Charles Sturt University

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Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project:

Edward/Kolety-Wakool River System Selected Area Summary Report 2021-22

Australian Government
Commonwealth Environmental Water Office

FLOW Monitoring Evaluation Research

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Cover photos:

Colligen Creek (Photo: Andre Siebers).

1. Monitoring and evaluation of environmental water in the Edward/Kolety-Wakool Selected Area

Background

The Commonwealth Environmental Water Office (CEWO) Monitoring, Evaluation and Research (Flow-MER) Program (2019 to 2023) is an extension of the Long-Term Intervention Monitoring (LTIM) and Murray-Darling Basin Environmental Water Knowledge and Research Project (EWKR) projects, with monitoring, evaluation and research activities undertaken within a single integrated program.

The Flow-MER Program provides the critical evidence that is required to understand how water for the environment is helping maintain, protect, and restore the ecosystems and native species across the Murray–Darling Basin (MDB) and informs management of Commonwealth water for the environment. The Flow-MER Program consists of evaluation, research and engagement at a Basin-scale and monitoring, evaluation, research and engagement across seven Selected Areas within the MDB.

This report summarises the key outcomes of monitoring and evaluation, research, communications and engagement that were undertaken in the Edward/Kolety-Wakool (EKW) Selected Area in 2021-22. Further details are available in the Edward/Kolety-Wakool 2021-22 Flow-MER Technical Report (Watts et al. 2022b). This project was undertaken as a collaboration between Charles Sturt University, NSW DPI (Fisheries), La Trobe University, and Murray-Darling Wetlands Working Group.

Edward/Kolety-Wakool Selected Area

The Edward/Kolety-Wakool (EKW) system is a large anabranch system of the Murray River in the southern MDB. The system begins in the Millewa Forest and travels north and northwest before discharging back into the Murray River (Figure 1). It is a complex network of interconnected streams, ephemeral creeks, flood-runners, wetlands and floodplain forests and woodlands. Under regulated conditions flows in the Edward/Kolety 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.

The area has a rich and diverse Indigenous history and supports a productive agricultural community and recreational uses such as fishing, birdwatching and bushwalking. First Nations including the Wamba Wamba (Wemba Wemba), Perrepa Perrepa (Barapa Barapa), Yorta Yorta, and Wadi Wadi maintain strong connections to Country.

The Barmah-Millewa Forest, Koondrook-Perricoota Forest and Werai Forest (Figure 1) make up the NSW Central Murray Forests Ramsar site (NSW Office of Environment and Heritage 2018), being one of the matters of national environmental significance to which the EPBC Act applies. Werai Forest has great cultural significance to the Wamba Wamba and Perrepa Perrepa Traditional Owners. Land use and occupancy mapping has identified over 12,000 sites of cultural significance to First Nations people in the Werai Forest. Traditional Owners have been working towards having Werai Forest established an Indigenous Protected Area to be cared for through an Indigenous Land Use Agreement.

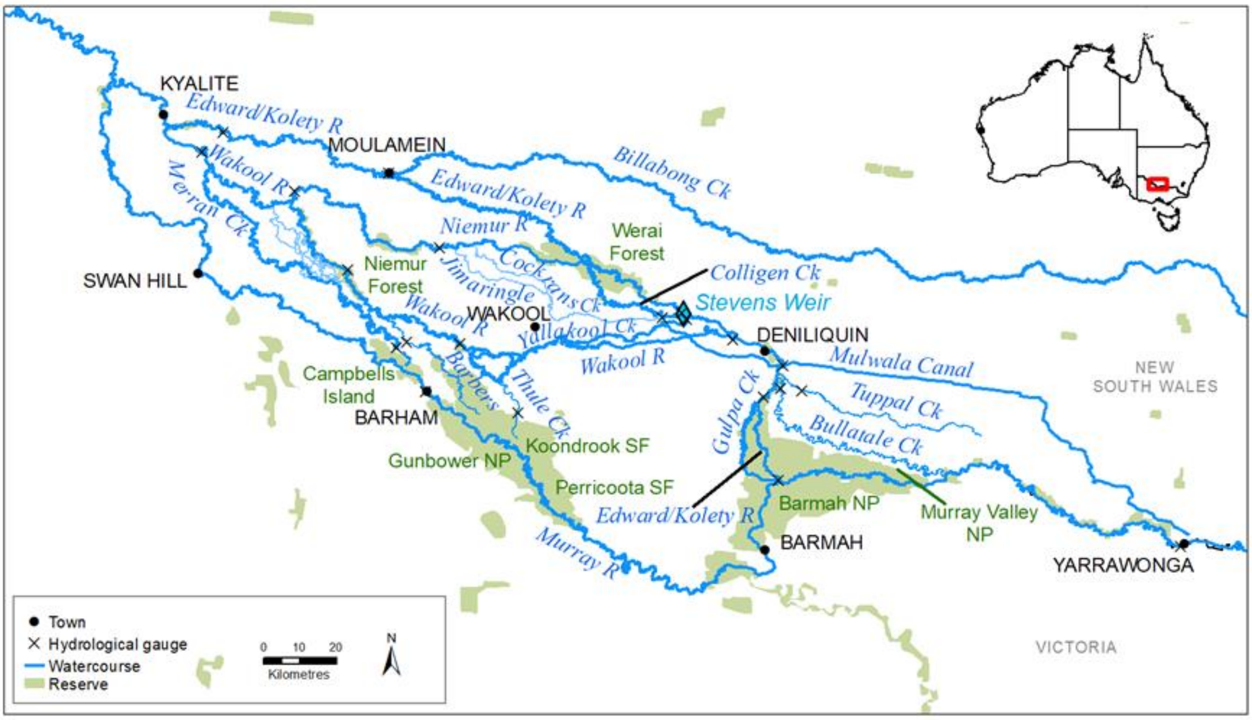

Figure 1. Map showing the main rivers in the Edward/Kolety-Wakool system.

The EKW system is important for its high native species richness and diversity including threatened and endangered fish, frogs, mammals, and riparian plants. It is listed as an endangered ecosystem, as part of the 'aquatic ecological community in the natural drainage system of the lower Murray River catchment' in New South Wales (NSW Fisheries Management Act 1994).

The multiple streams and creeks in the EKW system provide important refuge and nursery areas for fish and other aquatic organisms, and fish regularly move between this system and other parts of the Murray River. The EKW system includes three broad aquatic ecosystem types (Figure 2):

- *Permanently flowing Edward/Kolety River and semi-permanent Colligen-Niemur, Yallakool Creek and Wakool River.* These systems support biodiversity and provide drought refugia for aquatic biota.
- *Floodplain forests and woodlands.* These ecosystems are culturally significant and are important habitats for fish, support breeding colonies of birds, and are a source of carbon for the river system.
- *Ephemeral and intermittent creeks including Tuppal, Jimaringle, Cockran and Gwynnes Creeks.* These creeks provide habitat connectivity and support threatened and vulnerable species.

Figure 2. Photos showing examples of aquatic ecosystem types in the Edward/Kolety-Wakool system. Left: A permanent section of the Wakool River. Middle: Flood runner in Werai Forest. Right: Jimaringle Creek (Photo: Les Gordon).

Water management in the Edward/Kolety-Wakool system

The EKW system plays a key role in the operations and ecosystem function of the Murray River, connecting upstream and downstream river ecosystems. Like many rivers of the MDB, the hydrology of rivers in the EKW system has 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.

The main source of Commonwealth environmental water for the EKW system during regulated flows is from the Murray River, with flows entering the system via the Edward/Kolety River offtake, Gulpa offtake, Tuppal and Bullatale Creek (Figure 1). Stevens Weir, the main flow regulating structure within the system, creates a weir pool that enables environmental water to be delivered to the Colligen-Niemur system, Yallakool Creek, Wakool River, Edward/Kolety River and Werai Forest. Water diverted from Lake Mulwala into the Mulwala Canal can also be delivered into the system through 'escapes' or outfalls managed by the irrigator-owned company Murray Irrigation Limited. Delivery of regulated instream flows to the EKW system are managed within regular operating ranges, as advised by river operators to avoid third party impacts. Regulated flows remain within the channel, with small freshes connecting low-lying in-channel features such as backwaters.

When there are unregulated flows in the Murray River there is a lot of connectivity between the river channels, floodplains and the forests in the EKW system. In 2021-22 there were five main natural flood peaks in the Murray River between late-July to early-December, the largest briefly peaking at 46,700 ML/d from Yarrawonga on 11 September 2021. Translucent regulator operations in August/September diverted water through Millewa Forest until environmental water releases commenced in mid-October until mid- to late-December. Flows returning from Millewa Forest to the Edward/Kolety River had a large influence on the hydrograph of rivers and tributaries in the EKW system in 2021-22. In the hydrographs for the 2021-22 water year there were a sequence of freshes in spring/summer (Figure 3).

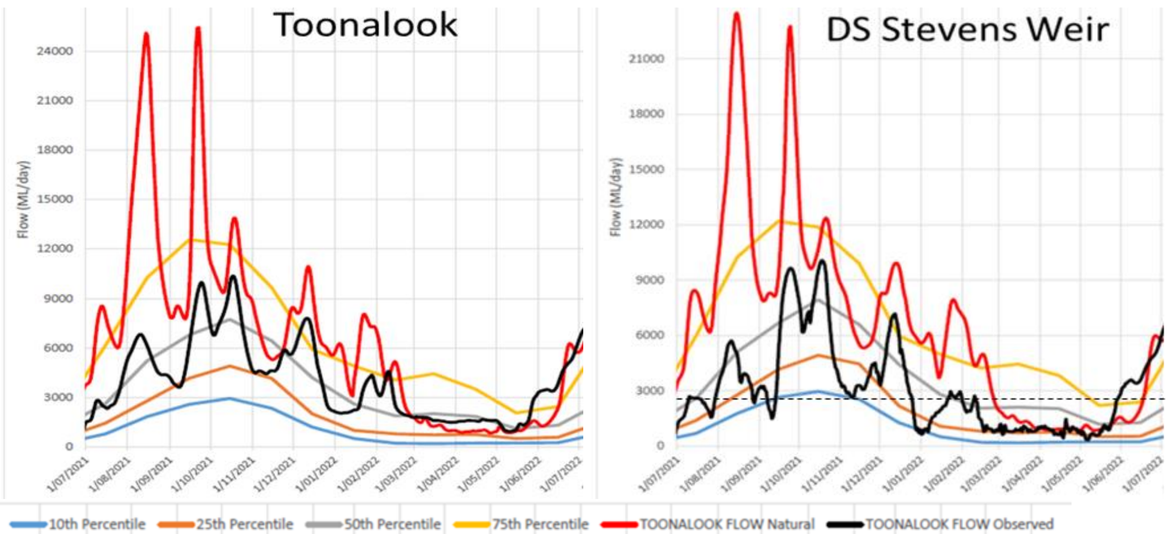

Figure 3. Hydrographs showing observed (black line) and modelled (red line) natural daily discharge in the Edward/Kolety River from 1/6/2021 to 1/8/2022 at the Toonalook gauge and downstream Stevens Weir gauge. (Source: MDBA). Flows downstream of Stevens Weir did not reach minor flood level (5.5 m) at any stage during the water year. Black horizontal dashed line on the DS Stevens Weir hydrograph is 2700 ML/d when water commences to flow over Tumudgery regulator into Werai Forest.

2. ENVIRONMENTAL WATERING IN THE EDWARD/KOLETY-WAKOOL SELECTED AREA IN 2021-22

Since 2009 Commonwealth environmental water has been delivered to the EKW system as base flows and freshes, has contributed to flow recession, and contributed to flows in ephemeral watercourses. Environmental water has also been delivered to rivers and creeks via irrigation canal escapes to create local refuges during hypoxic blackwater events. To date it has not been possible to use environmental water to deliver large within channel freshes or overbank flows due to operational constraints in the system. In addition to watering actions specifically targeted for the EKW system, water from upstream Commonwealth environmental watering actions and actions that are targeted for downstream watering actions transit through the EKW system in some years.

In 2021-22 there were 15 environmental watering actions in the EKW system (WUM10117-1 to 10117-15), as described in the Edward/Kolety-Wakool 2021-22 Water Acquittal report (CEWO 2022). Some of the watering actions delivered entirely Commonwealth environmental water, and other actions delivered NSW water or a combination of Commonwealth and NSW water. A table listing all of these actions is in Appendix 1 of the Edward/Kolety-Wakool 2021-22 Technical Report (Watts et al. 2022b). In this report we focus our evaluation on five of the fifteen watering actions WUM 10117-1, WUM 10117-4, WUM 10117-11, WUM 10117-12, WUM 10117-13 (Table 1) that delivered water to the permanent and semi-permanent rivers and creeks where Flow-MER long-term monitoring sites have been established. Note that WUM10117-1 relates to three different watering actions in Table 1.

Table 1. List of environmental watering actions that were the focus of the evaluation in 2021-22 in the Edward/Kolety-Wakool system, with cross reference to the Water Use minute watering action reference number.

Action	System	Watering Action Reference Number	Type (delivery point)	Dates
1	Wakool-Yallakool	WUM10117-11	Spring-summer hypoxic blackwater refuge (Wakool escape)	14/09/21 - 05/01/22
2	Edward/ Kolety	WUM10117-12	Spring-summer hypoxic blackwater refuge (Edward escape)	06/10/21 -07/11/21 02/12/21- 30/12/21
3	Colligen-Niemur	WUM10117-13	Spring-summer hypoxic blackwater refuge (Niemur escape)	07/10/21 -29/10/21 02/12/21- 08/12/21
4	Wakool-Yallakool	WUM10117-1	Autumn elevated variable base flow (Wakool offtake)	08/03/22 -09/05/22
5	Wakool-Yallakool	WUM10117-1	Autumn fresh (Yallakool offtake)	24/03/22 - 09/05/22
6	Colligen-Niemur	WUM10117-1	Autumn fresh (Colligen offtake)	03/04/22 -26/04/22
7	Tuppal Creek	WUM10117-4	Elevated flows	01/11/21-29/05/22

To mitigate the risks from hypoxic blackwater in spring and summer Commonwealth environmental water was delivered to the Wakool-Yallakool system from the Wakool Escape (action 1), to the Edward/Kolety River via the Edward Escape (action 2), and to the Colligen-Niemur River via the Niemur Escape (action 3) (Table 1). Three environmental watering actions were undertaken in autumn 2022. There was an Autumn elevated variable base flow delivered to the upper Wakool system (zone 2) via the Wakool offtake from March until early May 2022 (watering action 4). An Autumn fresh was delivered to Yallakool Creek via the Yallakool offtake from late March to early May (watering action 5), and an

Autumn fresh was delivered to Colligen Creek via the Colligen offtake in March (watering action 6). An elevated flow delivered to Tuppal Creek (watering action 7) was evaluated to water quality outcomes.

Environmental watering actions to ephemeral and intermittent creeks Jimaringle-Cockran-Gwynnes (WUM 10117-05), Murrain-Yarrien Creek (WUM 10117-06), Thule Creek (WUM 10117-07), Whymoul Creek (WUM 10117-08), Yarrien Creek (WUM 10117-09) and Buccaneit-Cunninyeuk Creek (WUM 10117-15) were qualitatively evaluated in terms of their contribution to longitudinal connectivity.

Objectives for planned watering actions in Yallakool-Wakool, Colligen-Niemur and Edward/Kolety River for 2021-22 are described in Water Use Minute WUM10117 (CEWO 2022) to achieve the following expected outcomes:

Primary expected outcomes

- support the recovery of in-stream aquatic vegetation and large bodied native fish 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 health of riparian and in-channel aquatic native vegetation communities
- maintain/improve water quality within the system, particularly dissolved oxygen, salinity and pH.
- maintain ecosystem and population resilience through supporting ecological recovery and maintaining aquatic habitat.
- support inundation of low-lying wetlands/floodplains habitats within the system.

Secondary expected outcomes

- 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.

In 2021-22 the southern spring flow delivered to the Murray River from Hume Dam contributed water to the Edward/Kolety-Wakool system via return flows from Millewa Forest (Figure 4). These watering actions are described in Water Use Minute WUM10115 for River Murray Hume to South Australia and WUM10115-08 for Barmah-Millewa Forest open regulators, in-channel flow (CEWO 2022).

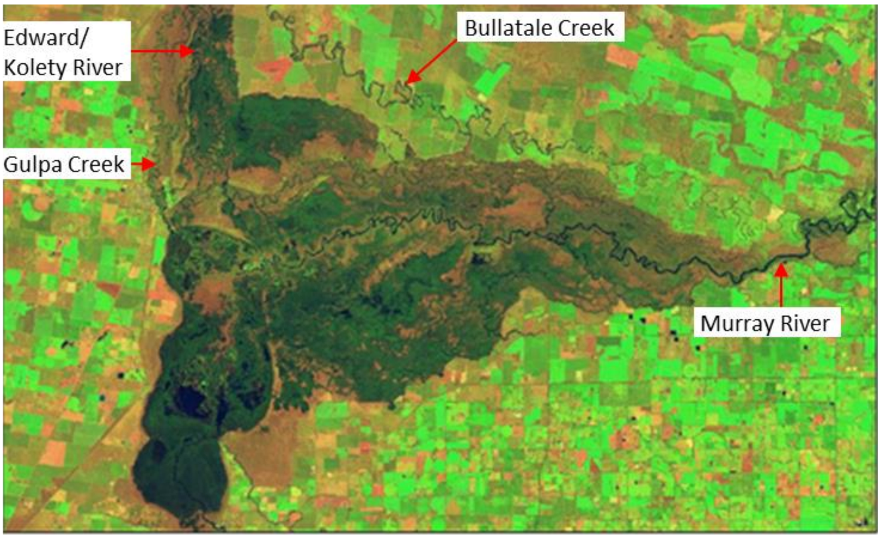

Figure 4. Colour enhanced Sentinel-2 satellite image of Barmah-Millewa Forest, taken 22 October 2021 representing nearest cloud-free image to the flood peak 42 days earlier at 45,700ML/d at Yarrawonga), showing extent of floodplain inundation and water flow path from Millewa Forest to the Edward River (from Sentinel-hub 2021).

The LTIM/Flow-MER program in the Edward/Kolety-Wakool system has been underway for eight water years, commencing in July 2014. Over the past eight years there has been a range of flows experienced in the hydrological zones in the system.

In six of the LTIM/Flow-MER water years (2014-15, 2015-16, 2017-18, 2018-19, 2019-20, 2020-21) there were only small freshes and base flows delivered in the Edward/Kolety-Wakool system. In these years the flows were largely constrained by normal regulated operating rules, with exception being two flow trials which delivered smaller freshes up to 800 ML/d in Wakool/Yallakool 2018-19 and 2020-21. In 2016-17 there was a very large unregulated flood, when flows were unregulated and resulted in widespread flooding and widespread hypoxic blackwater throughout the Murray River downstream of Yarrawonga Weir.

The 2021-22 water year had markedly different hydrology to the other seven years of LTIM/Flow-MER program. In 2021-22 there was an extended period of unregulated flows. All study reaches in the Edward/Kolety-system experienced a total annual discharge (ML/year) that was larger than all previous years of the LTIM/Flow-MER program, except for 2016-17 (Figure 5). This contrasting hydrology in 2021-22 provided an opportunity to compare responses to flows under different conditions to those that have previously been evaluated as part of the LTIM/Flow-MER program. One of the notable differences was that the relative contribution of environmental water to zone 2 (upper Wakool River) was considerably larger in 2021-22 than in previous years (Figure 5).

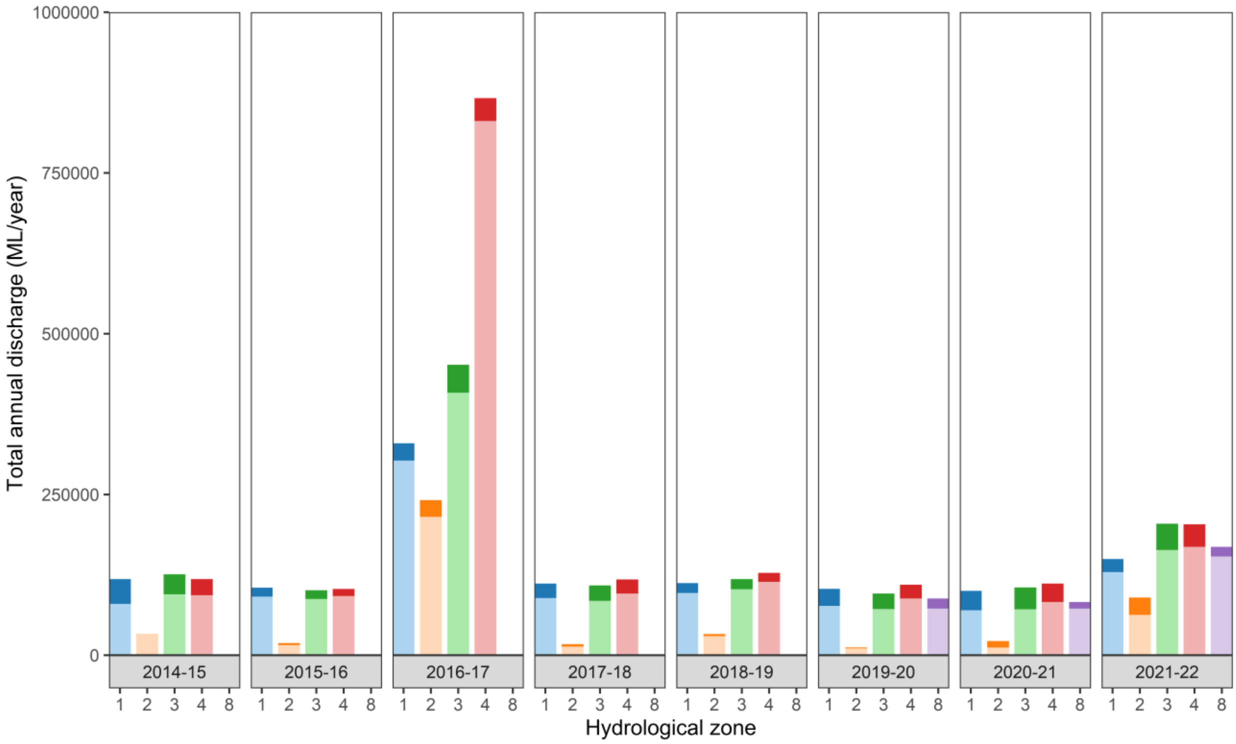

Figure 5. Total annual discharge (ML/year) for each of the study zones in the Edward/Kolety-Wakool system, calculated from 1/7/2014 to 1/7/2022. Dark portion of each column indicates the contribution of Commonwealth environmental water to the total annual discharge. Zone 1 Yallakool Creek (Blue), zone 2 upper Wakool River (orange), zone 3 mid-Wakool River upstream of Thule Creek (green), zone 4 mid Wakool downstream of Thule Creek (red), zone 8 Colligen Creek (purple).

The annual hydrographs (1 July 2021 to 30 June 2022) in Yallakool Creek, Wakool River and Colligen Creek shows the contribution of different sources of environmental water to the hydrographs (Figure 6). Some key observations are:

- The flow peaks during the unregulated flows in spring/summer were more evident in Yallakool Creek and the Wakool River hydrographs than the Colligen Creek hydrograph.
- The return flows from environmental watering of Millewa Forest contributed more to the total discharge in Yallakool Creek, mid-Wakool River and Colligen Creek (Figure 7) between August 2021 and January 2022 than to the upper Wakool River.
- The delivery of environmental water from the Edward Escape contributed only a very small proportion of the flows in all of these rivers over spring/summer.
- The environmental water delivered from the Wakool escape had a large influence on the hydrograph of the upper Wakool River, and also contributed to the flows in the mid-Wakool River
- The autumn 2022 environmental watering actions in April to early May 2022, resulted in a small fresh in Yallakool Creek, the mid Wakool River and Colligen Creek.

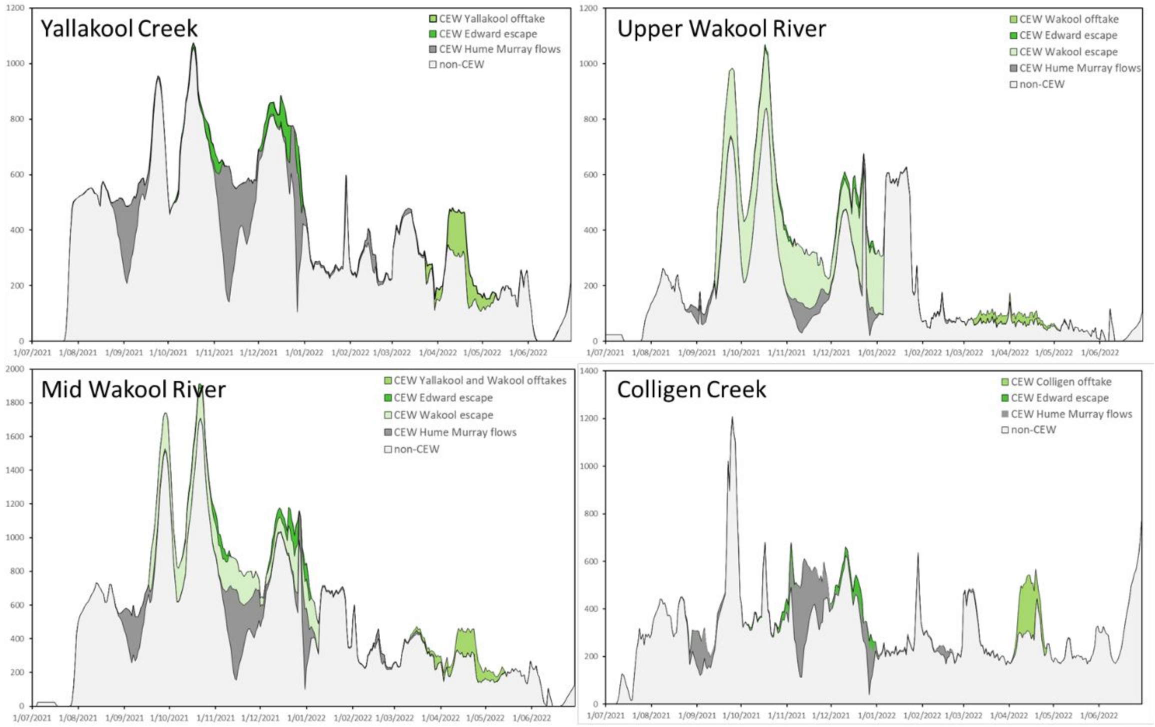

Figure 6. Hydrographs showing discharge (ML/day) for Yallakool Creek offtake regulator, upper Wakool River at 'Widgee', mid Wakool River at Wakool Barham Rd, and Colligen Creek offtake from 1 July 2021 to 30 June 2022. The shading indicates the portion of the hydrographs attributed to the delivery of different sources of environmental water. Note that the vertical axes differ for each river system.

3. KEY OUTCOMES FROM ENVIRONMENTAL WATER USE

Monitoring

The monitoring of the environmental watering actions was undertaken using methods and approaches described in the Edward/Kolety-Wakool Flow-MER Plan (Watts et al 2019). An evaluation of the outcomes of Commonwealth environmental watering actions in 2021-22 was undertaken for the following indicators: Hydrology, water quality and carbon, stream metabolism, aquatic and riverbank vegetation, fish reproduction, fish recruitment, and the adult fish community.

Responses to Commonwealth environmental water were evaluated in two ways:

i) Indicators that respond quickly to flow (e.g., water quality, stream metabolism, fish spawning) were evaluated for their response to individual watering actions. When possible, indicators were modelled to compare responses with and without environmental water.

ii) Indicators that respond over longer time frames (e.g., riverbank and aquatic vegetation, fish recruitment, fish community) were evaluated for their long-term response to environmental watering regimes over 8 years of the LTIM/Flow-MER project (2014-2021). This was undertaken by evaluating responses over multiple years, and/or comparing responses in reaches that received environmental water to reaches that received none or minimal environmental water.

Responses to flows across the 2021-22 water year and over multiple years

- In 2021-22 environmental water **increased the total annual discharge** (ML/year) in all reaches (14% increase in Yallakool Creek, 30% in upper Wakool, 20% in mid Wakool upstream Thule Creek, 17% mid Wakool downstream Thule Creek and 12% in Colligen Creek) (Figure 5).
- **The delivery of environmental water produced a slight reduction in the coefficient of variation across the whole water year** in Yallakool Creek (8%), upper Wakool (9%), mid Wakool (5%), and Colligen Creek (6%). This was partly due to the return flow of environmental water from Millewa Forest increasing base flows during spring, reducing the variation of flows.
- There was i**ncreased longitudinal connectivity throughout the EKW system in 2021-22**, particularly during spring and summer due to the increased flows in several intermittent and ephemeral creeks that connect to the main tributaries in the system (Figure 7).

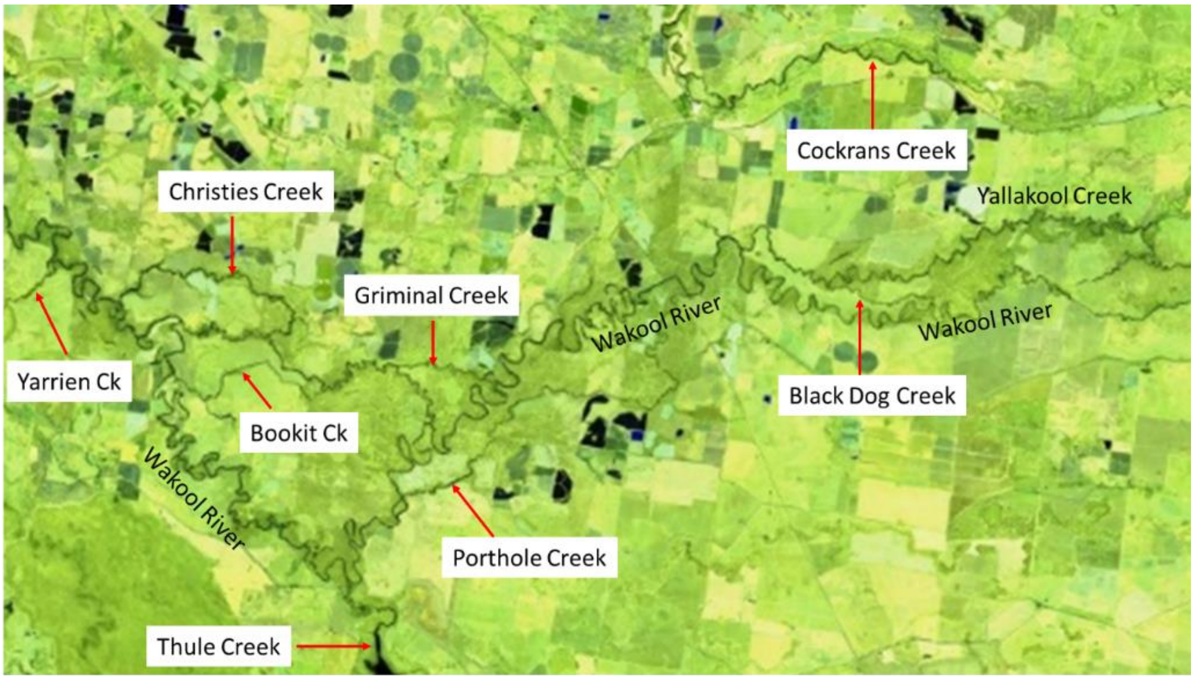

Figure 7. Colour enhanced Sentinel-2 satellite image showing extent of floodplain inundation (from Sentinel-hub 2021).

- **The flows in 2021-22 increased lateral connectivity throughout the EKW system**, particularly during spring and summer due to the increased flows in several intermittent and ephemeral creeks and due to flooding of Werai Forest and other low-lying areas (Figure 8, right).
- **Environmental water delivered in 2021-22 significantly increased the total annual carbon produced and total respiration** (Figure 8, left)**.**
- Carbon fluorescence scans (used to visualise type and amount of carbon) indicate **in 2021-22 there was more carbon and different mix of sources of carbon** (e.g., aged organic matter, fresh leachates and algal organic matter) (Figure 9). There was a gradual increase in sites downstream, suggesting that some of the carbon was from return flows from Millewa Forest, and some carbon was produced within the EKW system from newly wetted riverbanks, wetlands, and anabranches.

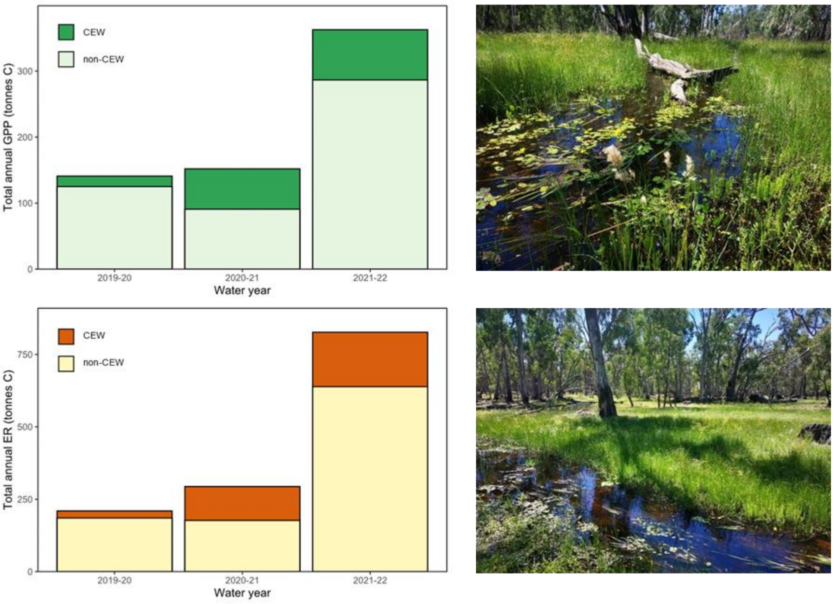

Figure 8. Left: The total primary production (GPP) and consumption (ER) of carbon (tonnes) in study zones attributable to environmental water delivery, relative to total annual production, during 2021-22 and two previous water years. **Right:** Plants responding following flooding of Werai Forest (Photos: J Trethewie).

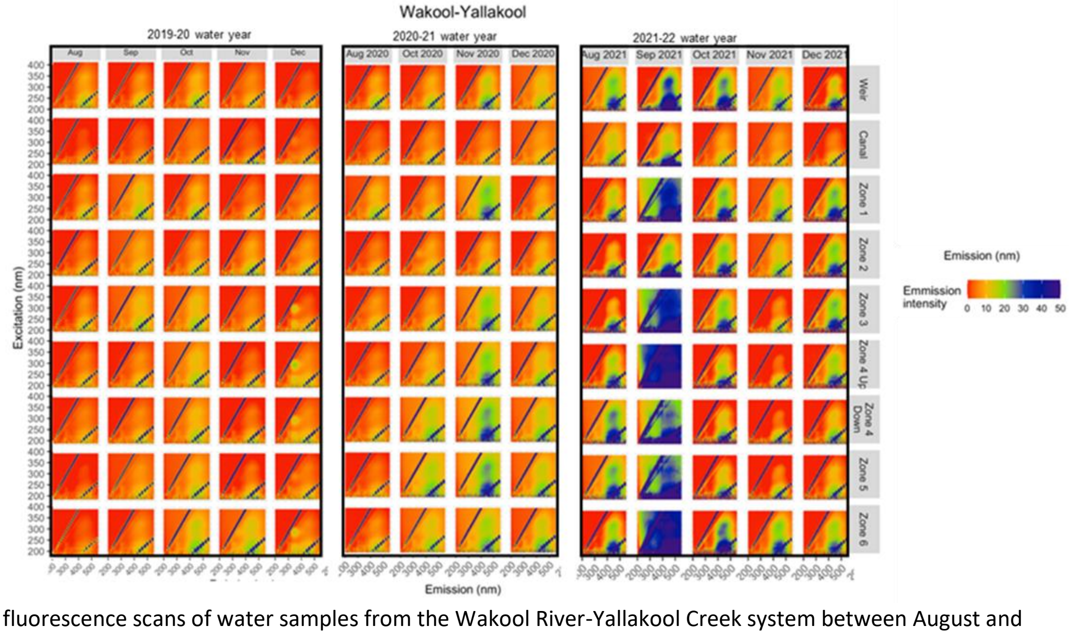

Figure 9. Carbon fluorescence scans of water samples from the Wakool River-Yallakool Creek system between August and December in 2019-20, 2020-21 and 2021-22. The blue and green colours indicate more carbon and different types of carbon. Sites are presented in order from upstream (top row) to downstream (bottom row).

- **In 2021-22 there was an increase in the total number of riverbank and aquatic plant taxa** in upper Wakool River, mid-Wakool River and Colligen Creek relative to previous years, but a reduction of two plant taxa in Yallakool Creek.
- The inundation of riverbanks from to the watering actions combined with unregulated flows and return flows from Millewa Forest **supported riverbank and aquatic plant germination.**
- **In 2021-22 there was increased percent cover of submerged plant taxa at all sites** (Figure 10).

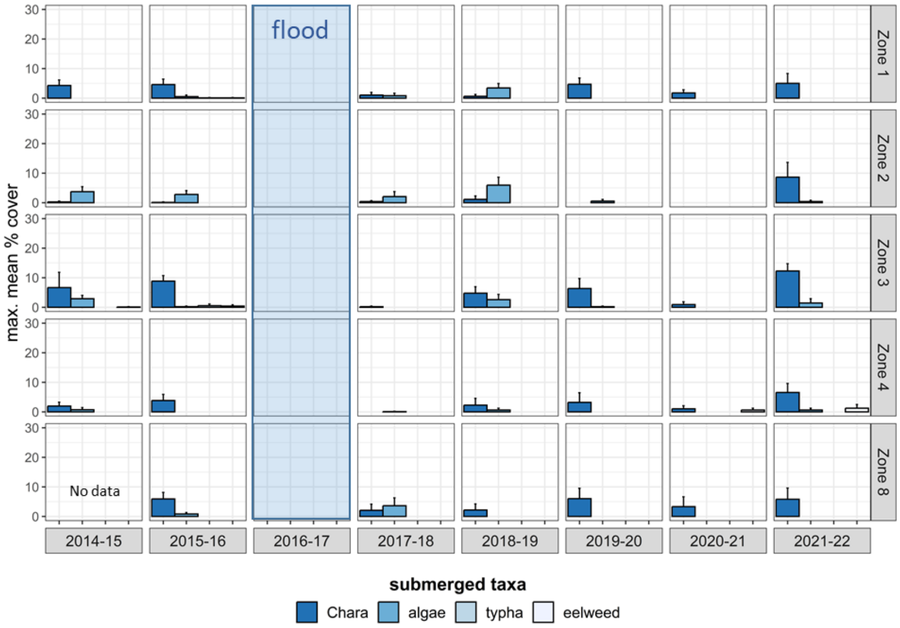

Figure 10. Mean percent cover of four submerged vegetation taxa monitored monthly across five hydrological zones in the Edward/Kolety-Wakool system between 2014 and 2022. Zone 1 Yallakool Creek, zone 2 upper Wakool River, zones 3 and 4 mid Wakool River, zone 8 Colligen Creek.

- **In 2021-22 the abundance and biomass of native bony herring in mid-Wakool River upstream of Thule Creek in 2022 was higher than all previous years**. As few of these fish were recruits, the increased abundance may have been due to immigration into the system in response to the higher flows and increased connectivity.
- **In 2021-22 there was a continued increase in the range of river blackfish.** In 2015-16 they were detected at only two sites in the upper Wakool, but over time their range has increased. In 2021-22 they were detected throughout the upper Wakool River, Yallakool Creek, as well as the mid-Wakool River downstream of Wakool Reserve. Larval river blackfish were caught at eight survey sites, the highest number since the beginning of the project (Figure 11).

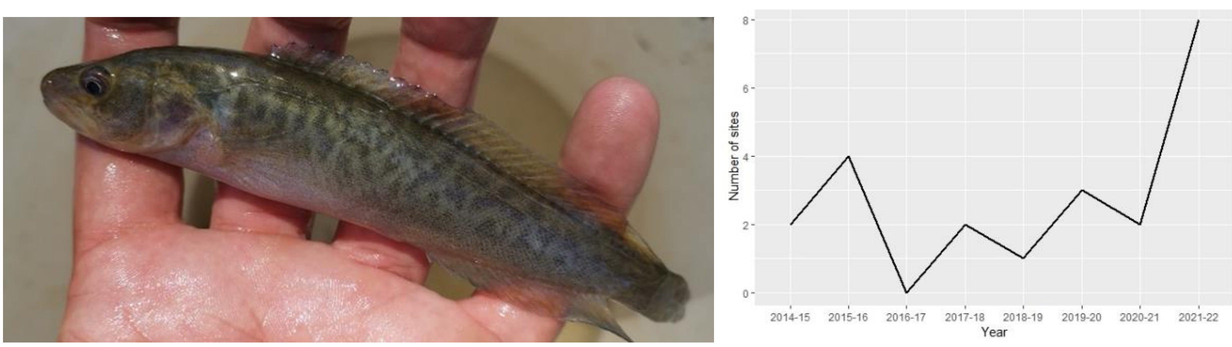

Figure 11. Left: Adult river blackfish from the Wakool River system. (Photo: John Trethewie). Right: Number of sites where river blackfish larvae have been detected in the Wakool River and Yallakool Creek from 2014 – 2022.

- **In 2021-22 the abundance of flathead gudgeon larvae was highest on record** since the beginning of the project. This species has been increasing in abundance every year since 2018-19.
- **Murray cod young-of-year abundance and growth rates were highest in 2021-22 than in the previous two years. Young-of-year Murray cod were generally bigger than those caught in the last 3 years.** The YOY Murray cod caught in 2021-22 had similar growth rates to those caught in 2014, 2015 before the flood and 2016 following the flood (Figure 12).

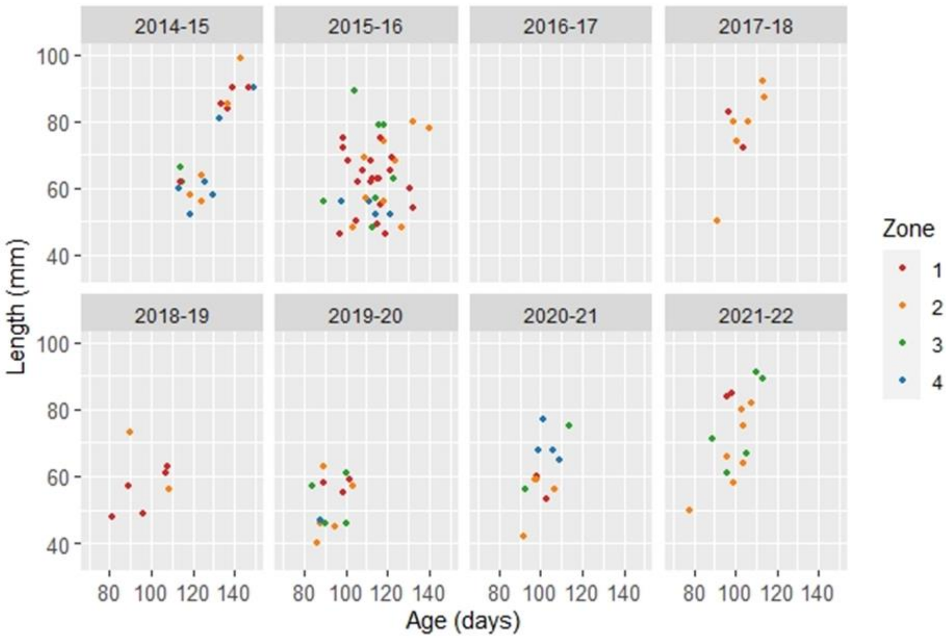

Figure 12. Length-at-age for each YOY Murray cod captured between 2014-15 and 2021-22. Different coloured dots relate to different river reaches. red = upper Wakool River (zone 1), orange = upper Wakool River (zone 2), green = mid Wakool River upstream junction with Thule Creek (zone 3), blue = mid Wakool River downstream junction with Thule Creek (zone 4).

- **The flows in 2021-22 did not trigger local golden or silver perch spawning in the Wakool River or Yallakool Creek.**
- **The highest catch rates of 1+ silver perch were recorded in 2021-22 since monitoring commenced in 2015** (Figure 13), with juveniles widespread throughout Yallakool Creek and Wakool River.

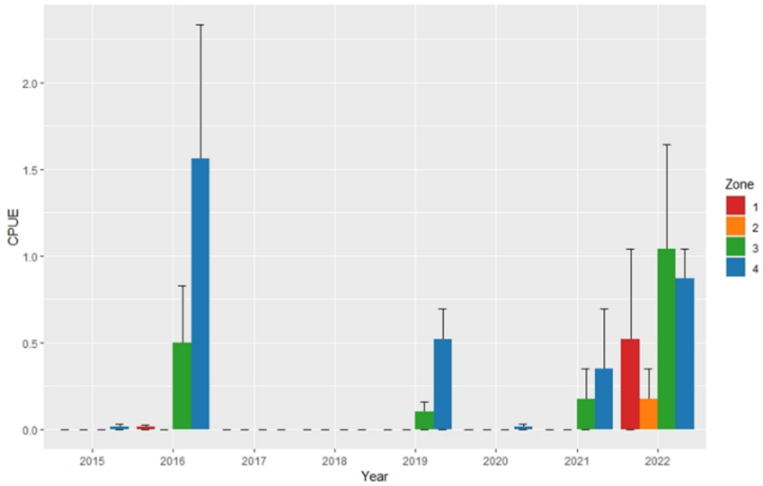

Figure 13. Mean (+SE) catch per unit effort (CPUE; number of fish caught per 10 000 seconds of sampling time) of 1+ age class silver perch in the Edward/Kolety-Wakool LTIM/Flow-MER zones using setlines and angling from 2014-15 to 2021-22. red = upper Wakool River (zone 1), orange = upper Wakool River (zone 2), green = mid Wakool River upstream junction with Thule Creek (zone 3), blue = mid Wakool River downstream junction with Thule Creek (zone 4).

- **Two juvenile (1+) golden perch (*Macquaria ambigua*) were detected in the mid-Wakool River (Figure 14), which is the first time juveniles have been found since monitoring began in 2014-15**. The increase in juvenile golden and silver perch (species not known to spawn regularly in the EKW system) may have been due to fish immigration into the system in response to the high unregulated flows and the Southern Connected Spring Flow.

Figure 14. 1+ Juvenile golden perch (*Macquaria ambigua*) from mid-Wakool River upstream of Thule Creek (Zone 3).

- **Catch rates of adult fish across the broader Edward/Kolety River system wide surveys were twice as high in 2022 than in previous surveys conducted in 2015 and 2019.**
- **In 2021-22 there were high recruitment responses for small-bodied fish species,** including Australian smelt, carp gudgeon, unspecked hardyhead and Murray Darling Rainbowfish as well as bony herring (Figure 15). Introduced species carp and goldfish also displayed strong recruitment in 2021-22 compared to 2015 and 2019.

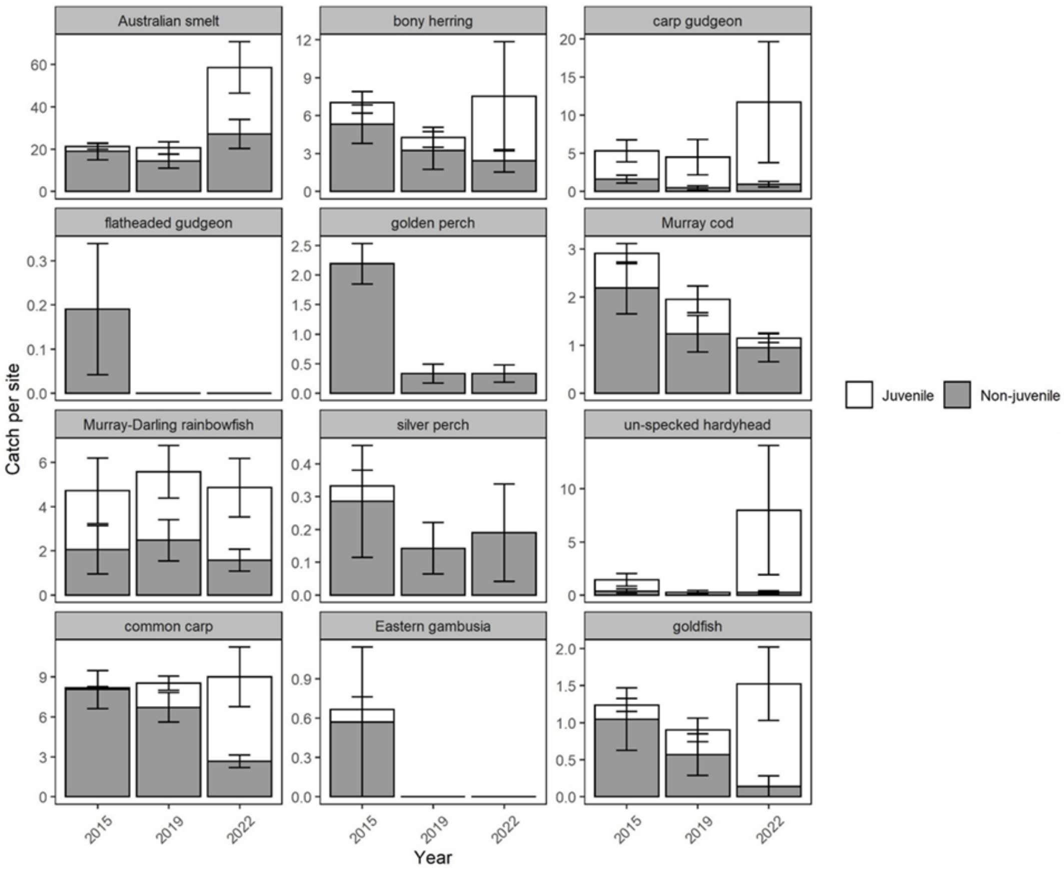

Figure 15. Catch per site (number of fish; mean ± SE) for fish species within the Edward/Kolety-Wakool river system, sampled in 2015, 2019 and 2022 at 20 sites in the Edward/Kolety-Wakool system. Cumulative stacked bars separate the catch of juveniles (white bars) and non-juveniles (grey bars) based on length ranges presented in Watts et al. (2022b).

Responses to watering action 1 (Wakool escape) to Wakool River

In 2021-22 environmental water was delivered to the upper Wakool River from Murray Irrigation Limited Wakool escape to mitigate the risks from hypoxic blackwater in spring and summer. At the same time as watering action 1 (WUM 10117-11) there were large unregulated flows in the system and also return flows of environmental water from Millewa Forest due to the southern spring flow delivered to the Murray River from Hume Dam (Figure 6).

The delivery of CEW from the Wakool escape during watering action 1 had the following outcomes:

- Extended the recession of the events from November through to January, thus **increasing the duration of the longitudinal connections in the Wakool River** (Figure 6).
- **Increased the lateral connectivity and hydraulic diversity in study reaches** compared to flows in previous study years. The additional environmental water from the Wakool escape increased the extent and duration of inundation of low lying in-channel features and the total wetted area of riverbank compared to operational flows. Increasing lateral connectivity can increase river productivity and trigger germination and growth of aquatic and riverbank plants that provide habitat for invertebrates, frogs and fish.
- Return flows from Millewa Forest during spring/early summer increased the concentration of dissolved organic carbon (DOC) in the river, whereas **watering action 1 from the Wakool escape mitigated the extent of increases in DOC and nutrients in the Wakool River**, thus helping to maintain water quality and prevent the development of hypoxic blackwater.
- **Significantly increased the total carbon produced and total respiration in all reaches of the Wakool River** compared to Yallakool Creek and Colligen Creek that did not receive the environmental water from the Wakool escape (Figure 16).

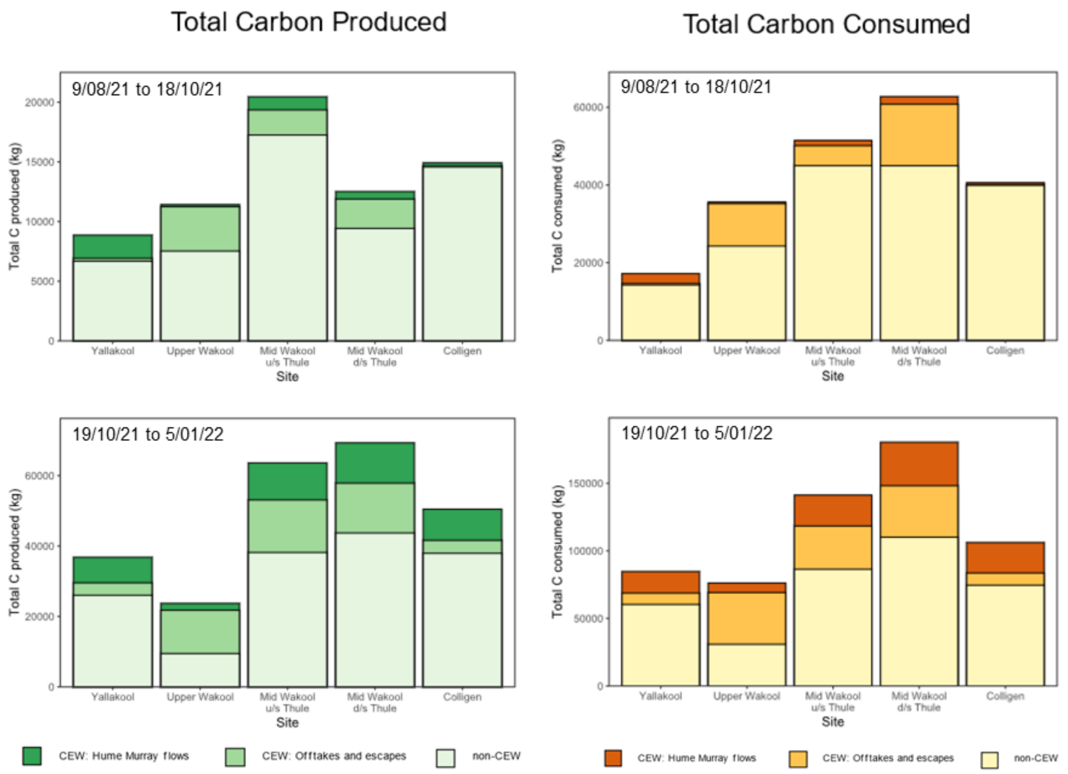

Figure 16. Left: The average daily additional production of carbon (kg C/day) during spring/summer 2021-22. Right: The total additional production of carbon (kg) during spring summer 2021-22. The contribution from the CEW Murray flows and the offtakes and escapes in the EKW system are shown in darker colours. The contribution from non-CEW is in lightest colour.

Responses to watering action 2 (Edward Escape) to Edward/Kolety River

The environmental watering actions from Edward Escape (Watering action 2, WUM 10117-12) delivered water to the Edward/Kolety River upstream of Deniliquin. This water was subsequently a component of the water that flowed into Yallakool Creek, the Wakool River, Colligen Creek and Edward/Kolety River downstream of Stevens Weir.

- Relative to other sources of environmental water in spring/early summer 2021 (e.g., return flows from Millewa Forest and watering action 1 from Wakool escape), **the environmental water from the Edward Escape had minimal impact on the hydrographs of Yallakool Creek, the Wakool River, Colligen Creek** (Figure 6).
- Watering action 2 would have had a small local effect in the Edward/Kolety River in the immediately downstream vicinity of the Edward Escape but those local effects were not monitored.

Responses to watering action 3 (Niemur escape) to Niemur River

The discharge from Niemur Escape during watering action 3 (WUM 10117-13) did not exceed 10 % of the overall flow in 2021-22 water year. Thus, while there was a local effect visible in the immediate vicinity of the escape (Figure 17, right) there was no detectable difference between upstream and downstream water quality (Figure 17, left) due to the limited capacity for the watering action to dilute river water downstream of the escape.

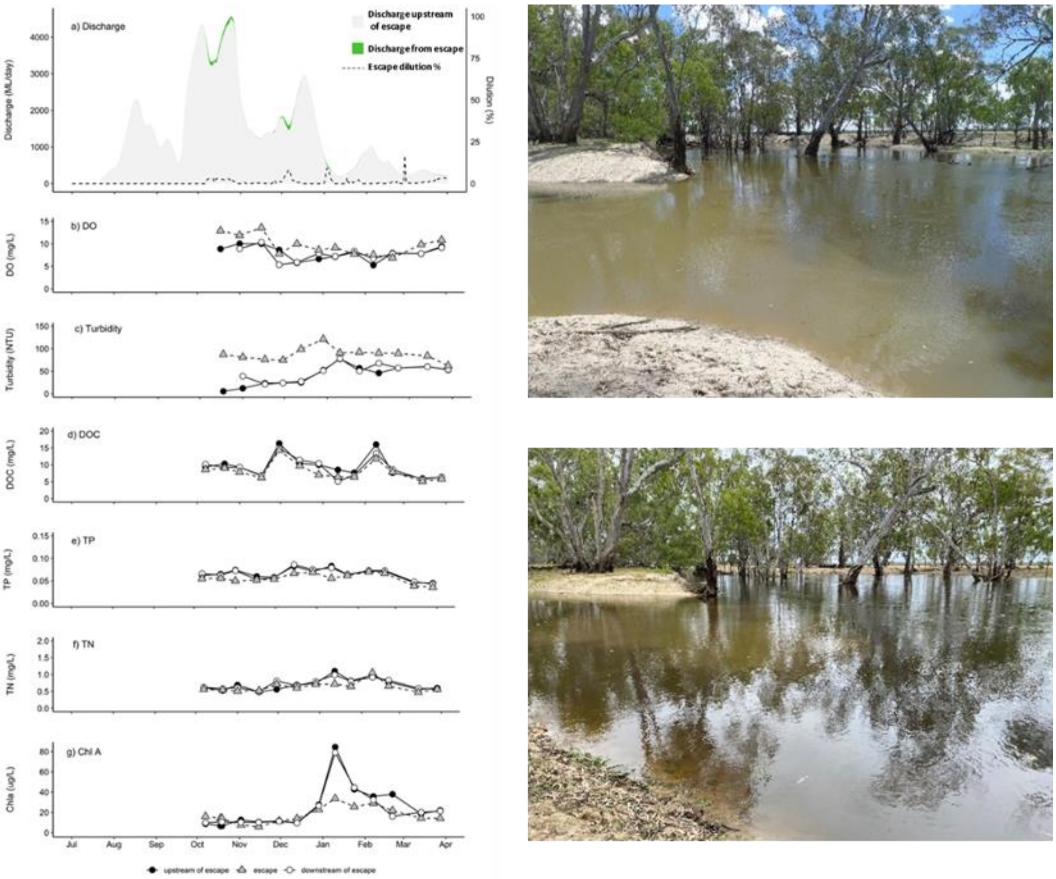

Figure 17. **Left:** Discharge (ML/d), Dissolved oxygen (DO), turbidity, dissolved organic carbon (DOC), total phosphorus (TP), total nitrogen (TN) and chlorophyll a (Chl *a*) at the Niemur Escape over the 2021-22 watering action. Dotted grey line on the hydrograph indicates the percent contribution of environmental water to total discharge downstream of the escape. Right: Junction of Northern Branch Canal and Niemur River on 30 November (top) and 15 December (bottom) 2021. (Photos: Xiaoying Liu). The turbid water being released from the Niemur Escape can be seen on the left of each photo and darker carbon rich river water on the right of each photo.

Responses to watering action 4 Autumn elevated variable autumn base flow (Wakool offtake)

- Watering action 4 (WUM 10117-1) **resulted in higher autumn base flow similar to that observed during autumn variable base flow watering action 8 in 2020-21.** The elevated variable autumn base flows maintained good dissolved oxygen concentrations in the upper Wakool River. It demonstrated that using environmental water in the upper Wakool River that has low flow in hot months is a proactive approach to improve water quality and prevent potential hypoxic water events.
- **The high base flows in the upper Wakool River in 2020-21 and 2021-22 contributed to supporting long-term recovery of aquatic and riverbank plants in this reach.** This zone showed the largest increase in mean total richness of riverbank and aquatic plants in 2021-22 (Figure 18). Submerged plant taxa were absent in the upper Wakool River in 2020-21 but the cover increased significantly in 2021-22 (Figure 10). Aquatic and riverbank plants play an important role in the functioning of aquatic ecosystems, supporting riverine food webs and providing habitat for waterbugs, frogs, birds and fish.
- The spring/summer flows stimulated germination and growth of riverbank and aquatic plants. The autumn flows **extended the survival and growth of seedlings, and potentially may have contributed to the flowering of plants and dispersal of seeds.**

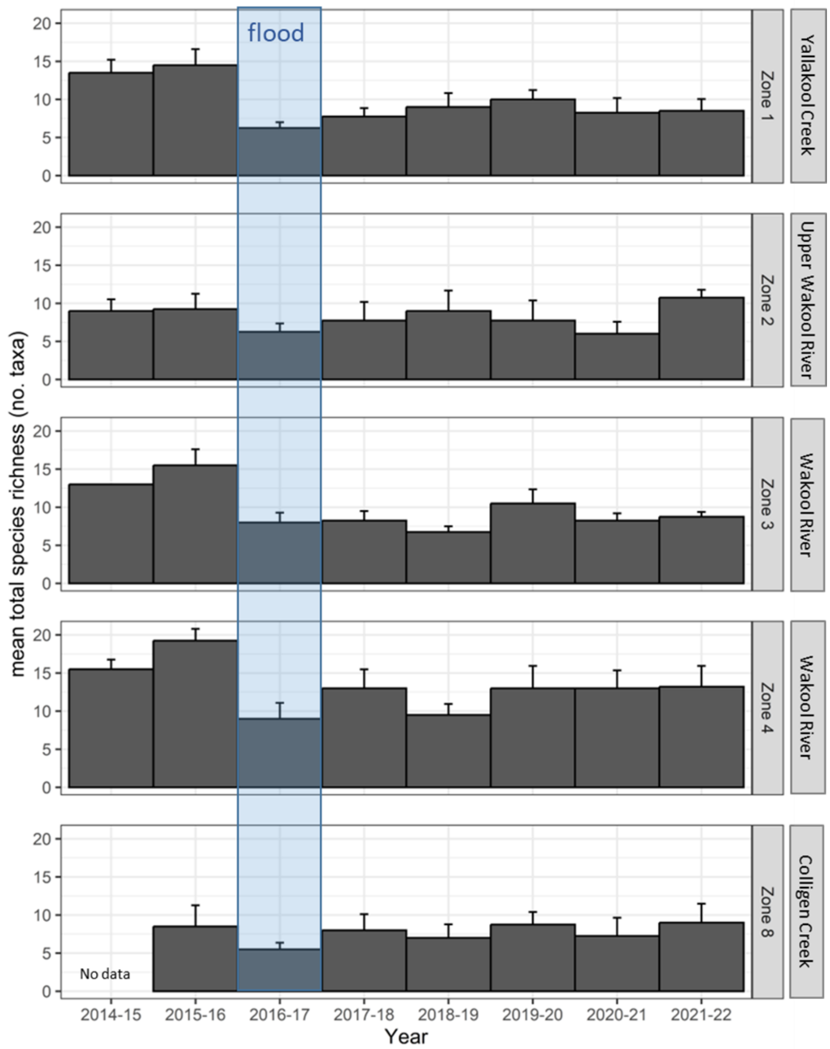

Figure 18. Mean total richness of vegetation taxa monitored monthly in five zones in the Edward/Kolety-Wakool system between 2014 and 2022. Blue shading indicates the unregulated flood in 2016-17 water year.

Responses to watering action 5 Autumn fresh (Yallakool offtake) and action 6 Autumn fresh (Colligen offtake)

Environmental watering actions 5 and 6 (WUM 10117-1) autumn freshes in Yallakool Creek and Colligen Creek had the following outcomes:

- **increased the maximum discharge during autumn** compared to operational flows.
- **increased the lateral connectivity** in study reaches during autumn.
- **maintained DO levels** in the Wakool-Yallakool system and Colligen-Niemur River.
- **maintained stable nutrients levels** in the Wakool-Yallakool system and Colligen-Niemur River system.
- **diluted dark coloured carbon rich water** in the Wakool-Yallakool system and the Colligen-Niemur system in autumn.

Responses to watering action 7 Elevated flows in Tuppal Creek

Watering action 7 (WUM 10117-4) in Tuppal Creek helped maintained dissolved oxygen levels in November 2021 and between mid-March and May 2022, but it did not prevent the further decline in dissolved oxygen levels (below 2 mg/L) during hot summer months. This suggests the magnitude of environmental water delivered to Tuppal Creek was not sufficient to improve dissolved oxygen condition and mitigate the occurrence of hypoxic blackwater events in hot weather.

Watering actions in intermittent and ephemeral creeks

During 2021-22 environmental water was delivered to several intermittent Creeks in the Edward/Kolety-Wakool system (see watering actions in Appendix 1 of Technical Report). This included watering actions in Jimaringle-Cockran-Gwynnes Creek System (WUM10117- 05), Murrain-Yarrien Creek (WUM10117- 06), Thule Creek (WUM10117- 07), Whymoul Creek (WUM10117- 08), Yarrein Creek (WUM10117- 09), and Buccaneit-Cunninyeuk Creek (WUM10117- 15).

The ephemeral and intermittent creeks are not currently part of the core monitoring in the Flow-MER monitoring program. However, here we offer a qualitative evaluation of the environmental watering actions to these ephemeral creeks in 2021-22, in the context of the benefits to the broader EKW system.

- The combination of unregulated spring/early summer flows in the Murray River, combined with environmental watering of ephemeral and intermittent creeks **increased longitudinal and lateral connectivity in the Edward/Kolety-Wakool system in 2021-22** more than has been seen in any other year, except during the 2016 flood year. Even though the unregulated flows in 2021-22 remained within channel, **many of the ephemeral and intermittent creeks in the system were connected and/or were able to receive environmental water, creating connectivity that is not usually seen under operational flows** (Figure 7).
- **The increased connectivity would have provided a wide range of ecosystem benefits throughout the Edward/Kolety-Wakool system**. Increased connectivity increases productivity, provides opportunities for fish to move, supports populations of birds, amphibians and invertebrates, and provides appropriate conditions to support the germination, growth and reproduction of plants and dispersal of seed. All of these un-monitored parameters would provide immediate and longer-term benefits to the broader EKW system.

Research Outcomes

Several research projects have been undertaken as part of the Edward/Kolety-Wakool Flow-MER Program (2019-2022) to address knowledge gaps and improve the delivery, monitoring and evaluation of environmental water in the Edward/Kolety-Wakool system.

In 2021-22 three research projects were undertaken in Werai Forest where there are considerable knowledge gaps that need to be addressed to inform the future delivery of environmental water to the Edward/Kolety River and the management of the Forest. Werai Forest, located on the Edward/Kolety River downstream of Deniliquin, is part of the NSW Central Murray Forests Ramsar site. The health of the forest has been negatively impacted by logging, cattle grazing, drought, past management practices, and altered water regimes that have resulted in a reduction in the frequency and duration of spring wetland inundation. The Werai Forests are currently managed by the National Parks and Wildlife Service and are in the process of being transferred to the Werai Land and Water Aboriginal Corporation through an Indigenous Land Use Agreement.

Three projects undertaken in Werai Forest in 2021-22 were:

- Hydrological modelling to examine the relationships between flows downstream of Stevens Weir and patterns of inundation in the forest. This research examined the timing and duration of different flood events in the forest and found that the duration of inundation in Werai forest after flooding was short-lived, relative to other redgum forests.
- A study evaluating the effectiveness of drones for assessing the response of groundcover plants to inundation was undertaken by Streamology scientists in collaboration with the Kolety Werkul Rangers employed through Yarkuwa Indigenous Knowledge Centre, and scientists from Charles Sturt University and the Murray-Darling Wetlands Working Group (Figure 19). This research developed a method that uses 3D elevation data from the drone surveys to 'see around' the canopy, to monitor the ground cover that would usually be obscured by the tree canopy.
- A field experiment undertaken by researchers from La Trobe University and Charles Sturt University to examine primary productivity in flooded areas of Werai Forest following an unregulated flow event in December 2021. They found there were very high rates of productivity in the flooded part of the forest.

The findings of this research have been shared through meetings, online stories, magazine articles, the Flow-MER website and the Werai Forest Research Report (Watts *et al.* 2022a)

Figure 19. Field team from Streamology, Yarkuwa Indigenous Knowledge Centre, Murray-Darling Wetlands Working Group, and Charles Sturt University in Werai Forest in January 2022 doing research on groundcover vegetation.

Communications and engagement

The EKW Environmental Flows Team is committed to undertaking collaborative projects and sharing the findings of monitoring and research with others. Information about the Edward/Kolety-Wakool Flow-MER program is shared through news articles, newsletters, the Flow-MER website, reports, and refereed scientific journal publications. We organise or participate in events to share project findings with managers and the local community. Presentations on the monitoring and research are given to the Edward/Kolety-Wakool Environmental Water Reference Group twice per year. Through collaboration with managers and other stakeholders the results from the Edward/Kolety-Wakool Flow-MER program are used to inform the adaptive management of environmental water. Findings from this project have contributed to annual and long-term watering plans for the system.

In May 2022 a community field day was held at Four Posts campsite near Deniliquin, where more than 75 people came together to share knowledge, learn about the river monitoring and research being undertaken by different organisations, and to take part in the 'hands on' activities (Figure 20). The activities began with a Welcome to Country by Jeanette Crew, OAM, a Wamba Wamba Pereppa Pereppa Nation woman, and a Smoking Ceremony.

> *"The message I want to get across is the importance of people working collaboratively or in partnership, not in isolation of each other" Jeanette Crew, chairperson from the Yarkuwa Indigenous Knowledge Centre*

The day was a great success in terms of collaboration, people sharing knowledge and learning, and everyone just having fun and enjoying the day.

Figure 20. Top left: Dr Nicole McCasker (CSU) shows Dakota Dunn (age 3), a fish larvae. Top right: Dr Shasha Liu and Judy and Frank Bond from Deniliquin. Bottom left: Attendee Trevor Clark (Chair of the Yanco Creek and Tributaries Advisory Council) with Dr Jason Thiem (NSW DPI Fisheries). Bottom right: Smoking Ceremony (Photos: Margrit Beemster)

The Edward/Kolety-Wakool Flow-MER Team have contributed to informal meetings focussed on Werai Forest. Through these meetings Wemba Wemba and Perrepa Perrepa Traditional Owners, other stakeholders and water managers have identified some key information that is needed to inform the future management of the forest and delivery of Commonwealth environmental water to the forest. Participants in the Werai Forest Group meetings usually meet online, but in May 2022 they had the opportunity for a face-to-face meeting at the Yarkuwa Indigenous Knowledge Centre, Deniliquin (Figures 21 and 22). Through these discussions the Traditional Owners have identified information, training, and other support that they need to be able to manage Werai Forest. The Kolety Werkul River Rangers Team have worked in collaboration with the Flow-MER on several research projects including turtle research (Watts *et al.* 2021) and project in Werai Forest (see page 19). Through these informal discussion Traditional Owners and other stakeholders will identify knowledge gaps, and the Flow-MER team may be able to contribute to addressing some of the questions that are related to flows and environmental water management.

Figure **21.** The Werai Forest Group came together for a meeting at Yarkuwa Indigenous Knowledge Centre in Deniliquin in May 2022 (Photo: Margrit Beemster)

Figure 22. The Werai Forest Group met at Yarkuwa Indigenous Knowledge Centre in Deniliquin in May. (Photo: Margrit Beemster)

4. Implications for management of environmental water

The Edward/Kolety-Wakool system plays an important role in the mid-Murray River system. The complex network of interconnected streams, ephemeral creeks, flood-runners, wetlands and floodplain forests in the EKW system provide a wide variety of habitats for aquatic life including aquatic plants, waterbugs, tadpoles and frogs, fish and waterbirds. Due to the geomorphological complexity of the system, even relatively small volumes of environmental water (compared to large Murray River flows) can create flow pulses that inundate low lying areas, providing food and creating newly inundated habitats.

The results from the LTIM and Flow-MER program have demonstrated that there have been many positive outcomes of environmental watering actions in the EKW system. The watering actions have increased longitudinal and lateral connectivity, increased variability of discharge, maintained water quality, and increased primary productivity, increased germination, flowering and dispersal of riverbank plants, and increased spawning in some fish species. In addition, the sequence of watering actions over several years have contributed to the ongoing fish recruitment outcomes, fish population outcomes, and aquatic plant recovery observed in 2021-22. These outcomes support the long-term recovery of the ecosystem and make the ecosystem resilient to endure future disturbances, such as drought or floods.

There have been some notable outcomes that have not yet been observed in the EKW system in response to environmental watering. Eggs or larvae of golden perch have not been detected over the 8 years of LTIM/Flow-MER, and there has been only a very small number of silver perch eggs and larvae found. The presence of juvenile silver perch in the EKW system does, however, indicate that successful spawning and recruitment of this species is occurring in the southern MDB, but most likely at a much broader geographic scale than the Edward/Kolety Selected Area (see Tonkin et al. 2019). The life cycle of golden and silver perch is considered to require unimpeded flowing water habitats encompassing at least hundreds of kilometres. Therefore, delivering environmental water to maintain connectivity within the EKW system and between the EKW system and the mid-Murray River will ensure that bi-directional movement of juveniles and adults of both species will continue to help support recovery of fish populations in the EKW system (Thiem et al. 2017). CEWO's overarching objective for environmental watering for fish populations in the EKW system was to provide flows to "support habitat (including longitudinal connectivity and bench inundation), food sources and promote increase movement/dispersal, recruitment and survival/condition of native fish" (CEWO 2020). The strategy of maintaining connectivity within the Edward/Kolety-Wakool system and with the Murray River is consistent with objectives.

Recommendations for management of environmental water

A summary of recommendations from previous Edward/Kolety-Wakool LTIM annual reports (Watts *et al.* 2015, 2016, 2017b, 2018, 2019) and Edward/Kolety-Wakool Flow-MER annual reports (Watts *et al.* 2020, 2021) is provided in Appendix 1 of the 2021-22 Technical Report. These recommendations relate to the contribution of Commonwealth environmental water to different types of watering actions including:

- Base flows
- Small freshes
- Medium and larger in- channel freshes
- Recession flows
- Winter flows
- Actions to mitigate issues arising during hypoxic blackwater events

- Actions to mitigate issues associated with managed flows operations, including constant regulated flows (low variability), rapid recession of flows, and winter cease to flow.

Some of the flow recommendations refer to specific targeted ecological objectives, such as fish movement, spawning of Murray cod, or river productivity. In previous LTIM/Flow-MER reports there are also recommendations that have addressed more general aspects of environmental water management, such as the need to implement flow trials, the setting of flow objectives, and the need to improve sources of hydrological data to facilitate the evaluation of environmental watering actions.

The following nine recommendations are based on findings from the 2021-22 Edward/Kolety-Wakool Flow-MER Technical Report, with reference made to recommendations and findings in previous reports.

Recommendation 1

The hydrographs in 2021-22 for the rivers and tributaries of the EKW system were more complex than in previous LTIM/Flow-MER years. The flows included unregulated freshes during spring and summer as well as delivery of Commonwealth environmental water from a wide range of sources; Edward escape, Wakool escape, Niemur escape, Yallakool offtake, Colligen Offtake, Wakool offtake, and return flows from Millewa Forest due to the delivery of environmental water from Hume Weir. At times there was more than one source of water contributing to the hydrograph.

The return flows from Hume Weir in combination with the unregulated freshes from mid-August to December 2021, provided benefits for the EKW system by contributing carbon rich water to boost productivity. Compared to years when flows were highly regulated, the magnitude of variation between low flows and peak flows was larger in 2021-22 than in previous years. However, the environmental water returning from Millewa Forest to the EKW system in 2021-22 reduced the magnitude of variation between low flows and peak flows in Yallakool Creek, and Colligen Creek compared to what would have occurred in 2021-22 in the absence of CEW returning from MIllewa Forest. Thus, there is a trade-off between the benefits of the EKW system receiving carbon rich water returning from Millewa Forest, versus possible detrimental effects of reduced variability of daily discharge.

Recommendation 1: Explore ways to gain benefits from Commonwealth environmental water returning from Millewa Forest, whilst at the same time maintaining variability of flows in the Edward/Kolety-Wakool tributaries.

Recommendation 2

Environmental water delivery to Wakool River and Yallakool Creek combined with unregulated flows in spring/early summer 2021-22 was the closest yet (since the LTIM/Flow-MER project commenced in 2014) to achieving environmental flows that included the timing, magnitude, duration of freshes that could potentially support spawning of golden perch and silver perch. The continued absence of any evidence of major spawning activity in these two species in Yallakool Creek and the Wakool River monitoring sites supports the hypothesis that these two river systems are not a key location for spawning of golden perch and silver perch.

Recommendation 2: Do not include spawning of golden perch as one of the key objectives for future environmental watering actions in Yallakool Creek and the Wakool River.

Recommendation 3

The outcomes of environmental watering actions in 2021-22, combined with outcomes from previous years, provide strong evidence that one of the key roles of the EKW system in the context of the broader Murray River system is to provide suitable spawning habitat for some fish species (e.g Murray cod, River blackfish, small bodied native fish), support recruitment and growth of juvenile fish, and provide habitat and refuge for adult fish. These benefits for fish and other components of the ecosystem can be supported by maintaining and enhancing connectivity within the system, and connectivity between the EKW system and Murray system throughout the year.

Recommendation 3: Undertake watering actions each watering year that promote connectivity within the EKW system, and connectivity between the EKW system and the Murray River. This includes; i) deliver in-channel freshes in late winter/spring that exceed the current normal operating rules to increase connectivity within tributaries and connectivity via runners between tributaries, ii) deliver continuous base environmental flows during autumn and winter to promote the temporal availability and continuity of instream habitat and prevent negative consequences of winter cease-to-flow; iii) Undertake watering actions to improve the connectivity and other outcomes in intermittent and ephemeral streams and flood runners in the EKW system.

Recommendation 4

The management of the offtake regulator for Colligen Creek is automated, and thus can be more easily operated than some of the other manually operated regulators in the EKW system. In addition, Colligen Creek is closer to the Stevens Weir structure and the offtake for Wakool Main Canal, so it is more convenient for water managers to use the Colligen Creek offtake to facilitate the balance of operational water in Stevens Weir when there is excess water in the system, such as water orders being withdrawn due to rain.

Consequently, Colligen Creek continues to experience short-lived flow peaks and rapid recession of flows that can be detrimental for maintaining a balance of erosion and sedimentation on riverbanks. Rapid recession of flows means that the sediment removed by natural processes during a rise is not the replaced by deposition of sediment on recession. In addition to this negative physical outcome, rapid recession of flows can also have negative ecological outcomes such as reducing the replenishment of seedbank.

Recommendation 4: Mitigate the negative consequences of rapid rises and falls in Colligen Creek hydrograph by working with water managers and river operators to achieve better outcomes through planning options such as i) increasing the rate of recession following rapid rises in flows due to river operations, ii) delivery of the excess water to other parts of the system instead of delivering a short flow peak to Colligen Creek.

Recommendation 5

The delivery of environmental water through irrigation escapes to improve water quality has proven to be an effective management tool that has provided benefits but has not resulted in recorded negative outcomes in the river system.

Recommendation 5: Continue to include a water use option in water planning that enables environmental water to be used to mitigate adverse water quality events and potential fish kills. Work with a range of organisations and the community to 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}.

Recommendation 6

In 2020-21 and 2021-22 environmental watering actions from the Wakool escape delivered variable base flows to the upper Wakool River to maintain water quality during warmer months. In addition to achieving this water quality outcome, these watering actions provided other significant outcomes, including increasing longitudinal connectivity, increasing flow variability, and helping to improve riverbank plant outcomes. These findings suggest that there are benefits to be gained from using the Wakool Escape to deliver environmental water to the Wakool River, even at times when there are no refuge flows required.

Recommendation 6: Undertake further watering actions from the Wakool escape to improve the connectivity and ecosystem outcomes in the Upper Wakool River and reaches further downstream in the mid- and lower Wakool River. Deliver larger freshes with increased variability to maintain water quality, enable riverbank vegetation to establish and be maintained, and support good fish outcomes.

Recommendation 7

There are many ecosystem and cultural benefits to be gained from watering Werai Forest. The multiple unregulated pulses in 2021-22 resulted in high flows downstream of Stevens Weir and several events inundated Werai Forest and returned flows from Werai Forest to Colligen Creek. This did not result in adverse outcomes for water quality or any recorded deaths of fish in the Colligen-Niemur system in 2021-22. Research undertaken in 2021-22 showed that response of aquatic plants and algae in Werai Forest can assist the productivity and help maintain good water quality of outflows from the forest. Research on patterns of inundation in Werai Forest (Watts *et al.* 2022a) showed that return flows from the forest into the Edward/Kolety River commenced when the discharge downstream of Stevens Weir was between 3,152 - 3,237 ML/d, and return flows from Tumudgery Creek into Colligen Creek commenced when the discharge DS Stevens Weir was between 5,471 ML/d and 9,340 ML/d.

Recommendation 7: Explore options to use environmental water to support high flow event downstream of Stevens Weir (>2700 ML/day) that inundates low lying parts of Werai forest. If possible, use environmental water to support higher flow events downstream of Stevens Weir (> 5471 ML/d) to inundate low lying part of Werai forest as well as support return flows to Colligen Creek and the Edward/Kolety River.

Recommendation 8

Evidence from the fish recruitment monitoring and adult fish strongly suggests that there was immigration of silvers and golden juveniles/sub adults into the EKW system during the high unregulated flows in 2021-22 which may have been enhanced by environmental water delivered from irrigation escapes. We continue to support recommendation 4 from 2019-20 report that encourages the use of environmental water to support movement of native fish.

Recommendation 8: Consider adaptive use of water to coincide with high Murray River flows to maximise attraction/immigration of upstream migrating juvenile golden perch and silver perch in late summer.

Recommendation 9

The combination of unregulated spring/early summer flows in the Murray, environmental watering of ephemeral and intermittent creeks, and environmental watering from MIL escapes, created increased connectivity in the EKW system in 2021-22 more than has been seen in any other year, except during large flood years. The river ecosystem greatly benefits from connectivity, that includes the maintenance of flow during winter that promotes temporal availability and continuity of instream habitat, fish movement, and survival of aquatic plants.

Winter shutdown of regulators is an operational norm to facilitate maintenance of infrastructure. Unfortunately, this means that some of the benefits from the increased connectivity created by environmental watering in spring, summer and autumn will be diminished due to winter operational shutdown periods that occur in tributaries in the EKW system. It would maximise the benefit to the river ecosystem if an operational solution was implemented to enable the delivery of winter flows to the tributaries every year.

Recommendation 9: Facilitate the benefits of connectivity flows by working with river managers and river operators to maximise the opportunities to deliver environmental water to tributaries during winter and eliminate the impact of operational shutdowns in winter.

5. Acknowledgements

The authors of this report as well as the Commonwealth Environmental Water Office respectfully acknowledge the Traditional Owners of the Murray-Darling Basin, their Elders past and present, their Nations, and their cultural, social, environmental, spiritual and economic connection to their lands and waters. We are honoured to work on the ancestral lands of the Wamba Wamba or Wemba Wemba, Perrepa Perrepa or Barapa Barapa, Yorta Yorta and Wadi Wadi People. We recognise their unique ability to care for Country and their deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices. We are committed to genuinely partner and meaningfully engage with Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

We extend our thanks to the Edward/Kolety-Wakool Environmental Water Reference Group, Wakool River Association, Edward/Kolety-Wakool Angling Association, Yarkuwa Indigenous Knowledge Centre Aboriginal Corporation, the Colligen and Niemur Group, Western Murray Land Improvement Group, and landholders in the Edward/Kolety-Wakool River system for their keen interest in this project and for providing access to monitoring sites on their properties.

Thanks to staff from Commonwealth Environmental Water Office, NSW Department of Planning and Environment, Murray Local Land Services, WaterNSW, Murray-Darling Basin Authority, Murray Irrigation Limited for providing water planning information and access to hydrological and water use data.

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Maps were prepared by Simon McDonald and Deanna Duffy (Charles Sturt University Spatial Analysis Unit). John Pengelly (CSIRO) processed carbon and nutrient samples. Larval and juvenile fish sampling was carried out under NSW Fisheries license (larval fish P19/0006-1.0, juvenile fish P19/0051). Projects were approved by the CSU Animal Care and Ethics Committee (larval fish surveys: A19260, recruitment surveys: A19384). Sampling in the Murray Valley National Park was permitted under the National Parks and Wildlife Act 1974 (Scientific License: SL101403). Adult fish surveys were conducted by DPI Fisheries under Fisheries NSW Animal Care and Ethics permit 14/10.

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Colligen Creek near confluence with Tumudgery Creek on 21 October 2021 (Photo: Robyn Watts)