



Commonwealth Environmental Water Office Monitoring, Evaluation and Research Program

Goulburn River Selected Area Summary Report 2020-21

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1. Monitoring and evaluation of environmental water in the lower Goulburn River

1.1. Description

The Goulburn River extends from the northern slopes of the Great Dividing Range north to the Murray River near Echuca (Figure 1). The upper catchment lies within the lands of the Taungurung Nation and the lower reaches, across the northern plains, lie within the lands of the Yorta Yorta and Bangerang Nations. The lower Goulburn River is known as the Kaiela to the Yorta Yorta Nation. Mean annual flow for the catchment is approximately 3,200 GL (CSIRO, 2008), and approximately half of that is on average diverted to meet agricultural, stock and domestic demand.

Two major flow regulating structures are located on the Goulburn River; Lake Eildon and Goulburn Weir. The reach from Lake Eildon to Goulburn Weir is referred to as the mid-Goulburn and the reach from Goulburn Weir to the Murray River is the lower Goulburn. Flows in the mid-Goulburn River are now lower than natural in winter and spring (flow is stored in Lake Eildon) and higher than natural in summer and early autumn (flow is released from Lake Eildon and then mostly diverted from the river at Goulburn Weir to supply irrigation and consumptive needs).

Downstream of Goulburn Weir the overall flow volume is decreased compared to natural levels, but inflows from tributaries such as the Broken River and Seven Creeks have helped to retain the natural seasonal flow patterns (i.e. higher winter flows and low summer flows). However, more recently, there has been an increase in summer and autumn flows through the lower Goulburn River as a result of Inter-Valley Transfer (IVT) flows from Lake Eildon to supply users further downstream in the Murray River. Historical river regulation and more recent IVT flows have significantly impacted the ecological condition of the river. Managing these impacts through environmental flows is a critical outcome for the environmental water management program.

The lower Goulburn River Selected Area includes the main river channel and associated habitats connected to the river by in-channel flows up to bankfull between Goulburn Weir and the Murray River. Environmental flows in the lower Goulburn River are not currently used to deliver overbank flows or to water the floodplain because of operational constraints. However, this does not preclude the possibility of delivering environmental water to the lower Goulburn River floodplain in future.

1.2. Monitoring sites

The Goulburn Monitoring, Evaluation and Research (MER) Program builds on findings of its predecessor the Long-Term Intervention Monitoring (LTIM) Project. Like the LTIM Project, the MER Program divides its monitoring locations into two zones: 1) Goulburn Weir to the Broken River, 2) Broken River to the Murray River. Zone 1 and Zone 2 are physically similar, have similar hydrology and are not separated by significant barriers. Moreover, they are equally affected by the delivery of Commonwealth Environmental Water (CEW), which is controlled by the regulator at Goulburn Weir. Monitoring efforts are focused on Zone 2 to provide deeper understanding across a range of monitoring matters that would not be possible if the program were spread evenly over the two zones (Webb *et al.*, 2019b).

Ecological Matters being investigated at each site are: physical habitat - hydraulic (river flow and depth characteristics) and bank condition (erosion and sediment deposition); stream metabolism (photosynthesis and respiration as a potential source of food for macroinvertebrates and fish); macroinvertebrates (large water bugs with a focus on the biomass of crustaceans such as shrimps and prawns); bank vegetation (abundance and diversity of plant cover); and native fish spawning and populations (composition and abundance).

1.3. This report

This report is a summary of the environmental watering outcomes in the Goulburn River Selected Area in 2020-21 and:

- Introduces the lower Goulburn River area and describes how it is treated for monitoring purposes (Section 1)
- Describes the Commonwealth environmental watering actions that occurred in the lower Goulburn River during 2020–21 (Section 2)
- Summarises the key outcomes from monitoring across the five Ecological Matters and compares and contrasts findings between years. An overview of the research being undertaken, and communications and engagement activities is also provided (Section 3)
- Considers the implications of the monitoring results for future management of CEW (Section 4).

More specific detail on the monitoring, including detailed descriptions of methods, results and outcomes are provided in the Goulburn River MER 2020–21 Scientific report (Webb *et al.*, 2021), which can be considered a technical appendix to this summary report.



Figure 1. Map of the lower Goulburn River, with all monitoring sites marked, along with flow gauges used to generate flow data used in the MER Program. Some sites extend into the Broken River. Colours denote different monitoring activities, with some sites being used for multiple activities. Sites are indicated with site numbers, with the key providing the site name. Monitoring Zone 1 runs from Goulburn Weir to the confluence of the Broken River near Shepparton, with Zone 2 downstream from this point to the confluence with the Murray River.

2. Environmental water in the lower Goulburn in 2020-21

As of 30 September 2020, the Commonwealth held 360 GL of environmental water entitlements in the Goulburn River. The Goulburn River receives other environmental flows including from the Victorian Environmental Water Holder (VEWH) and The Living Murray (TLM) program, but the Commonwealth environmental water entitlement provides most of the environmental water used to meet specific environmental flow objectives in the lower Goulburn River channel. IVT flows have also previously been used to meet environmental flow targets when possible. CEW for the lower Goulburn is stored in Lake Eildon and delivered via Goulburn Weir. Throughout the year, river flows are assessed to see how well they are meeting identified flow targets in the lower Goulburn River. If required, environmental water can be used to increase flow rate and duration to meet these targets.

High priority watering actions planned for 2020–21 in the lower Goulburn included: continuous baseflows throughout the year to support habitat; variable winter baseflows, continuing an approach first trialled in 2018–19; and freshes in winter, spring and autumn primarily to support bank vegetation, with fish spawning also targeted by a second spring fresh (GBCMA, 2020).

During 2020–21, around 239 GL of environmental water was delivered in the lower Goulburn River; CEW contributed 151 GL to this total (CEWO, 2021) (Figure 2). High unregulated flows from tributaries downstream of Lake Eildon provided several winter freshes with a peak flow of 12,618 ML/day in late August 2020. Environmental water was used to slow the recession of the August event to meet the recommendations of bank inundation duration for the winter fresh. A spring fresh was delivered in September/October. Due to wet conditions a natural flow event occurred during delivery of this fresh with an unregulated spill at Goulburn Weir, which, combined with tributary flow in the lower Goulburn led to a higher natural peak of 10,695 ML/day at Shepparton, which attenuated to 9,768 ML/day at McCoy's Bridge. At both locations (McCoy's and Murchison) there were 7 days over the target of 6,600 ML/day. CEW was then used to extend the recession of the October fresh and maintain elevated base flow (>1000 ML/day) in the lead up to delivery of a fish spawning fresh in November (peak 6,784 ML/day at Murchison). The extended recession/elevated baseflow was designed to intentionally maintain inundation of the lower bank and delay vegetation until after the fish spawning fresh.

IVT flows commenced in November 2021, helping to contribute to the fish spawning fresh, and continued through to end-May 2021. Interim operating arrangements introduced by the Victorian Water Minister in 2019 limited IVT delivery volumes to a maximum of 40 GL/month over the 2020–21 summer. The GBCMA advised that to reduce damage to the riverbanks, IVT flows should not exceed 1,000 ML/day for more than 20 consecutive days, with a minimum of 7 days between pulses of up to 2000 ML/day. This target was met, and the delivery pattern also allowed monitoring to occur.

An autumn fresh was delivered during April 2021 and was designed to achieve flows >5,600 ML/day for 2 days at Murchison. The event was delivered using primarily IVT with environmental water added to achieve the autumn fresh target outcomes. Due to MDBA demand for water in the Murray River to meet Lake Victoria filling targets, the peak flows were extended by one day and the recession steepened to provide an extra 9 GL of water without extending the fresh duration. CEW was then used to maintain low flows during June 2021.

3. Key outcomes from environmental water use

3.1. Monitoring

Over the five years of the Goulburn Selected Area LTIM Project (2014–19), and now the first two years of the MER Program, environmental water has been delivered with the objective of enhancing native fish spawning, notably golden perch, reducing the extent of bank erosion and enhancing opportunities for the establishment and maintenance of water dependant vegetation on the riverbanks, contributing to overall ecosystem carbon production, and optimising conditions for macroinvertebrate abundance.

Previously, environmental water has predominantly been delivered as spring freshes to stimulate native fish spawning, vegetation germination/recruitment and growth, enhance macroinvertebrate production (as food for native fish), and to augment regulated baseflows throughout the year to maintain access to habitat for biota. In more recent years, including 2020–21, adaptive management of the flows program has also seen environmental water delivered:

- As winter freshes to promote sediment and seed deposition on bars and banks to prime them for vegetation recruitment in the subsequent spring (2018, 2019, 2020);
- In autumn to promote fish migration back into the Goulburn River from the Murray River (2018), encourage seed germination, improve water quality, flush fine sediment to encourage biofilm growth, and improve food and habitat for waterbugs (2021);
- To control the rates of fall during the drawdown of IVT flows and following natural freshes in an attempt to minimise bank surcharge and mass-failure that can happen as a result of rapid flow drawdown (2019, 2020, 2021), and;

• To extend the recession of the spring fresh to delay vegetation germination until after the November fish spawning fresh (2020).

At the start of the LTIM Project we developed a conceptual model describing the linkages between flow and various ecosystem responses. Over the years we have refined the conceptual model and confirmed a number of the linkages (Figure 3).

Based on monitoring outcomes over the course of LTIM and now MER, the strongest and most consistent relationships have been demonstrated between flow, bank condition, hydraulic habitat and vegetation dynamics. The response of native fish to flows has also been strongly demonstrated, notably increased flows in spring that also coincide with increasing water temperature have been shown to consistently stimulate spawning of golden perch and silver perch (Treadwell *et al.*, 2020; Webb *et al.*, 2021). No linkages between system components/matters/variables have been disproven throughout the LTIM Project and MER Program.

As with previous years, the largest knowledge gap within the conceptual model remains the linkages between other monitoring matters and adult fish populations in the Goulburn River. Issues with determining relationships include:

- Although eggs and larvae of species like golden perch and silver perch are often recorded, the juvenile 'young of year' fish that should appear are rarely caught during the electrofishing surveys approximately six months later. Golden perch were recorded spawning in spring 2020 and a single juvenile golden perch was collected in community fish surveys in 2021.
- Moreover, although there are strong links between flows, metabolism and carbon production and increased biomass of large-bodied macroinvertebrates in summer (i.e. fish food), the current category-1 fish sampling methods are not suited to being able to detect any direct link between increased macroinvertebrates and changes in the numbers and species of fish being caught. The integrated research project currently underway may be able to shed some light on this linkage.
- Similarly, a link between improved near-bank habitat condition that results from improved bankside vegetation and improved fish populations (composition and abundance) has not yet been demonstrated because the adult fish sampling does not target these habitats specifically.

Watering actions for 2020–21 targeted a winter and early spring fresh for bank condition, vegetation and macroinvertebrate outcomes, a late spring fresh to encourage native fish spawning, an autumn fresh to stimulate germination and improve water quality, and autumn base flows and recession flows to slow draw down to minimise riverbank erosion following IVT flows and natural freshes. Table 1 summarises the main outcomes associated with each watering action over 2020–21. More details are provided in Section 3.1, including how results from 2020–21 have built on our previous knowledge and strengthened the conceptual model. We also explore interactions between monitoring matters that have become apparent through the course of LTIM and MER to date. All results, figures and tables are reproduced from Webb *et al.* (2021) unless otherwise referenced.



Figure 2. Relative sources of water contributing to total Goulburn River flows in 2020–21 (https://fchmccoys.hydronet.com/) at McCoy's Bridge and specific flow magnitudes targeted by particular CEW deliveries. Inset shows the general flow components targeted with CEW in the lower Goulburn River. Note, bankfull flow is ~28,000 ML/d.



Figure 3. Conceptual model of the linkages among the different monitoring matters/components in the lower Goulburn River Monitoring, Evaluation and Research Program (Webb *et al.*, 2019a). Dark blue – ultimate drivers of the system dynamics. Orange – physical matters/components/variables. Green – intermediate environmental matters/components/variables. Aqua – ultimate environmental matters/components/variables. Arrows indicate hypothesised causal linkages. Ticks indicate linkages that have been demonstrated, or at least strongly suggested, by monitoring data. Question marks indicate linkages that are yet to be demonstrated. Table 1. Summary of objectives and observed outcomes in response to CEW delivered over 2020–21. Shaded cells indicate the Ecological Matter was not monitored for that flow event (specific details for each monitoring matter can be found in the 2019–20 Annual Scientific Report (Webb *et al.*, 2021))

Monitoring Matter	Winter fresh and variable base flows (July - August 2020)	Spring Fresh (Sept-Oct 2020)	Late Spring Fresh (Nov 2020)	Inter-Valley Transfer flows (summer 2020–21)	Autumn Fresh (Mar to April) of 6,000 ML/day at Murchison / McCoy's for 2 days
Watering objectives	Remove terrestrial vegetation from banks & re-establish flood tolerant native vegetation by inundating benches & banks to promote sediment & seed deposition & encourage plant germination.	Inundate vegetation on benches and the lower banks to facilitate recruitment, sustain growth, and encourage flowering, seed development and distribution.	Stimulate golden perch and Silver perch spawning flush fine sediment to encourage biofilm growth and improve food and habitat for waterbugs.	Current operating arrangements limited IVT to 40 GL/month over the 2020-21 summer and autumn period.	Encourage seed germination, reduce turbidity and mix water to improve water quality, flush fine sediment to encourage biofilm growth, and improve food and habitat for waterbugs.
CEW delivered (see Figure 2 for pattern of deliveries over 2020-21)	High unregulated flows from tributaries downstream of lake Eildon provided several winter freshes with a peak flow of 12,618 ML/day at Murchison in late August. CEW was used to slow the recession in early Sept	CEW was used to deliver a spring fresh during Oct. Unregulated flow added to this event leading to a peak of ~10,700 ML/day at Shepparton and 9,768 ML/day at McCoy's Bridge. The event lasted for 1 month with 7 days >6,000 ML/day. CEW accounted for 47% of the total volume of this event at McCoy's Bridge. Following the fresh, CEW was used to maintain an elevated base flow (>1,000 ML/day) prior to the Nov fresh. This aimed to maintain lower bank inundation and prevent vegetation germination that would be subsequently drowned by the planned Nov fresh.	CEW was used to deliver a fresh in mid Nov that peaked at ~6,784 ML/day and lasted for one month with 1 day >6,600 ML/day as planned. IVT contributed to part of this fresh.	To minimise the risk of ecological damage from prolonged high summer/autumn flows, the GBCMA advised the IVT delivery pattern to vary between 1,000-1,500 ML/day to avoid notching and provide an average flow of approximately 1,300 ML/day. This pattern of IVT delivery was met between December and April and only varied to provide a couple of short pulses up to 2,000 ML/day to reduce the risk of blackwater during summer rainfall events.	CEW and IVT was used to deliver an autumn fresh in late April and designed to achieve flows over 5,600 ML/day for 2 days at Murchison. Peak flow for the event was 6,295 ML/day at Murchison and 5,739 ML/day at McCoy's bridge. CEW was also used after the autumn fresh to maintain baseflow.

Monitoring Matter	Winter fresh and variable base flows (July - August 2020)	Spring Fresh (Sept-Oct 2020)	Late Spring Fresh (Nov 2020)	Inter-Valley Transfer flows (summer 2020–21)	Autumn Fresh (Mar to April) of 6,000 ML/day at Murchison / McCoy's for 2 days
Physical habitat – bank condition	No monitoring was undertaken of the winter fresh due to COVID restriction on field work	No monitoring was undertaken of the spring fresh due to COVID restriction on field work	Minor to medium (<30mm) erosion across the upper bank zones with high deposition on the lower bank. Deposition was higher for the spring fresh than other events, probably a result of a greater sediment load from tributary inflows. Tributary derived sediment and high deposition on lower banks is helping to repair prior erosion and reducing the bank gradient	Minor to severe (>30mm) erosion (more than all other flow events) across lower and mid bank zones corresponding to IVT flows. Minor notching on some inside banks. As with 2019-20, there was no evidence of wide-spread mass-failure (in contrast to 2018–19 IVT delivery), so current limits on IVT appear to be having a positive impact by minimising excessive erosion and mass-failure.	Minor erosion (less than the spring fresh) occurred across the mid and upper bank zones with deposition occurring on the lower bank. Some erosion did occur to areas of the lower bank that also experienced erosion during IVT flows. The height of autumn freshes needs to consider the height and duration of IVT flows to ensure the same sections of bank are not being inundated for prolonged periods.
Turf mats – sediment & seed	COVID restrictions prevented turf mat deployment and retrieval for the winter and early spring freshes. However, deployment and retrieval were completed pre and post the late spring fresh. Outcomes below are based on an analysis of several freshes over the past 2 years (winter and spring freshes in 2019 and the 2020 late spring fresh). Across most sites seed abundance, diversity and sediment mass increased with inundation height and inundation duration. Fifty-one different plant taxa germinated from sediment samples - 80% from 5 species. Higher sediment deposition also resulted in higher seed abundance and diversity. The greater the contribution of tributary flows to freshes the higher the sediment load and the higher the seed abundance and diversity.				
Macroinvertebrate composition and abundance		No monitoring was undertaken pre the early spring fresh due to COVID restriction on field work	The total number of macroinverteb caddisflies) were similar pre and im However, numbers increased in Jar declining in April 2021. It is unknow attributed to CEW versus seasonal daylight. Overall macroinvertebrate through the 2020-21 summer comp	prates (e.g. water bugs, mayflies and mediately post the late spring fresh. mary and February 2021 before yn what portion of the increase can be increases in temperature and hours of e numbers were also higher following pared to the 2019-20 summer.	

Monitoring Matter	Winter fresh and variable base flows (July - August 2020)	Spring Fresh (Sept-Oct 2020)	Late Spring Fresh (Nov 2020)	Inter-Valley Transfer flows (summer 2020–21)	Autumn Fresh (Mar to April) of 6,000 ML/day at Murchison / McCoy's for 2 days
Crustacean biomass and abundance		No monitoring was undertaken pre the early spring fresh due to COVID restriction on field work	The total number and biomass of co yabbies) were similar pre and imme increased slightly in January and Fe There were also high numbers of in December and January compared t in the 2020-21 summer following th in 2019-20. As with the general ma- unknown what portion of the incre seasonal increases in temperature a unregulated flows in the 2020 wint winter/spring.	rustaceans (e.g. shrimps, prawns and ediately post the late spring fresh but bruary 2021 before declining in April. nmature crustaceans observed in o pre the fresh and also higher numbers ne high unregulated winter flows than croinvertebrate community, it is ase can be attributed to CEW versus and hours of daylight, or higher er/spring compared to the 2019	
Bank vegetation abundance and diversity		COVID restrictions prevented surveys prior to the spring fresh, however, after the spring fresh, water dependant plants were observed across the bank elevation influenced by the fresh.	Surveys in November 2020 (after spring fresh) and again in December 2020 (after the fish spawning fresh) found that the cover of water dependant plants along the lower banks was low, suggesting that recruitment was suppressed by the elevated baseflows delivered between the early and late spring freshes. Following the recession of the fish spawning fresh, fringing vegetation recruited but it was unclear to what extent the strategy of suppressing germination along the fringing zone between the spring fresh and the fish fresh contributed to this positive outcome.	As in previous years, IVT contributed to the absence/loss of vegetation on the banks and a narrowing of the band of water dependant plants. Modelling indicates that vegetation on the banks steadily declines if the total duration of inundation >25 cm deep exceeds 40 days. This continues to support the current recommendation that the duration of individual inundation events should be less than 2 weeks.	

Monitoring Matter	Winter fresh and variable base flows (July - August 2020)	Spring Fresh (Sept-Oct 2020)	Late Spring Fresh (Nov 2020)	Inter-Valley Transfer flows (summer 2020–21)	Autumn Fresh (Mar to April) of 6,000 ML/day at Murchison / McCoy's for 2 days
Stream metabolism: carbon production and respiration	Over 36 tonnes of organic carbon were produced during winter. CEW contributed only 4% to this load because winter flow requirements were met by unregulated flows.	Over 113 tonnes of organic carbon were produced in spring, 38% (43 tonnes) was contributed by CEW.		Over 70 tonnes of organic carbon were produced in summer, with all of this attributable to the IVT flows and passing baseflows (no CEW was delivered over summer).	Over 58 tonnes of organic carbon were produced in autumn, 18% (10 tonnes) was contributed by CEW.
	The findings in this, and earlier rep The biggest benefit of CEW is in th in all seasons except winter becau objectives, including food resource	ports, show that augmenting natura e 'Medium Fresh' (~7,000 ML/day) se of light and temperature limitation e peaks for sustaining native fish po	terms of the amount of organic carbon created. higher one enhances organic carbon production should be managed to coincide with other		
Native fish spawning			Spawning of golden perch was detected in drift sampling in late October 2020 during a natural within-channel flow pulse. Spawning of golden perch, trout cod, silver perch was detected in mid-November 2020 coinciding with a targeted within-channel environmental flow pulse. Trout cod have now been detected spawning for two years in a row.		
Fish species occurrence and abundance	Trout cod, Murray cod, silver perch, Murray River rainbowfish, Australian smelt, a single unspecked hardyhead and a single young-of year-golden perch were detected in annual fish surveys in autumn 2021. A large proportion of the Murray cod were young-of-year fish indicating strong recruitment in the 2020-21 summer. It is the first time for 6 years that unspecked hardyhead have been detected in annual fish surveys. Young-of-year golden perch are rarely collected in the annual population surveys; this is likely because early life stages (eggs, larvae) drift downstream and into the Murray River. The individual collected in 2021 is likely to be a stocked fish. The abundances of Murray River rainbowfish and Australian smelt were the highest for several years.				

3.1.1. Flow, bank condition and vegetation

Bank condition is assessed based on rates of erosion and deposition. Erosion and deposition are critical natural processes, but excessive erosion can contribute to bank failure, impact on the ability for plants to establish and persist on the banks, reducing overall habitat quality for a range of animals. Flow, and more importantly flow variability, influences the velocity of water, depth of inundation, duration of wet and dry periods, and variations in rates of water level rise. All these forces contribute to how bank condition responds to flow, particularly the processes of erosion and deposition. The extent of vegetation on banks mediates these processes, for example, by helping to stabilise sediments and minimise erosion. However, these forces also influence the ability of vegetation to establish and persist, or to recover from disturbance events.

Environmental objectives for the lower Goulburn River are to minimise excessive rates of erosion and encourage the reestablishment and persistence of water dependant vegetation on the riverbanks. These objectives are closely linked and are achieved by using environmental water to provide flows that deposit sediment and seed on the banks, provide bank moisture to support vegetation growth, restrict encroachment of terrestrial vegetation, and manage recession events to minimise risks of bank slumping. Establishing and maintaining bank vegetation in turn helps to reinforce banks from excessive erosion and further promote sediment deposition.

On the Goulburn River, a drone is used to take images of the banks and compare changes in bank elevation before and after flow events. Artificial turf mats are also used to collect sediment and seeds at different elevations on the banks under different flow events, and vegetation abundance and diversity is assessed along bank elevation gradients. These measurements are undertaken in the same areas where erosion and deposition are measured, before and after flow events, and including both environmental water delivery and operational flows such as IVT flows.

COVID restrictions in 2020 meant that bank condition was only measured before and after the late (November) spring fresh and following 2020-21 IVT deliveries. Figure 4 shows the magnitude and duration characteristics of each event. The spring and autumn freshes were of similar magnitude and duration and spread across a wide range of flow bands, peaking at over 6,000 ML/day. However, the IVT delivery occurred across a narrower band of flow and with a long duration within the 1,000–2,000 ML/day flow band.



Figure 4. Histograms of flow durations for the three different flow events. Note different vertical axis scales (Webb et al. 2021)

The large natural flow events that occurred across winter and into early spring (see Figure 2) appear to have deposited sediment across the mid and upper banks. Following this, the late spring fresh (for perch spawning) resulted in minor to medium erosion (<30 mm) across the mid and upper bank and high deposition on the lower banks. It seems that the freshly deposited sediment over winter/early spring did not have time to consolidate on the banks before delivery of the late spring fresh and was removed and carried away from the site during this action.

Prior to 2019, IVT flows were delivered in a narrow flow range and this resulted in severe notching and mass failure. For the last two summers (2019-20 and 2020-21) IVTs have been delivered in a more variable pattern and this has helped to distribute erosion across a wider bank zone. However, the IVT flow delivery band is still relatively narrow compared to an environmental event (Figure 4) and erosion due to IVT is still severe (>30 mm) at some locations. However, the prevalence of widespread mass bank failure has substantially reduced and the strategy of more variable IVT flows appears to be helping to reduce the overall severity of erosion.

Towards the end of the 2020-21 IVT period an autumn fresh was delivered that comprised of increased IVT volume and CEW contributions. Overall erosion associated with this event was small on the upper banks, but there was some erosion on the lower banks within the zone of the previous IVT deliveries.

Figure 5 shows the distribution of deposition and erosion at Loch Garry for each monitored event. The spring 2020 and autumn 2021 freshes resulted in less erosion and more deposition than the IVT event, which also recorded higher erosion in the most severe erosion category (>30mm)



Figure 5. Histogram showing prevalence and magnitude of change at Loch Garry for the three 2020-21 monitored flow events (Webb et al. 2021)

In 2020, turf mat monitoring was restricted to just the November fresh. An analysis of turf mat data from the last three retrievals for which data are available (winter 2019, early spring 2019, late spring 2020) shows that across most sites seed abundance, diversity and sediment mass increased with inundation height and duration. Higher sediment deposition resulted in higher seed abundance and diversity (Figure 6). Furthermore, the greater the contribution of tributary flows to freshes the higher the sediment load and the higher the seed abundance and diversity.

The analysis of the entire 2020–21 period, along with observations from previous years, highlights that the sequencing of both natural events and planned environmental water actions, and particularly the antecedent conditions, is important with respect to the likely effects of future flows on bank condition (erosion and deposition) and sediment/seed deposition dynamics. The results suggest that:

Natural, CEW delivered events and IVT deliveries all result in varying amounts of erosion. Erosion tends to occur
across the inundated surface of the bank and deposition occurs on the lower bank. The greater the height of
bank inundated the more distributed the erosion and the lower the overall magnitude of erosion. This means
that erosion associated with natural and CEW events is spread across a wider bank zone. In contrast, erosion
associated with IVT flows tends to result in more severe erosion within a narrow band lower on the bank. The
introduction of a cap on IVT deliveries and a more variable IVT delivery regime in 2020-21 has been successful

at reducing the widespread severe erosion and mass failure seen in recent years, but there are still localised areas of notching occurring.

- The higher the tributary contribution to flow events, the greater the sediment deposition and the greater the abundance and diversity of seed deposition.
- The interval between events appears to be a factor in erosion and deposition characteristics. If freshly deposited sediment from one event has not had time to consolidate on the banks before the next inundation event, the more likely it is to erode, especially if the level of the subsequent event falls with the level of deposition of the previous event. This appears to be the case for the November 2020 fresh which may have eroded freshly deposited material from the earlier spring event. Furthermore, erosion associated with an event may be exacerbated by a subsequent event this appears to be the case for the autumn 2021 event where a large number of days of flow were at a similar level to the flow band experienced during IVT.



Figure 6. Relationship between sediment deposition and, A) seed abundance, and B) taxa richness of material deposited on turf mats across different geomorphic features (Bar, Bench, Ledge, Bank) across all three sites (pooled data for winter 2019, spring 2019 and spring 2020 freshes) (Webb et al. 2021)

The outcomes from these results suggest that:

- 1. It is important to consider the flow volume and duration of previous events so as to not inundate the same areas of bank for long periods of time. This will reduce the likelihood of additional erosion within those flow bands.
- 2. Deliver flows that gradually rise (to the upper bank zone related to flows >5,000 ML/day as a minimum but ideally >7,000 ML/day) and gradually fall (to the lower bank zone related to flows <900 ML/day) as this will (a) spread the influence of the event across a wider range of bank reducing defined erosion, and (b) allow for deposition in areas of past IVT-related notching near the toe of the bank.</p>
- 3. Attempt to increase sediment and seed content within flows by passing natural flow events where possible and piggybacking CEW on tributary inflows.

The presence of vegetation helps reinforce banks and limit erosion, provides habitat for animals and improves water quality. Vegetation monitoring over the course of the LTIM Project, and again in the MER Program during 2019-20 and 2020-21, has shown that the cover of water dependant vegetation tends to increase across the bank elevation zone equivalent to the magnitude of the spring fresh. This supports the contention that spring freshes deliver seed (confirmed through turf mat sampling where seeds were deposited evenly across the bank gradient) and provide a suitable

environment (moisture and inundation) for germination. The increase in cover is also likely to be driven by seasonal increases in temperature and photoperiod, but our results show that increase in cover is greater on those parts of the bank that are inundated by the spring fresh.

In contrast to 2019, when just one early spring fresh was delivered, two spring freshes were delivered in 2020, one in October to promote vegetation and one in November to support native fish spawning. In previous years when two spring freshes had been delivered, the second fresh resulted in the loss of juvenile plants that had germinated in response to the first event. In an attempt to avoid this occurring in 2020 an elevated baseflow was maintained between the two freshes to suppress vegetation recruitment on the lower bank until after the November event. Monitoring after the November event showed the cover of water dependent plants on the lower bank was low, but that germination did subsequently occur on the lower bank. However, it is not clear the extent to which the elevated base flow contributed to the suppression of germination such that those seeds then germinated after the November fresh, or whether germination would have occurred anyway.

Following the recession of the November fresh, a narrow band of fringing vegetation germinated and established around the level of IVT delivery on the lower bank. This band of vegetation became reasonably well established and set seed in autumn 2021 (Figure 7) prior to the autumn fresh. However, vegetation was still absent from the lower bank (below the level of IVT) due to prolonged inundation. The results do indicate however, that the current strategy of capped IVT flows and some variability in IVT flow delivery has resulted in increased fringing vegetation compared to the period 2017-19 when IVT levels were much higher. It is probable that multiple successive years of favourable flow conditions over the growing season are likely to be needed to allow re-established plants to expand their distribution and enhance local propagule pools.



Figure 7. Patch of plants re-establishing along the river fringe at McCoys Bridge in March 2021. Photo: Kay Morris

This year's monitoring outcomes in conjunction with observations from previous years reinforces the management necessary to promote the recovery of vegetation along the river fringe:

- 1. Synchronise freshes with tributary flows where possible to enhance propagule supply.
- Provide low flows for 6-8 weeks following the recession of the early spring Fresh to promote recruitment of vegetation before delivering higher flow pulses for environmental (e.g. late spring Fresh for native fish) or consumptive (i.e. IVT) purposes. Further windows of low flows should be provided over the growth season (Dec-Mar) to promote plant growth, flowering, seed set and vegetative expansion.

- 3. The total number of days plants are inundated by >25 cm over recommended baseflow levels over summer should not exceed 40 days and individual inundation events should be less than two weeks.
- 4. Provide adequate periods of low flows between inundation events to allow plants to recover.
- 5. All effort should be made to avoid submergence of plants (do not exceed recommended baseflows) during flowering or seed set. This period varies among species but is most commonly the summer months.
- 6. In some years provide low flows for ~13 weeks following the recession of the spring fresh to allow plants to set seed and replenish the local soil seed bank.
- 7. Provide successive years of low summer flows (do not exceed recommended baseflows) to increase the spatial extent and propagule supply of water dependant species in the fringing zone.

3.1.2. Flow and fish

The Goulburn MER fish monitoring program continues the work undertaken through the LTIM Project to evaluate the benefits of CEW to native fish populations, and to improve our understanding of flow-ecology and population dynamics of native fish to inform environmental water management for fish. Two fish monitoring methods are employed in the Lower Goulburn River, 1) Annual population surveys using electrofishing and netting (Figure 8); and 2) Surveys of eggs and larvae using drift nets, with the specific aim to examine the influence of flow on spawning of golden perch and silver perch. In 2020-21 additional larval surveys were also undertaken in the Murray River upstream and downstream of the Goulburn River to test whether fish spawned in the Goulburn River were making a measurable contribution to the larval drift in the Murray River.



Figure 8. Electrofishing and netting surveys in the Goulburn River. Photo: Wayne Koster

In the 2020-21 annual fish population surveys, nine native and three exotic species were collected from the ten survey sites. The nationally threatened trout cod (Figure 8) has now been collected in annual fish surveys in two consecutive years and four out of the past seven years. Spawning of trout cod was also detected for the fourth year in a row (2017-2020). Other species of conservation significance collected were Murray cod, silver perch and Murray River rainbowfish. A single unspecked hardyhead was collected in 2021. This species had not been collected in the previous six years but is occasionally encountered in the Goulburn River. A single young-of-year golden perch was also recorded. Similar to previous years, the small-bodied Australian smelt was the most abundant species collected, and the exotic carp was the most abundant large-bodied species collected. The abundance of Murray River rainbow fish was substantially higher than previous years.

Drift sampling for eggs and larvae were completed weekly from October to December 2020. Over 2800 individuals (eggs and larvae) representing 7 native species were collected from the four drift sampling sites. Similar to the results of previous surveys, Murray cod was the most abundant species collected, comprising 58% of the total abundance for all species.

Spawning of golden perch was detected in mid-October (8 eggs) coinciding with the early spring fresh (Figure 9). Water temperature around this time was about 17°C, which is the coolest temperature at which spawning has been detected

since the start of the LTIM Project in 2014. Spawning of golden perch (818 eggs and 14 larvae) and silver perch (18 eggs) was also detected in late November coinciding with a within-channel environmental flow pulse. Water temperature around this time was about 22-23°C. This is a good spawning temperature for golden perch but is probably towards the lower end of the range of suitable spawning temperatures for silver perch.



Figure 9. Mean (±se) number of golden perch (left panel) and Silver perch (right panel) per drift net collected in the Goulburn River in 2020. Mean daily discharge (blue line) and water temperature (broken red line) of the Goulburn River at McCoy's Bridge. Triangles denote sampling trips.

The results from 2020 further strengthen our previous conclusions that the probability of spawning of golden perch is related to discharge, with greatly increased spawning probability at flows between about 3500–4000 ML/day when water temperatures exceed ~18.6°C. Furthermore, flow conditions prior to spawning freshes are also important, with positive relationship between the probability of spawning and the average flows over the 5 weeks prior to spawning; put simply, the higher the prior flows, the higher the probability of spawning.

As noted above, in 2020 additional larval drift sampling was undertaken in the Murray River upstream and downstream of the Goulburn River confluence to determine the relative proportion of larval drift in the Murray River that is coming from the Goulburn River. While we know the flows required to stimulate golden perch spawning in the Goulburn River, we rarely detect young of year fish. It is assumed that larvae are swept to the Murray River and perhaps 'lost' from the Goulburn River. By examining the presence and abundance of eggs and larvae in the Murray River, we hoped to determine the proportion of golden perch larvae that have come from the Goulburn River, providing arguments in favour of continued investment in late spring flows pulses in the Goulburn as a means of supporting golden perch populations at larger scales.

Over 3200 individuals (eggs and larvae) representing five native (golden perch, silver perch, Murray cod, Australian smelt, flathead gudgeon) and one exotic species (common carp) were collected from the drift sampling around the junction of the Goulburn and Murray rivers. Golden perch was the most abundant species collected, comprising 67% of the total abundance for all species, followed by silver perch (24%).

Spawning of golden perch and silver was detected in the Murray River both upstream and downstream of the junction over a longer time frame encompassing late October to late November than in the Goulburn River. There was no noticeable increase in the catches of golden perch eggs in the Murray River following spawning in the Goulburn River, indicating possibly a minimal effect of Goulburn River larvae on the pool of larvae in the Murray River at this time. However, catches of silver perch eggs in the Murray River downstream of the junction increased slightly in late November, coinciding with spawning in the lower Goulburn River.

However, measurement uncertainty in larval monitoring is high because of high spatial and temporal variation in larval abundances. Repeating the new monitoring for several years would increase our chances of estimating the extent to which golden perch and silver perch spawned in the Goulburn River contribute to the numbers of larval fish in the Murray River.

3.1.3. Metabolism

Whole stream metabolism tells us how much food (also referred to as energy or organic carbon) is available in the river throughout the year for organisms (e.g. bacteria, fungi, algae) and animals (e.g. fish, shrimp, insects) to consume. Two processes are important to monitor as a means of determining this: photosynthesis and respiration. Photosynthesis

(also called gross primary production - GPP) is the conversion by plants of sunlight (energy) into organic material (algae and plants). Respiration is the breakdown of organic material by bacteria and fungi to produce nutrients and carbon dioxide (CO₂). The presence of oxygen (called dissolved oxygen (DO) when present in water) is essential to river life. Photosynthesis produces oxygen during the daylight and respiration consumes oxygen at night (Figure 10). If rates of photosynthesis are too low, this limits the amount of food resources for populations of larger organisms including fish and amphibians. If rates are too high this can result in algal blooms that block sunlight, produce toxins and can result in very low DO levels at night. These conditions can lead to the death of plants and animals in the affected parts of the river.



Figure 10. Relationships between photosynthesis (primary production), respiration and the production of organic carbon as a food resource for higher organisms such as macroinvertebrates and fish.

Within any body of water, these metabolic processes can take place in two main locations. *Pelagic* metabolism occurs within the water column. Photosynthesis occurs through water-borne phytoplankton; respiration also occurs through these phytoplankton and through other pelagic consumers such as micro-invertebrates (zooplankton) and bacteria. *Benthic* metabolism occurs on the bed and hard surfaces within the water body. Photosynthesis will occur in diatoms (microscopic plants that coat hard surfaces with slimy *biofilms*), in macroalgae (the larger visible water weeds) and in plants (macrophytes) on the stream bed. Hard surfaces like large woody debris and rocky substrates are ideal for the formation of biofilms (river slime). Respiration will occur within these same organisms and also in benthic bacteria and animals.

The core monitoring program measures whole-stream metabolism across these two compartments in the Goulburn River, by measuring the changes in the concentration of dissolved oxygen in the water column over the day-night cycle. In 2020-21 we added some additional metabolism monitoring to understand the relative contributions of benthic and pelagic environments, particularly with regards to organic carbon produced through photosynthesis. Specifically, we used the 'light and dark bottle method' (Grace et al. 2006) to determine pelagic gross primary production and respiration (Figure 11). By measuring change in oxygen concentration in sealed bottles at multiple depths, including some bottles from which light is excluded, it is possible to calculate water column (pelagic) primary production and respiration, which can then be compared with whole stream metabolism to determine the relative contributions of water column and benthic metabolism.



Figure 11. Schematic diagram of the light-dark bottle setup in the river.

For pelagic production occurring in the water column, the organic carbon produced by photosynthesis is incorporated into the cells of new phytoplankton. These phytoplankton will remain in the water column and a great proportion will be exported from the Goulburn into the Murray River. That carbon is not 'lost', but it will primarily be a food source for organisms in the lower Murray River and potentially down into the Lower Lakes and Coorong. Conversely, organic carbon produced on the benthic surfaces of the Goulburn River will be incorporated into new diatoms in biofilms, and new macroalgal and plant biomass. This provides a food resource for benthic invertebrates, which in turn provide a food source for larger invertebrates and small fish, and so on to the apex species such as Murray cod and golden perch. Put simply, the organic carbon produced by benthic photosynthesis will become a food source for higher-order consumers *within* the lower Goulburn system, rather than being exported to downstream reaches. Understanding the relative contribution of water column and benthic metabolism to organic carbon production and how flow affects the different sources could be important for optimising carbon production for different ecosystems (e.g. within the Goulburn River by maximising benthic production versus downstream reaches by maximising pelagic (water column) production). Our study showed that in the Goulburn benthic metabolism is considerably greater that metabolism in the water column.

Overall rates of primary production and respiration in the Goulburn River in 2020-21 were similar to previous years and typical of those in the southern Murray-Darling Basin, but at the lower end of the 'normal' range found in global comparisons. Low nutrients and reduced light availability due to turbidity are likely to be the main factors constraining primary production in the Goulburn River and rivers in the Murray Darling Basin in general. Across the entire seven-year data set of LTIM and MER, the highest primary production rates have been recorded during the summer, corresponding to the warmest temperatures and greatest light availabilities, and the lowest rates occur in winter.

As with previous years, rates of primary production per litre of water decrease with increased flows. We believe this to be mainly a result of dilution because most flow increases do not cause increased turbidity. But it is worth noting that increased water depth will reduce the amount of light reaching the stream bed, even if turbidity is unchanged, and this would be expected to reduce the overall rate of primary production. However, despite a reduction in the rate of primary production per litre, the total amount of organic carbon produced (load) increases with increases in flow volume. Previously held views were that significant increases in organic carbon load to the river channel required overbank flows to inundate floodplains and draw organic carbon (i.e. in the form of dead leaves, sticks and bark) and nutrients back to the river. The outcomes of the current monitoring are important because it continues to demonstrate observations from previous years that increased in-channel flows are important for increasing the amount of organic carbon that is produced within the river channel, even in the absence of overbank flows. This in-channel derived carbon is likely to be an important food resource for macroinvertebrates and fish, especially in rivers like the Goulburn River where regular overbank flows are not often experienced due to river regulation.

With seven years of data now available, we have analysed the amount of organic carbon that CEW contributes to the Goulburn River for a range of flow events at McCoy's Bridge (the site with the most comprehensive metabolism dataset) Over the seven-year period it is estimated that CEW produced nearly a quarter (21%) of the organic carbon produced in the river (454 of 2156 Tonnes). From an ecological perspective, CEW-enhanced production was most important in spring when 17 - 58% (38% in 2020-21, ~2/3 of the amount produced in the previous spring) of all carbon production was associated with CEW (except for 2016 when there was large flooding and CEW was only 2% of all flow and CEW-derived carbon was only 4% of the total load). CEW also contributed around 23-52% of winter organic carbon production, except in years with high natural winter flows (e.g. 2016 and 2020). CEW contributes very little carbon in summer because flows are either low (with no CEW contribution) or dominated by IVT delivery. From a flow perspective, most CEW-assisted carbon production occurs where CEW contributes to medium to large volume freshes (3,000-7,000 ML/day) in spring and autumn (Figure 12).

The outcomes of this analysis indicate:

- 1. The importance of CEW contributions to organic carbon creation, especially in winter and spring,
- 2. In winter, the same average daily organic carbon load is created at very low flows as it is for higher flows. Hence from this organic carbon perspective, there is no additional benefit from increasing flows above the very low category. However, there is still benefit of small increases in flow within the low flow bands.
- 3. Summertime CEW additions only provide a small increase in daily organic carbon loads, hence if water availability is low or there is the prospect of needing CEW to ameliorate the low DO events sometimes witnessed after large summer storm events, then retaining that water in storage is a good management option.

4. The best outcomes for CEW-assisted creation of organic carbon are found in the 'Medium Fresh' (peaking around 3,500 ML/day) flow category in spring and autumn where an average additional 800-1,100 kg organic carbon is created. The benefit of flow in this flow category is highest in autumn, where CEW contributions in the lower flow categories are much more modest (an additional 100-200 kg of organic carbon). In spring, substantial increases occur in all flow categories above low flow.



Figure 12. Estimated mean daily loads of organic carbon created by primary production, stratified by season and flow category (see Figure 2 for category definitions). Data are from 2014 to 21 and pooled across all sites

With regards to the relative proportions of benthic versus pelagic metabolism, pelagic primary production ranged from 1-25% of the daily primary productivity at the sites, demonstrating that the great majority of whole stream primary production was occurring in the benthic compartment. However, whole-stream primary production figures were much more variable than those for pelagic primary production meaning that as the whole-stream estimate increased, the percentage of this estimate explained by pelagic metabolism decreased (Figure 13).



Figure 13. Whole-stream primary production versus % pelagic primary production

There was no evidence of any relationship between primary production and water column nutrient or chlorophyll levels. Most variation in whole stream and pelagic metabolism appears related to light availability (Webb et al. 2021). On this basis, ensuring a lower flow in summer would increase light penetration to the stream bed and promote benthic primary production. This conclusion provides further evidence of the impacts of aseasonal IVT flows in the lower Goulburn River; those high flows will be limiting the amount of benthic primary production over the summer months by reducing the amount of light that reaches the riverbed.

Finally, benthic primary production will be higher on hard substrates on the riverbed. These allow the formation of biofilms and are much more stable than loose sediments. Another management action that could improve benthic primary production would be to increase the amount of benthic hard surfaces in the river. The integrated research project (Section 3.2) is investigating the benefit of habitat augmentation with wooden stakes for the trapping of organic matter and provision of habitat. With these stakes being placed in shallow, slow-flowing 'slackwaters', our results here suggest that such areas would also be hotspots for benthic primary production and provide an alternative line of evidence for the benefit of undertaking such habitat restoration works.

3.1.4. Macroinvertebrates

Macroinvertebrates (e.g. insects, snails, shrimps, prawns and yabbies) are an essential part of healthy, functioning aquatic ecosystems, providing essential ecosystem services that range from nutrient cycling to provision of food for larger aquatic organisms such as fish. Macroinvertebrate monitoring over the 5 years of the LTIM Project showed that macroinvertebrates, and particularly crustaceans (shrimp and prawns), tend to increase in numbers (abundance) and biomass following spring freshes (Webb et al., 2019a). However, the largest increases in biomass have been observed following natural overbank flows (e.g. in 2016-17) when presumably large amounts of organic carbon were washed into the river and subsequently consumed by macroinvertebrates. Relationships between increased flow, access to habitat and macroinvertebrate response have been hypothesised but not yet confirmed.

In 2020-21 sampling occurred before and after the November fresh – COVID 19 restrictions on field work prevented sampling prior to the September spring fresh. More than 75,000 macroinvertebrates from 54 taxa (different species, genera or families of macroinvertebrate) were collected across all sampling periods. This was up from the total of 49,000 collected in 2019-20. The most common taxa (where >100 individuals were collected) were mites, water bugs, the mayfly (Baetidae), the caddisfly (Leptoceridae) and shrimps (Atyidae). The average abundance of all these taxa increased after the November 2020 fresh with the highest abundances occurring in January and February 2021 (Figure 14). This was a similar pattern to that observed in 2019-20 and is most likely related to natural seasonal variation in macroinvertebrate abundance and biomass.



Figure 14. Average abundance of all macroinvertebrate taxa (± standard deviation, which is a measure of sample variation) pooled across all sites 2019-21. The light and dark orange bars indicate pre-spring fresh sample across the two years and blue bars post-spring fresh samples

Of all the macroinvertebrates collected, 2512 were crustaceans (shrimps, prawns and yabbies). Patterns in shrimp (*Paratya* sp.) biomass were similar between 2019-20 and 2020-21, with a decrease in biomass immediately following the spring fresh but an increase in January and February (Figure 14). However, for prawns (*Macrobrachium* sp.) there was a decline in biomass after the November 2020 fresh and little recovery during the following months. There was also an increase in abundance of immature of crustaceans in both 2019-20 and 2020-21 (Figure 16). This increase was greater in 2020-21 than 2019-20, and we hypothesize that this may have been caused by the greater organic carbon loads

brought into the river by the high unregulated flows of winter 2021. However, it is unclear how much of the observed increases in macroinvertebrate abundance and crustacean biomass following spring freshes is a result of changes in flow versus changes in season.



Figure 15. Results of crustacean sampling a) mean biomass for shrimps (± standard deviation) pooled across all sites and b) mean biomass for prawns (± standard deviation) pooled across all sites for 2019-21. The light and dark orange bars indicate pre-spring fresh sample across the two years and blue/yellow bars post-spring fresh samples.



Figure 16. Mean abundance (± standard deviation) for immature crustaceans 2019-2020 pooled across sites.

Habitat monitoring showed that shrimps are more likely to be detected in habitats where there is some physical habitat, usually plants rather than snags. Prawns do not show a consistent preference for any particular habitat type.

Over coming years, as we gather more concurrent data on carbon production and macroinvertebrate biomass, further analysis will be undertaken to explore relationships between the availability of organic carbon and macroinvertebrate abundance or biomass. This relationship is also being studied as part of the integrated research project (Section 3.2). Outcomes of the metabolism monitoring show that the largest amounts of organic carbon are produced in summer (see Figure 12 in section 3.1.3). As presented above, this also coincides with the highest abundances and biomass of macroinvertebrates. It is possible that macroinvertebrates are responding to the increased carbon availability, rather

than flows specifically. Confirmation of these relationships would help determine if CEW could be effective at generating additional food resources (as organic carbon) that could further enhance macroinvertebrate outcomes. This is particularly important for the lower Goulburn River if CEW could be used to help generate additional organic carbon for macroinvertebrate consumption and compensate for the impacts of the reduction in natural overbank flow events.

The outcomes of this analysis indicate:

- 1. Invertebrate abundance and biomass follow a seasonal pattern, with variations among years potentially related to flow.
- 2. We hypothesize that flow-related effects on macroinvertebrates will be driven by changes in organic carbon (food) resources available to macroinvertebrates.

3.2. Research

Through the development of the Goulburn MER Plan (Webb *et al.*, 2019b), a range of research questions were identified to help better understand the relationships between in-channel flow, hydraulic habitat conditions and ecological response:

- 1. What are the in-channel/hydraulic habitat types (e.g. slackwaters, backwaters, benches, etc. with different hydraulic characteristics) that are particularly important for ecological processes, specific organisms, or life history stages in the Goulburn River?
- 2. Does the distribution and quality of these habitat types change with different flow rates?
- 3. Can flow rates be manipulated to optimise the availability of habitat types that are shown to be important, or to minimise impacts on these habitats during river operations (e.g. IVT flows)?

These questions are important in the Goulburn River because the literature suggests that certain habitat types are important for various ecological processes, life history stages, etc. (e.g. as areas for organic carbon retention and processing, low-flow refuges for larval and juvenile fish, sites of sediment and seed deposition, etc.). Moreover, decades of regulation in the Goulburn river has reduced the complexity of the channel, reducing the amount of geomorphically complex habitat.

We are undertaking an integrative research project (IRP), with a focus on first understanding the extent of slackwater/retentive habitats in the lower Goulburn River, then assessing the biota and ecological processes occurring within those habitats. We are also investigating the extent to which surrounding physical habitat, including manipulations of that physical habitat, can make these habitats more resistant to disturbances that occur through either natural or managed flow events.

The following outlines our process for the project:

- 1. Question refinement/development of hypotheses
- 2. Mapping hydraulic/slackwater habitat
- 3. Experimental manipulation to assess whether slackwater habitats can be made more resilient through habitat manipulation
- 4. Field investigations to assess ecological processes supported by slackwaters
- 5. Analysis, reporting and recommendations for using environmental flows and/or complementary habitat restoration to optimise critical habitat types

In 2019-20 we completed a literature review of the ecological importance of slackwater habitats, convened an expert workshop and developed a conceptual model for the Goulburn River. In 2020-21 we have:

• Developed a number of hypotheses related to the importance of different types of slackwater habitats, their structural complexity and retentiveness:

H₁: Wide slackwaters support more species and greater densities of individuals than Narrow slackwaters.

H2: Slackwaters with more structural retentiveness (i.e. more wood and vegetation) will retain more resources of plant detritus.

H3: Slackwaters with more plant detritus will harbour higher abundance and diversity of invertebrates that require detritus resources.

H₄: Slackwaters with more wood and vegetation will harbour higher abundance and diversity of invertebrates and small-bodied fish that require complex habitats.

- Mapped slackwater habitats and modelled slackwater distribution under a range of flow magnitudes (Figure • 17).
- Surveyed different types of slackwater to characterise their physical complexity and sampled slackwater for • macroinvertebrates (results will be analysed and reported in future reports).
- Established a field experiment where we have increased complexity in narrow and wide slackwater using . garden stakes (Figure 18). We will make repeat visits to these locations to assess any changes in complexity/retentiveness and the macroinvertebrate community.





Figure 17. Example of 2D modelling output showing predicted wide and narrow slackwater areas (water depth ≤ 0.5 m; water velocity ≤ 0.05 m/s) at relevant summer discharges of 1,000 (baseflow), 2,000 and 3,000 ML/day. Site: **McCoy's Bridge**



Figure 18. Field experiments to assess the effect of increasing retentiveness (using garden stakes) in narrow and wide slackwaters

3.3. Engagement and communications

The Goulburn Broken Catchment Management Authority (GBCMA) coordinates the Goulburn River MER Program communication and engagement activities. These activities are complemented by activities undertaken by partner agencies and the basin-wide communications effort led by the basin-scale team. Activities aim to:

- Raise public awareness of the Goulburn MER Program.
- **Promote** the environmental, social and cultural benefits of water for the environment.
- Encourage the community to **advocate** for environmental water deliveries.
- **Provide feedback to key stakeholders** involved in planning, managing and delivering water for the environment.

The target audiences for communication and engagement activities include traditional owners, farmers, rural and town residents, businesses, recreational and industry groups, and local, state and federal government agencies, authorities and elected representatives. Communication and engagement activities occur through various means including community Natural Resource Management groups, management committees and advisory groups, and media (e.g. print, social, TV, etc.).

Key messages for communication and engagement aim to:

- Recognise the cultural, social, recreational and economic values and uses of the river.
- Highlight that the river has been impacted by water resource development and river regulation, and that climate change and ongoing water management are also affecting the river's flows.
- Acknowledge that river regulation and management has affected native fish and other animals that rely on the river for food and shelter as well as the condition of the banks and the bed.
- Demonstrate the way that environmental water is being used to protect and improve the river's health.
- Advocate for the adaptive management of river flows and environmental water delivery based on the outcomes of the Goulburn River MER Program.

During 2020-21 COVID-19 restrictions created challenges, but the GBCMA was still able to continue to communicate about the monitoring program, albeit slightly less frequently, by drawing on community networks and with support

from the CEWO and the Victorian Environmental Water Holder (VEWH). Activities included press releases, interviews, Tweets and Facebook posts. Of note, RMIT University staff ran two successful workshops in May (in between COVID-19 travel restrictions) on the macroinvertebrate monitoring undertaken as part of the Goulburn Flow-MER Program. The workshops were attended by the GBCMA's environmental water delivery partners (Goulburn-Murray Water, Parks Victoria, Greater Shepparton City Council, Department of Environment Land Water and Planning and CEWO) and youth members of the Burnanga Indigenous Fishing Group (https://burnanga.com.au/). The workshops included hands on experience in the water quality monitoring techniques and macroinvertebrate identification (Figure 19).

Through various advisory groups we have continued to involve and consult with Yorta Yorta Nation and Taungurung Land and Waters Council about environmental flows. Both Traditional Owner groups also contributed to the development of a new Lower Goulburn River Environmental Flows study, which will guide environmental water planning and management for the next 5-10 years.

In 2021 we also initiated a new communication tool to share research findings. This tool is a story map, an interactive map platform that combines a mixture of content from videos, pictures, and infographics to explain how environmental flows impact fish, vegetation, physical habitat, stream metabolism and macro-invertebrates. The story map is in the early stages of development and will be reported in more detail in next year's annual report.

In addition to community engagement and communication, team members promoted the Goulburn MER through a number of technical presentations and papers.



Figure 19. GBCMA and RMIT ran a workshop for the Burnanga Indigenous Fish Club to learn about macroinvertebrates as indicators of water quality and how they respond to flows in the Goulburn River

4.Implications for future management of environmental water

Results from monitoring in 2020-21 build further on those from previous years and the following observations are notable for informing future management of environmental water in the Goulburn River:

- Results underscore:
 - the importance of winter and spring freshes, when catchments are wetter and unregulated flows may also be entering the system, for depositing sediment and seeds on riverbanks with minimal erosion, particularly if associated with a high proportion of tributary inflows,
 - the importance of timing and magnitude of spring freshes for promoting water-dependant vegetation (early spring) and golden perch and silver perch spawning (late spring/early summer),
 - the contribution that CEW flows make to enhancing the amount of organic carbon generated by primary production as a potential food resource for macroinvertebrates and fish when delivered any time throughout year.
- In 2020-21 CEW was used to help maintain a high base flow between the early spring fresh for vegetation and the late spring fresh for fish spawning. This high base flow aimed to prevent germination of vegetation immediately following the early spring fresh so that young plants would not be affected by the later spring fresh. Seedlings were observed following the late spring fresh, so this strategy may have helped delay germination.
- Despite changes to the way IVT flows were delivered over the last two summers (capped monthly volumes and pulsed flows), results indicate that negative impacts are still occurring, albeit much less severe than pre-2019. These include notching and erosion of the upper banks, and the loss of water dependent vegetation established on the lower bank in the previous spring as a result of prolonged inundation. The loss of bank vegetation is concerning because bank condition monitoring has shown that where vegetation does exist it helps reinforce the banks against erosion and promotes sediment deposition. Hence the high volumes of IVT delivered represent a compounding problem by causing a loss of vegetation as a result of the extended inundation, which then exposes banks to further erosion associated with the IVT flow itself. Furthermore, additional metabolism investigations in 2020-21 revealed the importance of benthic metabolism for supporting ecosystem food webs, but that IVT flows may limit the amount of benthic metabolism that can occur over summer. The results demonstrate there have been some benefits associated with the revised operating rules, but more work is needed to further minimise negative effects.
- Analysis of multi-year results has highlighted the importance of event sequencing and the need to consider the
 magnitude of prior events and time since last event when planning future environmental water deliveries. In
 particular, it is important to not inundate the same areas of bank that were inundated in previous events for
 long periods of time. This will reduce the likelihood of additional erosion within those flow bands.
- Despite the continuing accumulation of knowledge for individual monitoring disciplines, and correlations between outcomes for different disciplines as suggested by our conceptual model (Figure 3), the monitoring data do not allow us to draw definitive links between the different monitoring results. This is because the activities were originally conceived and designed separately. The integrated research project is designed to detect causal associations between macroinvertebrate production, vegetation habitat and abundance of smallbodied larval fish within slackwater habitats.

Based on the cumulative outcomes of LTIM monitoring from 2014 to 2019, and the MER Program over 2019-21, the following recommendations are made:

1) At least one spring fresh is prioritised every year. The specific timing and duration of the fresh depends upon the target ecological endpoints: early spring for vegetation or late spring/early summer when temperature exceeds 18.5°C for golden perch and silver perch spawning. If two spring freshes are considered in a single year, there is a risk that native vegetation that germinated following the first fresh could be drowned by the second fresh before it has a chance to establish. In this case, consideration should be given to providing at least 8 weeks between events to allow vegetation to establish, or to maintain an elevated baseflow to delay germination until after the second fresh. Environmental water managers will need to consider limitations on the amount of environmental water available and antecedent conditions. In dry years, trade-offs may be necessary, and it is recommended that a strategy for identifying critical endpoints and hence timing of spring fresh deliveries be developed. The recent Goulburn River environmental flow assessment (Horne *et al.*, 2020) introduced a model-based method for flows

planning that takes into account flow sequences among years and antecedent ecological condition of the priority environmental responses. This approach will facilitate trade-off decisions.

- 2) Where environmental water allocations allow, deliver a winter fresh. This will help deliver sediment and seed to the banks and further enhance the likelihood of good vegetation establishment in association with subsequent spring freshes. Where possible, CEW for winter freshes should be delivered in unison with natural high flow events in tributary streams downstream of Goulburn Weir as these natural events carry a large sediment and seed load.
- 3) Continue to refine operational solutions to better manage high IVT volumes. New rules for IVT deliveries in the last two years 2019-20 and again in 2020-21 appeared to help reduce risks of mass bank collapse, however erosion was still high and vegetation was still impacted by the extended duration of inundation. Specific recommendations are to:
 - Continue with the variable, pulsed delivery of IVT flows to avoid stable water levels that lead to excessive notching.
 - Make further effort to reduce the number of days that flows exceeded 1000 ML/d over the IVT period to less than 55 days. Moreover, the total number of days plants are inundated by >25 cm over summer should not exceed 40 days and individual inundation events should be less than two weeks. This may require some higher short pulses to be delivered during summer in order to maintain some longer duration low flow periods.
 - Manage maximum rates of flow recession following the IVT period within current levels or even slower to avoid bank surcharging and mass failure.
 - Avoid delivering long duration events in autumn that inundate bank bands that were inundated during IVT. The extended duration of inundation appears to be contributing to additional erosion.
 - continue to include the MER Program team in the decision-making process to improve ecological outcomes when delivering environmental water and IVTs.

Further changes to operational rules are being introduced in 2021–22 and results from the associated monitoring will contribute to our knowledge about how to deliver IVT flows while minimizing negative ecological impacts.

- 4) Continue to investigate the potential to deliver overbank flows. Overbank flows are not delivered as part of the Goulburn environmental flows program because of third party risks. However, the results from the LTIM and MER monitoring underscore the importance of organic carbon input to the system as a potential food resource for macroinvertebrates and fish, and confirm that although in-channel flows can still create additional organic carbon, overbank flows remain the main source of significant carbon input to the channel.
- 5) Undertake targeted research. Results from the individual monitoring programs raise interesting questions relating to sequencing of results (e.g. this year's vegetation data) and the links between results of different monitoring disciplines (e.g. primary production and macroinvertebrate biomass). The integrated research project is investigating some of these links, but future programs should include research projects aimed at investigating these and other links between the components of the larger monitoring program.

5. References

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