen concentrations, particularly if organic carbon is mobilised by a higher flow pulse. Winter watering actions were designed to examine responses during the cooler part of the year. In 2018-19 the water temperatures in the Edward/Kolety-Wakool River system were similar across 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.

The remaining question was not addressed as these conditions were not present in the system because the conditions required to generate blackwater were not present in the Edward/Kolety-Wakool River system during this water year.

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

Long-term evaluation

The types of water quality parameters monitored in this study tend to respond very quickly to changes in flow and the delivery of Commonwealth environmental water. As a result, there are no specific long term evaluation questions for water quality. However, we can consider the general trends in water quality and the use of Commonwealth environmental water over the study period.

Considering the range of flows observed over the five years of this project, it is evident that input of nutrient and organic matter relies on the larger overbank flows (in this period these were unregulated flows) and that the smaller in-channel pulses do not have a lot of impact on water quality. An exception to this is that increasing flows within channel in the summer may be used to address short term DO declines during heatwave conditions. The increased operational flows in zone 2 during the summer of 2018-19 demonstrates that the use of environmental water in this zone has the potential to decrease the period of low DO commonly observed in this part of the system during summer.

Commonwealth environmental water has been used to create small areas of refuge during large-scale adverse water quality events, but the scale of the events and the amount of environmental water available means that it is not possible to prevent or fully mediate poor water quality events throughout the system. Delivery of environmental water through either the river network or via irrigation infrastructure provides a critical ability to add water of differing water quality to the system, depending on the water quality conditions within each source and the needs of the broader system at the time. Coordinated delivery of environmental water through other parts of the system (e.g. Millewa Forest or Koondrook/Perricoota Forest) has the potential to introduce DOC and nutrients into the Edward Wakool system and boost in productivity, provided there is appropriate dilution capacity within the river system and the timing of such flows is carefully managed.

Links to other indicators

Water quality and river flows are fundamentally linked. Water quality can be positively and negatively influenced by river flows and this can directly or indirectly influence productivity, aquatic vegetation and aquatic organisms including fish.

Inputs of DOC into river systems from small flow pulses can be beneficial for the river ecosystem. For example, a spring fresh delivered between August and September 2018 contributed small inputs of DOC that would help support microbial productivity and in turn provide food for higher aquatic organisms such as fish. High flow events can result in exchange of large amounts of nutrients and carbon between the river and the adjacent floodplain (Baldwin 1999; Baldwin and Mitchell 2000; Robertson et al. 2016) and can have positive or negative outcomes. Under certain temperature and flow conditions the input of DOC from large scale events can have the positive outcome of increasing productivity in the river ecosystem. Large scale events also have the potential to result in negative outcomes. For example, an extensive unregulated overbank flooding event in 2016 inundated the Edward/Kolety-Wakool floodplain (including forested areas, cropping and grazing land and urban areas) and introduced considerable quantities of DOC into the river system, causing a widespread hypoxic blackwater event that resulted in the death of native fish.

The turbidity of the water under different types of flows can also influence the river ecosystem. Light penetration into the water column is inhibited by high concentration of fine suspended particulate matter, which will decrease the PAR available for photosynthesis by benthic algae, aquatic plants, and to a lesser extent phytoplankton, thus influencing the productivity and biodiversity of the river system. In the Edward/Kolety-Wakool system turbidity levels range between 40-300 NTU, with highest levels of turbidity observed during the cyanobacteria bloom in 2015-16 and during higher unregulated flows. As noted in section 6, there can be increased productivity under a range of different flow actions, and this will be influenced by the turbidity of the water.

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 spring watering action (small fresh) in Yallakool Creek and mid- and lower-Wakool River 22nd August to 25th September 2018	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 DO concentrations?	DO concentrations were higher in zone 2 than in previous year	Logged DO concentrations	yes
		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.

6 STREAM METABOLISM

Key findings	
Gross Primary Production (GPP)	The 800 ML/day watering action had a beneficial effect on the total amount of primary production (more 'food' is better). Commonwealth environmental water increased organic carbon production in zones 1 to 4 by 36%, 134%, 71% and 38% compared to operational flows. By calculating rates of primary production that would have occurred at lower flows we estimate CEW added an additional 7.27 tonnes of organic carbon to the 13.9 tonnes generated by GPP without the CEW; an overall increase of 52%. This translates to a significant increase in energy available to support aquatic foodwebs. Across all watering actions from 2014 to 2019, the size of the beneficial impact was largely related to the proportion of total flow that came from the watering action rather than the source of water. Carbon production was enhanced by between 0% and 330% over the ten watering actions assessed between 2014 and 2019, with a sum over all zones and watering actions of 52% more carbon produced compared to no Commonwealth environmental water being delivered. This is an important outcome given that competition for food resources can be a significant factor limiting the growth and survival of fish and other aquatic animals.
Ecosystem Respiration (ER)	As with GPP, the 800 ML/day watering action almost uniformly decreased the rates of ER when expressed as mg O_2/L/Day, simply through dilution. However, when ER was calculated as the amount of organic carbon consumed per day (kg C/day), then watering actions have a beneficial effect, with significant differences between sites. Increased flows from Commonwealth environmental water, resulted in increases in the amount (load) of organic carbon consumed, hence enhanced nutrient recycling. A higher amount of organic carbon consumed means more nutrient recycling and hence greater nutrient supply to fuel GPP. At no stage did the watering action create so much respiration that DO dropped below safe values for aquatic biota.

6.1 Background

Whole stream metabolism measures the production and consumption of DO gas, which occurs as a result of 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 and to recycle nutrients to enable growth to occur. Hence metabolism assesses the energy base underpinning aquatic food webs. The relationships between these processes are shown in Figure 6.1.

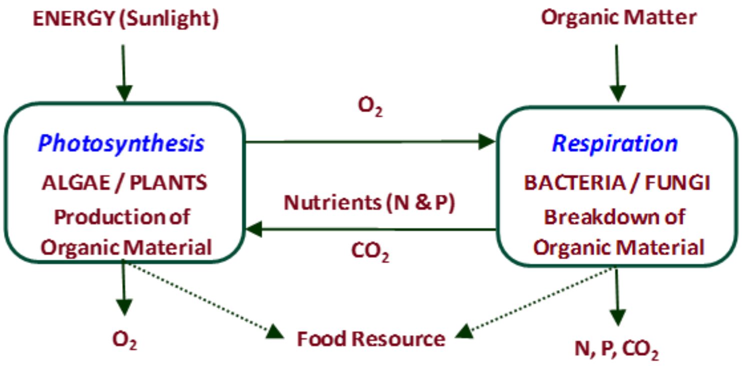


Figure 6.1 Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients

Metabolism is expressed as the increase through photosynthesis or decrease through respiration of DO concentration over a given time frame; most commonly expressed as the change in milligrams of DO per litre per day (mg O_2/L/Day). Typical rates of primary production and ER 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 ER (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 DO 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 higher concentrations of nutrients 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/Kolety-Wakool system.

This chapter reports on stream metabolism in response to flows in the 2018-19 water year and will consider changes in GPP and ER in the system.

6.2 Environmental watering actions in 2018-19

Two commonwealth environmental watering actions were delivered in the Edward/Kolety-Wakool system in 2018-19 (section 2). The response of stream metabolism to the first of these watering actions in the Wakool-Yallakool system (Table 6.1) was evaluated. The second action (planned watering action #5) commenced after logger removal in April 2019 and hence was not monitored during 2018-19.

Table 6.1 Commonwealth environmental watering actions in 2018-19 in the Edward Wakool River system. The winter flow action continued into the 2019-20 water year and will be evaluated in the 2019-20 annual report.

	Watering action	Action	Dates	Rivers
1	Spring fresh	small fresh	22 August to 25 September 2018	Yallakool Creek, mid- and lower Wakool River, Colligen-Niemur River
5	2019 winter flow	base flow	Commenced 16 May 2019 (Ongoing)	Yallakool Creek, upper, mid- and lower Wakool River, Colligen -Niemur River

6.3 Selected Area questions

Evaluation of the response of stream metabolism to Commonwealth environmental watering is being undertaken in the Edward/Kolety-Wakool River system at the i) Selected Area scale (Watts et al. 2014a), 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/Kolety-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 food web 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 GPP and ER in the Edward- Wakool River system, both at the short term and longer term scales?

The following hypotheses were developed, partially based on previous work in the Yallakool Creek – Wakool River system (Watts et al. 2014b), 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.
- 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 2018-19 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 2018-19).
- Primary production in the Edward/Kolety-Wakool system will be limited by low phosphorus concentrations.

As well as measuring the rates of photosynthesis and respiration (expressed in terms of the amount of carbon fixed or respired per litre of water) it is also important to consider how the total amount of carbon fixation and respiration vary, which is influenced by both the rates of fixation and respiration together with the total volume of flow. In general, as flows increase (as occurs through environmental watering actions), rates of carbon transformation tend to decrease per unit volume of water, but at an ecosystem level these reduced rates can be more than offset by the increase in discharge.

In addition to evaluating these hypotheses, we have examined rates of primary production at a whole of system level, by using the rates estimated from the field measurements of DO dynamics to quantify the total amount of carbon being produced each day. We have also extended these calculations to derive estimates of production likely to have occurred in the absence of Commonwealth environmental watering actions.

6.4 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 DO 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 DO concentrations (see Section 5) for each of the zones. For zones 3 and 4, logger deployment was from May 2018 (to complete a full winter data set encompassing June to August 2018) to mid-April 2019. For zones 1 and 2, the intention was to sample from mid-July 2018, but some problems with logger retrieval at the end of Year 4 and an accidental failure to restart the logger recording meant that for these two zones, data was collected from mid-August 2018 onwards. Logger deployment periods are summarised below in Table 6.2.

In accord with the LTIM Standard Protocol, water quality parameters (temperature (^oC), electrical conductivity (mS/cm), DO (%), 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 that 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. The 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 and the inherent uncertainty in both discharge and daily metabolism, concern over the exact value used for conversion efficiency at this stage is unwarranted.

Modelling rates of GPP with and without CEW

To assess productivity outcomes under different watering scenarios we developed predictive models relating rates of GPP (also referred to as productivity) to discharge, light and temperature. Overall, the model suggests that increasing flow has a weak but negative effect on GPP, while light and temperature both have positive effects. Having determined this relationship between GPP and the three predictor variables, the model was used to generate predictions of daily GPP under both the observed flow scenario (i.e. the flows that occurred in the river from 2014-2019), and a ‘without CEW’ scenario, in which the CEW water volumes were removed from each day in the time series.

6.5 Results

Stream metabolism 2018-19

Discharge during 2018-19, like 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. Estimates of GPP and ER for the 7 sites in 2018-19 were produced using the BASEv2 model (updated from Grace et al., 2015 according to Song et al., 2016). Details of the logger deployments are given in Table 6.1.

Using the acceptance criteria for each day's diel DO curve, the acceptance rate ranged from a low of 29% of all days with data available (87 from 304 possible days) for zone 3 Upstream up to a high of 65% (136 of 210 possible days) at zone 2 Downstream. All acceptance data are shown in

Table **6.2**. A comparison is made with acceptance criteria from 2016-17 and 2017-18. The acceptance criteria in 2018-19 were similar to, but generally higher than 2016-17 but in all but one case (zone 1 Downstream) were significantly lower than 2017-18.

Table 6.1. Summary of Logger Deployments, May 2018 - April 2019.

Hydrological Zone	Site	First Deployed	Last day Deployed	Periods of Missing Data (> 1 week)
1 Yallakool Creek	Upstream	3/8/2018	15/4/2019	-
	Downstream	4/8/2018	15/4/2019	-
2 Wakool River	Downstream	22/8/2018	15/4/2019	-
3 Wakool River upstream Thule Creek	Upstream	29/5/2018	15/4/2019	-
	Downstream	29/5/2018	15/4/2019	-
4 Wakool River downstream Thule Creek	Upstream	29/5/2018	15/4/2019	18/6 – 13/8
	Downstream	29/5/2018	17/3/2019	19/6 – 22/8; 17 - 28/12

Table 6.2. Summary of data availability for the seven data logger sites, May 2018 - April 2019.

Hydrological Zone	Site	Total Days	Days with Acceptable Data	% Acceptable Days Year 5 (2018-19)	% Acceptable Days Year 4 (2017-18)	% Acceptable Days Year 3 (2016-17)
1 Yallakool Creek	Upstream	240	111	46	58	42
	Downstream	239	152	64	65	48
2 Wakool River	Downstream	210	136	65	77	30
3 Wakool River upstream Thule Creek	Upstream	304	86	29	75	30
	Downstream	304	127	42	75	37
4 Wakool River downstream Thule Creek	Upstream	239	127	53	66	17
	Downstream	206	71	35	79	35

Table 6.3 summarizes the daily metabolism results and the P/R ratio (ratio of oxygen produced by GPP to oxygen consumed by ER) for each site. Each metabolic parameter is expressed as a median and mean with minimum and maximum values also included. The median GPP values for all seven sites fall within a narrow range of 1.2 to 2.0 mg O_2/L/Day; similar behaviour (but a slightly larger range of 1.5 mg O_2/L/Day) was found in 2017-18. This closeness in median GPP rates is unsurprising given the similarity in the biogeochemical environments as noted in previous years (Watts et al. 2015, Watts et al. 2016, Watts et al. 2017b, Watts et al. 2018). As in previous years, it is likely that the GPP rates were constrained by the very low bioavailable nutrient concentrations (see Figures 5.4 and 5.5) in conjunction with light penetration attenuated by suspended particulate matter, as indicated by the turbidity values at or well above 40 NTU.

Table 6.3. Summary of gross primary production (GPP) and ecosystem respiration (ER) rates and P/R ratios for the seven sites in four hydrological zones, May 2018 - April 2019. 'n' is the number of days for which successful estimates of metabolic parameters were obtained.

	Zone 1 Upstream (n = 111)				Zone 1 Downstream (n = 152)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	1.53	1.91	0.47	10.2	1.53	1.75	0.48	7.80
ER (mg O_2/L/Day)	3.35	4.35	0.62	17.9	3.16	3.29	0.06	9.86
P / R	0.48	0.50	0.08	1.00	0.57	1.03	0.17	10.7

	Zone 2 Downstream (n = 132)			
	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	1.52	1.66	0.48	4.82
ER (mg O_2/L/Day)	6.29	6.62	0.49	17.6
P / R	0.28	0.30	0.07	1.23

	Zone 3 Upstream (n = 86)				Zone 3 Downstream (n = 127)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	1.15	1.09	0.35	2.30	2.03	1.93	0.64	5.12
ER (mg O_2/L/Day)	2.64	3.48	0.46	9.5	3.16	3.69	0.78	10.7
P / R	0.32	0.41	0.16	2.00	0.59	0.61	0.19	1.25

	Zone 4 Upstream (n = 127)				Zone 4 Downstream (n = 71)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	1.95	2.85	0.74	19.8	1.06	1.14	0.53	2.8
ER (mg O_2/L/Day)	3.71	6.85	0.85	62	5.25	5.48	1.78	11
P / R	0.50	0.54	0.16	1.19	0.21	0.24	0.05	0.55

Median ER values in Table 6.4 spanned a wider range than GP, with the lowest median of 2.64 mg O_2/L/Day at the zone 3 Upstream site and the highest value of 6.29 mg O_2/L/Day at the Downstream site in zone 2. Unlike other years, the spread in median ER was higher rather than having six sites with similar ER and the zone 2 Downstream site with a much higher value.

The median P/R ratios range from 0.21 to 0.59 (Table 6.3). This indicates that for most of the time the system was strongly heterotrophic, hence much more carbon was being consumed by respiration in the river than being produced by photosynthesis. This organic carbon therefore 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-in organic carbon into the river channel, often in the form of small particulate matter and right up to large wood.

Figure 6.2 shows how these parameters (and net primary productivity) varied over the course of the year in each zone. For zones, 1, 3 and 4, where two sites are measured, the two sites' data are pooled.

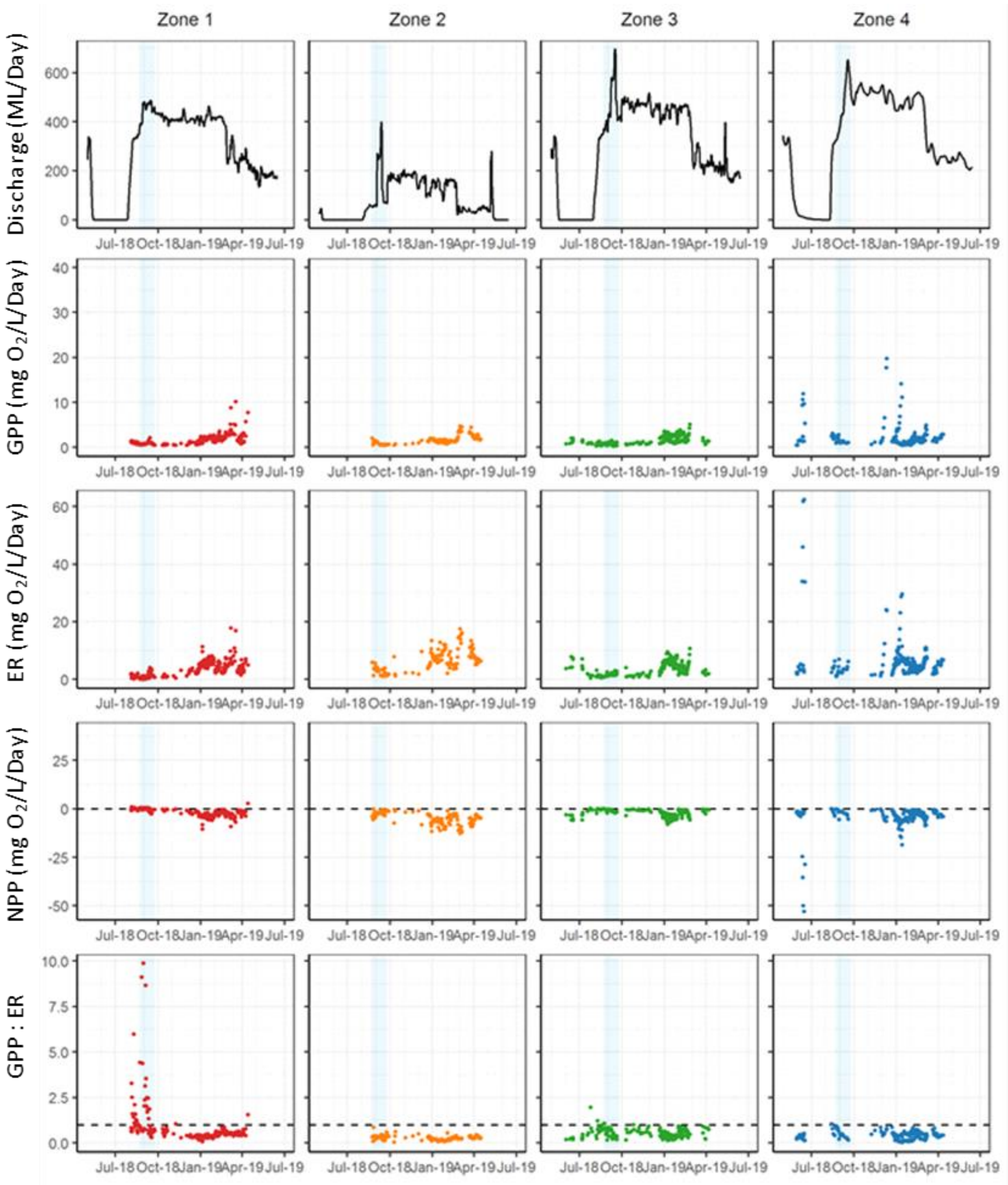


Figure 6.2. Plots of discharge, organic carbon production (GPP), consumption (ER), net production (NPP) and the production : consumption ratio (GPP : ER) over all sites, stratified into the four hydrological zones in 2018-19. The light blue vertical bar represents the period of the first watering action (Table 6.1).

One key feature of Figure 6.2 is that the watering action (shown as the vertical blue bar) had no significant effect on any of the four parameters presented. The highest GPP : ER ratios were found during this time in zone 1, but all the high values (including in the weeks preceding the CEW delivery) were associated with very low levels of ER rather than elevated primary production. Elevated rates of GPP and especially ER were found in July in zone 4. No comparable increases were found in the other three zones at this time or in the preceding weeks.

The elevated rates in late-summer to early autumn in zone 4 were slightly higher than the corresponding rates in zones 1 and 2 but with similar patterns in timing.

Stream metabolism across four years of LTIM (2014-15 to 2018-19)

Table 6.5 summarizes the full five-year (2014-19) stream metabolism data set stratified by zone and site. These data show that metabolism in zone 4 is slightly more variable than the other three zones across the five-year period, whereas GPP and ER rates were the highest in zone 2.

Table 6.5. Summary of gross primary production (GPP) and ecosystem respiration (ER) rates and P/R ratios for the seven sites in four hydrological zones, for the entire period of record (2014-19). 'n' is the number of days for which successful estimates of metabolic parameters were obtained.

	Zone 1 Upstream (n = 599)				Zone 1 Downstream (n = 696)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	1.62	1.94	0.14	10.2	1.38	1.86	0.04	17.0
ER (mg O_2/L/Day)	3.45	4.20	0.20	31.7	3.49	4.07	0.06	20.9
P / R	0.48	0.60	0.02	7.78	0.44	0.72	0.05	10.9

	Zone 2 Downstream (n = 774)			
	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	2.60	3.19	0.48	13.0
ER (mg O_2/L/Day)	8.07	8.67	0.49	40.1
P / R	0.35	0.42	0.04	5.4

	Zone 3 Upstream (n = 415)				Zone 3 Downstream (n = 627)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	1.31	1.91	0.28	10.5	1.91	2.19	0.09	7.1
ER (mg O_2/L/Day)	3.74	4.65	0.22	27.7	3.47	3.74	0.29	16.1
P / R	0.38	0.49	0.03	5.4	0.63	0.69	0.03	6.4

	Zone 4 Upstream (n = 585)				Zone 4 Downstream (n = 595)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
GPP (mg O_2/L/Day)	2.02	2.97	0.39	26.1	1.49	2.54	0.10	42.3
ER (mg O_2/L/Day)	3.72	5.58	0.40	62.5	3.53	4.11	0.03	27.1
P / R	0.54	0.63	0.13	1.91	0.47	0.91	0.02	32.7

For all sites within all zones and all three parameters (GPP, ER and P / R), the mean value was larger than the median value indicating that the mean was influenced by a number of much higher values, despite their relative infrequency. Both statistics are important as the median best reflects 'typical' conditions while the high rates influencing the mean represent periods in 2014-19 when photosynthetic rates were much higher than normal (including the impact of an algal bloom). Nevertheless, the range in median values for GPP (1.38 – 2.02 mg O_2/L/day) and ER (3.45 – 3.74 mg O_2/L/day) for the six sites in zones 1, 3 and 4 are remarkably similar. The zone 2 median rates (GPP = 2.60 and ER = 8.07 mg O_2/L/day) are significantly higher and are largely attributed to the much lower flows which enable still water habitats for significant algal and macrophyte growth. However, due to these lower flows, zone 2 makes a much smaller contribution to organic carbon loads moving down the Wakool River in zones 3 and 4.

The median P / R ratios in all seven sites (four zones) are again closely constrained in a narrow range from 0.35 (zone 2 Downstream) to 0.63 (zone 3 Downstream) again emphasizing that the Edward/Kolety-Wakool system is typically strongly heterotrophic. Thus, ER is supported by a large contribution from allochthonous organic carbon (organic carbon from upstream or from the banks, riparian zones etc.).

To put the Edward/Kolety-Wakool results into context with the other five Selected Areas for which Stream Metabolism is a Category 1 indicator (hence excluding the Gwydir), Table 6.6 is a summary of all pooled GPP and ER rates over the first four years of the LTIM project. The fifth year of Basin-level data will be presented with the Year 5 Basin Level Evaluation in 2020.

Table 6.6. Summary of gross primary production (GPP) and ecosystem respiration (ER) rates and P/R ratios for all LTIM Stream Metabolism data across the six Selected Areas, for the period of record (2014-18). 'n' is the number of days for which successful estimates of metabolic parameters were obtained.

	n	Median	Mean	Std. Dev	Std. Error	25th Percentile	75th Percentile
GPP (mg O_2/L/Day)	8465	1.7	2.4	2.5	0.03	1.1	2.8
ER (mg O_2/L/Day)	8465	3.2	4.3	4.1	0.04	1.7	5.4

In comparing results from Tables 6.5 and 6.6, it is important to note that Edward/Kolety-Wakool results make up around 41% of the overall database used to generate Table 6.6. Nevertheless, the median of the pooled LTIM data set for GPP (1.7 mg O_2/L/Day) is in the middle of the range in median GPP for six of the seven Edward Wakool sites; zone 2 downstream has a substantially higher median GPP as noted above. The median Edward/Kolety-Wakool ER data are higher than the pooled LTIM data. Part of this difference is due to very low (relative) rates of ER in the Murrumbidgee and Lower Murray Rivers. Nevertheless, differences of 1 mg O_2/L/Day are small considering the typical range in GPP and ER rates world-wide differ by an order of magnitude. The Edward/Kolety-Wakool results, along with the pooled LTIM data place the Murray-Darling metabolic rates at the lower end of 'typical' of rates throughout the world. It is likely that the same factors constraining primary production (mainly nutrients) and ER (organic carbon supply) are important in all southern Basin streams as well as the Edward/Kolety-Wakool system.

Seasonal Effects on Stream Metabolism

The summary statistics in Table 6.5 hide some recurring and strong patterns in the data that help explain how GPP and ER behave across the year. Tables 6.7 and 6.8 summarize this complete stream metabolism data set over all five years.

There was a strong seasonal increase in GPP from spring into summer in all four zones. This behaviour is expected due to the warmer days, 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.

The seasonal change from summer to autumn produced idiosyncratic changes rather than a common trend across all zones and sites. At the three most upstream sites (zones 1 and 2), the autumn GPP was generally higher than summertime, whereas for the four more downstream sites (zones 3 and 4), autumn GPP was generally lower than the corresponding summer-time values. Part of this effect is due to the timing of probe removal (Table 6.7). The DO probes were typically removed towards the end of April each year, hence the autumn data consisted of the warmer half of that season and did not include the coolest month with the shortest daylight hours (i.e. May). It is surmised that measurement across the whole season would have led to lower median and mean seasonal rates for autumn. In addition, the algal blooms found in the system occurred in late-summer and extended well into autumn, again, boosting the autumn averages. The lowest GPP rates were found, unsurprisingly, from the relatively small amount of winter-time measurements. Winter has the coolest water (hence suppressing cellular metabolic rates) as well as the fewest hours of sunlight per day. In addition, due to the angle of the sun, the sunlight intensity is also lowest. The similarity of some winter and springtime data is again due to wintertime measurements predominantly being collected in August rather than June and July.

The ER data in Table 6.8 shows that there is much more variability within each season than for the corresponding GPP data; the 'boxes' demarcating the 25th and 75th percentiles of the data are taller for ER, coupled with a larger Y-axis. The seasonal patterns in ER within each zone and Site are similar to those found with GPP. It is likely that the greater variability in ER is driven by the multiple sources of organic carbon that drives respiration. Given that these sites are strongly heterotrophic (as discussed earlier with the P / R ratio), the organic carbon is coming from GPP-derived material (including algal exudates) as well as allochthonous material from upstream, the banks (including benches), riparian zones and occasionally reconnected, accessible flood runners and backwaters. Depending on the source, the lability of this organic carbon may vary widely, contributing to variation in daily ER rates.

Table 6.7. Summary of seasonal gross primary production (GPP) for the seven sites in four hydrological zones, for the entire period of record (2014-19). 'n' is the number of days for which successful estimates of metabolic parameters were obtained.

Zone	Site	Season	Size	Mean	Std Dev	Std. Error	Min	Max	Median	25%	75%
1	1	Spring	162	1.20	0.79	0.06	0.14	4.11	0.96	0.75	1.30
1	1	Summer	261	2.20	1.16	0.07	0.32	7.80	1.96	1.46	2.54
1	1	Autumn	120	2.83	1.84	0.17	0.75	10.2	2.41	1.47	3.40
1	1	Winter	56	0.99	0.62	0.08	0.46	4.09	0.77	0.63	1.18
1	5	Spring	287	1.04	0.58	0.03	0.04	4.17	0.94	0.74	1.16
1	5	Summer	302	2.42	2.08	0.12	0.55	17.0	1.98	1.52	2.41
1	5	Autumn	69	3.26	1.20	0.14	1.23	7.80	3.08	2.40	4.07
1	5	Winter	38	0.99	0.25	0.04	0.60	1.51	0.95	0.78	1.25
2	4	Spring	228	2.11	1.81	0.12	0.48	11.4	1.53	1.08	2.48
2	4	Summer	320	3.41	1.75	0.10	0.77	12.2	3.28	2.05	4.14
2	4	Autumn	164	4.72	2.85	0.22	1.62	13.0	4.09	2.41	5.80
2	4	Winter	62	1.99	1.58	0.20	0.57	10.7	1.76	1.18	2.11
3	3	Spring	119	1.26	1.66	0.15	0.28	10.3	0.80	0.60	1.10
3	3	Summer	188	2.26	1.70	0.12	0.53	10.4	1.70	1.29	2.40
3	3	Autumn	90	2.27	2.10	0.22	0.58	10.5	1.45	1.11	2.40
3	3	Winter	18	0.85	0.37	0.09	0.37	1.53	0.83	0.47	1.16
3	5	Spring	226	1.38	0.42	0.03	0.09	2.85	1.35	1.10	1.62
3	5	Summer	219	3.05	0.71	0.05	1.15	5.84	2.97	2.56	3.40
3	5	Autumn	109	2.86	1.41	0.14	1.22	7.09	2.27	1.86	3.72
3	5	Winter	73	1.10	0.32	0.04	0.68	2.10	1.00	0.89	1.33
4	1	Spring	122	1.56	1.35	0.12	0.45	7.94	1.11	0.84	1.77
4	1	Summer	269	3.90	3.78	0.23	1.04	26.1	2.40	1.83	3.89
4	1	Autumn	144	2.71	1.44	0.12	1.10	6.97	2.25	1.58	3.18
4	1	Winter	50	2.18	2.65	0.37	0.39	11.9	1.13	0.78	2.22
4	5	Spring	155	1.37	1.48	0.12	0.10	14.78	1.06	0.62	1.53
4	5	Summer	232	3.45	5.25	0.35	0.53	42.3	2.21	1.49	2.93
4	5	Autumn	131	3.30	3.47	0.30	0.54	23.2	1.85	1.32	4.20
4	5	Winter	595	2.54	3.89	0.16	0.10	42.3	1.50	0.94	2.57

Table 6.8. Summary of seasonal ecosystem respiration (ER) for the seven sites in four hydrological zones, for the entire period of record (2014-19). 'n' is the number of days for which successful estimates of metabolic parameters were obtained.

Zone	Site	Season	Size	Mean	Std. Dev	Std. Error	Min	Max	Median	25%	75%
1	1	Spring	162	2.62	2.33	0.18	0.20	19.7	1.85	1.36	3.30
1	1	Summer	261	4.92	2.82	0.17	1.13	31.7	4.30	3.24	6.04
1	1	Autumn	120	6.19	4.43	0.41	1.47	22.4	4.36	3.12	8.52
1	1	Winter	56	1.11	0.49	0.07	0.25	2.16	1.10	0.71	1.48
1	5	Spring	287	3.47	2.76	0.16	0.09	20.9	2.72	1.71	4.33
1	5	Summer	302	5.02	2.84	0.16	0.79	17.0	4.49	3.19	5.91
1	5	Autumn	69	4.14	2.18	0.26	0.40	9.86	3.71	2.68	5.76
1	5	Winter	38	0.96	0.62	0.10	0.06	2.44	0.87	0.52	1.37
2	4	Spring	228	6.81	4.53	0.30	0.49	24.9	5.76	3.54	8.44
2	4	Summer	320	9.91	4.24	0.24	1.87	40.1	9.08	7.32	11.5
2	4	Autumn	164	10.7	4.65	0.36	3.05	33.3	9.81	7.40	12.7
2	4	Winter	62	3.89	2.98	0.38	1.36	17.0	2.78	2.20	4.46
3	3	Spring	119	4.47	5.14	0.47	0.22	27.7	2.68	1.63	4.60
3	3	Summer	188	5.22	3.72	0.27	1.36	21.3	3.97	3.03	6.09
3	3	Autumn	90	4.15	1.51	0.16	2.13	8.84	3.89	2.93	4.92
3	3	Winter	18	2.32	2.11	0.50	0.46	7.44	1.49	0.86	3.32
3	5	Spring	226	3.06	2.43	0.16	0.52	16.1	2.39	1.82	3.33
3	5	Summer	219	4.96	1.55	0.11	2.08	10.7	4.55	3.84	5.88
3	5	Autumn	109	4.25	1.59	0.15	1.46	10.1	3.73	3.26	4.84
3	5	Winter	73	1.44	1.26	0.15	0.29	7.87	1.17	0.89	1.44
4	1	Spring	122	3.42	2.91	0.26	0.40	19.8	2.33	1.56	4.29
4	1	Summer	269	7.04	6.01	0.42	1.35	29.6	4.52	3.00	8.73
4	1	Autumn	144	4.32	2.35	0.20	1.35	18.1	3.75	2.89	4.83
4	1	Winter	50	7.76	14.25	2.02	1.03	62.5	2.40	1.63	6.24
4	5	Spring	155	2.40	1.62	0.13	0.03	9.29	2.21	1.35	3.15
4	5	Summer	232	5.97	3.53	0.23	0.49	27.1	5.19	4.20	6.62
4	5	Autumn	131	4.00	2.62	0.23	0.89	16.4	3.43	2.84	4.19
4	5	Winter	595	4.11	3.14	0.13	0.03	27.1	3.53	2.21	5.11

Organic carbon loads

Figure 6.3 portrays the organic carbon load within each zone created by GPP (Carbon production) or consumed by ER (Carbon consumption), plus the difference in these daily estimates (Net C production) and the ratio of carbon produced to consumed. The data is plotted over the five years from 2014 to 2019. 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 5 years; and ii) the daily rates of GPP and ER which can readily 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 (Site 1 Upstream ER 2017-18) or more. 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), again indicating primarily heterotrophy.

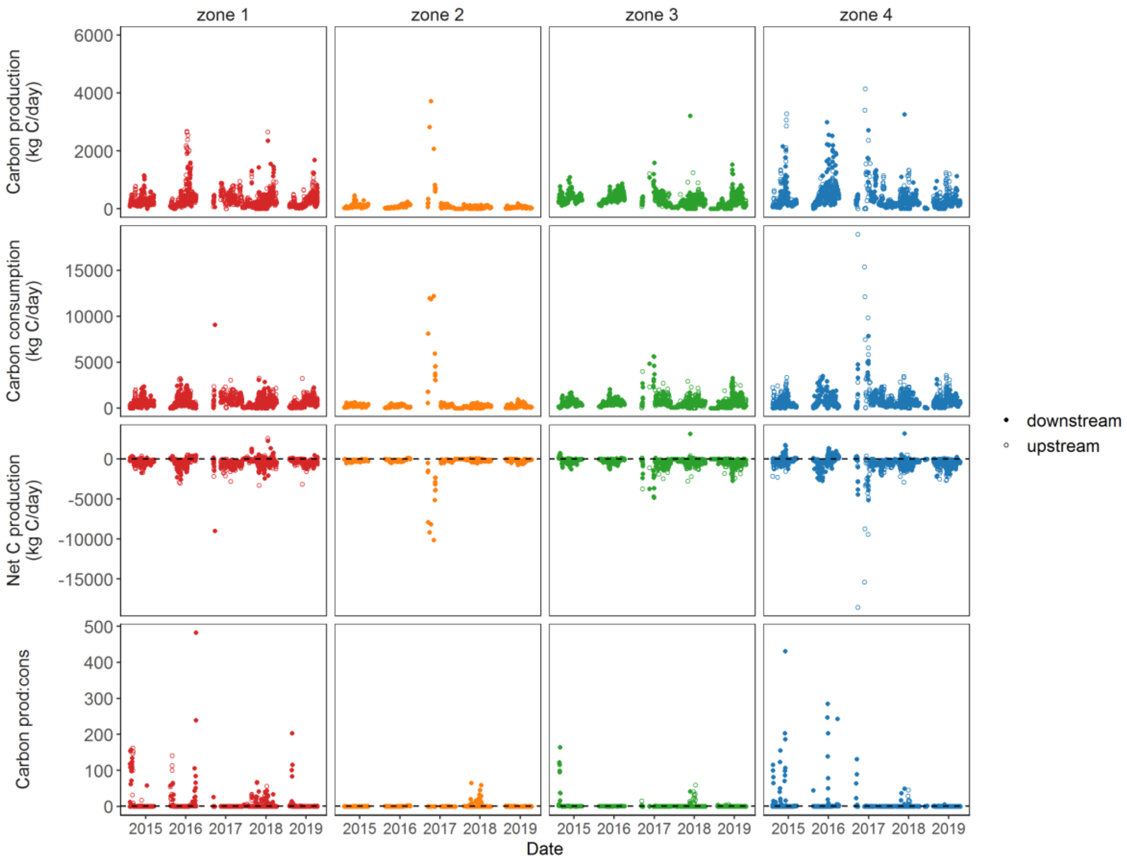


Figure 6.3 Plots of Organic carbon production (GPP), Consumption (ER), Net Production (GPP-ER) and Production: Consumption Ratio (GGP/ER) stratified by zone and year (2014-15 through to 2018-19) across each of the four study zones. Closed dots = downstream estimates, open dotes = upstream estimates. Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

As noted earlier in this report, the organic carbon loads from zone 2 are typically the lowest of all four zones, even though the rates of GPP and ER are the highest. This outcome is simply due to the much lower flows in zone 2 (as load = daily rate x flow). Most of the variation in daily load is a result of changes in flow, as increased flow typically dilutes (decreases) the volumetric rate of GPP and ER.

Response of stream metabolism to Commonwealth environmental watering actions

Environmental watering action 1 in spring 2018: The purpose of this watering action was a trial of an 800 ML/Day flow. The metabolism measurements through this period are illustrated in Figure 6.4. The rates can be compared with the seasonal (spring-time) rates in Tables 6.7 and 6.8. Median GPP rates for spring-time are in the range 0.8 – 1.5 mg O_2/L/Day and are 1.9 – 2.7 for ER with zone 2 ER being higher at 5.8 mg O_2/L/Day. Hence, the GPP rates shown in Figure 6.4 demonstrate very little effect of the watering action on volumetric GPP rates and consequently, the organic carbon loads produced are higher than otherwise expected due to the greater volume of water. This may provide ecological benefit with more organic carbon food for the native fish population. ER rates in zones 1, 2 and 3 were lower than seasonal medians whereas the zone 4 rates were right on the median for the entire period of record (Table 6.7). Nevertheless, due to the increased flows, the organic carbon load consumed by ER (resulting in nutrient recycling) is enhanced above other years without the additional CEW.

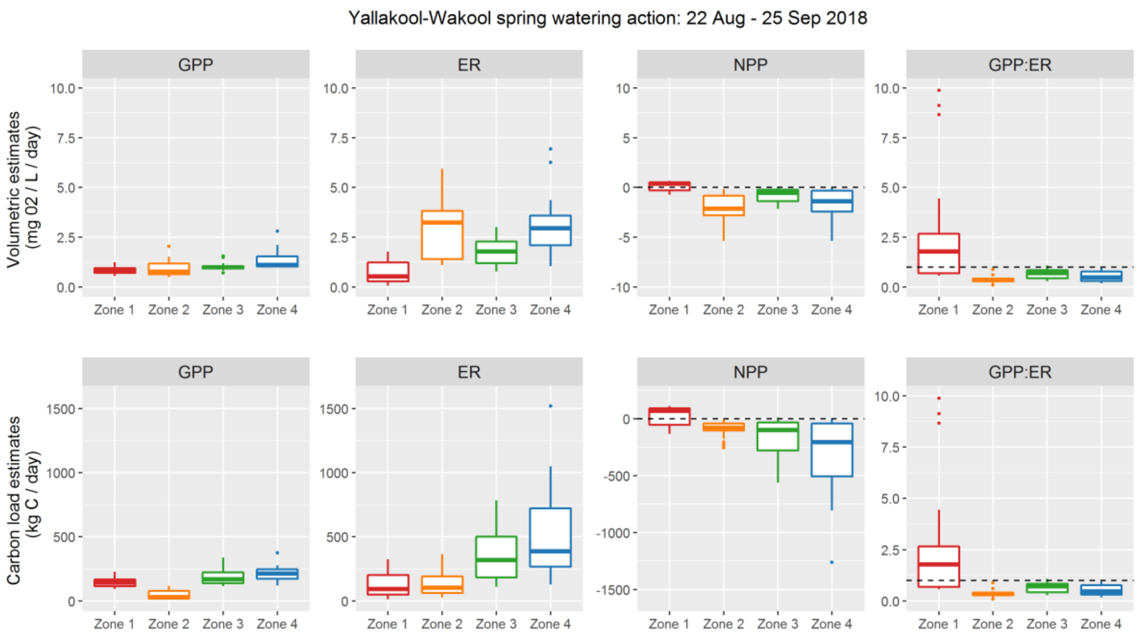


Figure 6.4. Watering action 1 spring 2018. Top panel: Volumetric estimate of carbon (mg O_2/L/day). Bottom panel: total carbon load (kg C/day). Values for organic carbon production (GPP), Consumption (ER), Net Production (GPP-ER) and Production: Consumption Ratio (GGP/ER) are shown. Different coloured box plots represent the four study zones. Zone 1 – red, zone 2 - orange, zone - green, zone 4- blue.

Figure 6.5 depicts the daily contribution of CEW and background flows (‘non-CEW’) to both the stream flow in each zone and the amount of organic carbon created by GPP. The CEW makes a major contribution to both the stream flow and the daily organic carbon load in zone 2 and significant contributions in the other three zones (Figure 6.5). Summing up the daily CEW contributions across the watering action, CEW increases organic carbon production by 36%, 134%, 71% and 38% above the summed loads from non-CEW sources. CEW added an additional 7.27 tonnes of organic carbon to the 13.9 tonnes generated by GPP without the CEW; an overall increase of 52% (Table 6.9). This increase in carbon fixation translates to greater amounts of carbon being available to aquatic foodwebs.

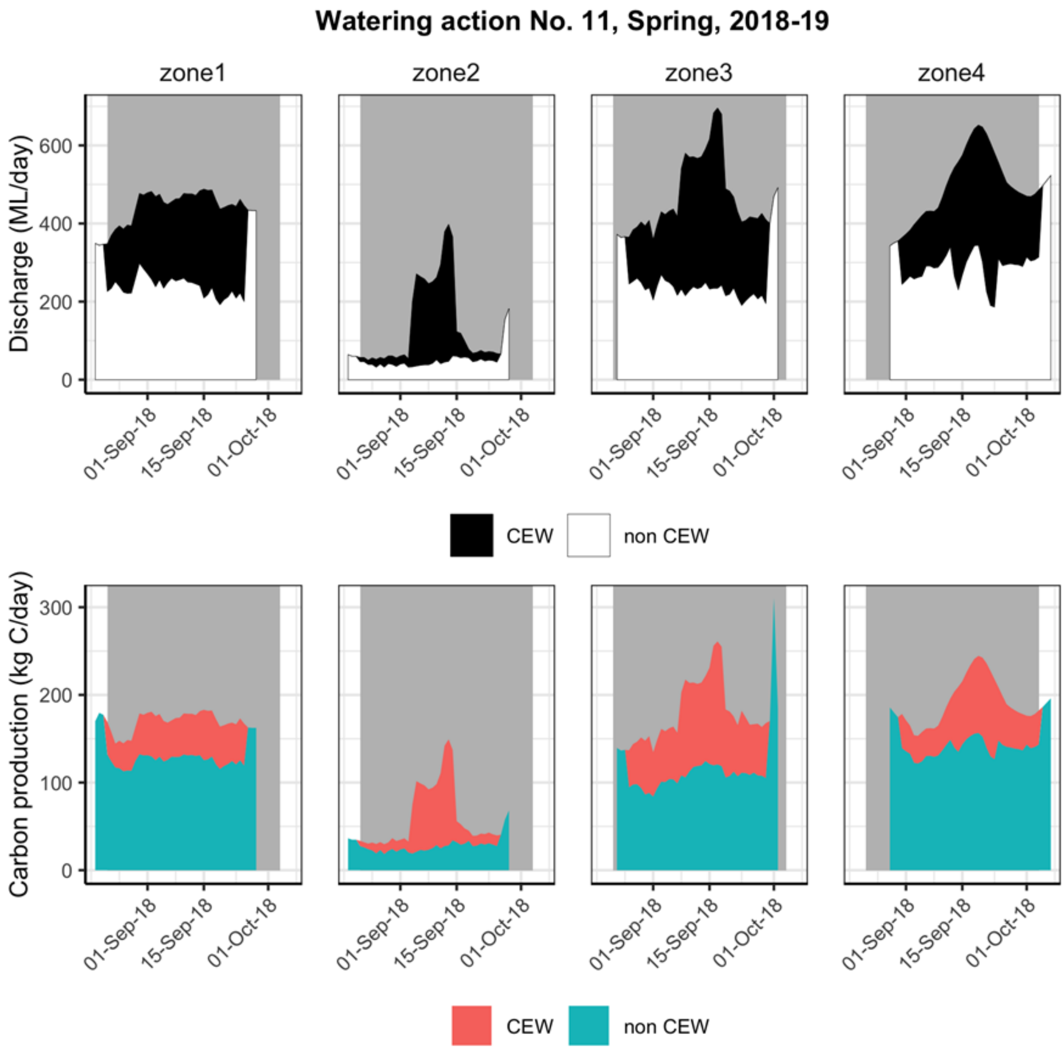


Figure 6.5. CEW and non-CEW contributions to stream flow and daily organic carbon production in each zone from watering Action 11, spring 2018.

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

This section of the report examines the role and influence of Commonwealth environmental water on the organic carbon load created through primary production across the 11 watering actions over the LTIM study period (2014-2019). Note that the winter watering action in 2019 will be reported in 2019-2020 as it continues into that year. The Figures for watering actions 1 to 9 from 2014 to 2018 are presented in Appendix 1.

Importantly, because discharge has only a weak effect on GPP rates per unit volume of water (i.e. a slight decrease in productivity per litre), the net effect of increased discharge on total GPP (i.e. on total production), is generally positive. As a result, watering actions delivered between 2014 and 2019 have had a clear net positive effect on overall rates of organic carbon production, which provides further food/energy at the base of the aquatic food web.

Table 6.9 provides the modelled estimates of the amount (load) of organic carbon created by GPP for each watering action, partitioned into contributions from CEW and non-CEW sources.

It is important to note that it is generally the amount of water rather than the source of water that is important for creating organic carbon load. However, in some circumstances, such as blackwater events, water source and the timing of delivery is critically important for ecosystem health, as discussed elsewhere in this report. Table 6.9 shows that CEW increased the organic carbon load created ranging from 0 % (no CEW in that zone, e.g. Watering Action 4, zone 1) up to 330% (Watering Action 6, zone 3).

Figure 6.6 shows the summed yearly contributions of CEW and non-CEW sources to organic carbon production in each of the four zones during the various watering events. This is achieved by adding up each contribution given in Table 6.9. It is important to note that this plot does *not* include organic carbon created at other times of the year. Notable here is the overall higher rates of production in relatively wetter years (e.g. 2016-17). This emphasises an important point, which is that high rates of productivity are naturally linked to high flow events, ostensibly being light limited, and hence increasing as a function of wetted area. Further analysis will examine the relationship between wetted surface area of the river-channel and overall production rates more closely. However, in simple terms it is evident from these plots that CEW has made a large and significant contribution (in the order of 7.3 tons) of additional carbon being fixed in the river system, which can contribute to sustaining in-stream biota, including native fish populations.

Caveats and limitations on this modelling approach

One important caveat is that the current analyses do not provide information on the length of the river channel over which the reported production estimates have occurred. This is primarily determined by average water velocity, which (in effect) determines the 'length' of the body of water that travelled past the DO loggers deployed to estimate rates of GPP. As stream velocity varies with flow, in principle the measurements reported here should be corrected (or standardised) to a fixed length of river (e.g. production occurring each day over a 1km river reach). This standardisation will be included in future analyses. To give some indication, at an average flow velocity of 0.1 m/s, the estimated carbon production would occur over approximately 8 km of the river channel (0.1 m/s x 60 s x 60 min x 24 hr). Because average flow velocities do not vary significantly over a broad range of discharge values in the Edward/Kolety-Wakool River system, we do not anticipate this correction significantly altering the general observations derived from the data presented here.

Finally, for the results presented here we developed separate regression models for each site. A preferred approach is to adopt a single hierarchical model that models the relationship for all sites simultaneously, whilst also taking into account temporal autocorrelation in the GPP estimates. At present the effects of autocorrelation in this model are not accounted for, which can bias the interpretation of coefficients. Preliminary results adopting a hierarchical model that also includes autocorrelation, suggests similar direction and rank order of the effects of each of the three predictor variables. Again, this gives added confidence to the broad effects of CEW on the overall production estimates shown here.

Table 6.9. Summary of the total organic carbon produced by GPP during each watering action over the LTIM project duration (2014-2019). Data are from the model and are stratified by zone, watering action and then into the CEW and non-CEW contributions.

Zone	Watering Action	Total GPP Created (kg Organic Carbon)	Source	Total GPP by Source (kg Organic Carbon)	GPP Percentage by Source	% Increase by CEW
Zone 1	1	41588	cew	18072	43	77
			non-cew	23516	57	
	2	31734	cew	7787	25	33
			non-cew	23946	75	
	3	31734	cew	7787	25	33
			non-cew	23946	75	
	4	43822	cew	0	0	0
			non-cew	43822	100	
	5	37254	cew	15301	41	70
			non-cew	21953	59	
	6	13921	cew	10250	74	279
			non-cew	3671	26	
	7	8630	cew	1807	21	26
			non-cew	6823	79	
	8	9734	cew	1480	15	18
			non-cew	8254	85	
	9	8671	cew	2275	26	36
			non-cew	6396	74	
	11	5937	cew	1565	26	36
			non-cew	4372	74	
Zone 2	1	14835	cew	0	0	0
			non-cew	14835	100	
	2	10156	cew	1982	20	24
			non-cew	8174	80	
	3	10156	cew	1982	20	24
			non-cew	8174	80	
	4	82092	cew	36832	45	81
			non-cew	45261	55	
	5	13866	cew	5058	36	57
			non-cew	8808	64	
	6	1289	cew	0	0	0
			non-cew	1289	100	
	7	3343	cew	1123	34	51
			non-cew	2219	66	
	8	1277	cew	93	7	8
			non-cew	1184	93	
	9	2562	cew	651	25	34
			non-cew	1911	75	
	11	2107	cew	1208	57	134
			non-cew	899	43	

Table 6.9. (cont.)

Zone	Watering Action	Total GPP Created (kg Organic Carbon)	Source	Total GPP by Source (kg Organic Carbon)	GPP Percentage by Source	% Increase by CEW
Zone 3	1	59637	cew	23975	40	67
			non-cew	35661	60	
	2	38487	cew	11141	29	41
			non-cew	27346	71	
	3	38487	cew	11141	29	41
			non-cew	27346	71	
	4	99890	cew	22295	22	29
			non-cew	77595	78	
	5	52081	cew	21006	40	68
			non-cew	31075	60	
	6	7743	cew	5944	77	330
			non-cew	1799	23	
	7	10447	cew	3025	29	41
			non-cew	7422	71	
	8	9106	cew	1485	16	19
			non-cew	7621	84	
	9	8189	cew	2645	32	48
			non-cew	5544	68	
	11	6358	cew	2633	41	71
			non-cew	3725	59	
Zone 4	1	62684	cew	30128	48	93
			non-cew	32555	52	
	2	89937	cew	24651	27	38
			non-cew	65285	73	
	3	89937	cew	24651	27	38
			non-cew	65285	73	
	4	110086	cew	15514	14	16
			non-cew	94572	86	
	5	62193	cew	17817	29	40
			non-cew	44376	71	
	6	8881	cew	5226	59	143
			non-cew	3655	41	
	7	10055	cew	2226	22	28
			non-cew	7829	78	
	8	8570	cew	1120	13	15
			non-cew	7451	87	
	9	6018	cew	1259	21	26
			non-cew	4759	79	
	11	6719	cew	1863	28	38
			non-cew	4856	72	

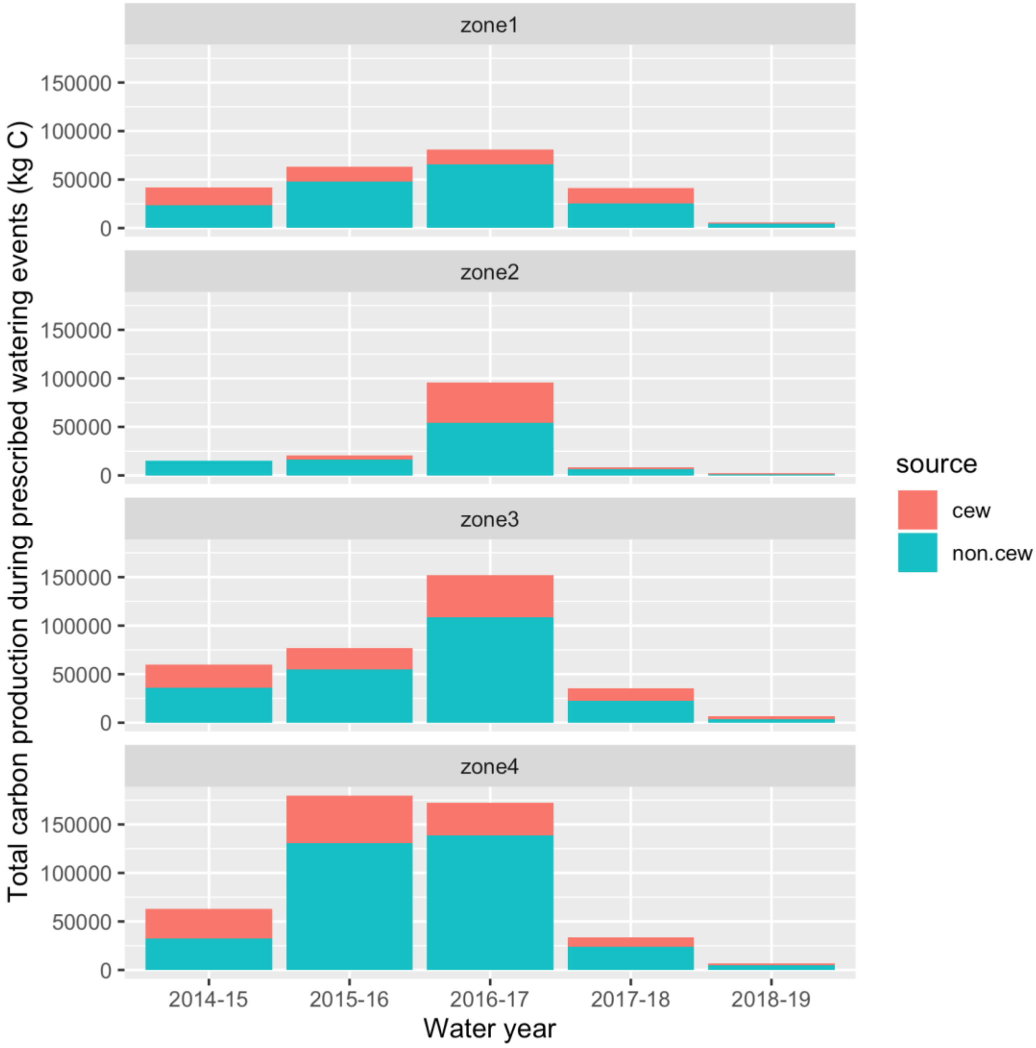


Figure 6.6. Organic carbon production attributed to operational water (non CEW) and Commonwealth environmental water (CEW) from watering events on an annual basis.

6.5 Discussion

Throughout the LTIM project in the Edward/Kolety-Wakool Selected Area, it has been consistently found that the immediate effect of a significant flow increase is a decrease in the rates of both GPP and ER. As noted previously, and in all other Selected Areas, this rate diminution is simply due to a dilution effect by the large increase in water. Except in conditions of major phytoplankton growth (e.g. an algal bloom), much of the metabolism in the Edward/Kolety-Wakool system appears to be from biofilms and microbial communities growing on, in the surface layers of the sediment and also on hard substrates within the channel e.g. rocks and logs etc. As the water level rises, the rate at which each photosynthetic or respiring organism is working, i.e. the amount of oxygen produced or consumed, may not change but the output i.e. change in oxygen concentration, is spread over a larger amount of water. Hence, solely on a volumetric basis, it appears that GPP and ER have been suppressed by this increasing flow resulting in less oxygen change per litre of water. However, as noted below, it is the total amount of organic carbon created that is much more important than the amount per litre.

Effect of Commonwealth environmental watering actions

As clearly demonstrated in the previous section of this report, Commonwealth environmental water contributed significantly to primary production in reaches where water was delivered. Generating more food and nutrients at the base of the food web from ER is a positive environmental outcome from these watering actions, even though water remained well within the defined stream channel at all times.

The total additional production from CEW varies depending on i) time of year, i.e. 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. As shown in Figure 6.6, higher CEW-related (and total) organic carbon loads were found in wetter years such as 2016-17. 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, which means that at some discharges, small additional water volumes may increase the surface area of the water significantly, which occurred 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 such a rule of thumb may also be useful here, 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.

In the 2017-18 Edward/Kolety-Wakool LTIM report (Watts et al 2018), analysis relied on average rates of production calculated for broad flow/seasonal categories. This was refined in 2018-19 by developing continuous relationships between daily productivity rates and changes in light and temperature and discharge. This enabled estimation of organic carbon loads on days with either no metabolism data or when the fit from the BASEv2 model did not meet acceptance criteria. In turn, this allowed estimation of the total amount of organic carbon created by GPP throughout an entire watering event. Partitioning of the total flow into CEW and non-CEW contributions then allowed estimation of how much additional organic carbon emanated from the CEW.

It is 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 will result in much larger positive outcomes. At this stage there is too much uncertainty in the relationships between discharge, light, temperature and metabolic parameters to extend the analysis done here to the relatively small number of days with much higher flows, but this will hopefully be achievable in the future. It is recommended that, when possible, consideration be given to providing a more variable flow regime in the Edward/Kolety-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/Kolety-Wakool River system, both at the short term and longer-term scales?

- 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. There were no 'ceased to flow' conditions during warmer months during the LTIM project, so this aspect could not be properly evaluated and hence remains speculative.
- 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 the five years of the LTIM project confirm that GPP is almost always constrained within this range, with ER typically between 3 and 5 mg O_2/L/day. The lower flows typically found in zone 2 led to higher volumetric rates of GPP and especially ER over the five years, but the organic carbon load from this zone was often relatively low due to the much smaller discharge volumes.
- 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 (these 'larger flows' either did not occur in 2014-19, or the data at these times did not meet the acceptance criteria from the BASEv2 model). Some results from the full five-year data record 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) on a load basis. Larger increases are expected with higher flows.
- Inundation and reconnection of backwater areas to the main channel during high flows will result in elevated rates of GPP and ER (There were no 'ceased to flow' conditions again in 2018-19, so this aspect was not evaluated this year).
- Primary production in the Edward/Kolety-Wakool system is limited by low phosphorus concentrations. This aspect is addressed below.

Constraints on Rates of Stream Metabolism

It is highly probable that the median rates of GPP and ER observed in the Edward/Kolety-Wakool and in all five of the southern Murray-Darling Basin Selected Areas 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, apart from the greatly elevated nutrient concentrations in the September-November 2016 period associated with unregulated flooding, all bioavailable nutrient concentrations in the Edward/Kolety-Wakool sites are low. 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. During 2018-19, turbidity levels at all seven sites were in the range 40-200 NTU (Figure 5.4). This means that light penetration into the water column will be inhibited by the fine suspended particulate matter, which in turn will decrease the PAR available for photosynthesis by benthic algae (and to a lesser extent, phytoplankton).

Links to fish and other outcomes

The quantifiable increases in carbon fixation are an important contribution to a range of broader ecosystem outcomes. For example, zooplankton and other invertebrates that feed on phytoplankton and periphyton benefit directly from the increases in resource availability created by greater plant growth, and in turn this increases food availability for fish and other higher order consumers. These effects are hard to measure at a population level, but are directly evident when examining growth rates of higher order consumers. As an example, there are clear increases in the individual growth rate of Golden perch and Murray cod during high flow years (Tonkin et al. 2017). These increases in growth rate are expected to translate to population outcomes – larger fish typically have higher survival rates and also produce more eggs.

However, this outcomes assumes other factors are not limiting (e.g. habitat availability and access to food resources outside the periods of CEW delivery). These are important factors that require ongoing investigation – both through continued monitoring and more targeted research. It is also difficult to distinguish the potential positive benefits of these outcomes when examining fish abundances, because abundance estimates are often highly variable, and are also influenced by a range of other factors (such as the 2016 blackwater event), and so long time-series will be required before the short-term benefits of CEW that are evident in the stream metabolism estimates are likely to become measurable within indicators such as fish.

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	**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?**
Early spring watering action (small fresh) in Yallakool Creek and mid- and lower- Wakool River 22nd August to 25th September 2018	To test the feasibility and impact of increasing winter-time flows to 800 ML/Day; above the operational constraint of 600 ML/Day.	*What did Commonwealth environmental water contribute to patterns and rates of decomposition? ER*	ER (mg O_2/L/Day) rates were slightly lower than in the absence of CEW in three of the four zones (zone 4 had no change in the expected ER rate at that time of year). Increased flows from CEW addition, resulted in increases in the amount (load) of organic carbon consumed (hence enhanced nutrient recycling).	Daily estimates of stream metabolism in seven sites within four zones. Seasonally relevant median GPP and ER rates were calculated from pooled data over this period from 2014-18. All daily estimates of GPP and 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.	Yes, by the very purpose of the watering action, which was specifically designed to test the effects of a flow 200 ML/Day higher than the nominal operational constraint. Further details are provided in the Hydrology Section of this report.
		What did Commonwealth environmental water contribute to patterns and rates of GPP?	Volumetric GPP (mg O_2/L/Day) rates were almost unchanged on addition of CEW. Increased flows from the addition of CEW resulted in increases in the amount (load) of organic carbon produced via GPP (hence more energy or fish food created to sustain aquatic food webs).		
		How does the timing and magnitude of Commonwealth environmental water delivery affect rates of GPP and ER in the Edward-Wakool River system?	As this watering action occurred during late-winter through early spring, then impacts on rates of GPP and ER were relatively minor due to their low magnitudes at that time of the year. The additional CEW did not affect GPP rates and slightly suppressed ER rates in three of the four zones. The ER rate in zone 4 was unchanged from that expected at that time of year.		

7 AQUATIC AND RIVERBANK VEGETATION

Key findings	
Total species richness	In 2018-19 riverbank and aquatic vegetation continued to recover following the flood of 2016. A total of 65 riverbank and aquatic plant taxa were recorded across the sixteen sites in 2018-19. This was the highest number of taxa recorded over the five years since the LTIM project commenced. Four of the taxa were submerged, 24 were amphibious and 37 were terrestrial. Twenty seven of the 65 taxa were recorded less than ten times across all sites across the entire year. Between 2014 and 2018 there was higher species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that had received minimal or no environmental water. In 2018-19 the combined effects of the 800 ML/d flow trial and the period of higher operational flows in the upper Wakool River (zone 2) increased the total and mean richness of plant taxa, and this zone had a similar average species richness as the other zones in 2018-19.
Richness of functional groups	The total species richness of submerged, amphibious and terrestrial taxa has increased since the 2016 flood. In 2018-19 there were overall more amphibious taxa than in the years prior to the 2016 flood.
Percent cover of functional groups	The maximum mean percentage cover of submerged taxa and some amphibious taxa increased in 2018-19 and was similar to findings in 2014-15 and 2015-16 prior to the flood. However there has been minimal recovery of some amphibious taxa, such as floating pondweed and milfoil. Small plants of these species have been observed outside the survey transects, suggesting there is the possibility of the recovery of these species that can be supported by environmental watering actions.

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/Kolety-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/Kolety-Wakool system. Community members and landholders report there were beds of ribbon weed (*Valisineria australis*.) within the channels and other plants occurring on the banks of the Edward/Kolety-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/Kolety-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 2018-19 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 by reducing the cover and richness of vegetation significantly (Watts et al. 2017b). In 2017-18 there was evidence of some recovery since the flood of 2016, however the total species richness and the percent cover of taxa in 2017-18 was lower than in 2015-16 prior to the 2016 flood.

This section reports on the recovery of riverbank and aquatic vegetation in the Edward/Kolety-Wakool system in 2018-19 since the flood of late 2016.

7.2 Specific environmental watering actions for vegetation outcomes

Two Commonwealth environmental watering actions were delivered in the Edward/Kolety-Wakool system in 2018-19 (Table 7.1). The responses to the first of these actions, the 800 ML/day flow trial from August to September 2018, is evaluated in this section. A winter watering action (planned watering action #5) commenced on 16 May 2019. This action will continue into the 2019-20 water year and will be evaluated in the 2019-20 annual report. All other planned flow actions in the Wakool system during spring, summer and autumn were suspended between 2 October 2018 and mid-May 2019 due to lack of operational capacity to accommodate environmental water in the river in addition to operational water that was required to be delivered through the system.

Table 7.1 Commonwealth environmental watering actions in 2018-19 in the Edward Wakool River system. The winter flow action continued into the 2019-20 water year and will be evaluated in the 2019-20 annual report.

	Watering action	Action	Dates	Rivers
1	Spring fresh	small fresh	22 August to 25 September 2018	Yallakool Creek, mid- and lower Wakool River
5	2019 winter flow	base flow	Commenced 16 May 2019 (ongoing)	Yallakool Creek, upper, mid- and lower Wakool River, Colligen Creek-Niemur River

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 middle 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 middle 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. Sites were established in areas where grazing impacts were minimal or absent, and were located a minimum of two kilometres apart. Monitoring was undertaken once per month from August 2018 to May 2019. 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 generally in the water at base operational flows, and the other four transects further up the riverbank have the potential to be inundated during 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 and macroscopic algae (e.g. Charophytes) 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 as far as possible. Plants were identified using the Flora of New South Wales Volumes 1–4 (Harden 1992, 1993, 2000, 2002) and keys and descriptions from PlantNet (RBGDT, 2019) and information from field guides (Sainty and Jacobs 2003, Cunningham et al. 1992). 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. Photo-points were established in 2014 at each site and photos were taken on every sampling 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 five years of the LTIM program (2014-2019) 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

Total species richness and cover

A total of 65 riverbank and aquatic vegetation taxa were recorded across the sixteen sites between August 2018 and June 2019 (Table 7.2). This was the highest number of taxa recorded over the five years since the LTIM project commenced. Four of the taxa were submerged, 24 were amphibious and 37 were terrestrial (Table 7.2). Twenty seven of the 65 taxa had as less than ten individual recordings across all sites across the entire year.

When compared to 2017-18 results, there was an increase in the number of species in 2018-19 at sites in Yallakool Creek zone 1 and the upper Wakool River zone 2 (Figure 7.1). The mean species richness in zones 1, 3 and 4 has not yet recovered to the same levels as prior to the 2016 flood (Table 7.2). The mean species richness in zone 2 in 2018-19 was similar to the mean richness in this zone observed prior to the 2016 flood (Figure 7.1).

Only a small percent of the taxa in the four hydrological zones were exotic (Figure 7.2). The overall increase in species richness in 2018-19 (Table 7.2) was due to an increase in the number of native taxa in zones 1 and 2 (Figure 7.2). There was a slight increase in percent cover of native taxa in 2018-19 (Figure 7.3).

Table 7.2 Total number of riverbank and aquatic vegetation taxa recorded at LTIM monitoring sites in the Edward/Kolety-Wakool system in years 1 to 5 of the LTIM project between 2014 and 2019.

	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
2018-19	4	24	37	65

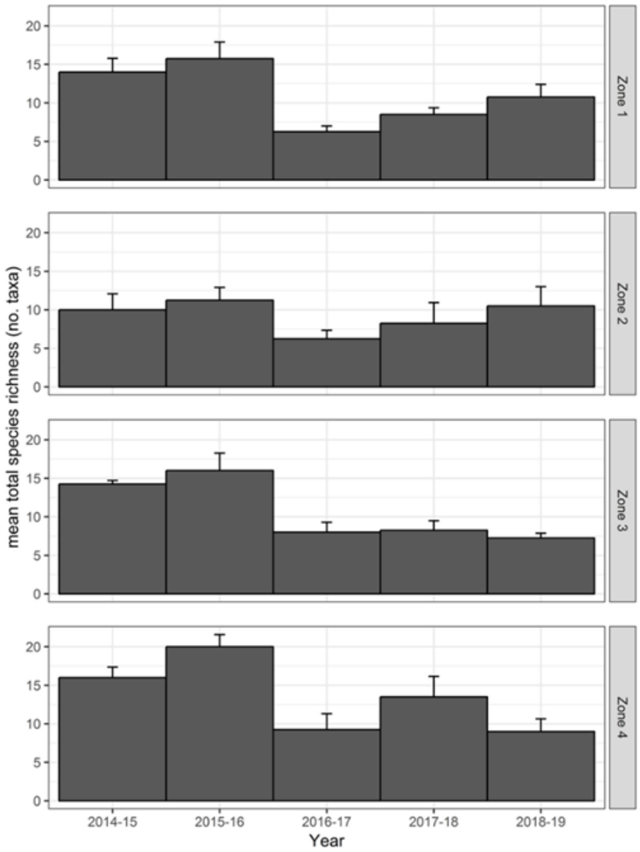


Figure 7.1 Mean total richness of vegetation taxa monitored monthly in four zones in the Edward/Kolety-Wakool system between August 2014 and May 2018. Zone 1= Yallakool Creek, zone 2 =upper Wakool River, zone 3 = mid Wakool River upstream of Thule Creek, zone 4=mid Wakool River downstream of Thule Creek.

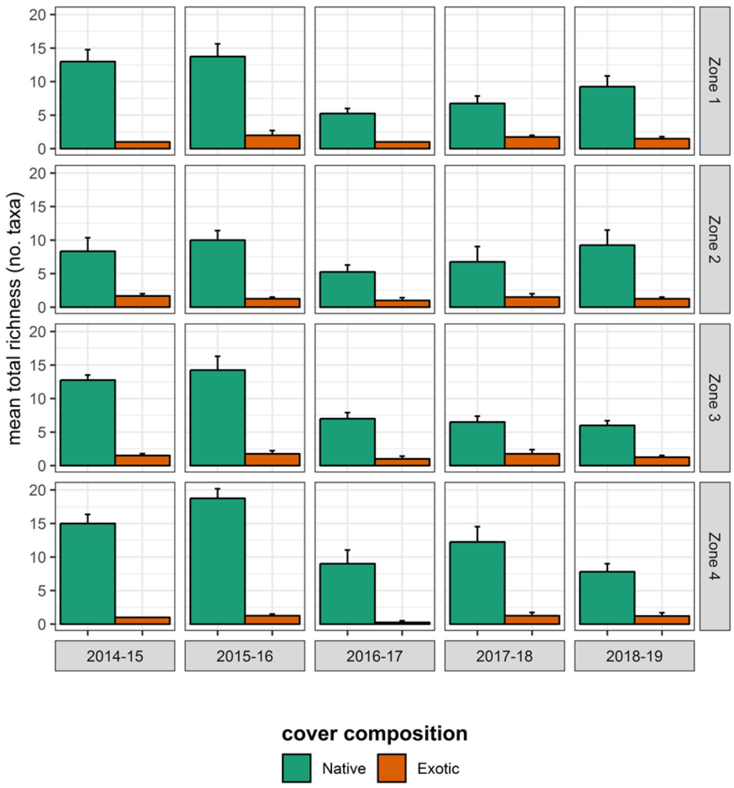


Figure 7.2 Mean richness of native and exotic vegetation taxa monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and May 2019.

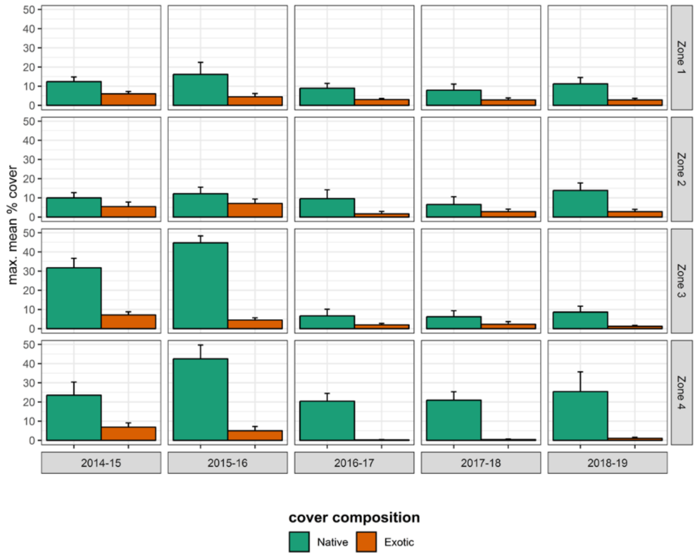


Figure 7.3 Mean percent cover of native and exotic vegetation taxa monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and May 2019.

Richness and cover of submerged taxa

Following the flood in 2016 there was a reduction in total and mean total richness of submerged taxa in all zones, however since 2017-18 there has been a recovery of submerged taxa in all zones (Figure 7.4). The maximum mean percentage cover of submerged taxa increased in all zones 2018-19 and was similar to that in 2014-15 and 2015-16 prior to the flood (Figure 7.5).

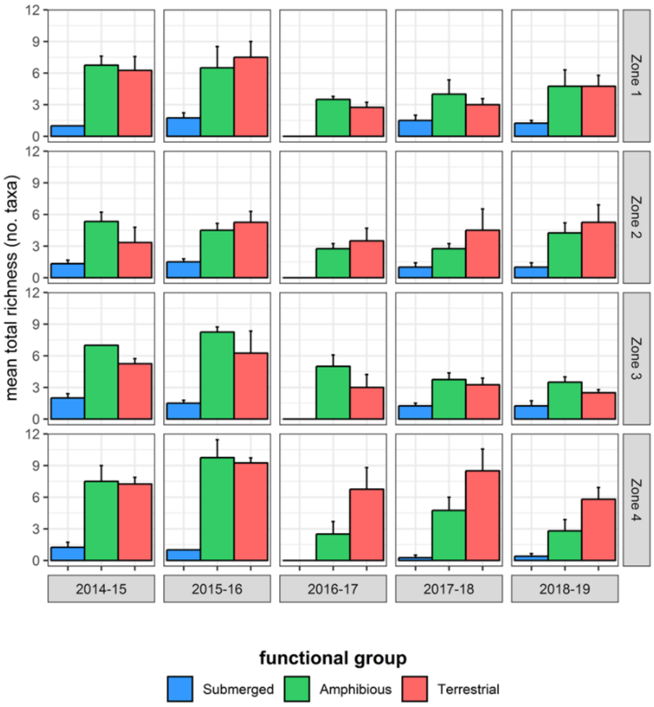


Figure 7.4 Mean total richness of vegetation taxa monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and May 2019. Taxa were classified as submerged, amphibious or terrestrial.

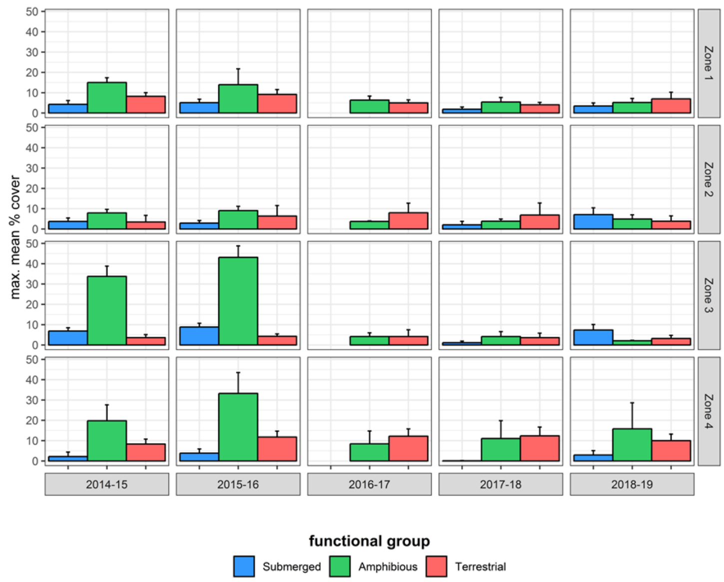


Figure 7.5 Maximum mean percent cover of vegetation taxa monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and May 2019. Taxa were classified as submerged, amphibious or terrestrial.

In 2018-19 there was a significant increase in *Chara* and algae in all hydrological zones (Figure 7.6). There were small patches of *Chara* detected in October in zones 1 and 3 during the recession of watering action 1 (Figure 7.8). This early watering action appeared to be beneficial for the germination of *Chara*. The extended period of operational flows that followed watering action 1 further increased the percent cover of *Chara* in zones 2, 3 and 4 in December 2018 during (Figure 7.7).

Figure 7.6 Mean percent cover of four submerged vegetation taxa monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and May 2019.

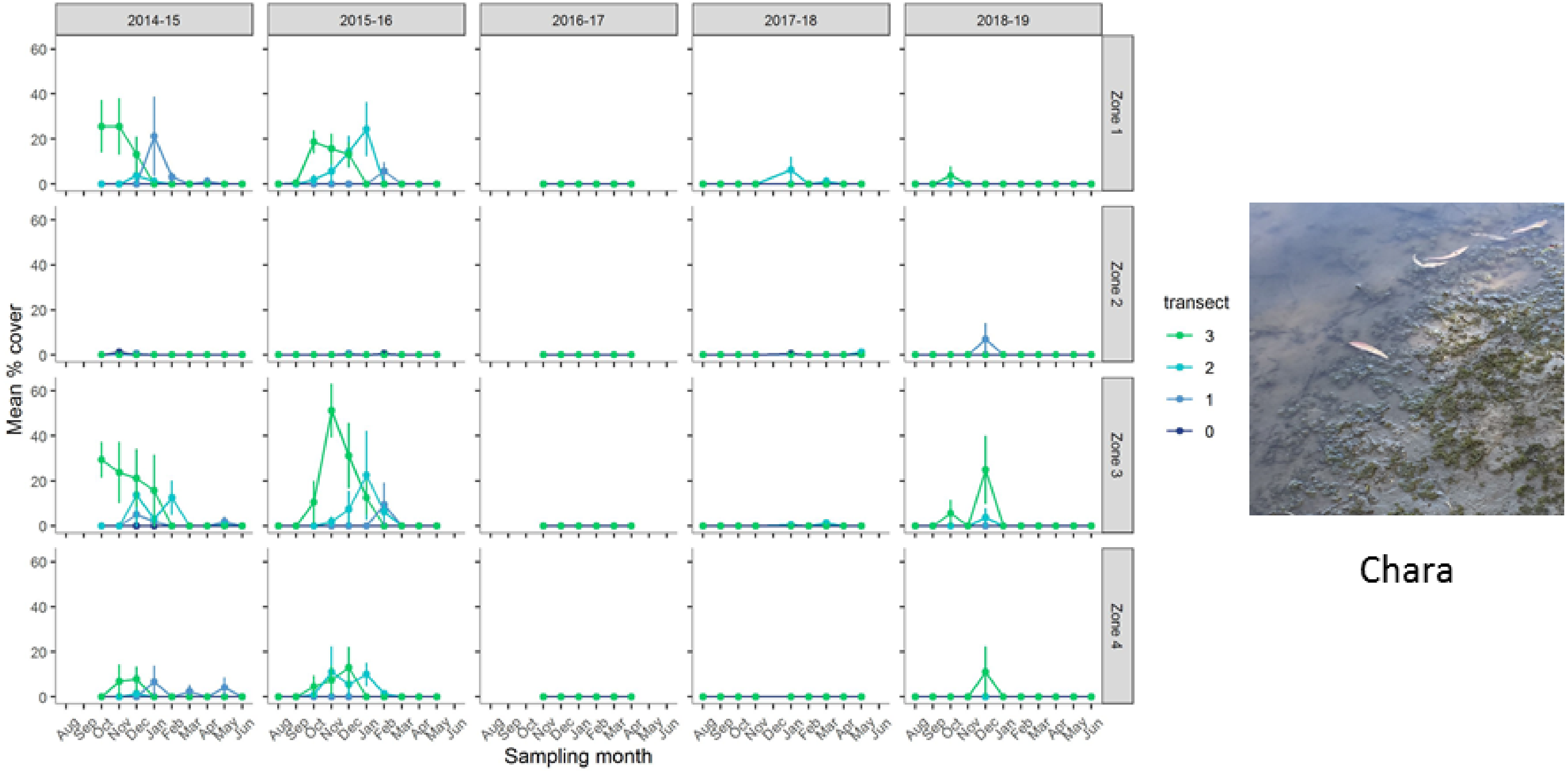


Figure 7.7 Mean percent cover of *Chara* monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and June 2019. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the river bank.

Richness and cover of amphibious taxa

In 2018-19 there were overall more amphibious taxa than prior to the flood (Table 7.2). However, most taxa had a lower maximum mean cover than in 2015-16 prior to the 2016 flood (Table 7.2 and Figure 7.8), the exception being spiny mud grass in zone 4 (Figure 7.8).

Between 2015 and 2018 there were generally fewer amphibious taxa in zone 2 that received very low or no environmental watering actions compared to zones 1, 3 and 4 that regularly received environmental water. However, in 2018-19 there was an increase in total and mean richness and cover of amphibious taxa in zone 2 (Table 7.2, Figure 3.2, Figure 7.4 and Figure 7.8) following a period of higher flows during the 800 ML/d flow trial in September 2018 and higher operational flows from the MIL Wakool escape between October 2018 and February 2019.

A number of amphibious taxa such as spiny mud grass (*Pseudoraphis spinescens)* (Figure 7.9) and rush tolerated the flood in 2016 and persisted and maintained cover in 2017 and 2018. Other amphibious taxa such as floating pondweed (*Potamogeton tricarinatus)* (Figure 7.10) and milfoil (*Myriophyllum spp)* (Figure 7.11) that had high percent cover prior to the flood were considerably reduced in cover or were killed during flood in 2016. In 2018-19, two years after the flood, there has been minimal recovery of these taxa. Small plants of these species have been observed outside the formal transects, suggesting there is the possibility of the recovery of these species following future environmental watering actions.

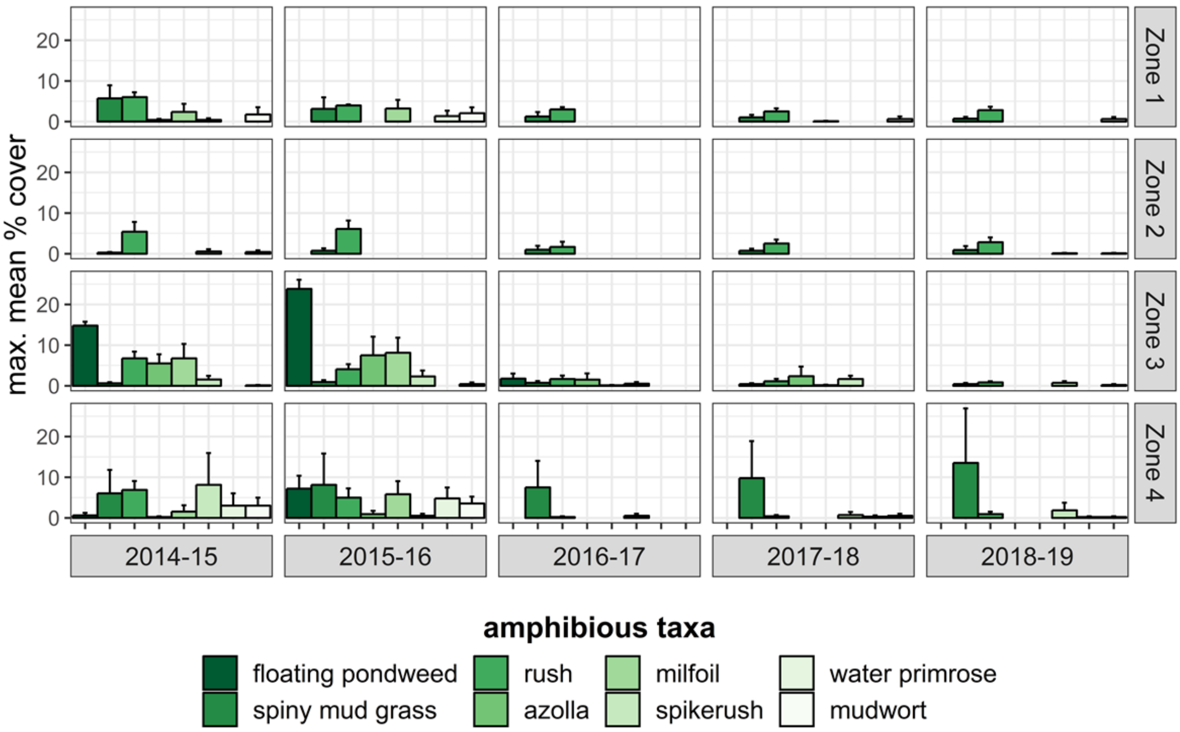
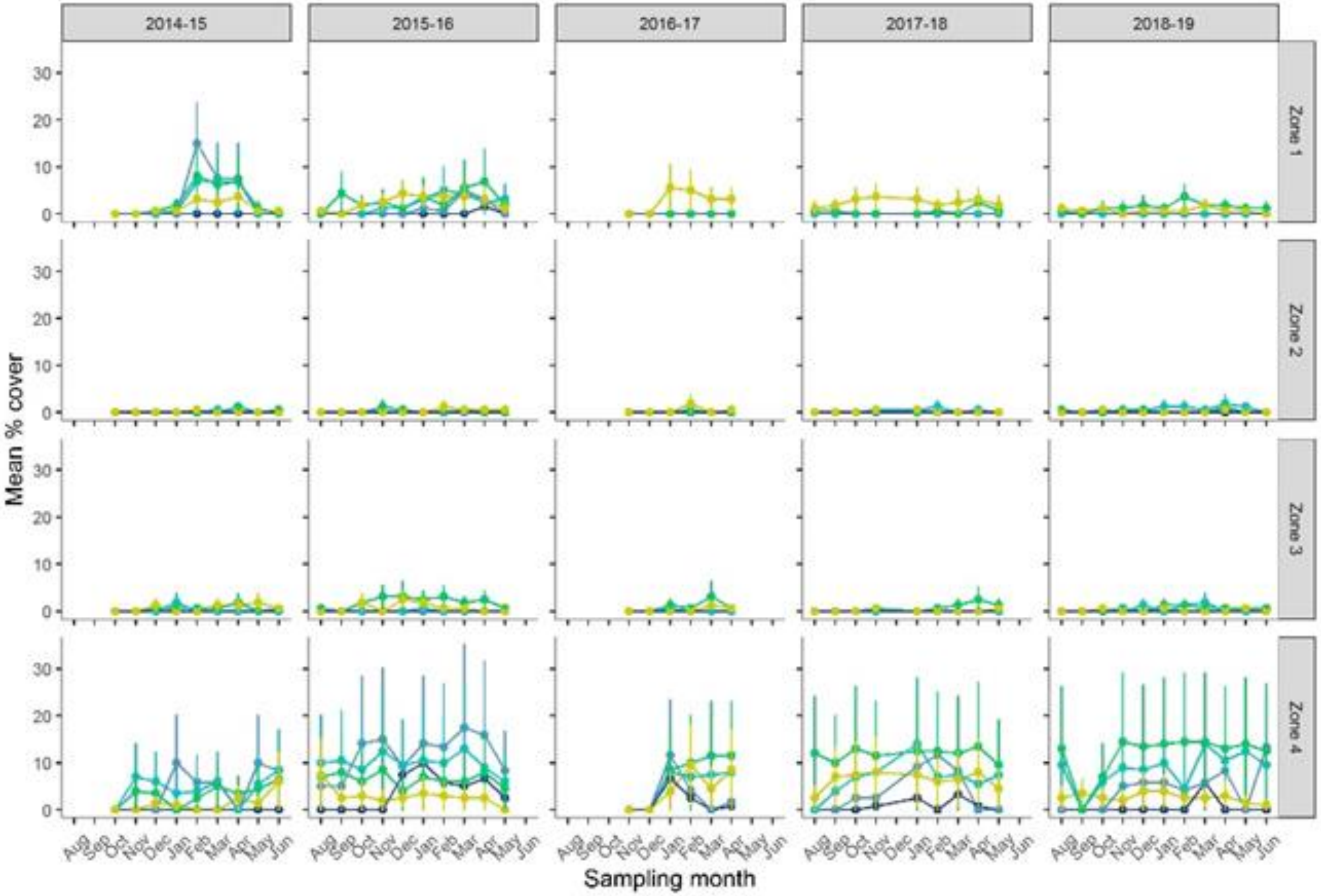


Figure 7.8 Mean percent cover of the eight most abundant amphibious vegetation taxa monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and May 2019.



spiny mud grass

Figure 7.9 Mean percent cover of spiny mud grass (*Pseudoraphis spinescens*) monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and June 2019. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the river bank.

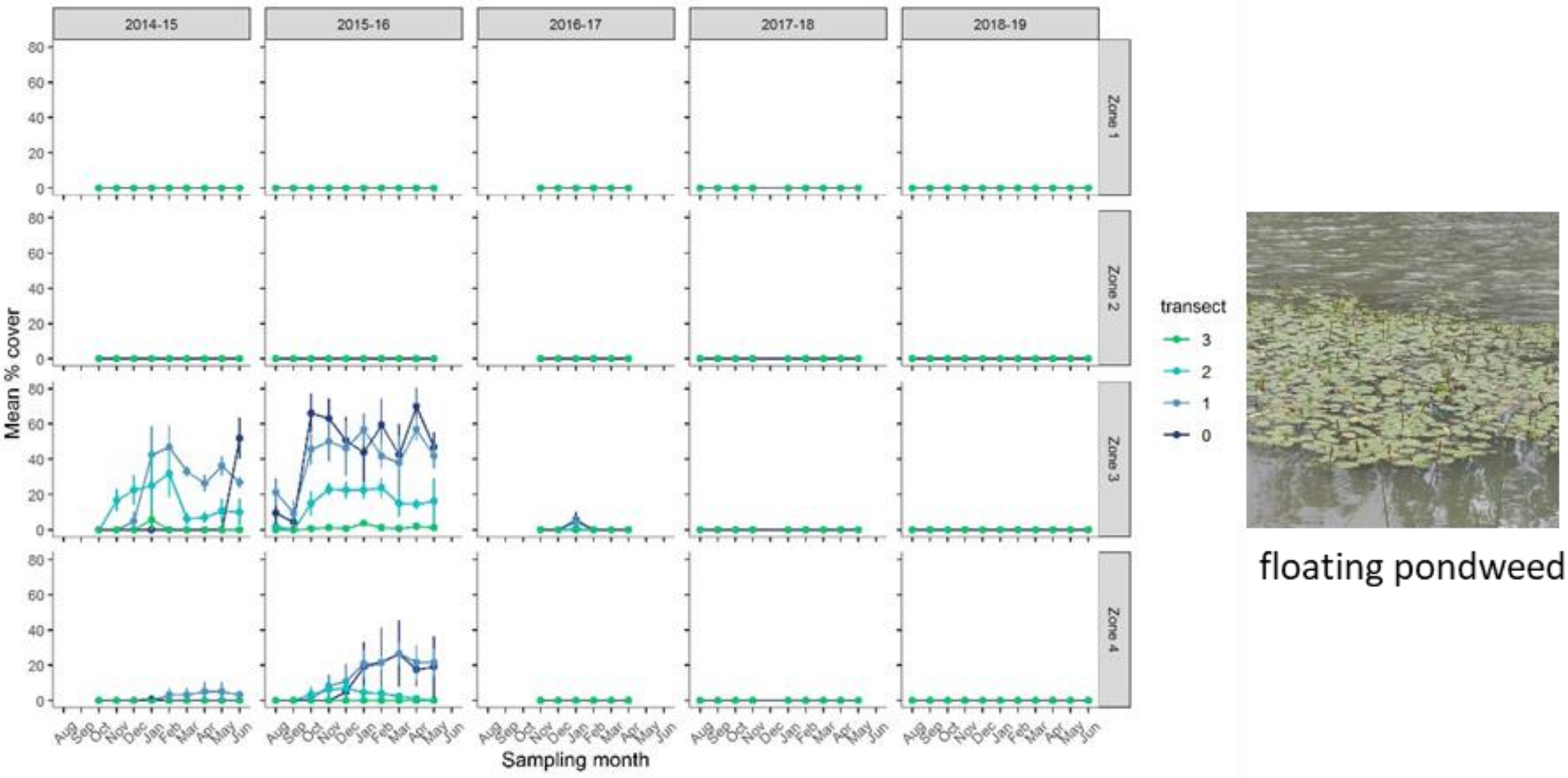


Figure 7.10 Mean percent cover of floating pondweed (*Potamogeton tricarinatus*) monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and June 2019. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the river bank.

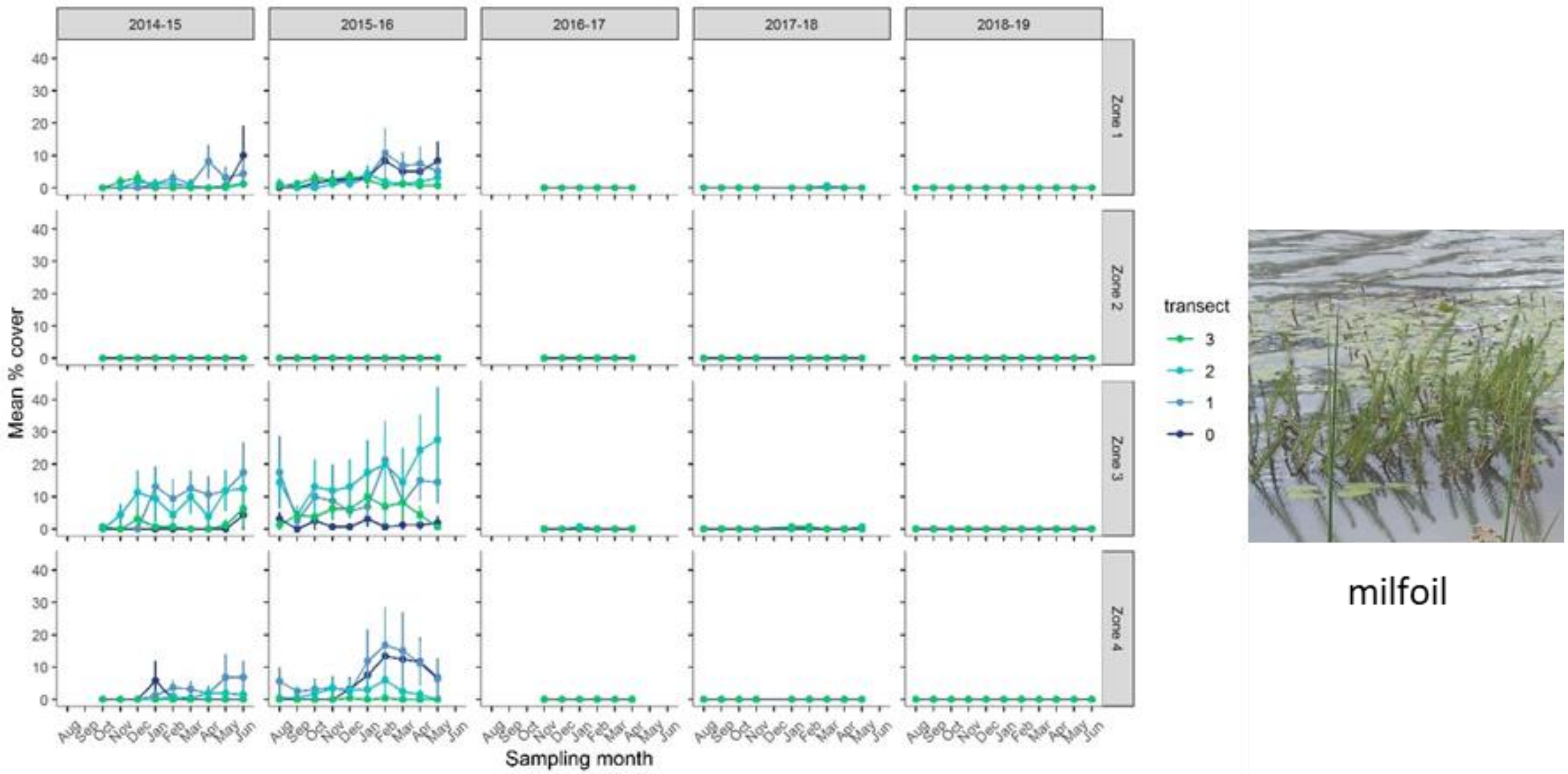
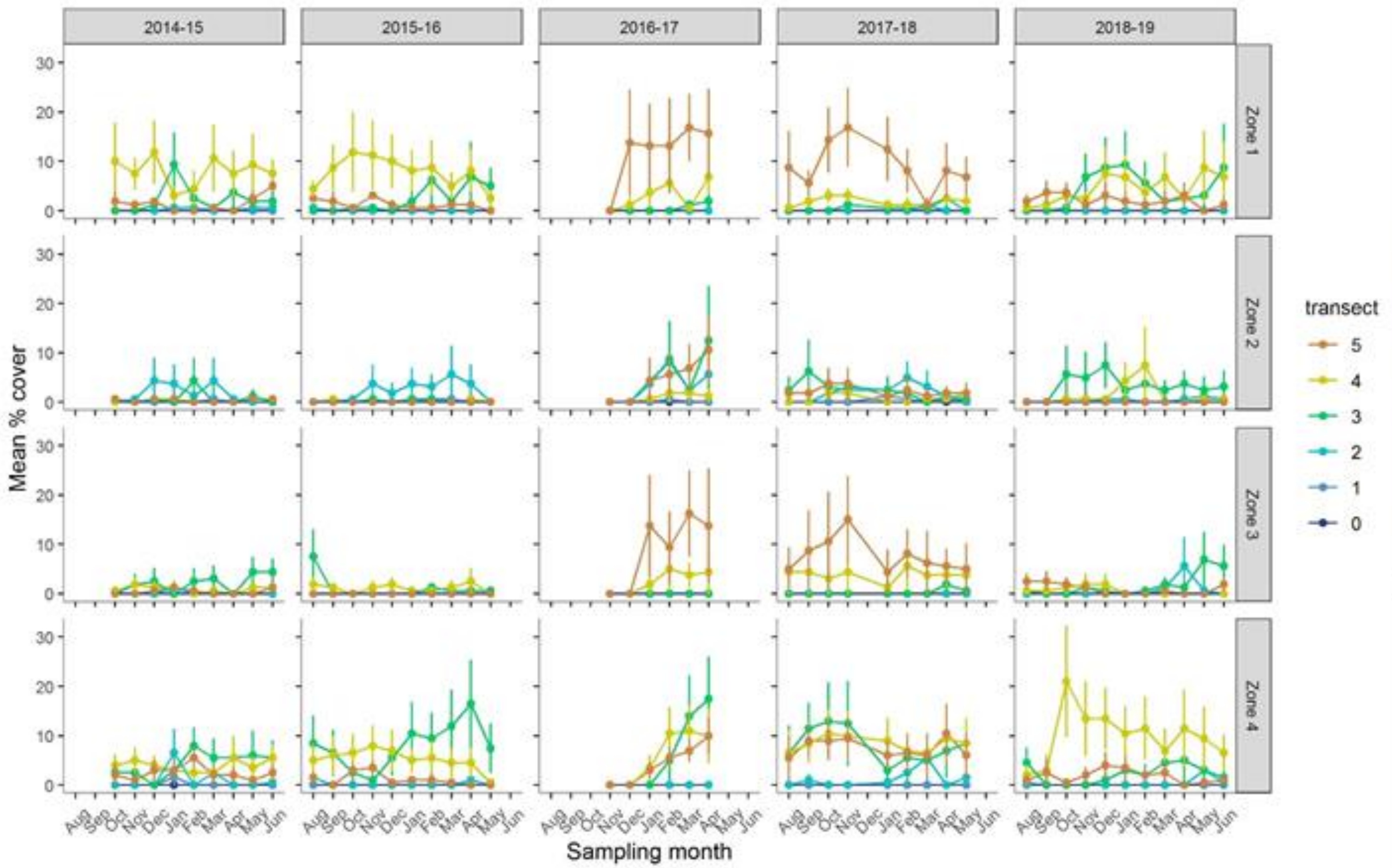


Figure 7.11 Mean percent cover of milfoil (*Myriophyllum spp*) monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and June 2019. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the river bank.

Richness and cover of terrestrial taxa

In 2018-19 there were overall more terrestrial taxa recorded than prior to the flood (Table 7.2) and there was an increase in mean total richness of terrestrial taxa in zones 1 and 2 (Figure 7.2), however, the average mean number of terrestrial taxa in zones 1, 3 and 4 had not returned to pre-flood levels (Figure 7.2). The change in cover of terrestrial taxa was variable (Figure 7.12). Some taxa, such as common sneeze weed (*Centipeda cunninghamii)* (Figure 7.13) increased in cover after the flood and other taxa decreased or did not show much change.

Figure 7.12 Mean percent cover of the eight most abundant terrestrial vegetation taxa monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and May 2019.



common sneezeweed

Figure 7.13 Mean percent cover of common sneeze weed (*Centipeda cunninghamii*) monitored monthly across four hydrological zones in the Edward/Kolety-Wakool system between August 2014 and June 2019. Transect zero is lowest on the riverbank and transects are labelled consecutively up to transect 5 highest on the river bank.

7.6 Discussion

Riverbank and aquatic vegetation in the Edward/Kolety-Wakool system continues to recover following the reduction in mean species richness and mean cover that occurred following the unregulated flood in 2016.

The floods in 2016 decreased the richness and cover of submerged and amphibious taxa throughout the Edward/Kolety-Wakool system. The reduction in the cover of submerged taxa and amphibious taxa may have been due to extreme physical disturbance experienced during the flood which can restrict access to atmospheric carbon dioxide and oxygen, causing anoxic soil conditions and depleted soil biota (Campbell et al. 2019). Some of the sites had overbank flows for over 1 month during late 2016 and most riverbank transects were underwater for 4 to 5 months and higher turbidity levels with values ranging from ~50 to 300 NTU were observed during this period (Figure 5.4). A reduced light climate during the 2016 flood would have potentially prevented submerged and amphibious plants from photosynthesising. Likewise, in a controlled experiment Doyle and Smart (2001) found that higher turbidity levels significantly affected *Vallisneria americana* in terms of producing less leaf production and biomass and causing a higher mortality rate of plants. In the 2018-19 reporting period the NTU ranged between ~40 to 200 NTU (Figure 5.4). This limitation on light penetration in the 2018-19 study period and may offer, at least in part, an hypothesis as to why the recovery of submerged and amphibious taxa is slow.

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 2017-18 there was some evidence of recovery of submerged and amphibious taxa (Watts et al 2018), and in 2018-19 there has been further evidence signs of recovery such a strong increase in the number of amphibious taxa. The total number of amphibious taxa has increased from 15 in 2017-18 to 24 in 2018-19. Although many of these taxa were recorded in low abundances, with subsequent environmental watering they may increase in cover. The notable increase in mean total species richness of amphibious taxa in the upper Wakool River zone 2 supports our hypothesis that increasing environmental flows in this river system would result in better environmental outcomes in this river.

The cover of terrestrial taxa also increased, particularly in zone 1 and 2. The increase in species richness and cover of the terrestrial taxa in the upper Wakool River zone 2 in 2018-19 is likely to be in response to the higher flows and increased variability in this river, and particularly increased wetted area of riverbank (section 4) that is not usually experienced in this system during operational flows.

These observations from 2018-19 combined with observations in 2014-15 (Watts et al. 2015), 2015-16 (Watts et al. 2016) and 2017-18 (Watts et al 2018) suggest that late winter/early spring freshes that inundate slackwater, in-channel benches or low lying 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 prior to the onset of hotter weather in summer that can quickly dry out the river banks. Further freshes delivered after the initial event that re-wet these areas can 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/Kolety-Wakool system was considerably impacted by the large unregulated flood in spring 2016. In 2017-18 and again in 2018-19 there was evidence that riverbank and aquatic vegetation is recovering, with the highest number of taxa recorded in 2018-19 since the LTIM project commenced.

There is evidence that Commonwealth environmental watering actions has contributed to this recovery. Spring freshes have increased opportunities for germination and follow-up freshes contribute to growth and survival. The winter watering action in 2017 would have prevented loss from frost and aided the recovery of vegetation.

In previous years the species richness and cover of vegetation was lower in the upper Wakool River zone 2 (received minimal or no environmental water) than in zones 1, 3 and 4 that had received environmental water. In 2018-19 a pulse of environmental water was delivered to zone 2 in September 2018 during the 800 ML/d flow trial and this was followed by a period of operational flows from the MIL Wakool escape between October 2018 and February 2019. These actions resulted in an increase in total and mean richness of vegetation taxa in zone 2, such that it now has similar average species richness as the other zones (see Figure 3.2).

Despite the increase in the total species richness, the mean species richness in zones 1, 3 and 4 has not yet recovered to the same levels as prior to the 2016 flood (Table 7.2). This is because 27 of the 65 taxa in 2018-19 were recorded at less than ten points across all sites across the entire water year. Some amphibious taxa such as floating pondweed and milfoil that had high percent cover prior to the flood were considerably reduced in cover or were killed during flood in 2016. In 2018-19, two years after the flood, there has been minimal recovery of these taxa. Small plants of these species have been observed outside the formal transects, suggesting there is the possibility of the recovery of these species over the next year or so that can be supported by 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?

The 800 ML/day flow trial in 2018-19 increased the maximum discharge and increased wetted area in all four hydrological study zones. This watering action was delivered slightly earlier than spring freshes in previous years. The observed strong germination in response to this action suggests that late winter/early spring freshes that inundate slackwater, in-channel benches or low lying areas of riverbank within the channel can have positive outcomes on the germination of river bank vegetation. Following the recession of flows, the damp banks provided ideal conditions for plant growth prior to the onset of hotter weather in summer that can quickly dry out the river banks. Further subsequent freshes (environmental actions or operational flows) that re-wet these areas can provide ongoing conditions that are suitable for amphibious plants to grow and survive the warmer conditions over the summer.

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.

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?**
Early spring watering action (small fresh) in Yallakool Creek and mid- and lower-Wakool River 22nd August to 25th September 2018	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. The 800 ML/day flow trial in 2018-19 has supported the recovery of aquatic and riverbank vegetation.
		How do vegetation responses to Commonwealth environmental water delivery vary among hydrological zones?	Prior to 2018-19 there was higher species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that received no or minimal environmental water. The delivery of environmental water to all zones in 2018-19 resulted in similar species richness in all zones.		
		What did CEW delivered as base flows and freshes contribute to the percent cover of riverbank and aquatic vegetation?	There is minimal difference in vegetation cover among the zones. The percentage cover of submerged and amphibious taxa was 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?	The environmental watering had positive outcomes on germination of riverbank vegetation in response to increased inundation of low lying areas of the riverbank.		

8 FISH

2018-19 key findings		
Movement	Movement of golden perch and silver perch	Watering action 1 in spring 2018 facilitated silver perch and golden perch movements of 57 km and 12.2 km (median) respectively. Watering action 1 was followed by reduced zone coverage by tagged silver perch (occurring in zone 3 and 4 only), but increased LTIM zone coverage by golden perch. Tagged adult silver perch were present in Wakool River (Zone 4) concurrent with the detection of spawning in this system in November 2018.
Spawning	Larval abundance of equilibrium species	Murray cod larvae were detected in greatest numbers in 2018-19 compared to the four previous years of LTIM, with the majority of Murray cod larvae collected from upper Wakool River (Zone 2).
	Larval abundance of periodic species	Silver perch eggs were collected in Yallakool Creek (zone 1) and Wakool River downstream of Thule Creek (Zone 4) in November-December 2018. This is the second year that silver perch spawning has been detected in the study zones since monitoring commenced in 2015.
	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 greater in 2018-19 compared to previous years.
Recruitment	Murray cod, silver perch and golden perch recruitment	Murray cod 1+ recruits were detected in highest numbers since the hypoxic blackwater event in 2015-16. Silver perch 1+ recruits were detected for the first time since the hypoxic blackwater event in 2015-16. Golden perch recruits appear to remain absent from the system, having not been recorded since the start of the LTIM program in 2015.
Adults	Adult fish populations	In 2018-19 nine native species of fish, including silver perch and trout cod, were captured at in-channel sites across the Edward/Kolety-Wakool system. New recruits were detected for 6 of the 9 native species, with the exception of golden perch, silver perch (note recruits of these species were captured through other monitoring), and trout cod. The health of the Edward/Kolety-Wakool fish community decreased from 2015 to 2019, although we argue that the fish assemblage is in a state of recovery following adverse water quality and associate fish deaths in 2016.

8.1 Introduction

The Edward/Kolety-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/Kolety-Wakool system and they are a key environmental asset valued by the broader Edward/Kolety-Wakool community. Historically, the Edward/Kolety-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/Kolety-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/Kolety-Wakool LTIM 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/Kolety-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 being monitored in the Edward Wakool system is described below.

In section 8.6 we bring together our results across the movement, spawning, recruitment and adult sampling to provide an overview of how the fish community in the Edward/Kolety-Wakool responded to watering events and Edward/Kolety-Wakool hydrological conditions in general.

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 2014-18
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*	
freshwater 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*	

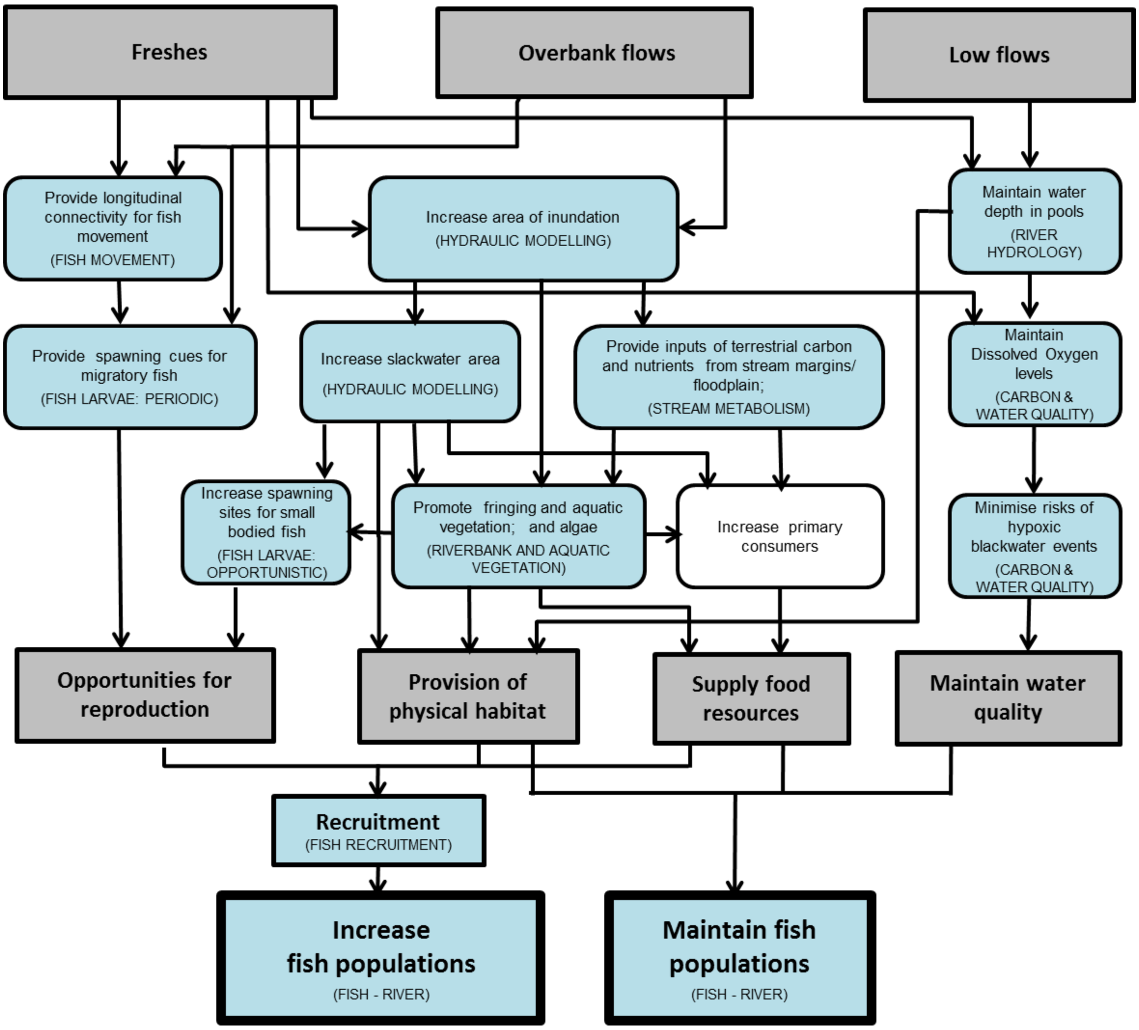


Figure 8.1 Conceptual diagram illustrating the linkages between different types of environmental watering (freshes, overbank flows, low flows) to fish populations via key ecological processes. Key ecological processes that are being monitored as part of the Edward/Kolety-Wakool Monitoring & Evaluation 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/Kolety-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/Kolety-Wakool system in order to target juvenile Murray cod, silver perch and golden perch. This monitoring enables comparison of juvenile growth rates among zones of the Edward/Kolety-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/Kolety-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 was undertaken in year 1 (2014-15) and year five (this current year, 2018-19). 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

There was one Commonwealth environmental watering action in the Edward/Kolety-Wakool system in 2018-19 (Table 8.2) that was evaluated in this report. One of the primary objectives for the spring flow trial was to deliver positive outcomes for native fish populations (CEWO 2018):

Table 8.2 Commonwealth environmental watering actions in 2018-19 in the Edward Wakool River system that had objectives targeting native fish.

	Watering action	Type of action	Dates	Rivers	Objectives
1	spring flow trial	small fresh (800 ML/day)	22 Aug - 25 Sep 2018	Yallakool Creek, mid- and lower Wakool River	To support the recovery of large bodied native fish following the 2016 hypoxic blackwater event. To maintain the diversity and condition of native fish through maintaining suitable habitat and providing/support opportunities to move, breed and recruit.

8.3 Selected Area evaluation questions

Data from the Edward/Kolety-Wakool system is being evaluated at the Selected Area scale and will 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 La Trobe University and will be evaluated in a separate report.

This is the final year of reporting for the five year 2014-19 LTIM monitoring project. As such this report will provide a benchmark which will be used by the LTIM program to determine if there is a system-wide change in the fish community assemblage structure in the Edward/Kolety-Wakool system with respect to environmental water delivery. The short and long term Selected Area evaluation questions, as outlined in the MER Plan for the Edward/Kolety-Wakool system (Watts et al. 2014a) are outlined in Table 8.3. This report will evaluate environmental water against the short-term and long-term evaluation questions.

Table 8.3 Selected Area evaluation questions relating to the effect of Commonwealth environmental water on Edward/Kolety-Wakool fish population.

Key components	Selected Area-scale evaluation questions
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/Kolety-Wakool river system? • Does CEW contribute to the recovery of fish communities following negative conditions within the Edward/Kolety-Wakool river system? *Long-term evaluation questions* • Does CEW contribute to maintain or enhance existing levels of fish recruitment in the Edward/Kolety-Wakool river system? • Does CEW contribute to maintain or increase native fish diversity and abundance in the Edward/Kolety-Wakool river system? • Does CEW contribute to maintain or increase native fish biomass in the Edward/Kolety-Wakool river system?

8.4 Methods

Fish movement

A total of 71 acoustic receivers (VEMCO VR2W) were installed in the Edward/Kolety-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/Kolety-Wakool system to monitor any potential emigration out of the system. The installation of these 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 4 years of data collection as well as specific movements in response to watering events in 2018-19. 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 2018-19.

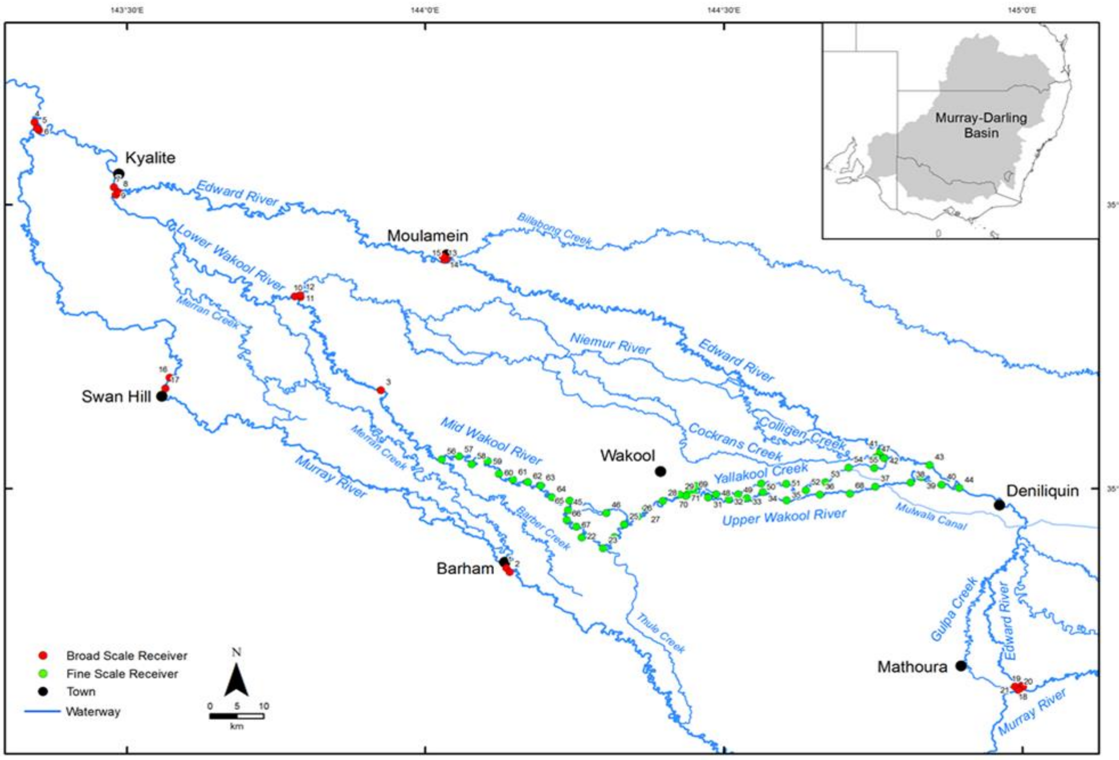


Figure 8.2 Location of acoustic telemetry receivers (green dots) moored in the Edward/Kolety-Wakool system to determine movements of acoustically tagged golden perch and silver perch. Red dots indicate the 20 additional receivers placed at key entry/exit points and major junctions to monitor any potential 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/Kolety-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/Kolety-Wakool system), an individual between two receivers and not moving, tag failure (battery expiration) or mortality.

We used generalised additive mixed models (GAMM) with a binomial distribution to model the probability of movement for each of the three species in response to river flows. We aggregated daily river flows (ML day^{-1}) to a five day time step, as mean daily flow for each five day period. We classified individuals as having moved during a 5 day time step when they were tracked at a receiver that was different from their last known location. A random intercept was included in each of the models to account for the fact that individual fish were considered a random draw from the overall population with potentially different tendencies toward movement.

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.

Fish spawning and reproduction

Field sampling

Fish larvae were sampled fortnightly within the Edward/Kolety-Wakool Selected Area from the week of 10 September 2018 – 29 February 2019 (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/Kolety-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*). Cat 3 drift net methods consisted of drift nets deployed fortnightly for 7 sampling trips from 10 October – 23 December 2018. 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 10 September – 23 December 2018 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.

Total larval catch rates (light traps and drift nets combined) were compared across years. 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, 2018-19, and 'zone' (zone 1, zone 2, zone 3, zone 4) were treated as a random effect. The distribution of larval counts were non-Gaussian so Gamma distributions with a log-link were used in the statistical models. A poisson distribution was not considered because of the large number of non-positive values (zeros) in the data set. 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.

Fish recruitment

Four sites were sampled in each of four river zones within the Edward/Kolety-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; 2017-18 and 2018-19.

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 euthanised.

Continuous backpack electrofishing, using a 12 V DC battery with a Smith-Root LR-20 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.

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, year and the interaction between 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.

Adult fish community

Fish community sampling was undertaken in April through June in 2015 and 2019 at 18 sites throughout the Edward/Kolety-Wakool system (Figure 8.4) using standardised Sustainable Rivers Audit (SRA) protocol (i.e. a standardised effort of electrofishing and unbaited bait traps at each site) as described in Watts et al. (2014a). All fish captured were identified to species and enumerated, and a subset weighed (g) and total or fork length (mm) recorded. Length was used to distinguish new recruits for each species (Table 8.4), and when a subset of fish was measured proportions of juveniles and non-juveniles were scaled to total catch by method for each species. Similarly, species and method-specific biomass was scaled to total catch when subsampling had occurred during measurement.

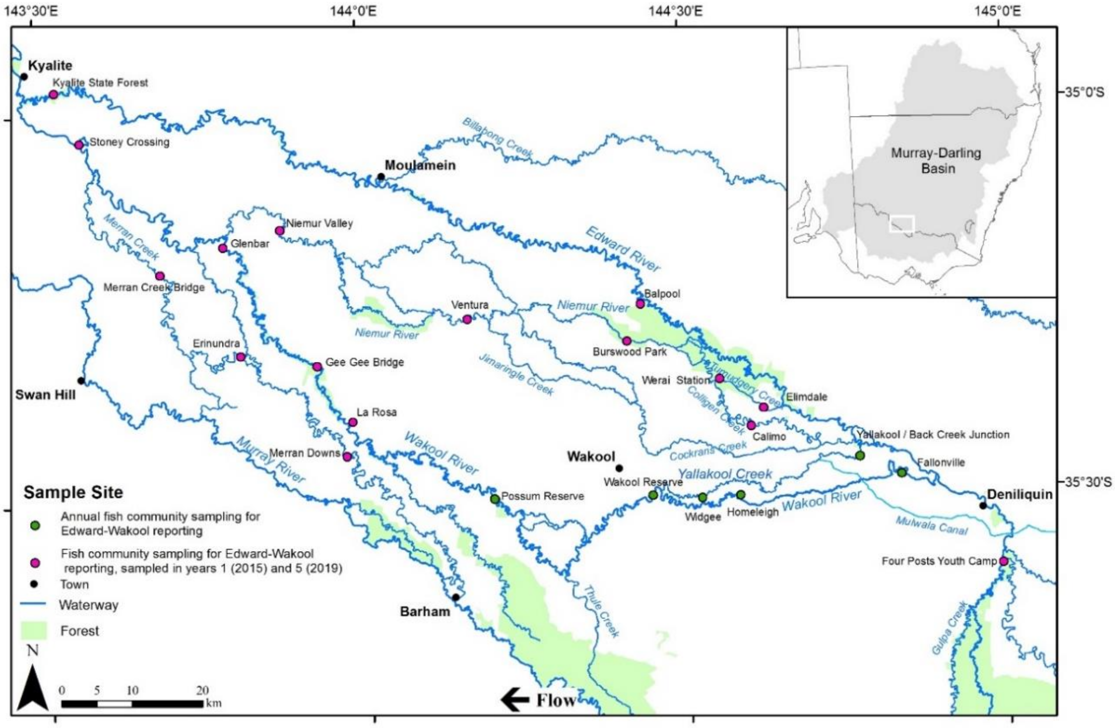


Figure 8.4 Locations of fish community sampling sites in the Edward/Kolety-Wakool river system. Note that data collected from Balpool, Fallonville and Werai Station sites were not used in an historical analysis as they were not sampled annually over six years (2010–2015). In addition to these excluded sites, the Four Posts Youth Camp site was not included in the current analysis (2015–2019) as the water level was too low for boat electrofishing in 2019.

To place the 2015 and 2019 fish community assemblage data in the context of previous monitoring programs, analysis was undertaken using annual data collected from the same in-channel sites plus one extra (19 sites in total) in the preceding six years (i.e. 2010–2015). These 19 in-channel sites represent a sub-sample of those previously sampled (*see* Watts et al. 2014a, b). To determine differences in fish communities among years, abundance and biomass data were analysed separately using one-way fixed factor Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al., 2008). Raw data were initially fourth root transformed and the results used to produce a similarity matrix using the Bray-Curtis resemblance measure. All tests were considered significant at $P < 0.05$. Where significant differences were identified, pair-wise post-hoc contrasts were used to determine which years differed. Similarity percentage (SIMPER) tests were used to identify individual species contributions to average dissimilarities.

Sustainable Rivers Audit (SRA) fish community indices were calculated to quantify overall condition of the fish community assemblage, and to place 2015 and 2019 in the context of previous years. Data were first portioned into recruits and non-recruits. Large-bodied and generally longer lived species (max. age >3 years) were considered recruits when length was less than that of a one-year-old. Small-bodied and generally short-lived species that reach sexual maturity in less than one year were considered recruits when length was less than average length at sexual maturity. Recruitment lengths were derived from published scientific literature or by expert opinion when literature was not available (Table 8.4). Eight fish metrics were calculated using the methods described by Robinson (2012). These metrics were subsequently aggregated to produce three indices (Nativeness, Expectedness and Recruitment), and to derive an overall fish community condition score. Metric and indicator aggregation used Expert Rules analysis in the Fuzzy Logic toolbox of MatLab (The Mathworks Inc. USA) (Davies et al. 2010, Carter 2012).

Table 8.4 Size limits used to distinguish new recruits for each species. Values represent the length at 1 year of age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year.

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)
Native species	
Australian smelt	40 mm (Pusey et al. 2004)
bony herring	67 mm (Cadwallader 1977)
carp gudgeon	35 mm (Pusey et al. 2004)
flathead gudgeon	58 mm (Pusey et al. 2004; Llewellyn 2007)
golden perch	75 mm (Mallen-Cooper 1996)
Murray cod	222 mm (Gavin Butler, *Unpublished data*)
Murray River rainbowfish	45 mm (Pusey et al. 2004: for *M. duboulayi*)
silver perch	75 mm (Mallen-Cooper 1996)
trout cod	150 mm
unspecked hardyhead	38 mm (Pusey et al. 2004)
Alien species	
common carp	155 mm (Vilizzi and Walker 1999)
eastern gambusia	20 mm (McDowall 1996)
goldfish	127 mm (Lorenzoni et al. 2007)
oriental weatherloach	76 mm (Wang et al. 2009)
redfin perch	60 mm (maximum reported by Heibo & Magnhagen 2005)

Expectedness represents the proportion of native species that are now found within the relevant catchment and altitudinal zone, compared to a historical reference condition. This value is derived from two input metrics; the observed native species richness over the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (Robinson 2012). Nativeness represents the proportion of native compared to alien fishes, and is derived from three input metrics; proportion native biomass, proportion native abundance and proportion native species (Robinson 2012). The Recruitment Index represents the recent reproductive activity of the native fish community within each hydrological zone, and is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting (corrected for probability of capture based on the number of sites sampled), and the average proportion of total abundance of each species that are new recruits (Robinson 2012). The three indices were subsequently aggregated to generate a weighted overall Fish Condition Index (Carter 2012). Overall condition was then partitioned into five equal categorical bands to rate the condition of the fish community as; "Good" (81–100), "Moderate" (61–80), "Poor" (41–60), "Very poor" (21–40), or "Extremely Poor" (0–20).

8.5 Results

Fish movement

A total of 78 golden perch, 21 Murray cod and 42 silver perch contributed movement data from August 2015 until May 2019. 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 2019 a total of 29 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 8.5 and 8.6). 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 8.7). Maximum daily movements were 50.7 km for golden perch, 33.0 km for Murray cod and 48.1 km for silver perch.

The results indicate clear relationships between the probability of movement and observed river flow, however, the nature of this relationship was slightly different across species (Figure 8.8). Across all flows the probability of movement is below 0.5 which is due to the fact that not all individuals moved at all times on any given flow. During times of zero flow, there was an almost zero probability of movement for all species and there was little to no probability of movement for golden perch and Murray cod during times when flow was below 250 ML day^{-1}. When flows begin to exceed this level, the probability of movement increases gradually for golden perch and sharply for Murray cod before both stabilise. For silver perch, there was a general increasing trend of movement in response to flow across all flows experienced.

Silver perch ranged over all 4 LTIM zones in 2017–18 (between July 2017 and July 2018) including during winter watering in 2017, however this contracted to zones 2 to 4 in 2018–19 (Figures 8.10, 8.12). Golden perch rather resided mostly in zones 3 and 4 in 2017–18, and then expanded their range into zones 1, 3 and 4 in 2018–19. Of the 30 silver perch recorded in 2017–18, 5 (17%) were in Yallakool Creek (zone 1) and 4 (13%) were in the upper Wakool River (zone 2). In 2018–19, 2 (11%) of 18 silver perch were detected in zone 2. For golden perch, 2 (7%) of 29 individuals were recorded in zones 1 and 2 in 2017–18, while 3 (13%) of 23 individuals were recorded in both zones 1 and 2 in 2018–19.

Fish movement distances and the proportions of fish moving varied slightly between Spring 2018, when a watering action occurred, compared to the previous Spring 2017 (Figure 8.12, 8.13). Fifteen (93%) of 16 silver perch moved in spring 2018, whereas 28 (100%) of 28 silver perch moved in spring 2017. For golden perch, 14 (67%) of 21 individuals moved in spring 2018 compared to 19 (73%) of 26 individuals in spring 2017 (Figure 8.10 and 8.13). The spring flows in 2018 resulted in silver perch movements (median and 25th – 75th percentiles) of 57 km (25–142 km) compared to 108 (35–190) km in spring 2017. In contrast, golden perch moved 12.2 (0–51.7) km in spring 2018 relative to 11.7 (5.8–24.4) km in spring 2017 (Figure 8.13). The spring 2018 flows were followed by reduced LTIM zone coverage by silver perch, but increased LTIM zone coverage by golden perch (Figure 8.12).

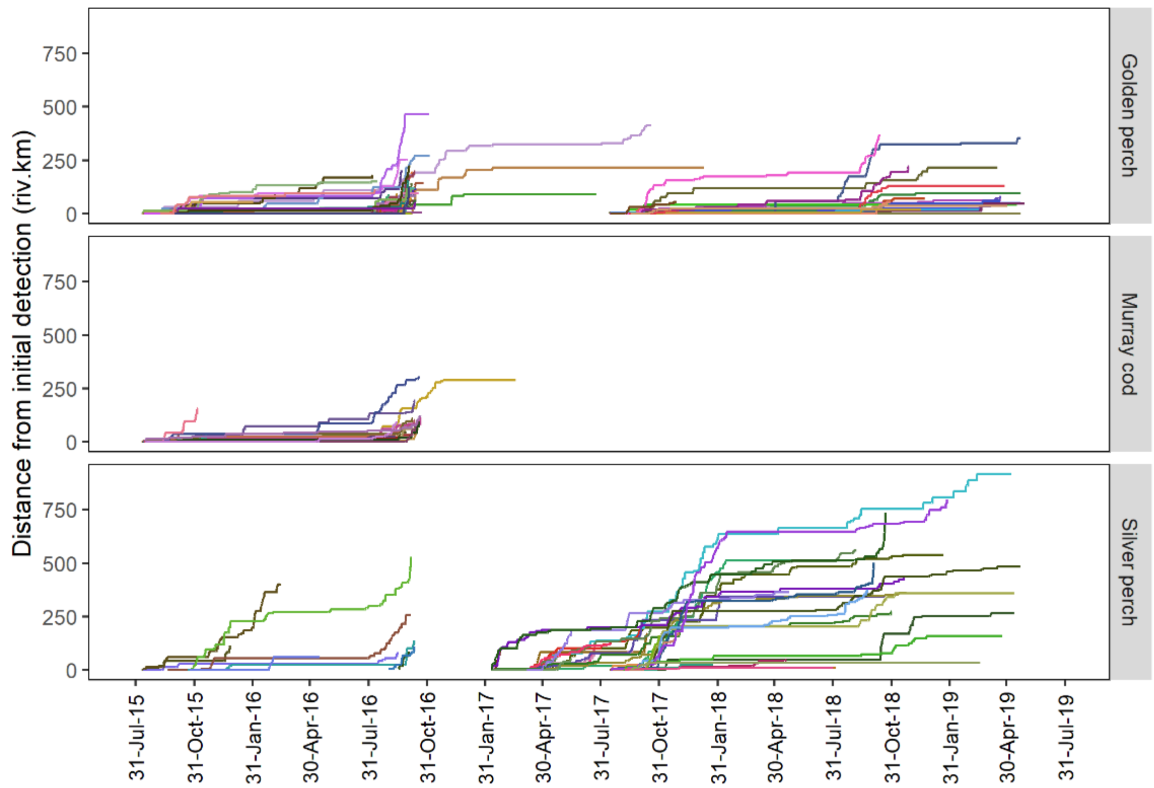


Figure 8.5 Cumulative daily distance moved (irrespective of direction) of acoustically tagged golden perch, Murray cod and silver perch in the Edward/Kolety-Wakool system between Aug 2015 and May 2019. Different lines represent different tagged individuals and 0 km represents the first detection of an individual fish. Note that when the individual line finishes this represents the last detection of this individual fish within the acoustic array.

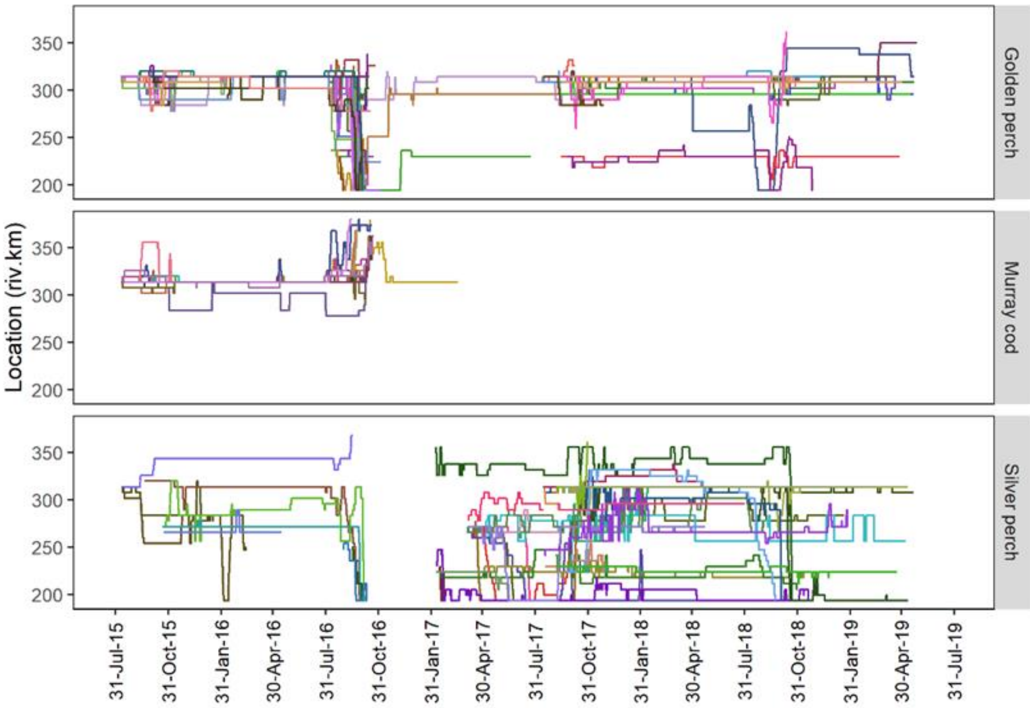


Figure 8.6 Daily locations of acoustically tagged golden perch, Murray cod and silver perch in the Edward/Kolety-Wakool river system from Aug 2015 to May 2019. Different coloured lines represent different tagged individuals and the km value represents the location (distance in km from the junction of the Wakool and Murray rivers).

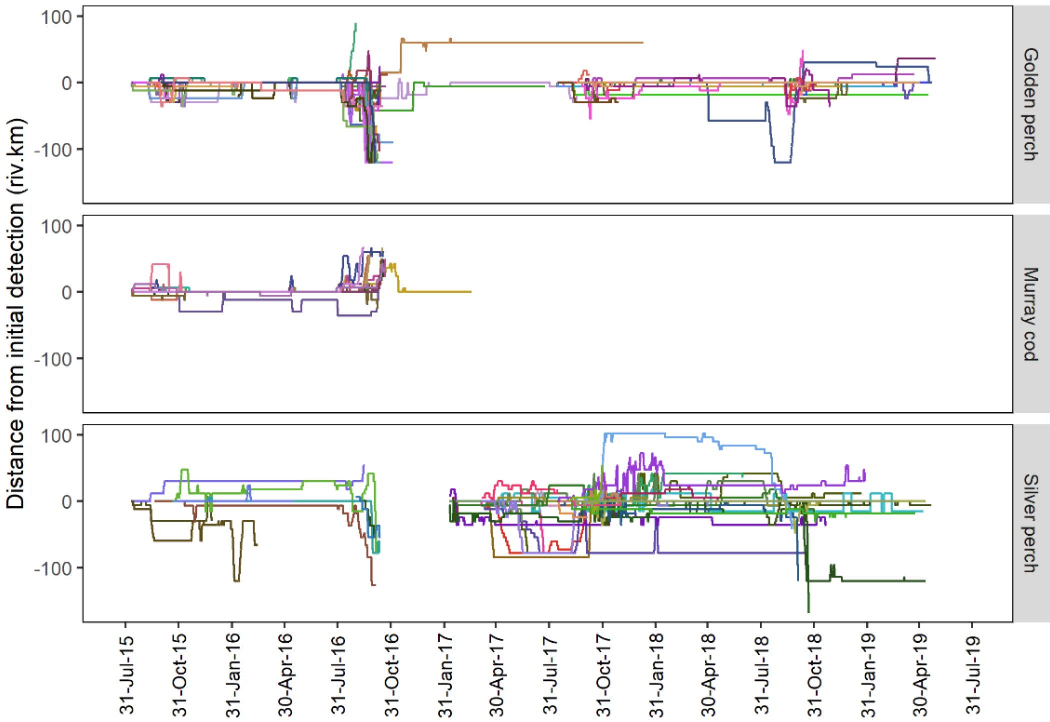


Figure 8.7 Daily locations of acoustically tagged golden perch, Murray cod and silver perch in the Edward/Kolety-Wakool river system from Aug 2015 to May 2019. Different coloured lines represent different tagged individuals and 0 km represents the initial detection (i.e. first location).

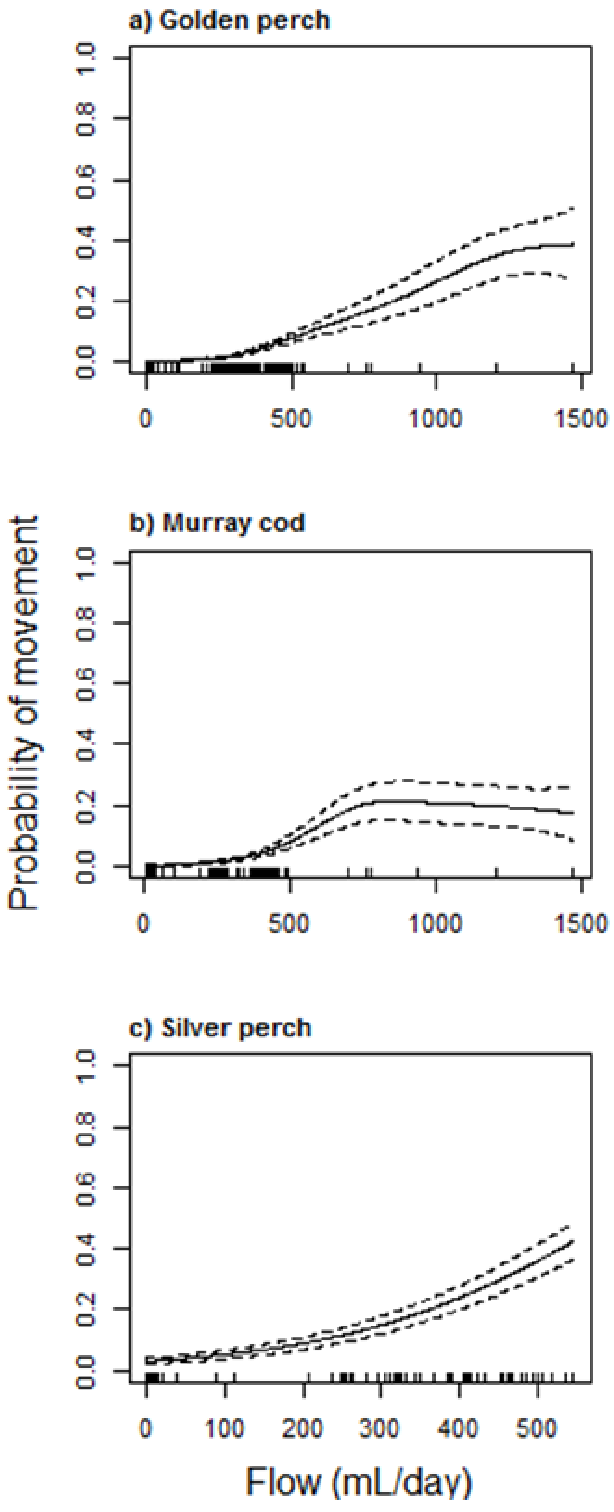


Figure 8.8 Probability of movement for each species in response to flows. Dashed lines are approximate 95% confidence intervals. Tick marks on the x-axis show the occurrences of each observed mean daily flow.

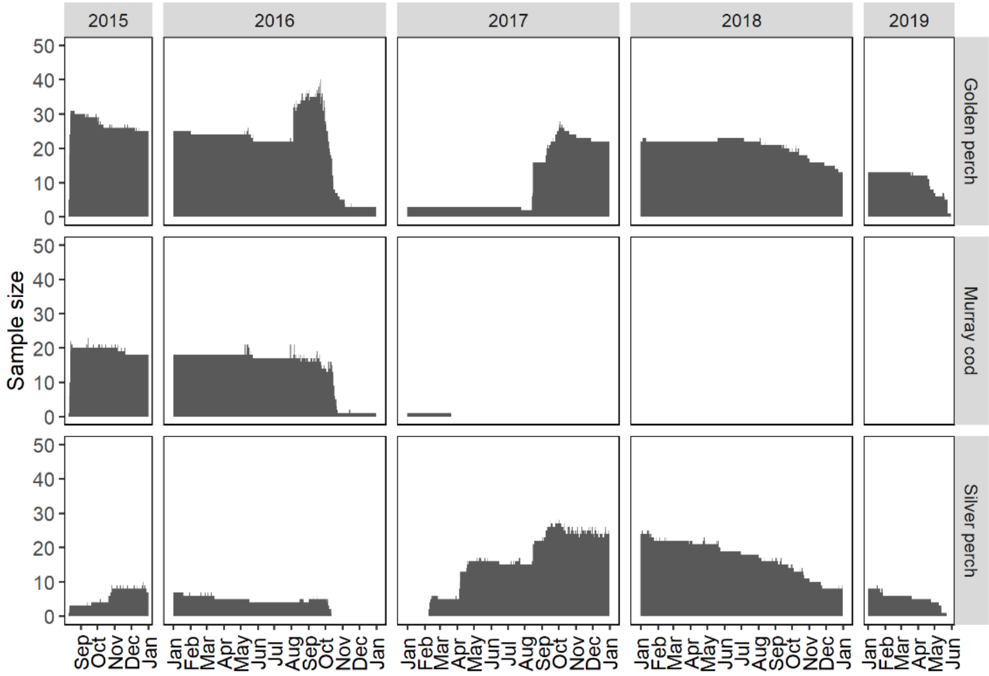


Figure 8.9 Sample sizes of golden perch, Murray cod and silver perch fitted with acoustic tags and contributing to fish movement data on any given day in the Edward/Kolety-Wakool river system. Note that individual records are truncated to the last valid detection on an acoustic receiver, and after this period individuals may have either left the array, may occupy a position between two receivers, or may be considered a mortality.

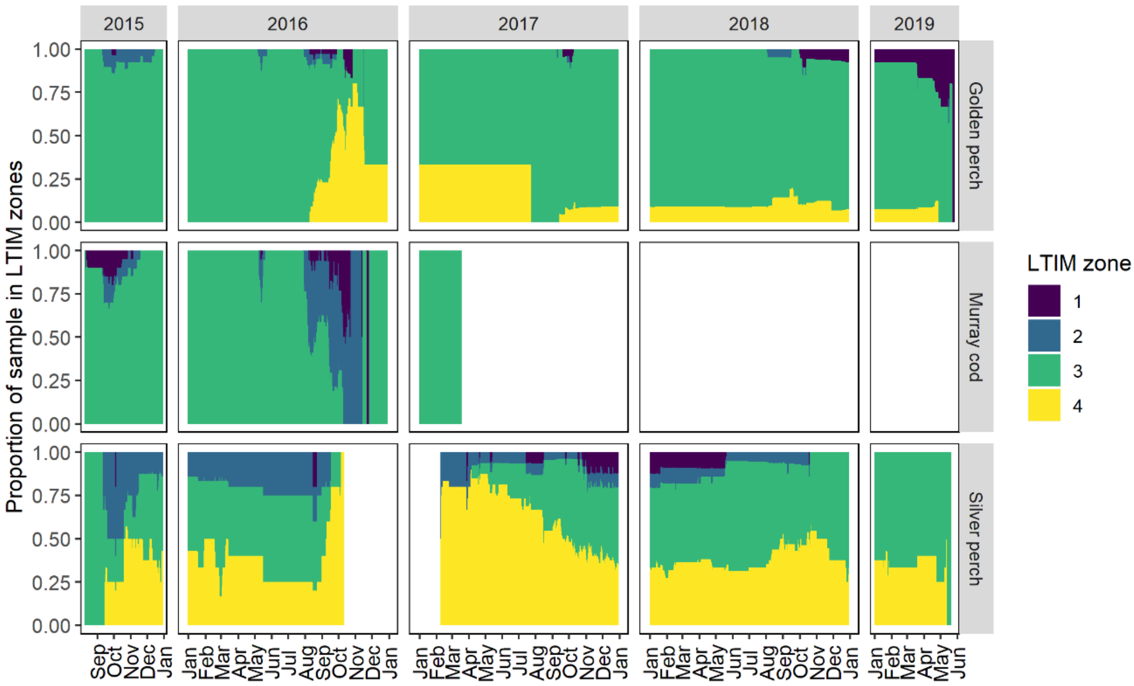


Figure 8.10 Proportionate daily location of acoustically tagged golden perch, Murray cod and silver perch within each LTIM focal zone for the duration of the study.

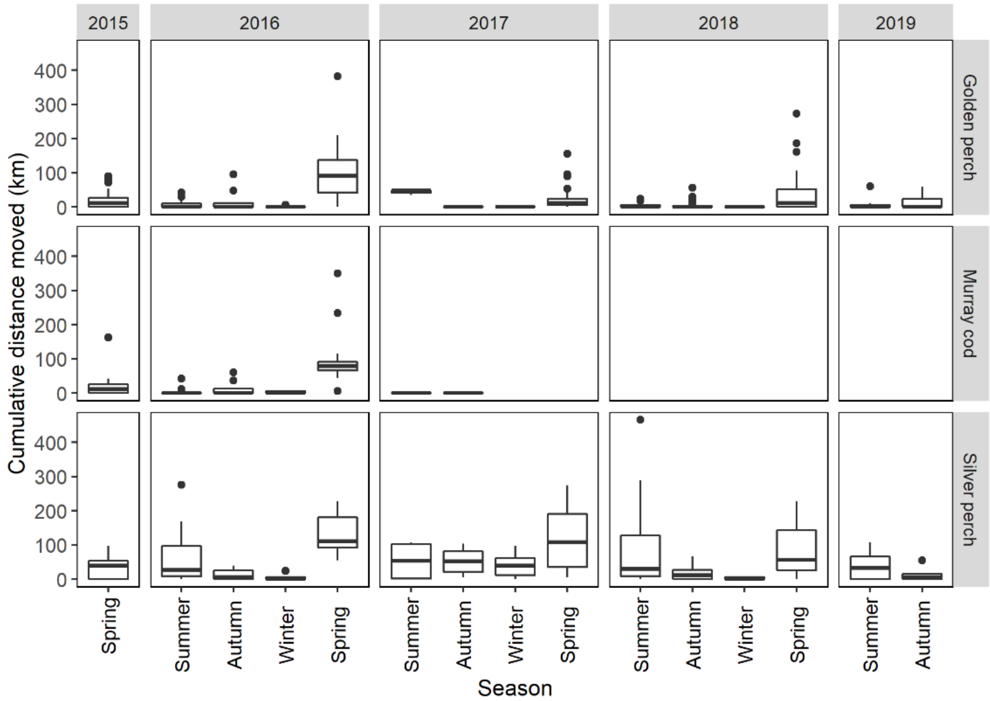


Figure 8.11 Seasonal cumulative movements of golden perch, Murray cod and silver perch in the Edward/Kolety-Wakool river system for the duration of the study. Data are represented as median, 25th and 75th percentiles (box) and 5th and 95th percentiles (whisker).

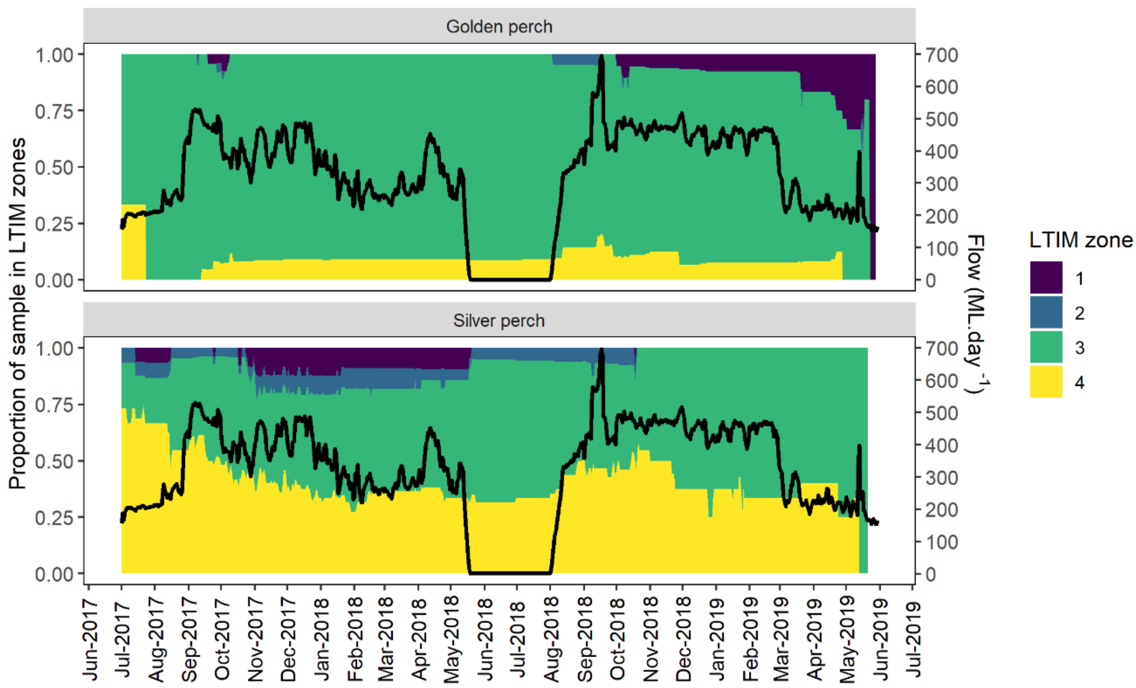


Figure 8.12 Proportionate daily location of acoustically tagged golden perch and silver perch within each LTIM focal zone from July 2017 until May 2019. Daily discharge is also plotted (black line) to help explain fish movements between zones.

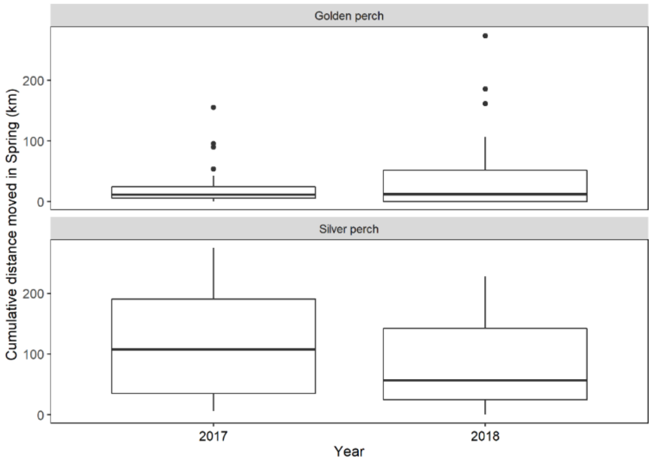


Figure 8.13 Cumulative movements of golden perch and silver perch in the Edward/Kolety-Wakool system in spring 2017 compared to spring 2018 during the Commonwealth environmental watering action. Data are represented as median, 25th and 75th percentiles (box) and 5th and 95th percentiles (whisker).

Fish spawning and reproduction

A total of 3,509 fish eggs and larvae, representing ten species, were collected in 2018-19 from light traps (n=1,791) and drift nets (n=1,718) (Table 8.5). Across the four zones, the greatest number of larvae were collected in Wakool River zone 2 (45%), followed by Wakool River zone 3 (30%), Yallakool Creek zone 1 (19%) and Wakool River zone 4 (7 %). The 2018-19 total larval catch was similar to 2014-15, 2015-16 and 2017-18 spawning seasons where 4249, 3418 and 4428 larvae were sampled respectively. All these years were characterized by in-channel flows during the spring/summer. Considerably more larvae (n= 12,667) were collected in the flood year of 2016-17 despite the reduced sampling effort caused by flooding and access issues (Watts et al. 2017b).

Ten of the eleven fish species collected as larvae in 2018-19 were native. Murray cod larvae were the most numerically abundant larvae caught in 2018-19 (*Maccullochella peelii*, n=1,791), with nearly half (45%) of the larvae collected from the Wakool River zone 2. Australian smelt (*Retropinna semoni* n=935), and carp gudgeon (n=734) larvae were also detected consistently across the four study zones. Other small-bodied fish found spawning during 2018-19 were flathead gudgeon (*Philypnodon grandiceps*, n=4), obscure galaxias (*Galaxias oliros,* n=3) and Murray River Rainbowfish (*Melanotaenia fluviatilis*, n= 1). Notably, this is the second year that silver perch eggs (*Bidyanus bidyanus, n=7*) have been detected in the Edward/Kolety-Wakool Selected Area (Figure 8.14), a positive indication that local spawning of silver perch took place in 2018-19. Silver perch eggs were collected in Yallakool Creek and the Wakool River zone 4, and one late staged larvae was also collected in the Wakool River zone 4. The presence of this late stage larvae suggests that some survival of eggs through to the late larval stage took place within in the Edward/Kolety-Wakool Selected Area. Other large bodied species collected as larvae in 2018-19 were bony herring (*Nematolosa erebi, n=5*) and river blackfish (*Gadopsis marmoratus, n=1*). Similarly to previous years, we did not detect golden perch spawning in the study zones in 2018-19 (Table 8.6). Freshwater catfish larvae (*Tandanus tandanus),* detected for the first time in 2017-18, were not found in 2018-19 (Table 8.6). Carp (*Cyprinus carpio*) was the only introduced species captured as larvae in the 2018-19 spawning period, and were only collected in very small numbers (n=5) (Table 8.5,Table 8.6).

Table 8.5 Total abundance of fish larvae sampled using light traps (LT) and drift nets (DN) in the four study zones of the Edward/Kolety-Wakool River system in spring/summer 2018-19. Fish species listed are those known to occur in the Edward/Kolety-Wakool system. To date, trout cod have been detected in the Edward Wakool Selected Area but not in the study zones. 'e' denotes collected as eggs.

Common name	Yallakool Ck Zone 1		Wakool River u/s Yallakool Creek Zone 2		Wakool River u/s Thule Creek Zone 3		Wakool River d/s Thule Creek Zone 4		Total	
	LT	DN	LT	DN	LT	DN	LT	DN	LT	DN
Native										
Australian smelt	225	2	168	12	496	-	41	-	930	14
carp gudgeon	15	34	86	1	455	1`	110	41	666	77
flathead gudgeon	2	-	-	-	-	-	2	-	4	-
dwarf flathead gudgeon*	-	-	-	-	-	-	-	1	-	1
unspecked hardyhead	-	-	-	-	-	-	-	-	-	-
Murray River rainbowfish	-	-	-	-	-	-	1	-	1	-
obscure galaxias	-	-	2	-	1	-	-	-	3	-
bony herring	-	-	-	-	-	-	5	-	5	-
silver perch	-	6(e)	-	0	-	-	1	1(e)	1	7
golden perch	-	-	-	-	-	-	-	-	-	-
freshwater catfish	-	-	-	-	-	-	-	-	-	-
river blackfish	-	1	-	-	-	-	-	-	-	1
trout cod	-	-	-	-	-	-	-	-	-	-
Murray cod	82	282	19	1284	66	27	9	23	176	1616
Introduced										
gambusia	-	-	-	-	-	-	-	-	-	-
oriental weatherloach	-	-	-	-	-	-	-	-	-	-
redfin perch	-	-	-	-	-	-	-	-	-	-
carp	1	-	2	-	-	-	2	2	5	2
goldfish	-	-	-	-	-	-	-	-	-	-
Other										
tadpoles	-	-	-	-	-	-	-	-	-	-
Grand total	325	325	277	1298	1018	25	171	63	1791	1718

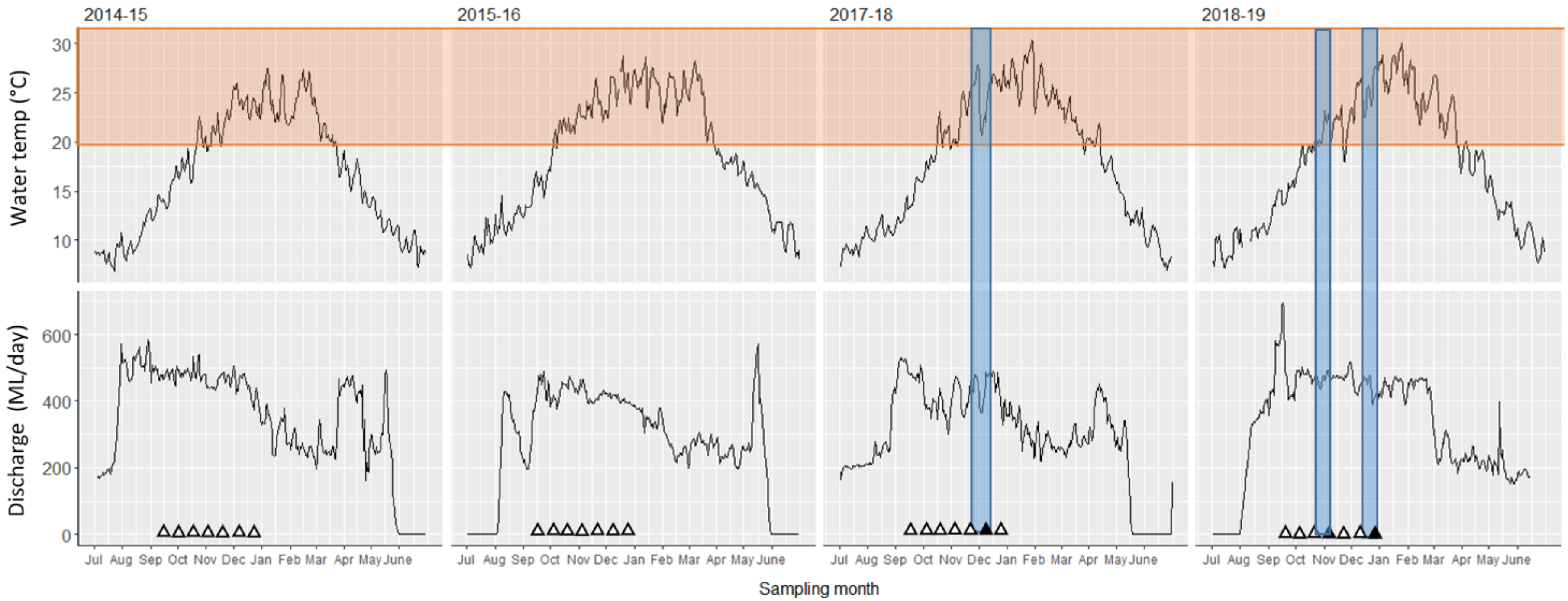


Figure 8.14 Dates in which silver perch eggs were detected in the Edward/Kolety-Wakool study zones (shown as black triangles), plotted with discharge (ML/day) and water temperature (°C). 2014-15, 205-16, 2017-18 and 2018-19. 2016-17 sampling year is not presented, as flooding conditions prevented standard sampling effort to take place. Drift net sampling dates are denoted with open triangles. The dates on which silver perch eggs were not detected is shown as open triangles. In 2017-18, 17 silver perch eggs were collected in drift nets from zone 1. In 2018-19, 7 silver perch eggs were collected in drift nets from zone 1 and 4. Discharge data is from calculated from zone 3, and temperature data obtained from automatic gauge on Wakool River at Barham Bridge. The orange shaded bar represented when temperatures >20 degrees (considered suitable spawning temperature for silver perch in the southern Murray darling Basin). The blue shaded bar represents the antecedent conditions two weeks prior to when eggs were collected.

Table 8.6 Fish species detected as eggs/larvae in the Edward/Kolety-Wakool Selected Area 2014-2019.

	Survey year				
Fish species	2014-15	2015-16	2016-17	2017-18	2018-19
native					
small bodied opportunistic species					
Australian smelt		●	●	●	●
carp gudgeon	●	●	●	●	●
flathead gudgeon	●	●	●	●	●
unspecked hardyhead	●	●	●		
dwarf flathead gudgeon					●
Murray River rainbowfish	●	●	●	●	●
obscure galaxias	●	●		●	●
periodic, flow-cued species					
bony herring			●	●	●
silver perch				●	●
golden perch					
equilibrium species					
freshwater catfish				●	
river blackfish	●	●		●	●
trout cod					
Murray cod	●	●	●	●	●
introduced					
gambusia	●	●	●	●	
oriental weatherloach			●		
redfin perch					
carp		●	●		●
goldfish					
total number of species					
native	8	8	7	11	10
introduced	1	2	3	1	1
total	9	10	10	12	11

Comparisons of larval catch across years and study zones

Periodic 'flow-cued' species

Silver perch eggs first appeared in drift nets on 5-8 November 2018 in zone 4 (Wakool River downstream Thule Creek, n=1), and again on 17-21 December 2018 in zone 1 (Yallakool Creek). At the time when eggs were first detected in zone 4, water temperatures were 22°C, with temperatures exceeded 20°C for the first time in the season in the two weeks prior. Small-scale fluctuations in discharge were noted in the two weeks leading up to eggs being sampled, from approximately 450-500 ML/day (Figure 8.14). The second event of eggs being detected on 17-21 December 2018, coincided with warmer water temperatures (26°C) and greater short term variability in discharge from 480-390 ML/day in the two weeks prior (discharge from zone 3) (Figure 8.14).

Bony herring larvae were collected for the third consecutive year since long-term monitoring commenced in 2015. Similarly to patterns reported previously, where bony herring larvae have only been collected in the lower Wakool River in zones 3 and 4 during Jan-March, in 2018-19 bony herring larvae were collected across all five sites in zone 4, from late Jan to late February 2019. Consistent with previous years, bony herring were not found in Yallakool Creek (zone 1) or the upper Wakool River (zone 2) (Figure 8.15a). Numbers of larvae were too low to warrant formal statistical comparison across years or zones.

Presence of carp larvae were detected in light traps in 2018-19, albeit in very small numbers (n=5). The low levels of carp spawning in 2018-19 are match similar trends of low level spawning observed in previous years when flows have remained in channel, including 2014-15, 2015-16 and 2017-18 (Figure 8.15a).

Equilibrium species

Late-staged Murray cod larvae appeared throughout the Edward/Kolety-Wakool Selected Area from 22 October to20 December 2019. Combining data from drift nets and light traps, we detected the largest number of Murray cod larvae in 2018-19 compared to all previous years. Unlike in previous years where the vast majority of Murray cod larvae are collected in light traps (Watts et al. 2015, Watts et al. 2016, Watts et al. 2017b), in 2018-19 the majority of Murray cod larvae were detected in drift nets (Table 8.5). In previous years the number of Murray cod larvae in light traps has not been significantly different across zones (Watts et al. 2017b), however in 2018-19 more than 70% of the Murray cod larvae sampled (from both drift nets and light traps) came from the upper Wakool River (zone 2). Discharge in the upper Wakool River is typically operated at low base flows of 50 ML/d, however in 2018-19 this section of river received flows up 200 ML/day from October 2018 through to January 2019. Zone 2 is structurally complex, with benches and woody-debris. We have previously hypothesised that spring flows that allow the recolonization and nesting in zone 2 by Murray cod after winter draw down would be beneficial for spawning. The results from this year support this hypothesis. The high number of larvae detected in drift nets compared to light traps may also suggest that dispersal of larvae downstream may have exceeded local settlement.

River blackfish larvae were collected for the second consecutive year since the large-scale fish kills of 2016-17. Previously only collected in the upper Wakool River (zone 2), river blackfish larvae were recorded for the first time in 2018-19 in the Yallakool River (zone 1). Similarly to patterns observed for Murray cod larvae, larval river blackfish, which have typically only been collected in light traps, were collected solely in drift nets in both Yallakool Creek (22 November 2018, n=1) and Upper Wakool River (24 October 2018, n=1). Higher than normal flows during this time may have facilitated dispersal of larvae downstream over localised retention within each study zone.

Opportunistic species

Larval abundance of small-bodied opportunistic species was numerically dominated by Australian smelt in 2018-19. The abundance of Australian smelt in 2018-19 was significantly greater compared to other years (Figure 8.15*c*). Australian smelt and carp gudgeon were all found to have spawned right throughout the four study zones (Figure 8.15*c*); Australian smelt were captured from late September to early December 2018, and carp gudgeons were captured from mid-September 2018 through to late March 2019.

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 8.15*c,* Table 8.7).

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 8.15*c*). Numbers of unspecked hardyhead, obscure galaxias, oriental weatherloach and dwarf-flathead gudgeon were too low for any statistical comparisons across years or zones. Murray River rainbowfish larvae were only detected in Wakool River zone 4 in November 2018; obscure galaxias larvae were collected in zone 2 and zone 3 in mid-September 2018. There were no unspecked hardyhead or oriental weatherloach sampled in 2018-19.

Table 8.7 Results of mixed-models which tested for significance differences in total annual catch of fish larvae (light traps and drift net catch combined) across years, for each species (year= fixed factor, zone = random effect). 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^	695	year	4	130.5	<0.001	***
equilibrium species						
Murray cod	3426	year	4	42.7	<0.001	***
opportunistic species						
carp gudgeon	19782	year	4	4953.8	<0.001	***
flathead gudgeon	597	year	4	31.4	<0.001	***
Australian smelt	1565	year	4	69.7	<0.001	***

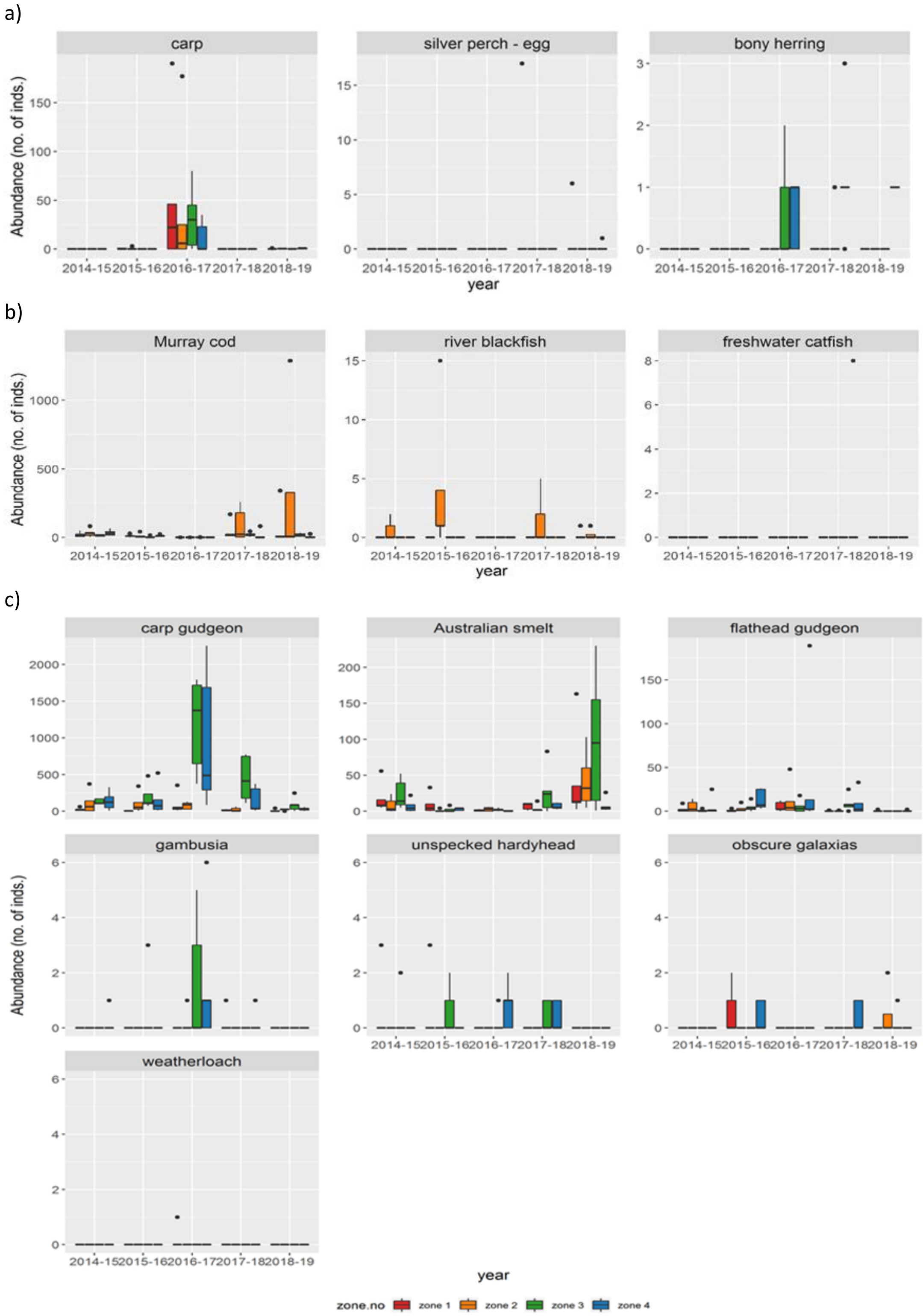


Figure 8.15 Boxplots of the annual total abundance of fish larvae (light traps and drift nets catch combined) for the five years of LTIM for a*) periodic species* (those expected to spawn in relation to certain flow conditions) b) *equilibrium species* (large, long lived species whose spawning is independent of flow) and c) *opportunistic species* (small bodied, protracted spawning species. Red = zone 1 (Yallakool Creek); Orange = zone 2 (upper Wakool River), Green = zone 3 (Wakool River upstream of Thule Ck), and Blue = zone 4 (Wakool River downstream of Thule Creek).

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 2018-19 as part of fish recruitment monitoring. Silver perch (*Bidyanus bidyanus*) age-class 1 (1+) recruits were detected for the first time since 2015-16, occurring in zones 3 and 4 (Table 8.8). Murray cod (*Maccullochella peelii*) young-of-year (YOY) and 1+ recruits were detected in zones 1 and 2, and 1+ recruits were detected in zone 3 for the first time since 2015-16 (Table 8.8). Juvenile river blackfish (*Gadopsis marmoratus*) were detected in zone 1 for the first time since surveys began in 2014-15 (Figure 8.16), following on from adults being detected there for the first time in 2017-18. Golden perch (*Macquaria ambigua*) recruits have not been detected during any year since surveys began.

Table 8.8 Number of young-of-year (YOY), age class 1 (1+) recruits and older juveniles or adults (JA) of the three target species sampled in recruitment and growth monitoring in the Edward/Kolety-Wakool system for 2014-15 through 2018-19.

	2014-15			2015-16			2016-17			2017-18			2018-19		
Zone	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA	YOY	1+	JA
Murray cod															
Zone 1	5	15	17	2	8	1	-	-	-	2	-	4	5	2	1
Zone 2	5	11	11	9	16	19	-	-	-	6	1	2	2	6	4
Zone 3	3	14	13	8	9	16	-	-	-	-	-	-	-	2	-
Zone 4	7	6	14	5	17	11	-	-	-	-	-	-	-	-	-
Silver perch															
Zone 1	-	-	7	-	1	5	-	-	12	-	-	2	-	-	1
Zone 2	-	-	2	-	-	3	-	-	3	-	-	1	-	-	-
Zone 3	-	-	6	-	4	9	-	-	13	-	-	9	-	7	1
Zone 4	-	1	1	5	15	14	-	-	7	-	-	14	-	3	4
Golden perch															
Zone 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zone 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zone 3	-	-	1	-	-	3	-	-	-	-	-	-	-	-	-
Zone 4	-	-	2	-	-	1	-	-	-	-	-	-	-	-	-


Photos: John Trethewie, CSU

Figure 8.16 Left; Juvenile river blackfish (*Gadopsis marmoratus*), Right; Juvenile Murray cod (*Maccullochella peelii*) from Yallakool Creek (zone 1).

Murray cod

A total of seven YOY and ten 1+ Murray cod recruits were detected in 2018-19 sampling (Table 8.8). The abundance and location of YOY recruits was very similar to 2017-18 with individuals only being detected in zones 1 and 2 (Figure 8.17). This is the highest number of 1+ recruits since the blackwater event in 2016, with only one detected in 2017-18 and none in 2016-17 (Figure 8.18). This trend of increasing abundance suggests signs of recovery in the system. The results of the GLMMs continue to show highly significant differences in recruitment among years (Table 8.9) but not amongst zones.

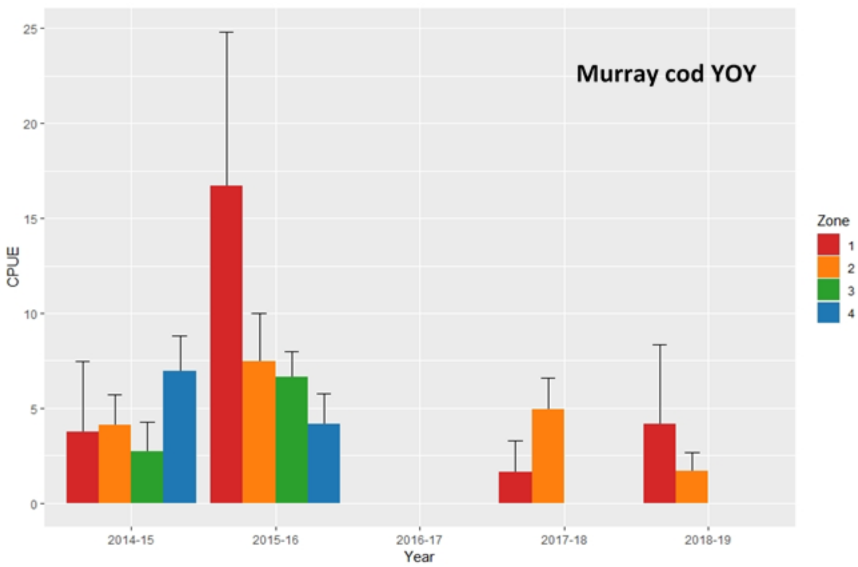


Figure 8.17 Mean (+SE) catch per unit effort (CPUE; number of fish caught per 10 000 seconds of backpack electrofishing) of YOY Murray cod in the Edward/Kolety-Wakool LTIM zones from 2014-2019.

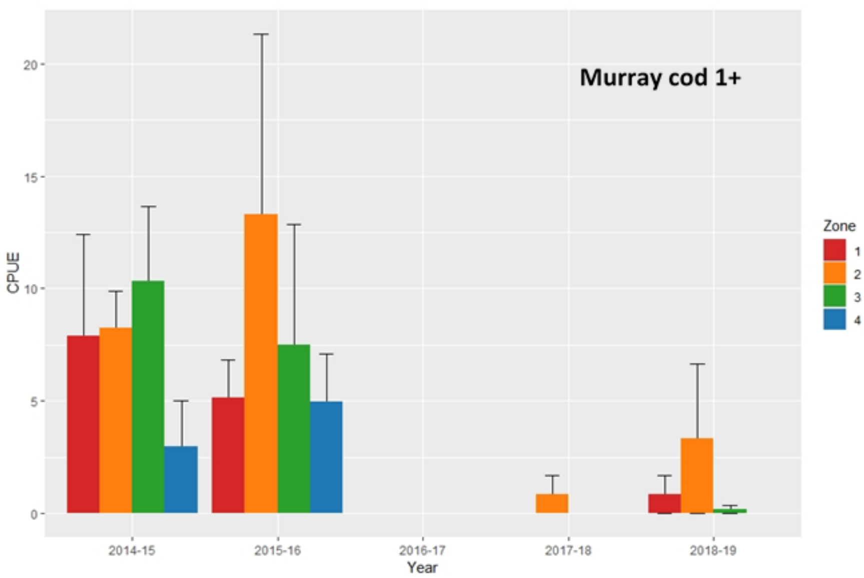


Figure 8.18 Mean (+SE) catch per unit effort (CPUE) of 1+ Murray cod among the Edward/Kolety-Wakool LTIM zones using all gear types from 2014-19.

Table 8.9 Statistical results of GLMMs evaluating differences in recruitment of Murray cod and silver perch among four zones of the Edward/Kolety-Wakool between 2014-15 and 2018-19. NS = not significant.

Species	Response variable	Factors	DF	F-value	P value
Murray cod	YOY recruitment	sampling gear	2	26.4	< 0.0001
		year	4	6.0	0.0001
		zone	3	1.5	NS
		zone x year	12	1.0	NS
	1+ recruitment	sampling gear	2	22.7	< 0.0001
		year	4	6.8	< 0.0001
		zone	3	1.1	NS
		zone x year	12	0.4	NS
silver perch	1+ recruitment	sampling gear	2	2.9	NS
		year	4	5.5	0.0003
		zone	3	5.0	0.0181
		zone x year	12	3.3	0.0002

Silver perch

Eleven silver perch were retained for ageing with all but one proving to be 1+ recruits between 113 and 178 mm in length. This is the first evidence of silver perch recruitment since 2015-16 in the system and like that year all recruits were captured in zones 3 and 4 (Figure 8.19). It is unknown if these recruits have come from within the Edward/Kolety-Wakool system or have migrated in from elsewhere, but microchemistry analysis could be performed on the retained otoliths in the future to determine this. Results of the GLMMs show significant differences in recruitment amongst both years and zones (Table 8.9). No YOY silver perch recruits were detected in 2018-19.

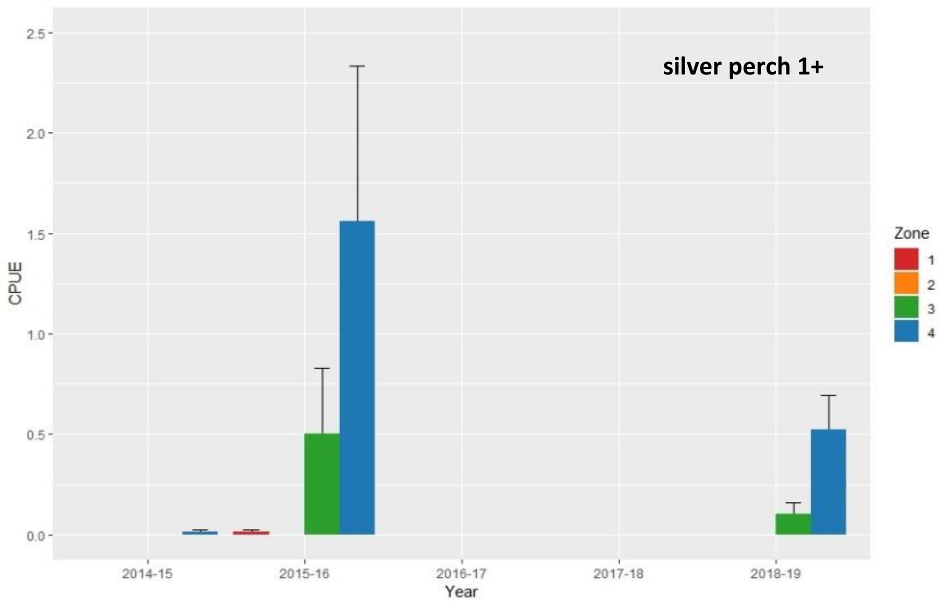


Figure 8.19 Mean (+ SE) CPUE of 1+ silver perch in the Edward/Kolety-Wakool LTIM zones using setlines and angling (number of fish per 10 000 seconds of sampling) between 2014-15 and 2018-19.

Growth of Murray cod

Growth per day (mm) of YOY Murray cod in 2018-19 was lower than that of 2017-18, particularly in zone 1 (Figure 8.20). The cohort of Murray cod in 2017-18, the first detected since the blackwater event in 2016, grew much faster than those in any previous year. This trend is evident in the same cohort in zone 3 in 2018-19 (Figure 8.21), possibly due to lower competition arising from lower abundance and high productivity within the river.

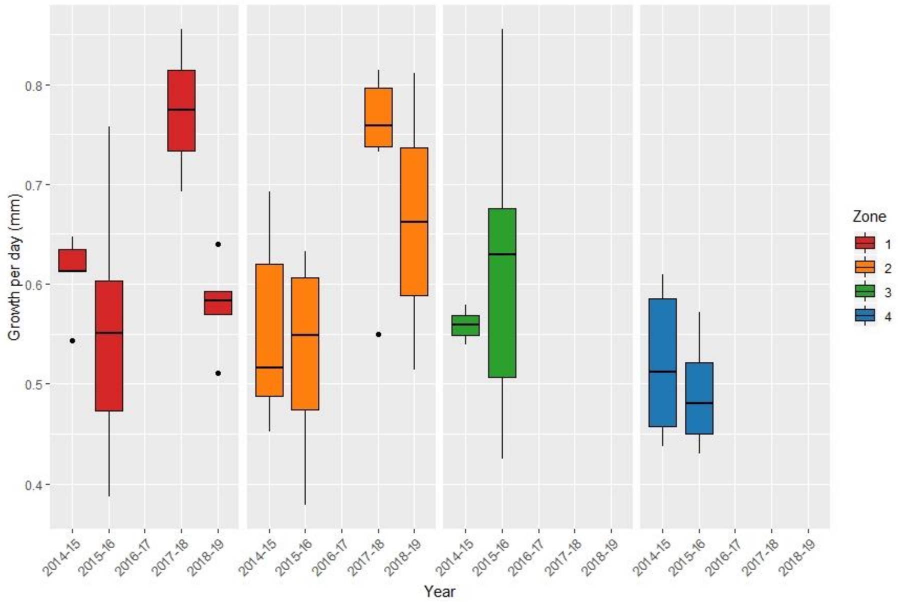


Figure 8.20 Boxplots of the annual growth rates (mm per year) of YOY Murray cod in each zone between 2014-15 and 2018-19. Number of individuals (*n*) per zone: 2014-15 *n* = 5, 5, 3, 7; 2015-16 *n* = 20, 9, 8, 5; 2016-17 *n* = 0, 0, 0, 0; 2017-18 *n* = 2, 6, 0, 0; 2018-19 *n* = 5, 2, 0, 0.

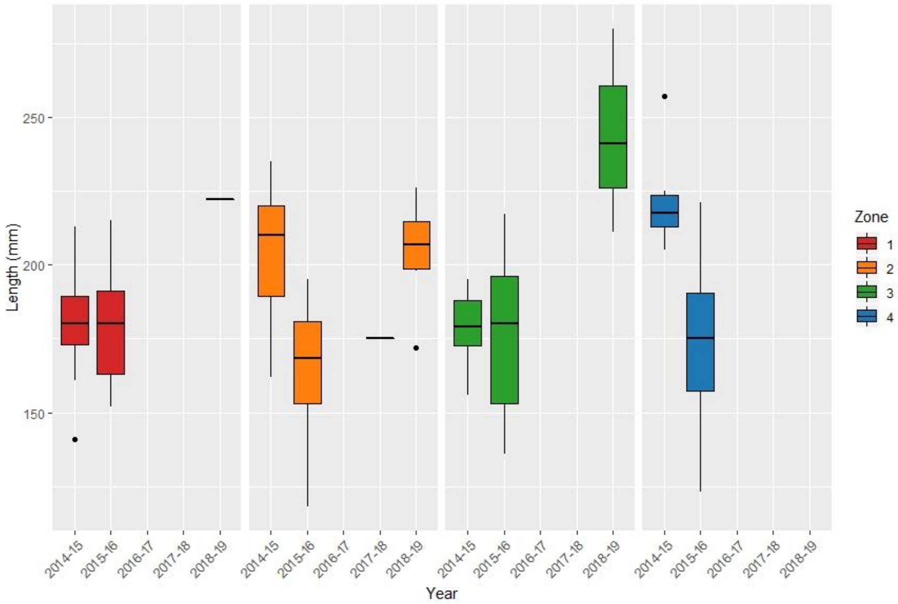


Figure 8.21 Boxplots of the annual length-at-age (mm) for 1+ Murray cod in each zone between 2014-15 and 2018-19. Number of individuals (*n*) per zone: 2014-15 *n* = 15, 11, 14, 6; 2015-16 *n* = 8, 16, 9, 17; 2016-17 *n* = 0, 0, 0, 0; 2017-18 *n* = 0, 1, 0, 0; 2018-19 *n* = 2, 6, 2, 0.

Adult fish community

Nine native and three alien fish species were captured across 18 in-channel sampling sites in both 2015 and 2019. A total of 1,016 fish were caught in 2015, while only 909 fish were sampled in 2019 (Table 8.10). Threatened silver perch (vulnerable; Fisheries Management Act, critically endangered; EPBC Act) and Murray cod (vulnerable; EPBC Act) were caught in 2015. Whereas in 2019, silver perch, Murray cod and trout cod (endangered; Fisheries Management Act, EPBC Act) were captured.

Table 8.10 Presence of fish species (denoted with Y) sampled as adults in the Edward Wakool Selected Area, using the Pre-European (PERCH) list of the expected native species present in the central Murray region of the Murray-Darling Basin. Rarity scores of 0.10, 0.45 and 0.85 correspond to rare or cryptic, locally abundant and common and abundant species, respectively, and are based on expert opinion of the probability of detection at a single site. Note that 19 in-channel sites were used to compare years from 2010–2015 (grey shading), while only 18 sites are used to compare 2015 and 2019.

		Pre LTIM monitoring (2010-15, 19 sites)						LTIM monitoring (18 sites)	
Common name	**Rarity score**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2015**	**2019**
Native - recorded									
small bodied native fish									
Australian smelt	0.85	Y	Y	Y	Y	Y	Y	Y	Y
carp gudgeon	0.85	Y	Y	Y	Y	Y	Y	Y	Y
unspecked hardyhead	0.45	Y	Y	Y	Y	Y	Y	Y	Y
Murray River rainbowfish	0.45	Y	Y	Y	Y	Y	Y	Y	Y
flathead gudgeon	0.45	Y	Y			Y	Y	Y	
periodic species									
golden perch	0.85	Y	Y	Y	Y	Y	Y	Y	Y
silver perch	0.85	Y	Y	Y	Y	Y	Y	Y	Y
bony herring	0.45	Y	Y	Y	Y	Y	Y	Y	Y
equilibrium species									
Murray cod	0.85	Y	Y	Y	Y	Y	Y	Y	Y
trout cod	0.10					Y	Y		Y
river blackfish	0.45								
freshwater catfish	0.45								
Native - expected									
southern purple spotted gudgeon	0.45								
Murray hardyhead	0.45								
olive perchlet	0.45								
southern pygmy perch	0.45								
flathead galaxias	0.45								
dwarf flathead gudgeon	0.10								
Macquarie perch	0.10								
mountain galaxias	0.10								
shortheaded lamprey	0.10								

Overall Condition for the fish community ranged between “Very Poor” and “Moderate” bands in the period covering 2010–2015 using 19 sites (Figure 8.22). In the current analysis using 18 sites, Overall Condition decreased from “Poor” in 2015 to “Very Poor” in 2019, but remained within the bands previously observed. Expectedness and Recruitment similarly decreased from “Poor” in 2015 to “Very poor” in 2019, but stayed within band ranges previously observed for these metrics from 2010–2015. Nativeness was “Moderate” in both 2015 and 2019, despite previously varying between “Very poor” to “Moderate” over 2010–2015.

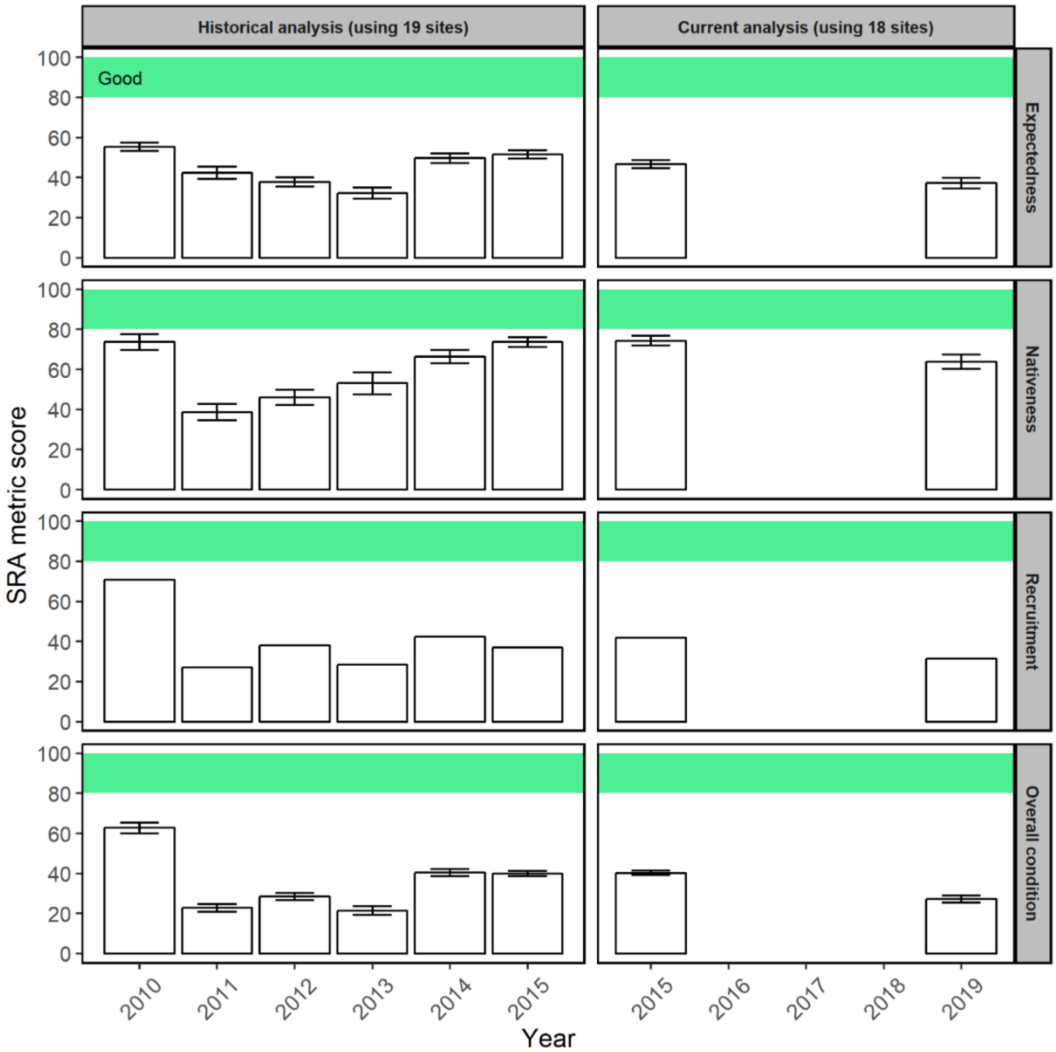


Figure 8.22 Sustainable Rivers Audit (SRA) indices, separated among sampling years, in the Edward/Kolety-Wakool river system. Note that data collected from the same 19 in-channel sites were used in a historical analysis of these metrics between 2010-2015, while data from the same 18 in-channel sites were used in a current analysis from 2015-2019. The “good” classification for SRA metric scores is shown with green shading.

Australian smelt, bony herring, Murray River rainbowfish and common carp were the four most abundant species in descending order in 2015. This shifted to Australian smelt, common carp, Murray River rainbowfish and carp gudgeon in 2019 (Figure 8.23). In 2015, less commonly observed individuals (<10 individuals) were silver perch and flat-headed gudgeon in 2015. In 2019, trout cod and oriental weatherloach were also detected at <10 individuals, along with unspecked hardyhead and golden perch which were previously more abundant in 2015, and silver perch which were less common in both years.

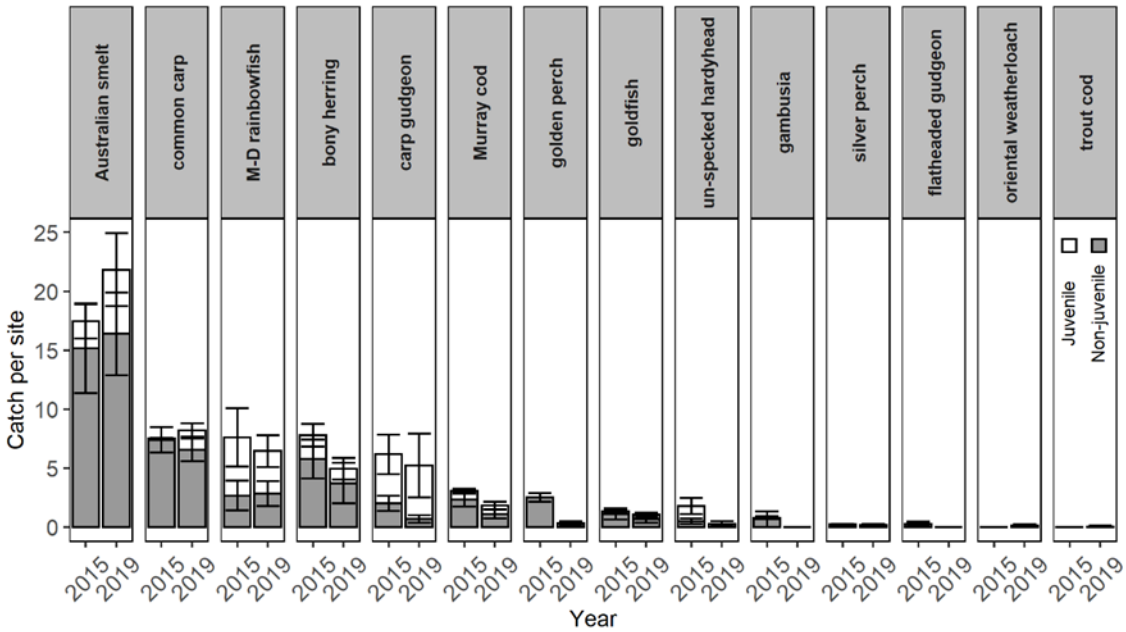


Figure 8.23 Catch per site (mean ± SE) of fish species sampled in the Edward/Kolety-Wakool river system from 18 in-channel sites that were sampled in 2015 and 2019. Juveniles and non-juveniles were defined based on the length cut-offs in Table 8.4 and are shown as stacked bars.

The fish community assemblage varied between 2015 and 2019 in terms of abundance (*Pseudo*-$F_{1,35}$ = 4.365, P = 0.002). SIMPER analysis revealed that separation among years was the result of a decrease in the abundance of carp gudgeon, bony herring and golden perch but an increase in abundance of Murray River rainbowfish in 2019 (Figure 8.23, Table 8.11).

Biomass of the fish community assemblage also differed among years (*Pseudo*-$F_{1,35}$ = 7.525, $P <$ 0.001). According to SIMPER analysis, this was driven by decreased biomass of Murray cod, golden perch and bony herring in 2019 (Figure 8.24, Table 8.11). In 2015, common carp, Murray cod, golden perch and goldfish contributed most to biomass with an average biomass per site of 10823 ± 1702, 4118 ± 1232, 2949 ± 445 and 273 ± 131 g, respectively (Figure 8.24). Whereas in 2019, common carp, Murray cod, golden perch and bony herring were the biggest contributors to biomass with an average biomass per site of 10465 ± 1736, 1616 ± 784, 623 ± 367 and 196 ± 99 g, respectively.

Table 8.11 The contribution of fish species abundance to variability between 2015 and 2019 in the Edward/Kolety-Wakool river system, determined through SIMPER analysis. Note only species contributing ≥10% to changes in community composition are included.

Indicator	Comparison	Species	Contribution to difference (%)	Year with greater value
Abundance	2015 vs 2019	carp gudgeon	14	2015
		Murray River rainbowfish	14	2019
		bony herring	14	2015
		golden perch	11	2015
Biomass	2015 vs 2019	golden perch	22	2015
		Murray cod	11	2015
		bony herring	10	2015

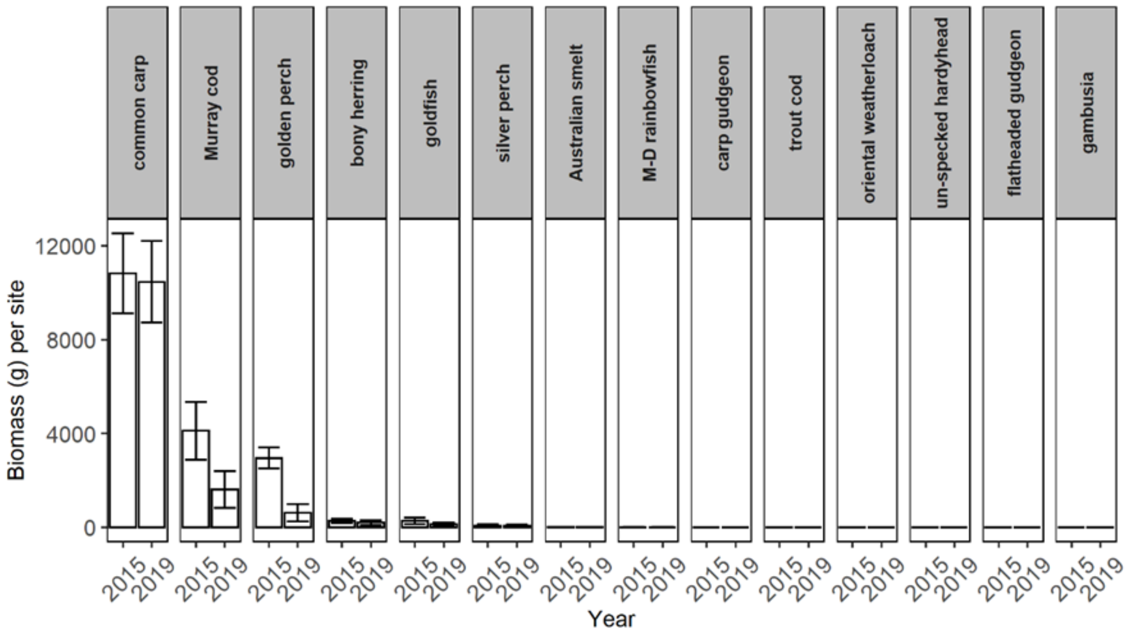


Figure 8.24 Biomass per site (g; mean ± SE) of fish species sampled in the Edward/Kolety-Wakool river system from 18 in-channel sites that were sampled in 2015 and 2019.

Fish size structure shifted between 2015 and 2019 for 6 out of the seven most abundant species (Figure 8.25 and 8.26, Table 8.12). Australian smelt, carp gudgeon, common carp and Murray cod became smaller in 2019. In contrast, bony herring and golden perch became larger in 2019. The size structure of Murray River rainbowfish did not vary among years.

Recruits were detected in three native longer-lived species (bony herring, Murray cod and silver perch), and four native short-lived species (Australian smelt, carp gudgeon, Murray-Darling rainbowfish and un-specked hardyhead) in 2015 (Figure 8.22, 8.25 and 8.26). This was similar in 2019, except silver perch recruitment was not detected. No recruitment was observed for native long-lived trout cod when present in 2019 or for native short-lived flat-headed gudgeon when present in 2015. Alien common carp, goldfish and eastern gambusia recruits were found in 2015. In 2019, alien common carp and goldfish recruits were also present, however eastern gambusia recruits and non-recruits were absent.

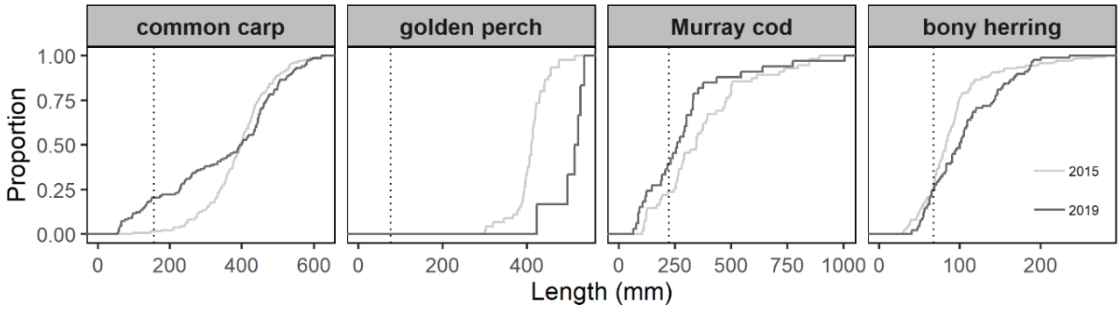


Figure 8.25 Length-frequency distributions of the most commonly encountered large-bodied species captured in the Edward/Kolety-Wakool river system between 2015 (light grey) and 2019 (dark grey).

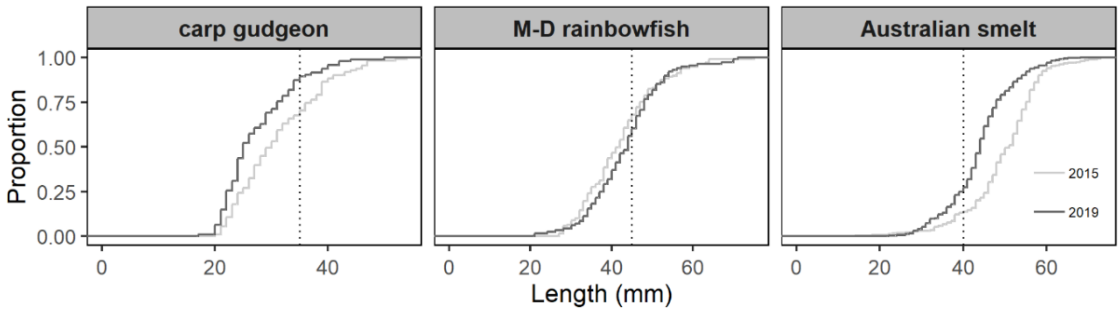


Figure 8.26 Length-frequency distributions of the most commonly encountered small-bodied species captured in the Edward/Kolety-Wakool river system between 2015 (light grey) and 2019 (dark grey).

Table 8.12 Significance of length-frequency distribution comparisons between 2015 and 2019 for the most abundant fish species captured in the Edward/Kolety-Wakool rivery system. Significant differences are indicated by the *P* values below < 0.05 in bold.

Species	2015 vs 2019
	P
Australian smelt	**<0.001**
bony herring	**<0.001**
carp gudgeon	**0.003**
common carp	**<0.001**
golden perch	**0.002**
Murray cod	**0.033**
Murray River rainbowfish	0.297

8.6 Discussion

Targeted watering actions in 2018-19

In 2018-19 CEWO delivered a small early spring fresh through Yallakool Creek and the Wakool River, with the key objective of supporting the recovery of large bodied native fish following the 2016 hypoxic blackwater event and maintaining the diversity and condition of native fish through maintaining suitable habitat and supporting opportunities to move, breed recruit.

It was hypothesised that the provision of early commence to flow conditions would facilitate the earlier recolonization and pre-spawning movements of adult fish back into these river reaches. Though movement of Murray cod in 2018-19 was not monitored, tagged silver perch and golden perch showed movement responses in relation to the spring watering action. This was followed by the successful detection of silver perch eggs in Yallakool Creek and Wakool River in November-December 2018. Recruitment surveys in autumn 2019 however did not detect any young-of-year silver perch, indicating that the spawning event did not translate into a strong recruitment outcome within the survey area. A study by Tonkin et al. (2018) on silver perch recruitment in the Mid-Murray concluded that strong year classes of silver perch is correlated with flooding conditions the year after spawning. Consideration of delivery of flows targeting enhanced silver perch populations may therefore be most effective during wet-climatic scenarios.

Other early spring spawners that may have benefited from the early spring flows and extended period of operational flows from October 2018 to February 2019 were Australis smelt and Murray cod, as indicated by the highest catches of larvae in 2018-19 compared to previous year. It may be that the presence of flow throughout early spring facilitated earlier recolonization opportunities for breeding adults of spring spawners. While obscure galaxia have been found in most years of the LTIM monitoring, 2018-19 was the first time they have been recorded in zone 2. This appearance also coincides with spring flows in the upper Wakool River, which, suggests these types of flows can be beneficial for the dispersal of this pelagic species. Juvenile obscure galaxias were later found in November/December indicating successful recruitment to the juvenile stage had taken place in 2018-19 for this species.

2018-19 was the first time that the upper Wakool (zone 2) has received managed flows of 400 ML/day compared to the normal operational flows of approximately 40-80 ML/d in this zone. Habitat structure and availability of course-woody debris is noticeably complex in zone 2, and we have previously hypothesised (Watts et al. 2015, 2016, 2017b) that if flows sufficient enough to inundate this habitat, it would be beneficial to species who favor highly structurally complex habitat. The results from this year support this hypothesis, as we detected the largest number of Murray cod larvae in 2018-19 compared to the previous four years of LTIM, with the majority of Murray cod larvae collected from upper Wakool River (zone 2). In addition, the greater number of larvae detected in drift nets compared to light traps, suggests that dispersal of larvae downstream may have exceeded local retention, and may contribute to further re-establishment of Murray cod within the wider Selected Area.

Detection of Murray cod YOY, and 1+ fish in highest numbers since LTIM monitoring commenced in 2015, along with the presence of 1+ silver perch in the system, indicate that the Edward Wakool fish assemblage is showing positive signs of recovery post the 2016-17 hypoxic blackwater event that resulted in large scale fish kills in the southern Murray-Darling Basin.

Long term trends 2014-19

This study demonstrates the value of the Edward/Kolety-Wakool river system in supporting populations of native freshwater fish, nested within the broader Murray catchment. Throughout this five year study, using a range of sampling techniques, we captured 15 species of native fish representing various life-stages (Table 8.13). System-specific trends, indicated through the use of SRA fish 'health' indicators, suggest a decline in indicators in 2019 from 2015. However, we argue that the Edward/Kolety-Wakool system is currently in a state of recovery, rather than decline, following flood-induced hypoxic blackwater and associated fish kills in 2016. Similar declines and associated recovery were observed in fish health metrics following 2010 and 2012 hypoxia events. Promisingly, adults of the majority of species were captured post-2016 within the system, and regular spawning and recruitment through to the juvenile stage was observed for numerous species. A number of flow-related mechanisms may contribute to the recovery of these populations at a local scale. These include 1) the persistence of refuge habitat at low flows or during adverse water quality events, 2) the presence of diverse in-channel and off-channel habitats, and 3) opportunities for movement that enable the re-distribution of individuals and promote emigration and immigration. Flow delivery within the Edward/Kolety-Wakool system has targeted all three mechanisms at various times and locations throughout this five year study, and the current ecological value of the system, given numerous adverse events over the past decade, is in-part testament to the effectiveness of these delivery outcomes.

The absence of representatives from some life-stages for individual species in this study is likely an artefact of a combination of factors including sampling gear and locations, detection probability associated with species in low abundance, and/or life-history strategy including the spatial scale of movement. For example, Murray cod are present as larvae, juvenile and adults within the Edward/Kolety-Wakool system, and would generally be expected to complete their entire lifecycle at this local scale. Immigration from the nearby Murray River and Edward River is presumably important to facilitate recovery of adult stocks following fish kills, followed by localised spawning and recruitment (Thiem et al. 2017). In contrast, golden perch and silver perch likely complete their lifecycles over a broader geographic scale, with immigration of juveniles from the nearby mid-Murray River, and sometimes as far afield as the Darling River, playing a major role in structuring the populations (Mallen-Cooper and Zampatti et al. 2018). Indeed, the nearby reach of the mid-Murray River represents the longest stretch of free-flowing (lotic) habitat in the Murray River (Mallen-Cooper and Zampatti 2018), a necessary requirement over 100's of kilometres for obligate riverine species to complete all aspects of their lifecycle. Species observed at low abundance in this study, such as trout cod, freshwater catfish, obscure galaxias and dwarf flathead gudgeon likely complete their lifecycles at a local scale, although may be at such low abundance or sampled inefficiency that detection of all life-stages within the Edward/Kolety-Wakool system did not occur in this study.

Table 8.13 Summary of Edward/Kolety-Wakool fish assemblage. Stars denote the presence of larvae (indicating successful spawning), recruits (indicating successful recruitment) and adults from sampling effort during the 2014-19 LTIM monitoring. [A] denotes introduced species. Note - detection of a particular life history stage may be a limitation of sampling location or equipment and is not definitive.

Common name	eggs/larvae	juveniles (YOY, 1+)	adults
Species – recorded			
Equilibrium species			
Murray cod	*	*	*
river blackfish	*	*	*
trout cod		*	*
freshwater catfish	*		
Periodic species			
bony herring	*	*	*
common carp[A]	*	*	*
silver perch	*	*	*
golden perch			*
goldfish[A]		*	*
redfin perch[A]	*		
Opportunistic species			
carp gudgeon	*	*	*
Australian smelt	*	*	*
flathead gudgeon	*	*	*
unspecked hardyhead	*	*	*
Murray River rainbowfish	*	*	*
obscure galaxias	*	*	
dwarf flathead gudgeon	*		
eastern gambusia[A]	*		*
oriental weatherloach[A]	*		*
Species – expected but not recorded			
Agassiz's glassfish (olive perchlet)			
flathead galaxias			
Macquarie perch			
mountain galaxias			
Murray hardyhead			
shorthead lamprey			
southern purple spotted gudgeon			
southern pygmy perch			

Eight species of native freshwater fish predicted to have historically occurred within the mid-Murray River region, including the Edward/Kolety-Wakool system, are absent (Table 8.13) following almost a decade of intensive sampling including this current study. This reflects localised extinction, and while the mechanisms contributing to this are varied, natural recolonization is an unlikely recovery pathway for the majority of these. Subsequently, it is important to manage the expectations of any future water delivery events within the Edward/Kolety-Wakool system, acknowledging that conservation stocking or translocation, and the subsequent re-establishment of resident populations, can be supported by appropriately targeted water delivery actions, but that water delivery in isolation will not re-establish locally extinct populations (Baumgartner et al. 2019).

Flow-recommendations for fish outcomes

Recommendation: provide continuous base winter flows (no winter cease to flow) in Edward/Kolety-Wakool tributaries to promote the temporal availability and continuity of instream habitat for fish. Future use of CEWO in the Edward/Kolety-Wakool River System could have a positive influence on the condition, and therefore subsequent spawning and recruitment, for many of the large bodied species.

Recommendation: trial the delivery of an environmental watering action in the Edward River downstream of Stevens Weir to target golden perch and silver perch spawning and recruitment.

Recommendation: continue to provide attraction flows to promote immigration and juveniles and adults of golden and silver perch into the system from the Murray may also be beneficial

8.6 Evaluation (short term)

Table 8.16 Summary of fish responses to Commonwealth environmental watering. 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 (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?*
Fish movement	Spring flow trial (800 ML/day)	To maintain the diversity and condition of native fish through providing/support opportunities to move.	Were periodic species (golden and silver perch) present in the target reaches during Commonwealth environmental water delivery?	Tagged golden perch and silver perch were present in target reaches	Fish movement data using acoustic telemetry	Not assessed.
			Did periodic species remain within the target reaches during Commonwealth environmental water delivery?	Delivered flows resulted in some zone re-distribution of individuals but no emigration from the focal reaches	As above	Yes, opportunities for increased movement were provided
			Did Commonwealth environmental water stimulate periodic fish species to exhibit movement consistent with reproductive behaviour?	The timing of flows occurred prior to the documented reproductive period for periodic species, but individuals of both species exhibited strong directional movements presumably associated with pre-spawning movements	As above	Flow delivery occurred outside of reproductive periods, but some medium-scale pre-spawning movements potentially occurred for a small number of fish. Based on 4 years of movement data, strong directional movement by the majority of the tagged sample only occurred during an unregulated flooding event in 2016. Larger flow deliveries would be required to trigger these types of movements in the future, which may be important to facilitate golden perch connectivity with the Murray, and presumably spawning outside of the Edward/Kolety-Wakool system.
			Does Commonwealth environmental water enable periodic species to disperse from and return to refuge habitat?	Increased movements occurred in comparison to winter, associated with flow delivery and increasing water temperatures.	As above	Yes, opportunities for increased movement were provided

Spawning		To maintain the diversity and condition of native fish through providing/support opportunities to breed	What did commonwealth environmental water contribute to increased spawning activity of equilibrium species (e.g. Murray cod?)	Record catch of Murray cod larvae compared with previous years. Majority collected in Upper Wakool (zone 2) in drift nets.	Drift nets were set fortnightly across the four study zones from late September to late December 2018.	Large numbers of Murray cod larvae collected in zone 2. Adult Murray cod may have benefited from earl spring flows that allows recolonization and pre-spawning movements into the Selected Area. Higher larval abundances may have been associated with the greater instream flows delivered to zone 2. While some of these flows were not environmental water, they provide a strong illustration of the benefit of water delivery through structurally complex habitats such as the Upper Wakool, and could be mimicked in future years for environmental watering.
			What did Commonwealth environmental water contribute to 'periodic' flow dependent spawning species (e.g. silver perch?)	Silver perch spawned in Wakool River (zone 4) in November 2018, and Yallakool Creek (zone 1) in December 2018.	Eggs found in drift nets. Drift nets were set fortnightly across the four study zones from late September to late December 2018.	Similarly to 2017-18, the silver perch spawning event in 2018-19 may have been associated with greater instream flow variability experienced in these two years compared to the first three years of LTIM. These flows were due to inter-valley transfers, 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 2018-19 compared with previous years.	Fortnightly light trap sampling from Sep-March, 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 have been advantageous. Similar results also reported in 2017-18.
Recruitment	Spring flow trial (800 ML/day)	To maintain the diversity and condition of native fish through providing/support opportunities to recruit	Did Commonwealth environmental water affect the growth rate of Murray cod, silver perch and golden perch during the first year of life?	Growth rates of YOY Murray cod were lower than in 2017/18. Zone 1 growth rates were similar to 2014-16 and in zone 2 growth rates were higher than in 2014-16.	Length at age data derived from otolith analysis	N/A – Flow trial ceased prior to fish hatching

			Did Commonwealth environmental water contribute to the recruitment of Murray cod, golden perch and silver perch?	YOY Murray cod were present however no YOY silver perch or golden perch were detected	Recruitment survey catch data	N/A – Flow trial ceased prior to fish hatching
Adult populations	Spring flow trial (800 ML/day)	To support the recovery of large bodied native fish following the 2016 hypoxic blackwater event. To maintain the diversity and condition of native fish	Does Commonwealth environmental water contribute to maintain or enhance existing levels of fish recruitment in the Edward/Kolety-Wakool river system? Does Commonwealth environmental water contribute to maintain or increase native fish diversity and abundance in the Edward/Kolety-Wakool river system? Does Commonwealth environmental water contribute to maintain or increase native fish biomass in the Edward/Kolety-Wakool river system? Does Commonwealth environmental water contribute to maintain or enhance fish condition in the Edward/Kolety-Wakool river system? Does Commonwealth environmental water contribute to the recovery of fish communities following negative conditions within the Edward/Kolety-Wakool river system?	There has been no loss of native fish species from the Edward/Kolety-Wakool system detected in this monitoring program. Environmental water has been delivered to maintain refuges, including during adverse water quality events, and to facilitate a diversity of habitats and movement/dispersal. There is evidence from this program that native fish are benefitting from these types of deliveries.	Adult fish community sampling, taken in conjunction with fish movement, spawning and recruitment information.	yes

9 800 ML/DAY FLOW TRIAL IN THE YALLAKOOL-WAKOOL SYSTEM DURING AUG/SEPT 2018

Key findings	
Planning	Planning for the action was undertaken over a period of more than one year, with the Wakool River Association, the Edward/Kolety-Wakool Environmental Water Reference Group and landholders engaged and involved in the planning and water delivery
Delivery	There were some operational limitations to deliver the environmental water via the Yallakool Creek regulator when Steven's weir pool was low. Some of the environmental water was delivered via the Wakool escape from Mulwala canal to achieve the maximum discharge of 800 ML/day
Third party impacts	The 800 ML/day discharge inundated one low level bridge in the Bookit Island area in the mid Wakool River and one creek crossing on Black Dog Creek, but this did not limit landholders access to their properties
Hydrological outcomes	The flow trial increased lateral connectivity within the river system, increasing the wetted area by an average of 10.2% (ranging from 3.7% in zone 2 site3 to 30.3% in zone 2 site 4. Using cameras to record water level changes and inundation was a cost-effective method of monitoring.
Ecosystem outcomes	Environmental water did not cause any detrimental water quality outcomes. The environmental water increased river productivity, and there was increased frog calling, waterbird activity and invertebrate activity observed in inundated areas around Bookit Island.
Perceptions of the flow trial	Interviews with landholders, water managers, river operators and other community members were undertaken through a complementary project by Charles Sturt University to explore stakeholder's perceptions of flow trials. In general, the flow trials were perceived by most stakeholders as an opportunity to explore how to act in a complex socio-ecological system. A dominant way that participants framed conversations was in a systems perspective. This emerged alongside other strong framings of engineering, accounting, ecology and power.

9.1 Background

Environmental flows are increasingly part of river restoration programs. In Australia, the Murray-Darling Basin (MDB) Plan aims to protect and restore water dependent ecosystems. In the Wakool River in the southern MDB, prior to river regulation the average daily discharge in this system was higher in winter and spring and lower in summer and autumn. Under regulated operating rules the infrastructure delivering water to Yallakool Creek and the Wakool River is usually closed during winter (ceasing the flow) and there are upper limits on discharge at other times of the year to avoid inundation of low-lying private bridges and land. These operational practices limits the extent to which environmental water can be delivered to help maintain and restore these river ecosystems.

Watts et al. (2015; 2016; 2018) have previously recommended that water managers consider working with stakeholders to explore options to implement a short duration environmental flow trial in late winter/spring 2016 at a higher discharge than the current operational limit of 600 ML/d at the Wakool-Yallakool confluence. This would facilitate a test of the hypothesis that larger in-channel environmental watering action will result in increased river productivity. This recommendation was discussed on several occasions between 2014 and 2018, initially at the Edward/Kolety-Wakool Stakeholder Advisory Group and later at Edward/Kolety-Wakool Environmental Water Reference Group meetings after its inception in 2016. In August 2017 the President of the Wakool River Association, John Lolicato, indicated that there may be opportunities to explore higher flows in the Yallakool-Wakool in the future, pending further discussions with the Wakool Rivers Association and the Reference Group. This discussion prompted a period more than one year of extensive engagement, consultation, discussions and planning involving, landholders, community members, water managers, river operators and scientists. The planning led to the implementation of the 800 ML/day flow trial in the Yallakool-Wakool system from 22 August to 26 September 2018.

The 800 ML/day flow trial involved changes to operating rules and practices, in specifically the need to exceed the maximum daily discharge of 600 ML/day at the confluence of Yallakool Creek and the Wakool River under regulated operating rules. The plan was for Commonwealth environmental water to be largely delivered to the Yallakool-Wakool system via the Yallakool Offtake regulator.

The Commonwealth Environmental Water Office contracted additional monitoring to be undertaken during the flow trial to examine the extent to which this flow trial could contribute to inform decision making and adaptive management of environmental water delivery in this system. This section reports on that additional monitoring with reference to other relevant monitoring undertaken as part of the LTIM program.

9.2 Environmental watering action

Two commonwealth environmental watering actions were delivered in the Edward/Kolety-Wakool system in 2018-19 (section 2). The response to the first watering action, the 800 ML/day flow trial in spring 2018 (Table 9.1), will be evaluated in this section of the report.

Table 9.1 Environmental watering actions in the Edward/Kolety-Wakool system in 2018-19 evaluated for the 800 ML/day flow trial.

	Watering action	Action	Dates	Rivers	Objectives
1	Spring fresh	small fresh	22 August to 25 September 2018	Yallakool Creek, mid- and lower Wakool River	To provide early season rise in river level to contribute to connectivity, water quality, stimulate early growth of in-stream aquatic vegetation, pre-spawning condition of native fish and/or spawning in early spawning native fish

9.3 Questions

- What was the pattern of environmental water delivery and the timing of peak flow through the Yallakool-Wakool system during the flow trial? Was the environmental water able to be delivered as planned to the Yallakool-Wakool system?
- What was the difference in inundation of riverbank during the 800 ML/day flow trial compared to operational flows?
- Did the peak discharge inundate any infrastructure including low level bridges, weirs or crossings?
- Where there any observations of ecosystem benefits during the flow trial?

9.4 Methods

In total 22 sites (Table 9.2, Figure 9.1) were selected to facilitate the evaluation of responses to Commonwealth environmental water delivered from Yallakool Offtake, Wakool Offtake regulator and Wakool escape and to examine hydrological connectivity, water levels and extent of inundation. The focus of the monitoring was in the area around Bookit Island and Merrabit Creek, where there were potential issues associated with inundation of low level bridges.

Field monitoring during the flow trial were undertaken weekly over 7 weeks from 6 August to 21 September 2018.

Hydrological data (daily discharge (ML/d)) from automated gauging stations at Yallakool Offtake (409020), Wakool offtake regulator (409019), Wakool River at Wakool- Barham Rd (409045) and eventually the Wakool Escape (Mulwala Canal, managed by Murray Irrigation Limited) were downloaded and daily discharge at these sites plotted.

Table 9.2. Monitored sites during the 800 ML/day flow trial. The presence of gauge boards, monitoring cameras, and water pressure loggers are indicated for each site.

Monitoring sites	River	LTIM site	Site Name	Gauge Board#	Camera	Water logger#
Sites with gauge boards	Yallakool Creek	zone1site1	Hopwood	29	yes	20
	Yallakool Creek	zone1site3	Cumnock	28	yes	
	Yallakool Creek	zone1site5	Windra Vale	30	yes	21
	Wakool River	zone2site1	Brassi Bridge	yes		
	Wakool River	zone2site4	Widgee	26	yes	22
	Wakool River	zone3site1	Wakool R -Deni Wakool Rd	62/34		07
	Wakool River	zone3site3	Cummins	23	yes	
	Wakool River	zone3site5	Llanos Park	25	yes	23
	Griminal Creek		Griminal Creek	65/ 08	yes	19
	Merrabit Creek		McLays Lane	64/ 10	yes	
	Merrabit Creek		Merrabit Creek – Lolicato Bridge	37	yes x 2	12
	Bookit Creek		Bookit Creek	31	yes	01
	Bookit island		Wakool R - Bookit Island Bridge	38	yes	15
	Wakool River	zone4site1	Wakool R - Barham Rd	63		
Infrastructure (bridges, weirs and crossings)	Yallakool Creek		Mascot bridge		yes	
	Yallakool Creek		Windra Vale bridge		yes	
	Wakool River		Bookit Island bridge #1		yes	
	Wakool River		Bookit Island bridge #2		yes	
	Bookit Creek		Bookit creek Ford		yes	
	Bookit Creek		Bookit Creek Weir		yes	
	Merrabit Creek		Merrabit Creek Weir		yes	
	Wakool River		Tilga bridge		yes	

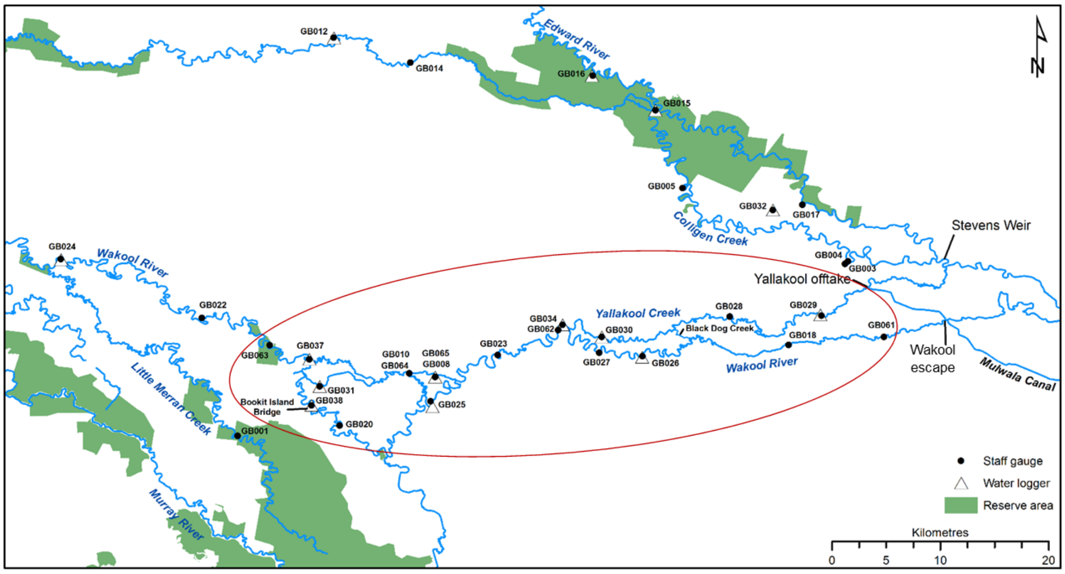


Figure 9.1 Monitored sites (within red circle) during the 800 ML/day flow trial in Yallakool-Wakool system.

The extent of riverbank inundation under operational flows and with the addition of Commonwealth environmental water, was estimated using 2-dimensional hydraulic modelling, as described in Watts (2015). A 2D hydraulic model was created for nineteen river reaches each 4 km in length; five reaches in Yallakool Creek, five in the Wakool River (zone 2), four in Wakool River upstream of Thule Creek (zone 3) and five in the Wakool River downstream of Thule Creek (zone 4). Between ten and twelve discharge scenarios were modelled for each reach, with the majority of the discharge scenarios being in the range of 30 ML/day to 1200 ML/day and one discharge scenario in each reach being just less than bankfull. The models were used to estimate the extent of wetted benthic surface area. The relationship between discharge and wetted benthic area for each study reach was determined using cubic smoothing spline regression modelling. The modelled curve for each reach (examples provided in Figure 9.2) was used to estimate the daily wetted area due to operational discharge and discharge including Commonwealth environmental water.

Cameras were installed at 19 sites in late July 2018 (Figure 9.3). Photos of gauge boards were taken by installed camera at 9.00am and 15.00pm each day during the flow trial. Photos were interpreted to estimate daily water level at each gauge board. Manual reading of staff gauges were also undertaken once per week. Twice daily photos of key assets, including bridges and weirs, were taken by installed cameras. Photos were visually assessed to determine the date(s) of the peak of the flow action. Photos of other key sites were taken during field visits to the study area.

Weekly spot water quality parameters (pH, DO (mg/L), turbidity (NTU), electrical conductivity (ms/cm), and temperature (°C)) were undertaken at each site. Observations of ecosystem responses to the flow, including observations of frog calling and bird activity, were recorded during field monitoring trips.

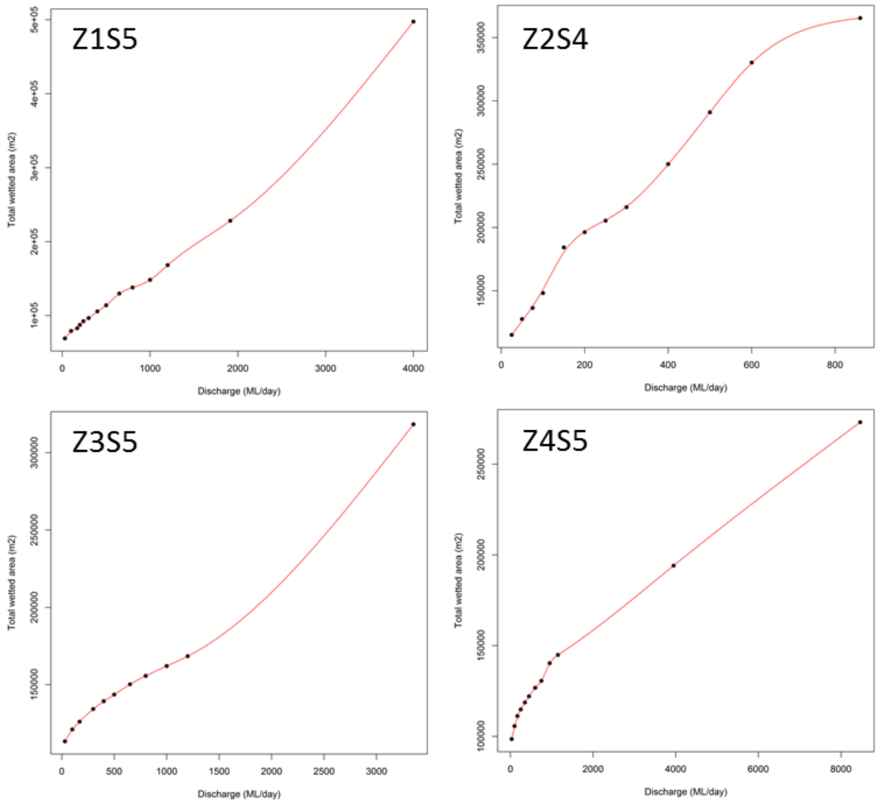


Figure 9.2 Examples of relationship between discharge (ML/d) and total wetted benthic area (m^2) for four of the nineteen 4 km reaches in the Yallakool-Wakool system. Estimates of wetted area were calculated from 2D hydraulic models. Curves were modelled using cubic smoothing spline regression approach, and were used to estimate the daily wetted area in each reach for each daily discharge during the flow trial.

Figure 9.3 Examples of camera installed to photograph water levels on staff gauge

A social research project funded by Charles Sturt University was undertaken at the same time as the biophysical monitoring. This research involved semi-structured interviews of landholders, water managers, river operators and other community members to explore stakeholder's perceptions of the flow trial. This study was not part of the LTIM project and results are to be published elsewhere. Some key findings from that study will be included in this LTIM report.

9.4 Results

Pattern of water delivery

The initial plan for 2018-19 was for the environmental water to be delivered via the Yallakool Creek offtake and Wakool River offtake regulator. However, it was not possible for WaterNSW to maintain the height of Stevens Weir to deliver the required discharge through those regulators, so the Wakool escape from Mulwala canal was used from 4/9/2018 to 17/9/2018 to contribute to the environmental watering action.

Watering action 1 increased the maximum discharge in all zones compared to operational flows. From a water accounting perspective the total discharge of water delivery reached a maximum of 870 ML/day on 13 September. However, the discharge did not exceed 800 ML/day at any site because water was delivered from different regulators. The maximum daily discharge was 488 ML/day in Yallakool Creek (15 September), 94 ML/day on 14th September at the Wakool offtake, 398 ML/day at Wakool River zone 2 site 4 at 'Widgee' (13 September), 696 ML/day in Wakool River zone 3 (17 September), 652 ML/d in Wakool River zone 4 (19 September) (Figure 9.4). The maximum daily operating discharge of 600 ML/day was exceeded in zones 3 and 4. The discharge in zone 2 downstream of the Wakool escape was higher than normal operational flows in this zone (40-80 ML/d).

As planned, the maximum discharge during flow trial exceeded the maximum daily discharge of 600 ML/day under regulated operating rules.

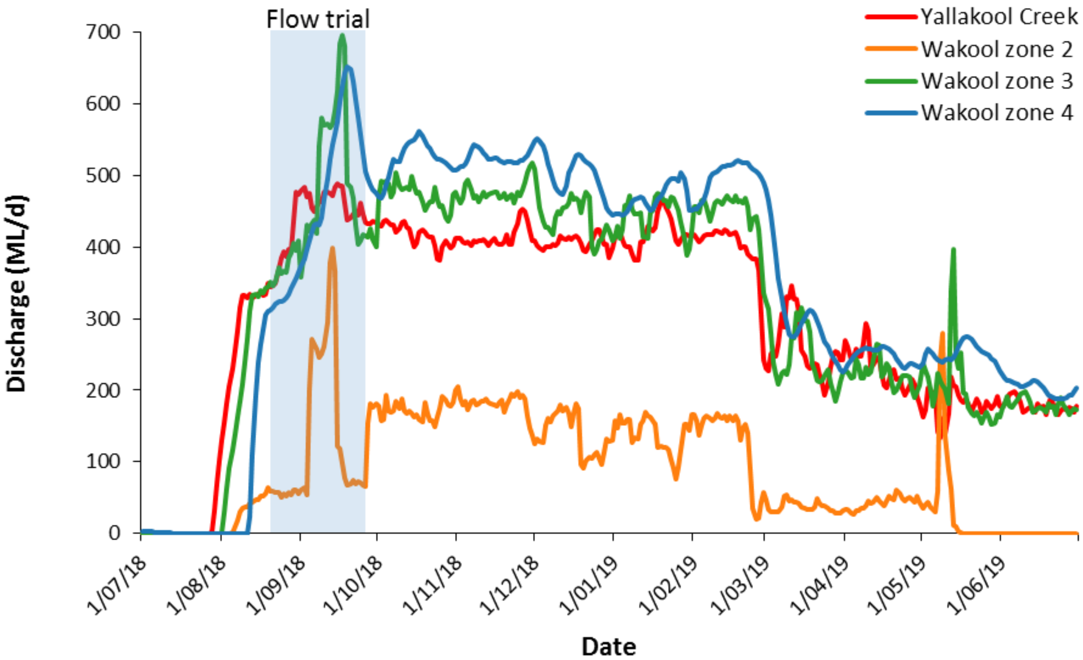


Figure 9.4 Hydrographs of zone 1 Yallakool Creek, and zones 2, 3 and 4 in the Wakool River from 1 July 2018 to 30 June 2019. The timing of the 800 Ml/d flow trial is shaded in blue.

Water level changes on staff gauges

Photos of the staff gauges prior to the watering action and at the peak of the flow are in Table 9.3. The change in water level during the flow can be seen by comparing the paired photos. Readings of gauge heights from these photos were compared to the readings made during the weekly site visits. The accuracy of readings from the photos was very high, suggesting that field cameras are a cost effective way to collect data on changes in flow heights at sites where there are no automated gauging stations.

Table 9.3. Photos of staff gauges in the Yallakool-Wakool system taken prior to the watering action and during the peak of the flow trial.

Site name	Photo of no watering action	Photo of peak flow during watering action
Hopwood (GB29) Yallakool Creek		
Cumnock (GB28) Yallakool Creek		
Windra Vale (GB30) Yallakool Creek		
Widgee (GB26) Wakool River		
Cummins (GB23) Wakool River		

Table 9.3 (continued)

Site name	Photo of no watering action	Photo of peak flow during watering action
Llanos Park (GB25) Wakool River		
Griminal Creek (GB65/08)		
McLays Lane (GB64/10) Merrabit Creek		
Merrabit Creek – Lolicato Bridge (GB37)		
Bookit Creek (GB31)		
Wakool R - Bookit Island Bridge (GB38)		

The peak flow of the flow trial occurred on different dates in different parts of the system between 14th and 20th September 2018 (Figures 9.5, 9.6). Some of the observed patterns are unusual. For example, the peak in zone 1 site 3 Yallakool Creek occurred several days later than the peak at zone 1 site 5 further downstream. This was because zone 1 site 5 received a pulse of water via Black Dog Creek that flows from the Wakool River zone 2 to the lower reaches of Yallakool Creek zone 1.

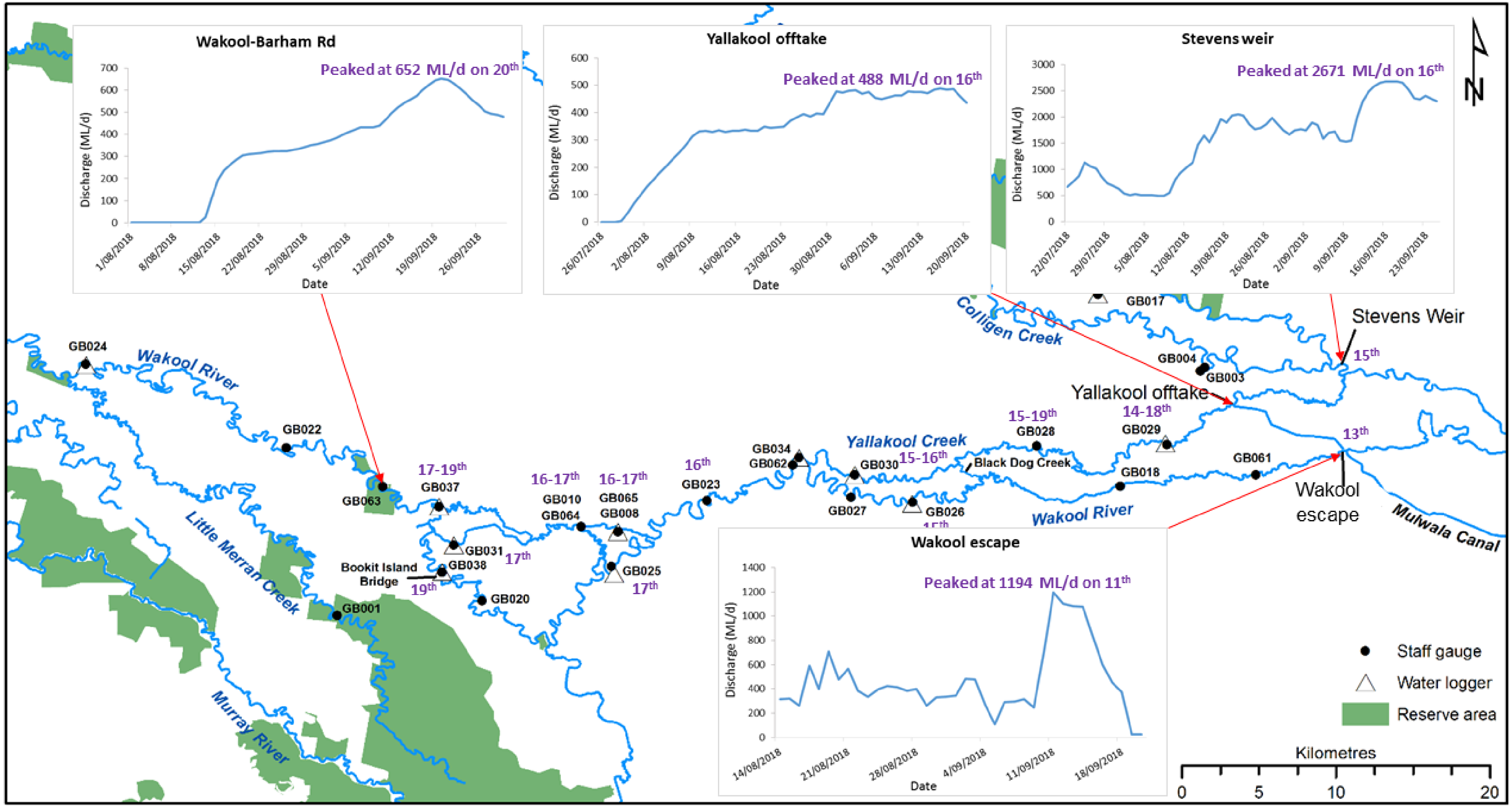


Figure 9.5. The daily water discharge (ML/day) and date of peak discharge (shown in purple) at gauged sites in the Yallakool-Wakool system during flow trial in August/September 2018.

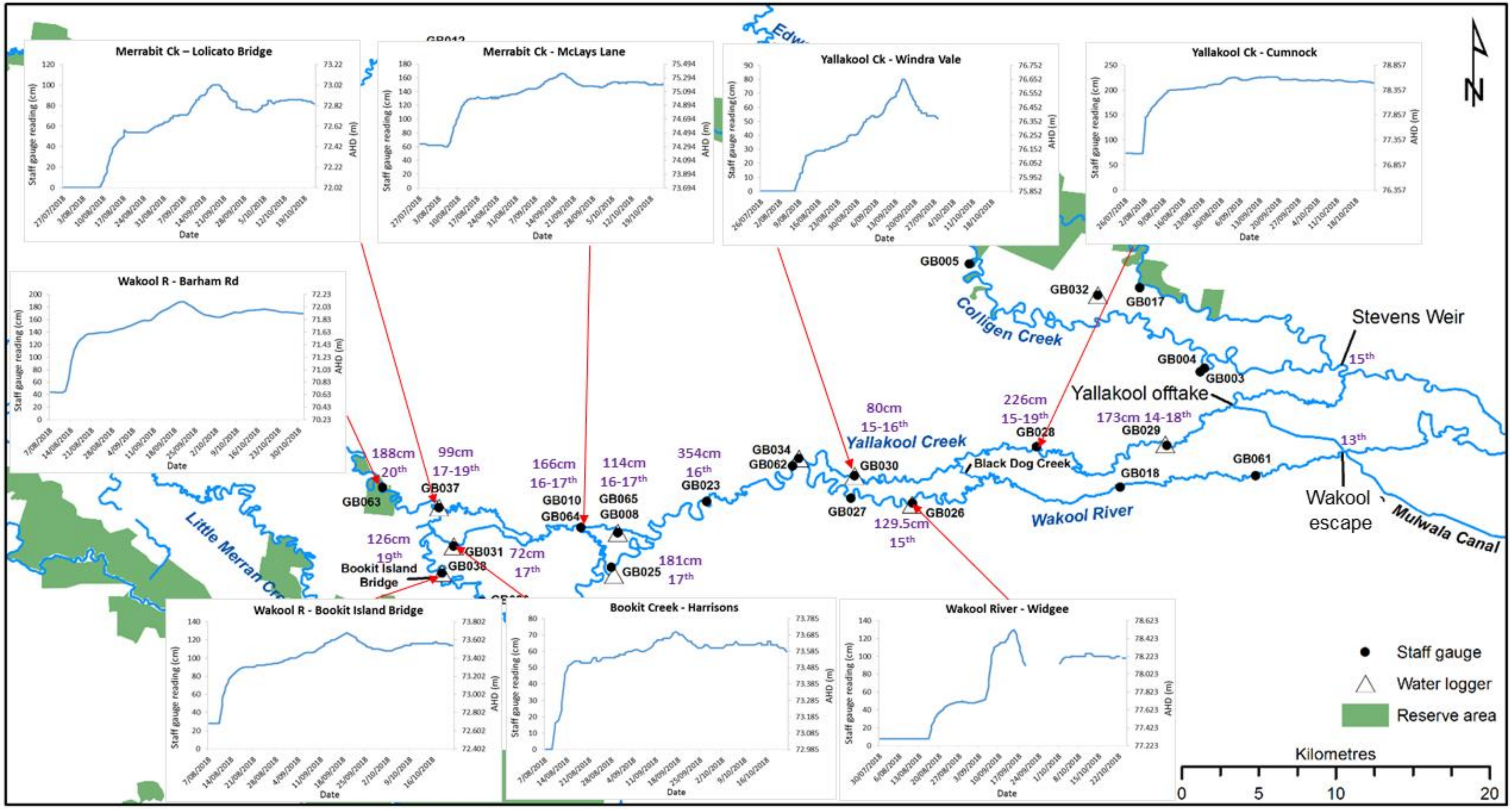


Figure 9.6. The water level (cm, Australian Height Datum readings on gauge boards) and the date of peak flow (shown in purple) at selected monitoring sites during flow trial in August/September 2018. Blank indicates no available data.

Extent of riverbank inundation

The Commonwealth environmental water delivered to the Yallakool-Wakool system via the Yallakool Offtake regulator, Wakool Offtake regulator and Wakool escape from Mulwala Canal increased lateral connectivity within the river system. There was considerable variation in wetted area among the study reaches (Figure 9.7), with some of this variability due to the local geomorphology of the reaches. The Commonwealth environmental water increased the wetted area by an average of 10.2%, ranging from an increase of 3.7% in zone 2 site3 and as high as 30.3% in zone 2 site 4.

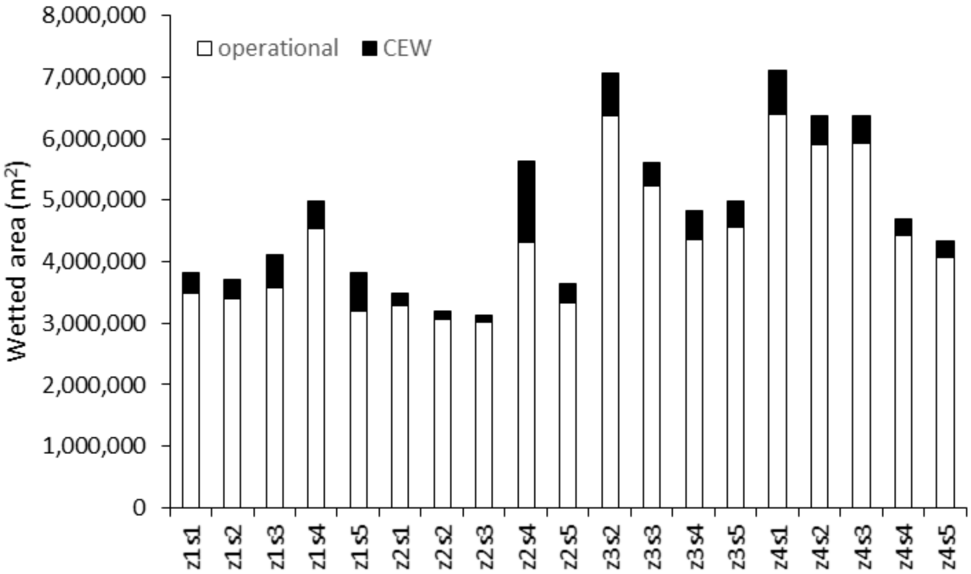


Figure 9.7. Total wetted benthic area (m^2) modelled for 19 reaches in the Edward/Kolety-Wakool system under operational flows and Commonwealth environmental watering action from 22 August to 25 September 2018. Total wetted area was calculated by adding the total area for each day of the watering action. Zone 1 = Yallakool Creek, zone 2 = upper Wakool River, zone 3 = Wakool River upstream of Thule Creek and zone 4 = Wakool River downstream of Thule Creek. Discharge levels for operational and environmental flows are in Figure 9.4.

Effect of increased water levels on infrastructure

Photos of private bridges, low level crossings and two weirs prior to the watering action and at the peak of the flow are shown in Table 9.4. The change in water level during the flow can be visualized by comparing the paired photos. The 800 ML/day discharge inundated one low level bridge (Bookit Island Bridge #1, Table 9.4) in the mid Wakool River.

Due to the need to deliver environmental water from the Wakool escape from Mulwala canal to meet the overall flow 800 ML/day target, the flows in the Wakool River (zone 1) were higher than originally planned. The higher flows enabled in Black Dog Creek to flow. This system exits the upper Wakool River near 'Widgee' (zone 2 site 4) and flows across to Yallakool Creek to 'Windra Vale' near zone 1 site 5 (Figure 9.1). The creek was observed to be flowing inundated on 13th September and on 17th September 2018 the flow was continuing, but the water level was slightly lower. Photos of inundation were manually taken during field monitoring activities (Figure 9.8).

Table 9.4. Photos of infrastructure (bridges, weirs and crossings) in the Yallakool-Wakool system taken prior to the watering action and during the peak of the flow trial.

Site name	Photo of no watering action	Photo of flow during watering action
Mascot bridge Yallakool Creek		
Windra Vale bridge Yallakool Creek		
Bookit Island bridge #1 Wakool River		
Bookit Island bridge #2 Wakool River		
Bookit Creek Ford Bookit Creek		
Bookit Creek Weir Bookit Creek		
Merrabit Creek Weir Merrabit Creek		
Tilga bridge Wakool River		

Figure 9.8. Photos showing the Black Dog Creek crossings during the flow trial. The crossings were inundated on 13 September 2018.

Bookit Island Bridge #1 was the only bridge that was inundated during the flow trial. A series of photos of Bookit Island Bridge #1 show the water level rising and receding (Figure 9.9). At the peak of the watering action the level of water over the bridge was quite shallow and rose up to approximately the bottom rail of the gate. The landholder from Bookit Island commented that "the bridge only went a little bit under, and we could use it anyway". Some tyre tracks were observed near the bridge suggesting it was used at some time during the flow trial watering action.

Figure 9.9 Inundation condition of Bookit Island Bridge #1 during the flow trial from 12th to 23rd September 2018 taken at 3pm each day.

Observations of ecosystem responses to the flow trial

No formal monitoring of the biota responses to the watering action were undertaken. However, several observations were noted during the field visits. On 17 and 18 September 2018 water levels were rising and there was evidence that the watering action had inundated low lying benches and edge habitats throughout zones 1 to 4 and in the Bookit Island area. For example, Figure 9.10 shows the increase in water level in a backwater on Bookit Island, inundating amphibious vegetation including *Juncus sp*. Throughout the system, including this site, a lot of frogs were heard calling during the day from these recently inundated habitats. Waterbirds were observed feeding in the shallow edges of inundated habitat. For example, a white-faced heron can be seen in most of the photos in Figure 9.9 feeding in the shallow water flowing over the Bookit Island Bridge #1.

Figure 9.10 Inundated backwater on Bookit Island during the peak of flow trial watering action.

Spot water quality during flow trial watering action

The range and median values of weekly spot water quality data (temperature, pH, turbidity, electrical conductivity and DO) between 16th July and 27th September 2018 are shown in Table 9.5. There were no negative water quality outcomes recorded within the Yallakool-Wakool system during the flow trial watering action. The water quality results for the study sites were assessed against the lowland river trigger levels for aquatic ecosystems in south-east Australia from the ANZECC (2000) water quality guidelines. The values of these parameters at all monitoring sites remained below the ANZECC (2000) trigger levels suggesting that the environmental water did not cause any water quality issues in the system.

Table 9.5 Range and median values of weekly spot water quality data of monitoring sites in the Yallakool-Wakool system during the flow trial watering action in winter/spring 2018.

Parameters / Sites	Temperature (°C)	pH	DO (mg/L)	Turbidity (NTU)	EC (ms/cm)
Hopwood	10.0-14.5 (11.2)	6.9-7.8 (7.2)	7.52-10.77 (8.47)	30-87 (36)	0.023-0.038 (0.028)
Cumnock	7.8-14.3 (11.1)	6.8-7.4 (7.2)	7.27-9.92 (8.42)	31-64 (41)	0.024-0.037 (0.027)
Windra Vale	9.9-14.4 (11.6)	6.7-7.4 (7.2)	7.83-10.13 (8.83)	10-57 (42)	0.023-0.048 (0.028)
Widgee	10.4-14.8 (12.0)	6.6-7.2 (7.0)	4.49-8.43 (6.90)	55-211 (95)	0.030-0.501 (0.108)
Cummins	9.3-14.6 (11.9)	7.0-7.5 (7.1)	6.94-9.74 (7.51)	28-63 (47)	0.029-0.096 (0.037)
Llanos Park	8.1-14.7 (12.0)	6.9-7.3 (7.1)	7.13-9.05 (7.84)	36-102 (56)	0.030-0.063 (0.041)
Griminal Creek	8.6-15.2 (12.4)	6.8-7.3 (7.2)	6.02-9.79 (7.65)	42-137 (75)	0.030-0.056 (0.04)
Merrabit Creek-McLays Lane	8.5-15.1 (12.3)	6.8-7.3 (7.2)	6.74-9.65 (8.04)	50-145 (77)	0.030-0.087 (0.043)
Merrabit Creek Weir	8.2-15.8 (11.2)	6.7-7.3 (7.1)	7.61-9.55 (8.53)	47-113 (77)	0.029-0.256 (0.035)
Merrabit Ck-Lolicato Bridge	9.3-15.8 (11.1)	6.7-7.3 (7.2)	7.77-10.3 (8.28)	33-105 (65)	0.030-0.256 (0.035)
Bookit Island main bridge	8.9-15.7 (10.9)	6.5-7.4 (7.0)	7.42-10.12 (8.23)	46-137 (70)	0.029-0.183 (0.036)
Bookit Island bridge #1	8.8-15.6 (10.9)	6.4-7.3 (7.1)	6.89-10.62 (8.63)	41-96 (79)	0.030-0.256 (0.035)
Bookit Island bridge #2	8.5-15.9 (11.1)	6.9-7.1 (7.0)	5.04-9.16 (8.63)	33-80 (66)	0.029-0.222 (0.036)
Bookit Creek Weir	7.5-14.9 (10.7)	7.3-6.8 (7.1)	7.43-9.37 (8.75)	58-379 (82)	0.029-0.176 (0.034)
Wakool-Barham Rd	7.2-15.2 (12.8)	7.0-7.6 (7.2)	5.88-10.56 (7.83)	60-114 (75)	0.031-0.060 (0.040)

9.5 Discussion

What was the pattern of environmental water delivery and the timing of peak flow through the Yallakool-Wakool system during the flow trial? Was the environmental water able to be delivered as planned to the Yallakool-Wakool system?

There were some operational limitations to deliver the environmental water via the Yallakool Creek regulator when Steven's weir pool was low. Some of the environmental water was delivered via the Wakool escape from Mulwala canal.

Watering action 1 increased the maximum discharge in all zones compared to operational flows. From a water accounting perspective the total discharge of water delivery reached a maximum of 870 ML/day on 13 September. However, the discharge did not exceed 800 ML/day at any site because water was delivered from different regulators. The maximum daily discharge was 488 ML/day in Yallakool Creek (15 September), 94 ML/day on 14th September at the Wakool offtake, 398 ML/day at Wakool River zone 2 site 4 at 'Widgee' (13 September), 696 ML/day in Wakool River zone 3 (17 September), 652 ML/d in Wakool River zone 4 (19 September). The maximum daily operating discharge of 600 ML/day was exceeded in zones 3 and 4. The discharge in zone 2 downstream of the Wakool escape was higher than normal operational flows in this zone (40-80 ML/d).

The peak flow of the flow trial occurred on different dates in different parts of the system between 14th and 20th September 2018. Some of the observed patterns are unusual. For example, the peak in zone 1 site 3 Yallakool Creek occurred several days later than the peak at zone 1 site 5 further downstream. This was because zone 1 site 5 received a pulse of water via Black Dog Creek that flows from the Wakool River zone 2 to the lower reaches of Yallakool Creek zone 1.

What was the difference in inundation of riverbank during the 800 ML/day flow trial compared to operational flows?

The Commonwealth environmental water increased lateral connectivity within the river system. There was considerable variation in wetted area among the study reaches, with some of this variability due to the local geomorphology of the reaches. The Commonwealth environmental water increased the wetted area by an average of 10.2%, ranging from an increase of 3.7% in zone 2 site3 and as high as 30.3% in zone 2 site 4.

Did the peak discharge inundate any infrastructure including low level bridges, weirs or crossings?

The peak discharge of 696 ML/day inundated one low level bridge in the Bookit Island area in the mid Wakool River and one creek crossing on Black Dog Creek, but this did not limit landholders access to their properties.

Where there any observations of ecosystem benefits during the flow trial?

Environmental water did not cause any detrimental water quality outcomes. The environmental water increased river productivity, and there was increased frog calling, waterbird activity and invertebrate activity observed in inundated areas.

Perceptions of the flow trial

Planning for the action was undertaken over a period of more than one year, with the Wakool River Association, the Edward/Kolety-Wakool Environmental Water Reference Group and landholders engaged and involved in the planning and water delivery. Interviews of landholders, water managers, river operators and other community members were undertaken through a complementary project by Charles Sturt University to explore stakeholder's perceptions of flow trials. The outcomes from this complementary project will be reported on in more details elsewhere. In general, the flow trials were perceived by most stakeholders as an opportunity to explore how to act in a complex socio-ecological system. A dominant way that participants framed conversations was in a systems perspective. This emerged alongside other strong framings of engineering, accounting, ecology and power.

10 KEY OUTCOMES OF ENVIRONMENTAL WATER DELIVERY 2014 - 2019

The volume of Commonwealth environmental water delivered to the Edward/Kolety-Wakool system across the five years of LTIM program was small in comparison to the large unregulated flow in 2016 (Figure 4.2). However, the environmental water provided a number of small freshes, slowed the recession of operational flows, and maintained connectivity by provision of winter base flows. A list of watering actions evaluated during the LTIM program is summarised in Table 10.1.

Table 10.1 Summary of watering actions evaluated across five years of Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2014-19.

#	year	watering actions	dates	description	LTIM zones
1	2014-15	small fresh and recession	12/08/14 to 15/01/15	Extended in-channel fresh of approximately 500 ML/day from Aug until 16 Dec 2014, followed by a recession of about 40cm over 30 days until it reached operational flows in the range of 200 to 240 ML/day	1,3,4
2	2015-16	base flow and fresh	10/11/15 to 30/01/16	Base flow and Fresh. Flow for spring-summer fresh in upper Wakool to have a flow range of between 50 ML/day and 100 ML/day to enable river operators to provide a level of variability into flows. A flow recession back to base flows of 25 ML/day every 14 days was targeted	2
3	2015-16	base flow and fresh	10/11/15 to 30/01/16	Flow for early fresh to increase from base flow level to peak of 550 ML/day, receding to 450 ML/day. Flow for spring-summer fresh to have a flow range of between 450 ML/day and 500 ML/day to enable river operators to provide a level of variability into flows. Flow recession to reduce from 500 ML/day in 25 ML/day increments	1,3,4
4	2016-17	Wakool River refuge flow	31/10/16 to 31/12/16	To provide refuges from hypoxic water for fish and other aquatic biota. Escape flows for hypoxic water refuge at the Wakool escape with flows of up to 500 ML/d	2,3,4
5	2016-17	Yallakool Creek recession flow	1/01/17 to 22/05/17	To prevent a rapid return to base flows following the hypoxic event. To provide recessions to flows of a rate and duration that contributes to ongoing recovery of instream in-stream aquatic vegetation. Autumn pulse and recession also to assist with movement of juvenile native fish.	1,3,4
6	2017-18	winter base flow	1/05/17 to 23/08/17	To contribute to reinstatement of the natural hydrograph, connectivity, condition of in-stream aquatic vegetation and fish recruitment	1,3,4
7	2017-18	small fresh and flow recession	7/09/17 to 22/10/17	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	1,2,3,4
8	2017-18	summer fresh at end of e-flow with flow recession	3/01/18 to 29/01/18	To encourage fish movement and assist dispersal of larvae and juveniles of fish species	1,3,4
9	2017-18	autumn fresh with flow recession	28/03/18 to 1/05/18	To encourage fish movement and dispersal of juveniles of a number of fish species	1,2,3,4
10	2018-19	Early spring fresh	22/08/18 to 25/09/18	Yallakool/Wakool spring watering action (800 ML/d trial)	1,2,3,4

A summary of key outcomes from environmental watering actions across the five years of the Long Term Intervention Monitoring Program 2014 to 2019 is presented in Table 10.2.

Table 10.2 Key results across five years of Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2014-19.

Theme	Indicator	Key result
Hydrology	Maximum and minimum discharge	All Commonwealth watering actions delivered between 2014 and 2019 increased the maximum discharge compared to operational flows. The majority of watering actions over the five years were delivered within normal operating ranges as advised by river operators to avoid third party impacts. However, following consultation with landholders, a flow trial in the Wakool-Yallakool system in 2018-19 exceeded the maximum daily operating discharge of 600 ML/day in the Wakool River; discharge peaked at 696 ML/d in zone 3 and 652 ML/d in zone 4. Two flow trials undertaken in the winter of 2017 and 2019 maintained winter base flows
	Longitudinal connectivity	Some of the watering actions between 2014 and 2019 increased the longitudinal connectivity in the river system. For example, the winter watering in 2017 maintained longitudinal connectivity in over 500 km of river channels in Yallakool Creek, the Wakool River and the Colligen-Niemur River. This provided opportunities for fish movement, dispersal seeds, and maintained critical overwinter habitat for turtles and taxa that have small home ranges. Under normal operations these systems usually experience extended periods of cease to flow during winter. The higher flows in the upper Wakool River (zone 2) in 2018-19 initiated flow in Black Dog Creek, instigating connectivity between the Wakool River and Yallakool Creek.
	Lateral connectivity	Hydraulic modelling showed that watering actions increased lateral connectivity and increased wetted area by as much as 30% at some sites.
	Flow recession	Some watering actions increased the duration of the flow recession. For example, in 2017-18 watering action 1 increased the recession over 32 days in Yallakool Creek compared to what would have been a rapid recession from 460 ML/d to 200 ML/d over 3 days under operational flows.
	Hydraulic diversity	Based on hydraulic modelling of study reaches, Commonwealth watering actions increased the hydraulic diversity in reaches receiving environmental water compared to modelled operational flows
Water quality and carbon	Dissolved oxygen concentration	None of the watering actions between 2014 and 2018 resulted in adverse DO outcomes. Several watering actions were specifically targeted to improve DO during poor water quality events; DO concentrations were consistently higher in zones receiving environmental water than in zones receiving none or minimal environmental water.
	Nutrient concentrations	Nutrient concentrations during watering actions remained within the expected range throughout 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	None of the watering actions undertaken between 2014 and 2018 had adverse organic matter outcomes. Some freshes resulted in small increases in organic carbon that had positive outcomes on river productivity.

Table 10.2 (continued) Key results across five years of Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2014-19.

Theme	Indicator	Key result
Stream metabolism	Gross Primary Production (GPP)	Commonwealth environmental watering increased the amount of GPP occurring in the river over the five year period. This increase in GPP translates to greater amounts of energy being created by plants and algae, which in turn are available to support aquatic food webs. Across all watering actions from 2014 to 2019, the size of the beneficial impact was largely related to the proportion of total flow that came from the watering action rather than the source of water. Carbon production was enhanced by between 0% and 330% over the ten watering actions assessed between 2014 and 2019, with a sum over all zones and watering actions of 52% more carbon produced compared to no Commonwealth environmental water being delivered. This is an important outcome given that competition for food resources can be a significant factor limiting the growth and survival of fish and other aquatic animals.
	Ecosystem Respiration (ER)	As with GPP, watering actions almost uniformly decreased the rates of ER (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 DO dropped below 'safe' values for aquatic biota.
Riverbank and aquatic vegetation	Total species richness and cover	Between 2014 and 2016 riverbank and aquatic plant richness and cover was increasing and recovering in response to the millennium drought. However a large unregulated flood in late 2016 considerably reduced the richness and cover and some previously abundant taxa were absent in 2017. Between 2017 and 2019 there was a slow recovery, and in 2019 the highest number of taxa were recorded over the five years since the LTIM project commenced. Environmental watering played an important role in the richness and health of riverbank and aquatic vegetation. Between 2014 and 2018 there was consistently higher species richness in zones 1, 3 and 4 that received environmental water than in zone 2 that received minimal or no environmental water. However, in 2018-19 the combined effects of environmental water and the period of higher operational flows in the upper Wakool River zone 2 increased the total and mean richness of plant taxa, such that this zone now has similar average species richness as the other zones. The delivery of environmental water in winter maintains aquatic taxa and can prevent potential frost damage to aquatic vegetation rhizomes.
	Richness and cover of functional groups	The total species richness of submerged, amphibious and terrestrial taxa decreased in 2016 following the unregulated flood. Between 2017 and 2019 there was a slow recovery, and in 2018-19 there were overall more amphibious taxa than prior to the flood. The cover of submerged and amphibious taxa was particularly negatively impacted by the unregulated flow. In 2018-19 the maximum mean percentage cover of submerged taxa and some amphibious taxa increased and was similar to that in 2015-16 prior to the flood. However there has been minimal recovery of some amphibious taxa, such as floating pondweed (*Potamogeton tricarinatus*) and milfoil (*Myriophyllum spp*.). Small plants of these species have been observed outside survey transects, suggesting there is the possibility that these species can recover with support from environmental watering.

Table 10.2 (continued) Key results across five years of Commonwealth environmental watering actions in the Edward/Kolety-Wakool system in 2014-19.

Theme	Indicator	Key result
Fish movement	Movement of golden perch and silver perch	Watering actions undertaken during the LTIM project supported fish movement. The winter watering in 2017 greatly increased river connectivity and fish moved longer distances than in previous periods of operational shutdown during winter. Spring watering actions facilitated movements of silver perch, golden perch and Murray cod.
Fish spawning	Larval abundance of equilibrium, periodic and opportunistic species	Over the 5 years of LTIM of 16 fish species (including 4 introduced species) were detected as larvae or eggs in the monitored zones of the Edward/Kolety-Wakool system. Murray cod larvae were detected in greatest numbers in 2018-19 compared to the four previous years of LTIM, with the majority of Murray cod larvae collected from upper Wakool River that for the first time in 2018 received substantial environmental water followed by higher operational flows. The abundance of Australian smelt larvae was significantly greater in 2018-19 compared to previous years, possibly due to increased water velocities during the higher spring fresh. Between 2016-2019 eggs or larvae of silver perch, catfish and obscure galaxias were detected for the first time in this system. It is difficult to confirm to what extent environmental watering contributed to this. However, the spawning of catfish may have been due to increased connectivity, and the spawning of silver perch may have been due to increased velocities or increased variability in some reaches during environmental watering actions.
Fish recruitment	Murray cod, silver perch and golden perch recruitment	In 2018-19 Murray cod YOY and 1+ fish were detected in highest numbers since LTIM monitoring commenced in 2015. Along with the presence of 1+ silver perch in the system, this suggests that the Edward Wakool fish assemblage is showing positive signs of recovery post the 2016-17 hypoxic blackwater event that resulted in large scale fish kills in the southern Murray-Darling Basin.
Fish populations	Adult fish populations	This project demonstrates the value of the Edward/Kolety-Wakool river system in supporting populations of native freshwater fish, nested within the broader Murray catchment. Throughout this five year study, and utilising a range of sampling techniques, we captured 15 species of native fish representing various life-stages. System-specific trends, indicated through the use of SRA fish 'health' indicators, suggest that the health of the Edward/Kolety-Wakool fish community decreased from 2015 to 2019, although we argue that the fish assemblage is in a state of recovery following adverse water quality and associate fish deaths in 2016. A number of flow-related mechanisms may contribute to the recovery of these populations at a local scale. These include 1) the persistence of refuge habitat at low flows or during adverse water quality events, 2) the presence of diverse in-channel and off-channel habitats, and 3) opportunities for movement that enable the re-distribution of individuals and promote emigration and immigration.
Other	Other observations	The watering actions in the Edward River, Wakool River and Niemur River 2016-17 during the unregulated flood aimed to create small refuges with higher levels of DO. The local community also installed aerators to create DO refuges. Fish were observed congregating in these refuges, suggesting these actions supported the survival of some fish and other aquatic animals. During watering action 1 in 2018-19 there was increased frog calling, waterbird activity and invertebrate activity observed in inundated areas around Bookit Island. Similar observations were made throughout the LTIM program during other watering actions that inundated backwaters.

11 RECOMMENDATIONS FOR FUTURE MANAGEMENT OF ENVIRONMENTAL WATER

Summary of recommendations from previous reports and progress made to date

A summary of recommendations from the 2014-15, 2015-16, 2016-17 and 2017-18 Edward/Kolety-Wakool LTIM annual reports (Watts et al. 2015, 2016, 2017b, 2018) and the extent to which they have been implemented to improve the planning and delivery of Commonwealth environmental water are summarised in Table 11.1.

Table 11.1 Summary of recommendations from Edward/Kolety-Wakool 2014-15, 2015-16, 2016-17 and 2017-18 LTIM annual reports, showing year implemented and details of actions undertaken. EWEWRG = Edward/Kolety-Wakool Environmental Water Reference Group, EWSC=Edward/Kolety-Wakool Stakeholder Committee, EWOAG= Edward/Kolety-Wakool Operations Advisory Group. R = recommendation number

Recommendation	Year(s) recommended	Year(s) implemented	Details of actions undertaken to implement the recommendation
Small in-channel freshes (within normal river operating rules)			
1. Consider a trial to increase the delivery of environmental water to the upper Wakool River	2014-15 (R3) 2015-16 (R6) 2016-17 (R5)	2018-19	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. **2018-19:** Environmental water was delivered from the Wakool escape to add to the total discharge during the 800 ML/d flow trial. The use of the escape was not included in the original plan for this action, but delivery was adapted during the action when the required discharge for the trial could not be delivered from the Yallakool regulator
2. 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) 2017-18 (R3)	Not yet implemented	This recommendation has not yet been implemented
In-channel freshes (higher than current normal operating rules to connect additional in-channel habitats)			
3. In collaboration with stakeholders explore options to implement a short duration environmental flow trial in late winter/spring 2016 at a higher discharge than the current constraint of 600 ML/d at the Wakool-Yallakool confluence. 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) 2017-18 (R4)	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 was implemented in Spring 2018.
Flows that contribute to flow recession			
4. 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/Kolety-Wakool system

Winter flows			
5. 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:** A continuous winter flow was implemented in Yallakool Creek,-Mid & Lower Wakool River and the Colligen - Niemur system.
6. Implement a second trial of continuous base winter environmental flow (no winter cease to flow) in the tributaries of the Edward/Kolety-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.	2017-18 (R2)	Winter 2019	**2018:** Winter watering was discussed during planning for 2018-19 but could not be delivered in winter 2018 due to maintenance of Stevens Weir. **2019:** Second inter flow trial was implemented in winter 2019 commencing on 16 May 2019. This action will continue into the 2019-20 water year and will be evaluated in the 2019-20 annual report.
Flow variability			
7. 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** Flow variability 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.
8. 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.	2017-18 (R1)		Watering actions were 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. However, this was not implemented because during spring 2018 CEWO actions were suspended due to lack of operational capacity to deliver environmental water in the system.
Flows to mitigate poor water quality events			
9. 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 2018-19	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.
10. 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 DO concentrations falling below 2 mgL^{-1}.	2016-17 (R1)	Not yet implemented	The opportunity to action this recommendation has not yet arisen.
Flows through forests and/or floodplains			
11. 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.	2017-18 (R5)	Not yet implemented via Barbers Creek	**2018-19:** An environmental flow through Koondrook-Perricoota Forest via Thule Creek is underway as art of the 2019 southern spring flow

Other flow related recommendations			
12. 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.
13. Undertake a comprehensive flows assessment for the tributaries of the Edward/Kolety-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/Kolety-Wakool system. These assessments contribute management decisions and long-term water planning by OEH.
14. 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/Kolety-Wakool Stakeholder Group (chair Murray LLS). **2016 - ongoing**: EWEWRG established **2014 - ongoing**: Edward/Kolety-Wakool Operations Advisory Group
15. The installation of a DO 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 DO loggers, both upstream and downstream of other forested areas that influence water quality in the Edward/Kolety-Wakool system	2016-18 (R2)	Not yet implemented	
16. Undertake in-channel habitat mapping for key reaches of the Edward/Kolety-Wakool system, which could then be combined with existing hydraulic modelling to facilitate learning about this system	2016-17 (R6)	Not yet implemented	
17. 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 of blackwater events was undertaken in 2017

Recommendations from 2018-19 watering actions

We continue to endorse the five recommendations that have not yet been implemented (R2, R10, R11, R15, R16), one recommendation that has been partially implemented (R13), and other recommendations that are ongoing from the previous Edward/Kolety-Wakool LTIM annual reports (Table 11.1).

In addition, we outline five new recommendations to improve the planning and delivery of Commonwealth environmental water in the Edward/Kolety-Wakool system. These recommendations are underpinned by monitoring and evaluation results from the Edward/Kolety-Wakool system.

Recommendation 1: Each year plan to deliver at least one flow event with higher than normal operating discharge to the upper Wakool River. This may include delivery of water through the Wakool offtake regulator or via the Wakool escape from Mulwala Canal.

Under normal regulated flows the discharge in the upper Wakool River is usually between 40 and 80 ML/day and has low variability of discharge. In most years only a very small volume of environmental water has been delivered to the upper Wakool River via the Wakool offtake. When Stevens Weir is at full supply level it is possible to deliver environmental water through the Wakool regulator. However, when Stevens Weir is below full supply level the extent to which environmental water can be delivered through the Wakool offtake is limited. However, water can be delivered to the upper Wakool River from the Wakool escape from Mulwala Canal, but the delivery costs are higher.

In 2014-15, 2015-16 and 16-17 we recommended that the CEWO Consider a trial to increase the delivery of environmental water to the upper Wakool River. In September 2018 Commonwealth environmental water delivered from the Wakool escape to the upper Wakool River zone 2 increased the total discharge downstream of the Wakool escape to a peak of 398 ML/day. The delivery of water from the Wakool Escape was not included in the original plan for this watering action, but the watering action was modified during the action when the required discharge for the trial could not be delivered from the Yallakool regulator.

The results of the flow trial in 2018-19 demonstrate that there are considerable benefits of delivering flow pulses and increased flow variability to the upper Wakool River:

- improved water quality in zone 2 compared to the same time in other years under lower discharge. In particular, there was higher DO concentration and lower conductivity during the higher flows (section 5)
- increased inundation of low lying slackwater and in-channel features
- increased germination of aquatic and riverbank plants (section 7). The early inundation of the riverbank is hypothesised to enable riverbank plants to germinate and develop roots prior to the onset of warmer weather, which would enable them to survive the warmer conditions over the summer period.
- higher abundance of Murray cod larvae than recorded previously in this zone (section 8)

This recommendation is an extension of flow recommendation 1 in Table 11.1.

Recommendation 2: Include variation in the timing of environmental watering actions among water years 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.

Australian river systems are intrinsically variable and freshwater mammals, fish, invertebrates and vegetation display a variety of life history characteristics and responses to flow. Thus there is a good logical basis for varying the timing of environmental watering actions. Although there are several operational constraints that limit the opportunity for environmental watering in the Edward/Kolety-Wakool system, annual water planning should aim to include variation in the timing of environmental watering actions among water years to promote the temporal availability and continuity of instream habitat. Water planning could include a window for the timing of flows, with the aim to include some variability in the timing of spring pulses or other actions from year to year to avoid repeating the same type of watering action every year.

Recommendation 3: Implement a second flow trial in-channel fresh in late winter or early spring that briefly exceeds the current normal operating rules, to increase the lateral connection of in-channel habitats and increase river productivity. The earlier timing of flows would help to prime the system and thus increase the outcomes of subsequent watering actions delivered later in spring or early summer.

Larger pulses (less than bankfull) have been shown to increase river productivity and benefit different life stages of animals and plants. In-stream pulses that occur in winter or early spring prior to the breeding season can increase river productivity (section 6) and enable animals to utilise the additional food resources for improving condition or move prior to spawning (section 8). Larger events may also trigger spawning and dispersal of larvae. Winter or early spring inundation of riverbanks and backwaters can trigger earlier germination or growth of riverbank vegetation (section 7), giving plants sufficient time prior to establish prior to the onset of hot weather. Subsequent freshes would then promote growth of the already established seedlings (section 7).

This recommendation is an extension of flow recommendation 3 in Table 11.1, but with a focus on delivering freshes in winter/early spring.

Recommendation 4: Explore options to implement in-channel pulses at any time of the year to connect additional in-channel habitats and increase river productivity.

Australian rivers have intrinsically variable timing of flow events. Examination of time series of flows in the Edward River from 1975 to 2019 showed that freshes that are higher than the current operational constraints occurred across a range of months, particularly winter and spring months of July to October, but also in summer and autumn. This suggests that plants and animals that occur in these lowland rivers would be biologically adapted to respond to these types of larger events at any time of the year. Thus, it is important to be flexible to take opportunities to deliver, extend or complete larger in-channel events whenever possible, focusing on achieving a hydrograph that avoids too long a period of constant discharge or too a rapid recession. This type of watering option may open up opportunities to complement other uses of water in the system, such as adding water on top of operational flows to create short pulses that exceed the operational constraint for short periods of time, or delivering flows that piggy-back on unregulated flows.

This recommendation is an extension of flow recommendation 3 in Table 11.1, but with a focus on delivering earlier pulses at any time of the year, and considering options to complement other uses of water in the river system.

Recommendation 5: Explore and develop a range of options for the delivery of environmental water during times of drought to ensure connectivity of habitat and avoid damage to key environmental assets. Inform the community of the factors limiting water delivery in extreme drought.

During periods of drought there can be an urgent need to maintain key refuges to avoid loss or irreversible damage to key environmental assets. During the millennium drought there was a cease to flow in several of the smaller tributaries (Wakool River, Yallakool Creek and Colligen Creek) resulting in fish kills and loss of established aquatic vegetation. At that time the Commonwealth environmental Water Holder was in the early stages of being established and there was no environmental water that could be used to mitigate this shutdown.

The Edward/Kolety-Wakool community feel strongly about the need to avoid this type of shut down in the event of a future drought. Under the CEWO water use framework there is the option to deliver environmental water at times when there is a high demand for environmental water and a low or very low water availability. However, during periods of extended drought it is possible that one or more delivery options will not be available when there is an urgent need to deliver water to avoid damage to the environment. Factors limiting water delivery in the Edward/Kolety-Wakool system include:

- occasions when the level of Stevens weirpool is low, such as periods of low water demand, during winter when Stevens Weir is fully open, or on occasions when Stevens weir is undergoing maintenance
- occasions when the irrigation canal network is empty, preventing the delivery of environmental water from irrigation canal escapes

- During critical drought/water shortage under stage 4 of the incident response framework of the NSW Extreme Events Policy there may be suspension of Water Sharing Plans and CEWO would not be able to provide refuge flows and keep the Colligen-Niemur and Yallakool connected to the Edward/Kolety River.

We recommend that a range of water delivery options are scoped, developed and discussed with the community prior to the onset of drought, to ensure that options for environmental watering actions under a range of scenarios can be implemented to avoid damage to the environment and maintain key assets. Also it is important to inform the community of the factors limiting water delivery in the Edward/Kolety-Wakool system during extreme drought.

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APPENDICES

Appendix 1. CEW and non-CEW contributions to Watering Actions 1-9.

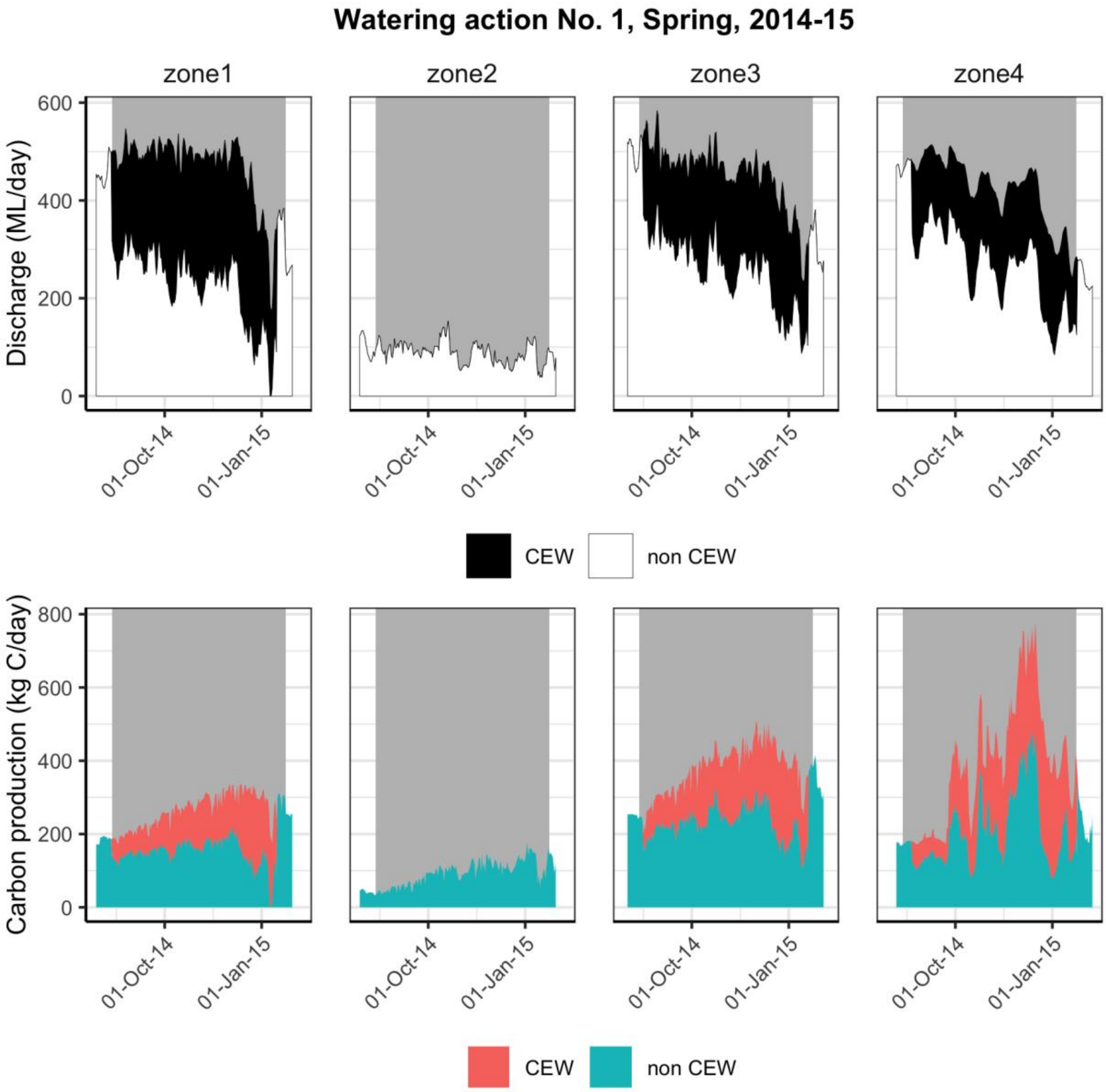

Figure A – 1. Watering Action 1, spring, 2014-15.

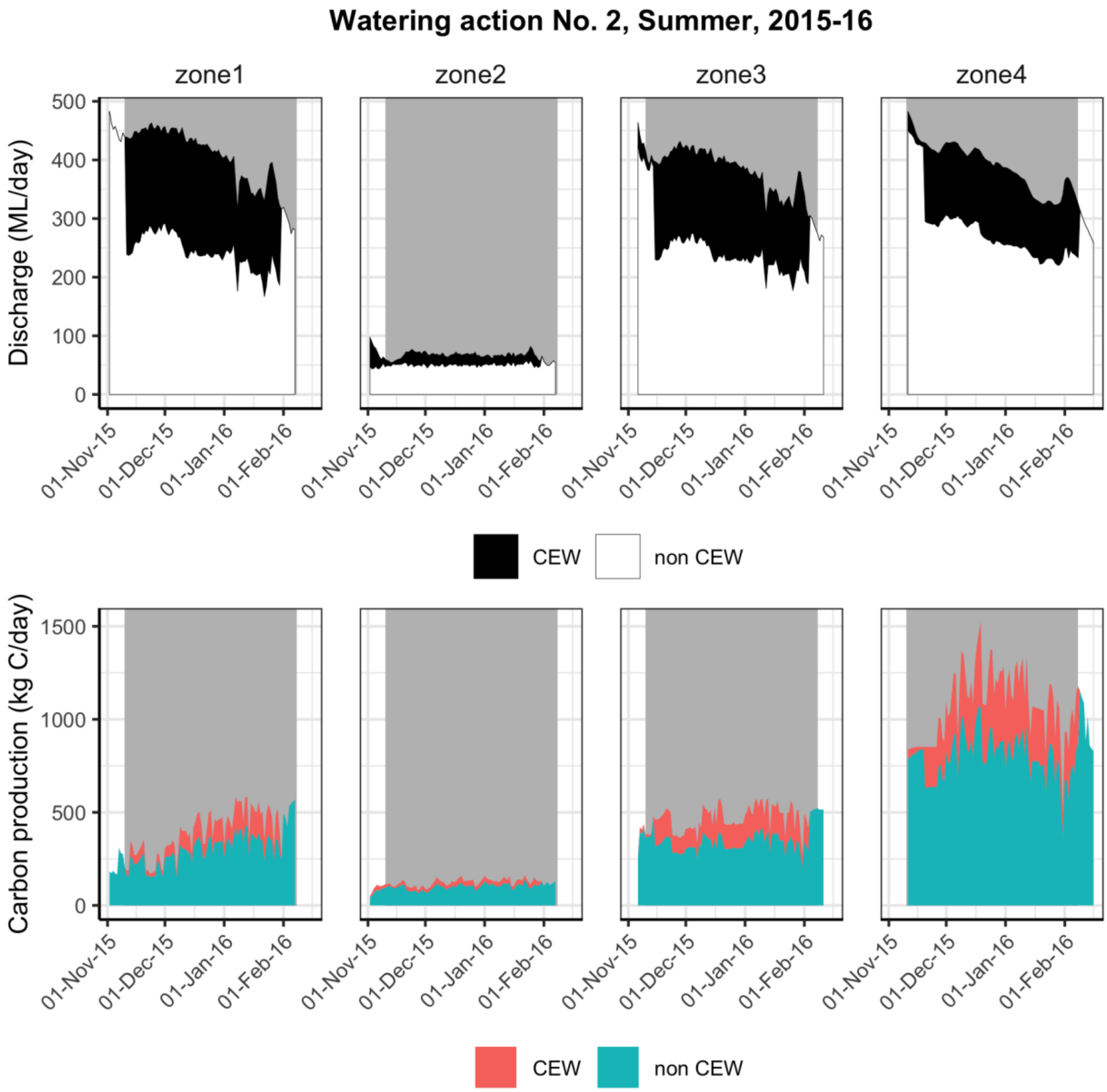

Figure A – 2. Watering Action 2, summer, 2015-16.

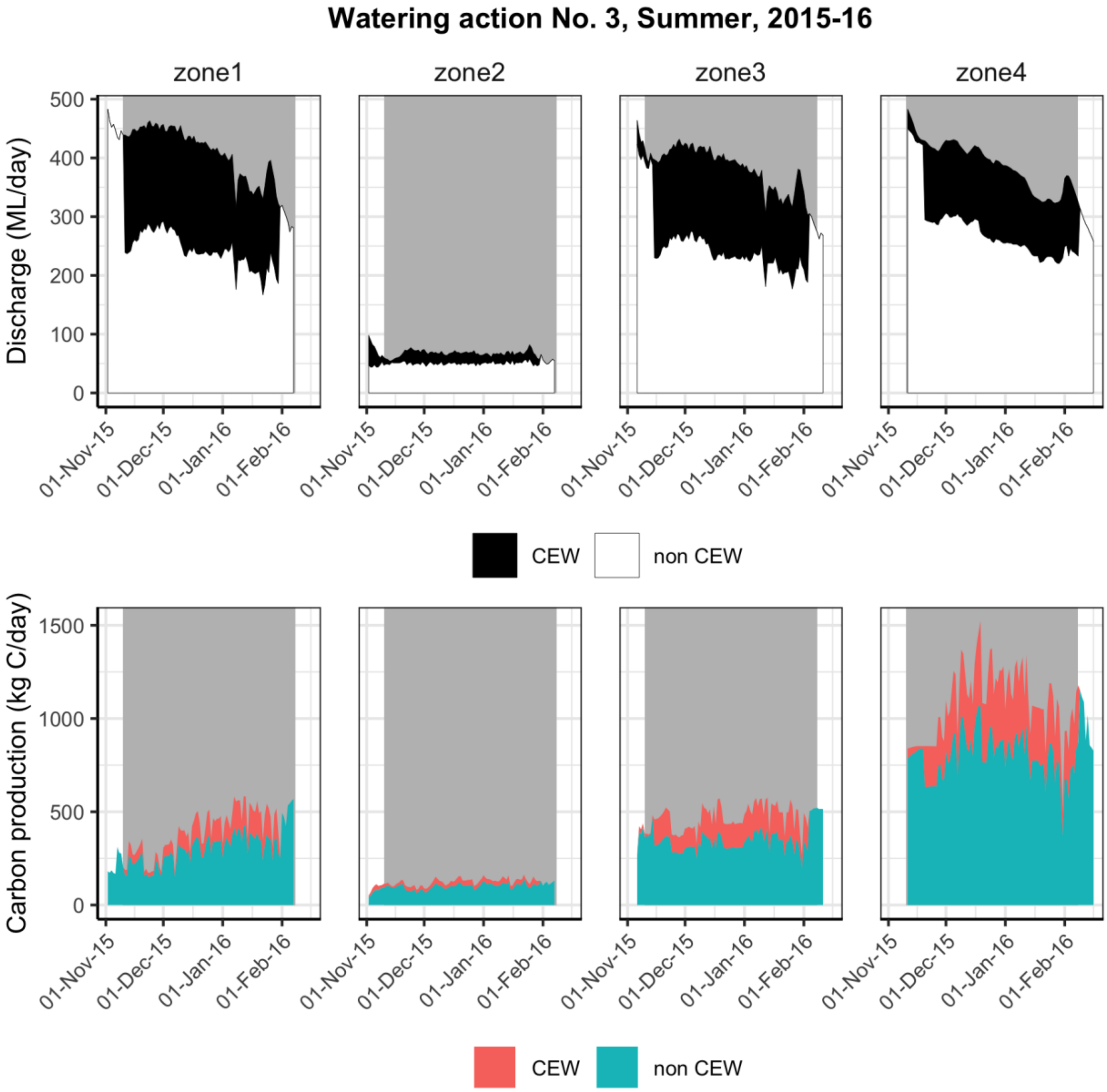

Figure A – 3. Watering Action 3, summer, 2015-16.

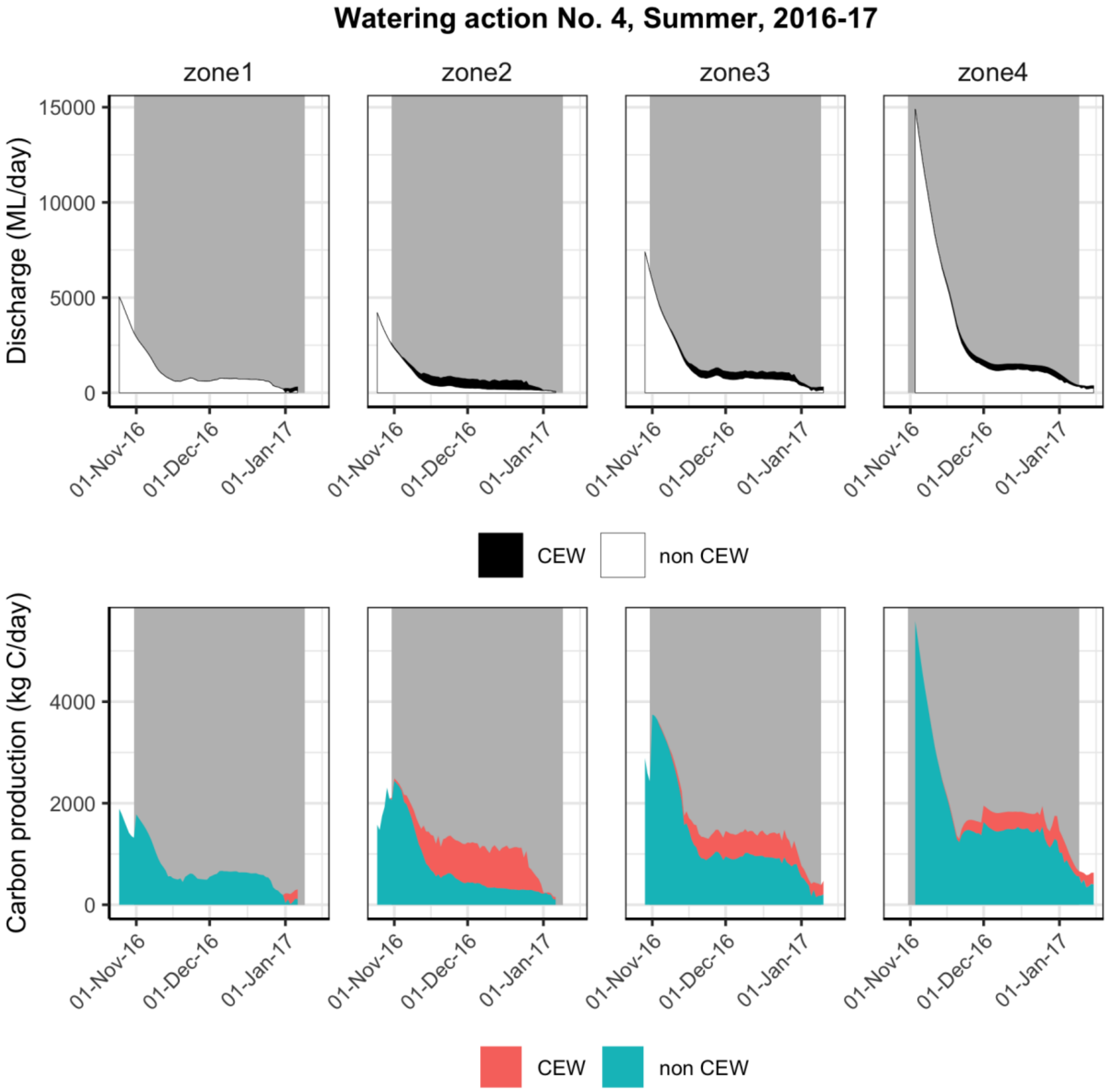

Figure A – 4. Watering Action 4, summer, 2016-17.

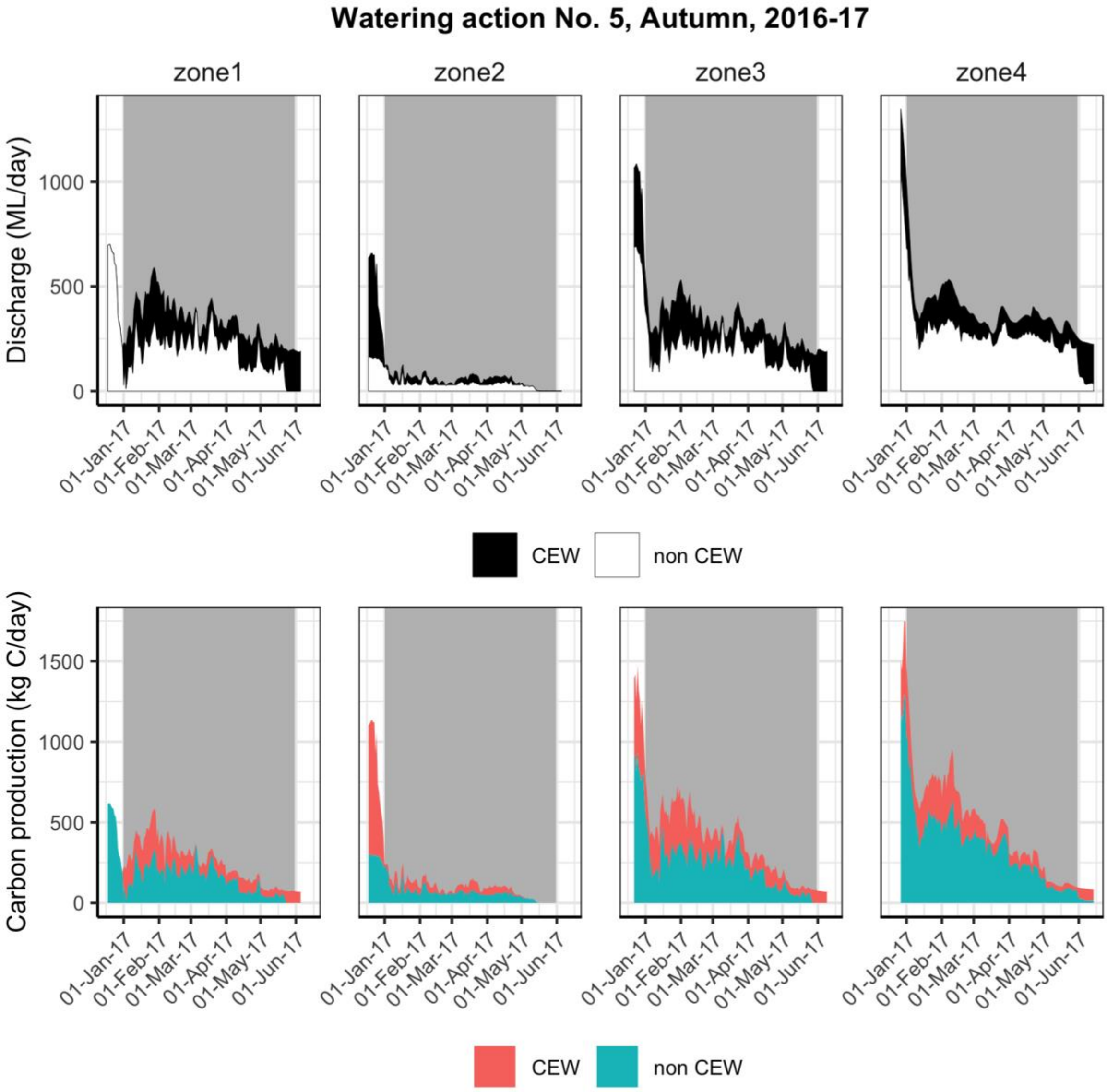

Figure A – 5. Watering Action 5, autumn, 2016-17.

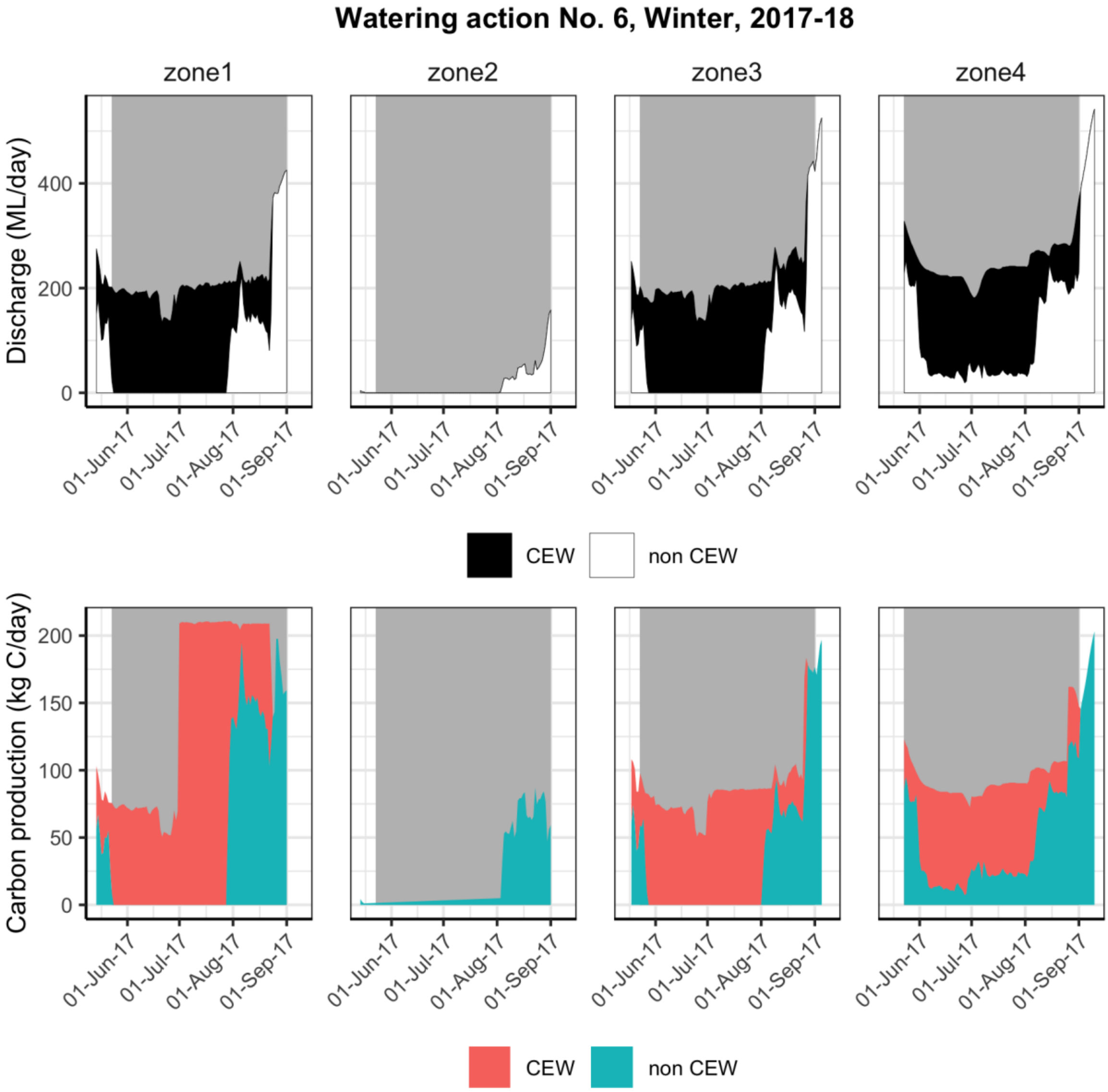

Figure A – 6. Watering Action 6, winter, 2017-18.

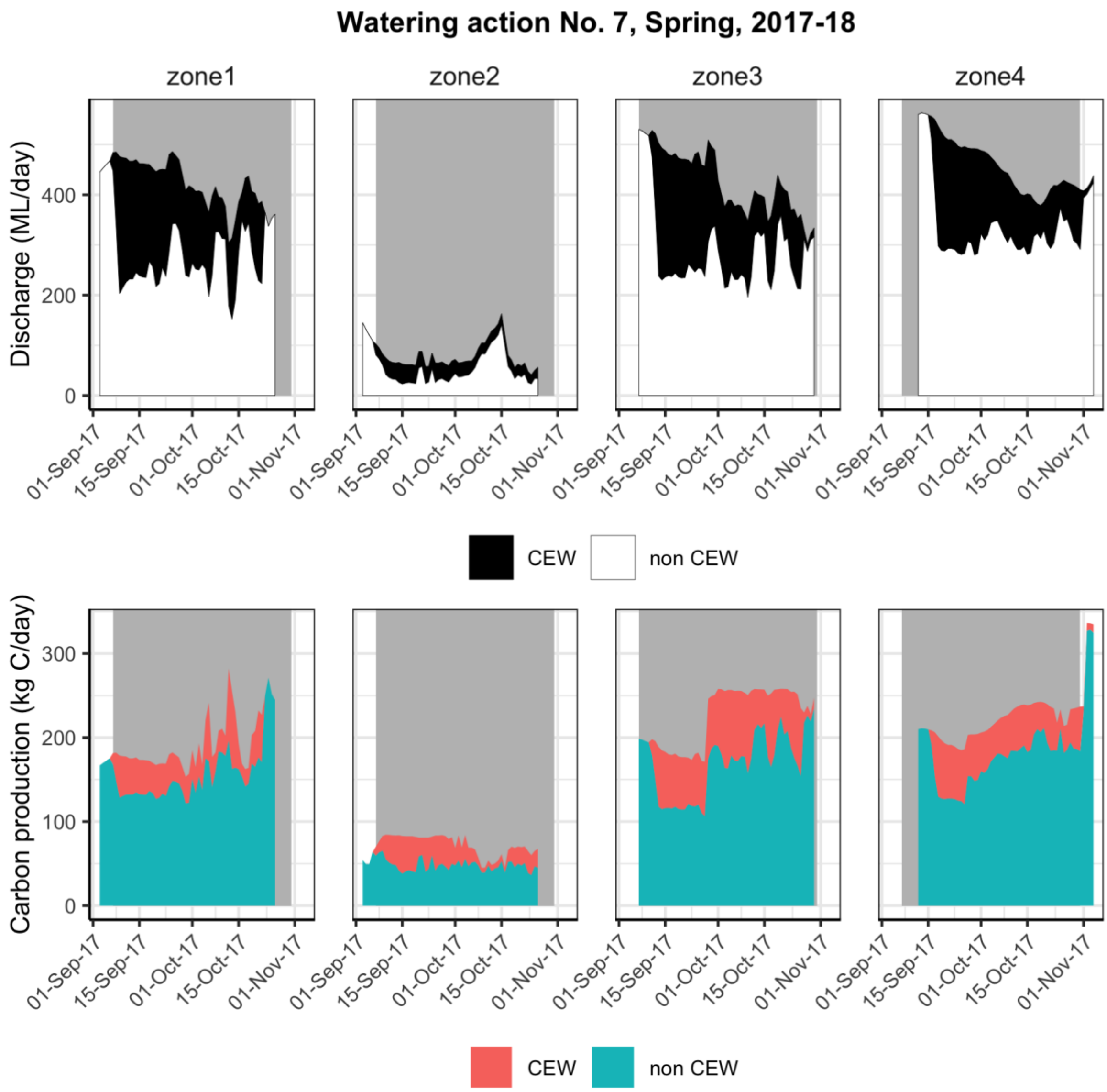

Figure A – 7. Watering Action 7, spring, 2017-18.

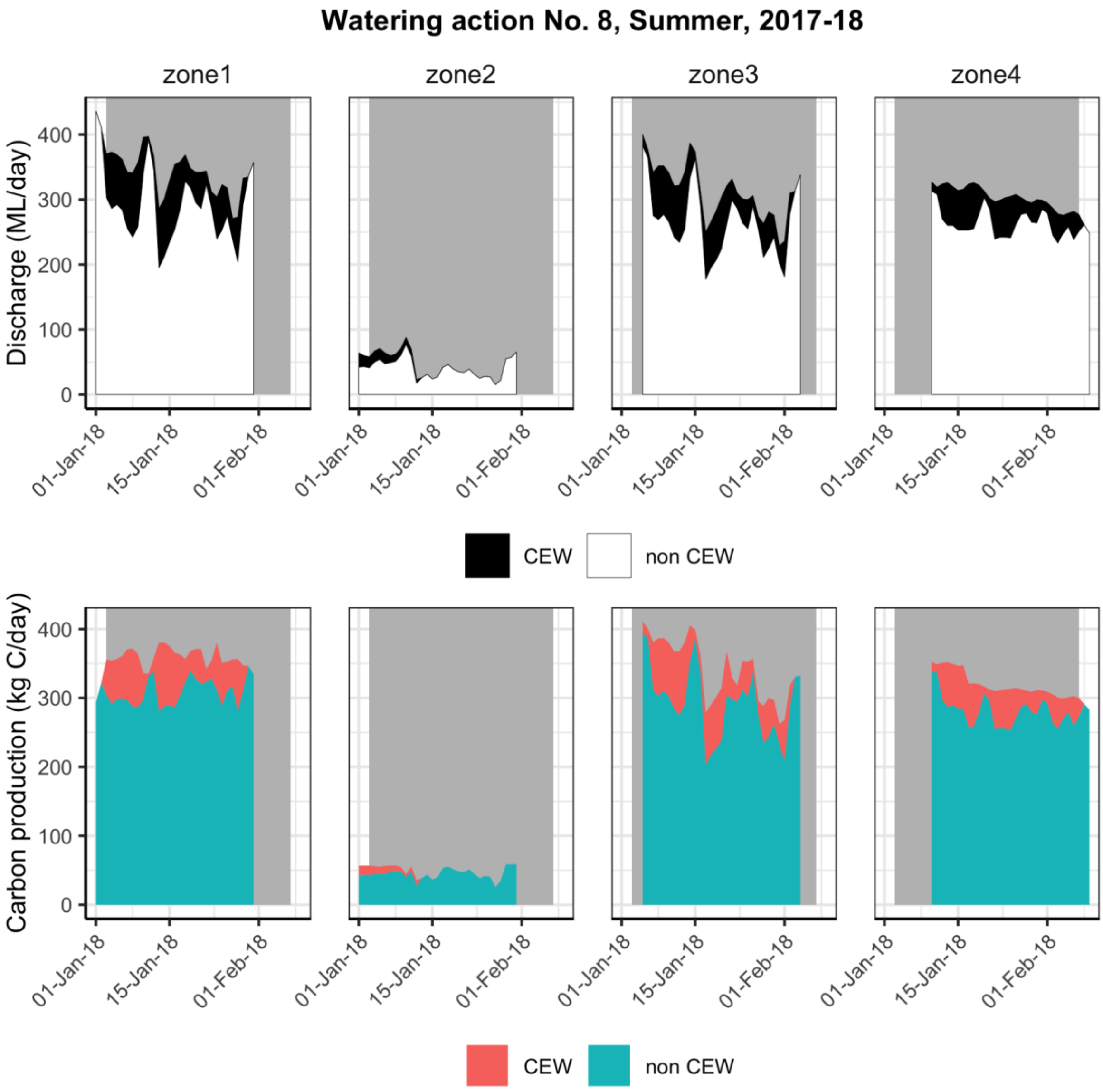

Figure A – 8. Watering Action 8, summer, 2017-18.

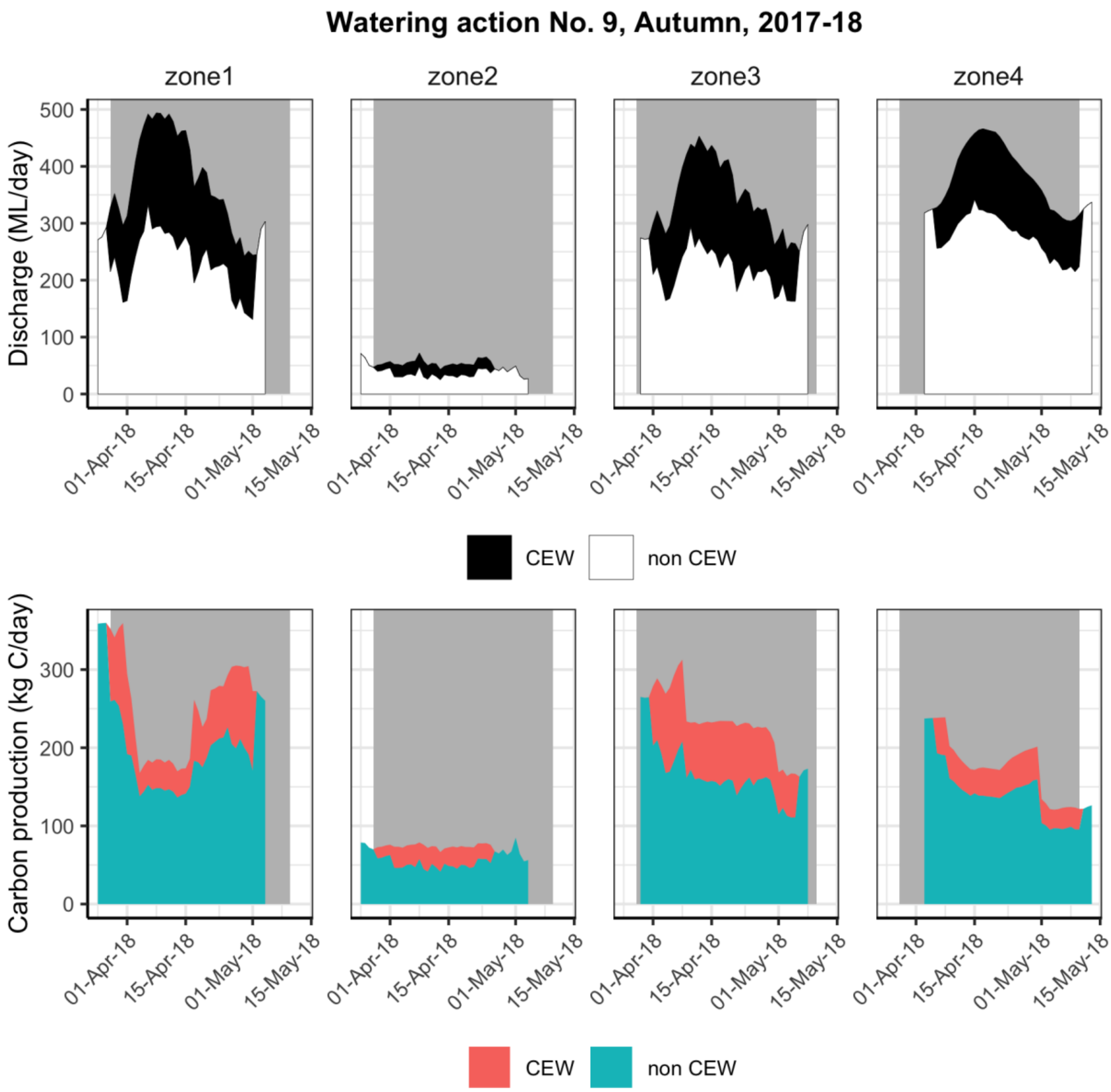

Figure A – 9. Watering Action 9, autumn, 2017-18.