Commonwealth Environmental Water Office
Monitoring, Evaluation and Research Project

Goulburn River Selected Area Scientific Report 2020-21

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1. Preamble

This *Scientific Report* is a companion volume to the *Summary Report* for the Goulburn River Monitoring, Evaluation and Research (MER) Program (Webb et al. 2021). The two documents complement each other and overlap very little.

The Summary Report:

- Introduces the lower Goulburn River selected area and describes how it is treated for monitoring purposes
- Describes the Commonwealth environmental watering actions that occurred in the lower Goulburn River during 2020-21
- Provides the key outcomes for the five different monitoring disciplines undertaken: Hydraulic and Physical Habitat, Stream Metabolism, Macroinvertebrates, Vegetation, and Fish
- Integrates these findings to update the conceptual model originally presented in the Monitoring and Evaluation Plan (Webb et al. 2019b) that describes links among the different monitoring disciplines and the effects of flow upon them
- Considers the implications of the monitoring results for future management of Commonwealth Environmental Water

The separate Summary Report stands alone, in that it provides enough detail on the background and detail of the Goulburn River MER Program to be understood without reference to other documents.

This Scientific Report, on the other hand, is intended to be read alongside the Summary Report for those readers seeking more detail on different aspects of the Goulburn River MER Program than is possible within the space constraints of the Summary Report. In the sections below, the Scientific Report includes:

- For context, a brief description of the Goulburn River and monitoring locations, a summary of environmental water delivery in 2020-21 and of monitoring for 2020-21 versus what was planned
- Detailed chapters on each of Physical Habitat, Stream Metabolism, Macroinvertebrates, Vegetation, and Fish. The chapters include:
    - Introduction, methods, results and discussion in the format of a standard report/paper
    - Evaluations of the area-specific monitoring questions being asked
    - Main findings from each of the monitoring disciplines for 2020-21 and how these build upon understanding developed in the 5 years of the predecessor to the MER, the Long-Term Intervention Monitoring (LTIM) Project
- Reports on research and contingency monitoring activities
- A report on our engagement and stakeholder communication activities for 2020-21

In this sense, the Scientific Report can be considered as a major appendix to the Summary Report.

2. Lower Goulburn River Selected Area Description and Monitoring Locations

2.1. Description

The Goulburn River extends from the northern slopes of the Great Dividing Range north to the Murray River near Echuca (Figure 2-1). The upper catchment lies within the lands of the Taungurung Nation and the lower reaches, across the northern plains, lies 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 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 lower 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 consumptive users further downstream in the Murray River. Historical river regulation and more recent IVTs significantly impact 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 (235 km). Environmental flows in the lower Goulburn River are not currently used to deliver overbank flows or to water the floodplain.

2.2. Monitoring sites and 2020-21 monitoring

2.2.1. Sites

The Goulburn MER Program divides its monitoring locations by *zones* (Figure 2-1). These are equivalent to the *reaches* used in previous environmental flow assessments (e.g. Cottingham & SKM 2011):

- Zone 1 – Main channel of the Goulburn River and associated wetlands and backwaters that are connected to the main channel at flows less than bankfull between Goulburn Weir and the confluence of the Broken River near Shepparton (i.e. Environmental Flow Reach 4).
- Zone 2 – Main channel of the Goulburn River and associated wetlands and backwaters that are connected to the main channel at flows less than bankfull between the confluence of the Broken River and the Murray River (i.e. Environmental Flow Reach 5).
- There is one ecological monitoring site (macroinvertebrates), along with a corresponding hydrological monitoring site outside these zones, being a site in the lower Broken River, and one macroinvertebrate site upstream of Zone 1 in Goulburn Weir.

Zone 1 and Zone 2 are physically similar, have similar hydrology and are not separated by significant barriers. Moreover, they are equally affected by Commonwealth environmental water, 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). Monitoring sites are marked on Figure 2-1. Sites are detailed in Table 2-1, which also includes several additional sites only used for the contingency monitoring programs.

Ecological Matters being investigated 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 (focusing on the biomass of larger bugs particularly crustaceans); bank vegetation (abundance and diversity of plant cover); and native fish spawning and populations (composition and abundance).

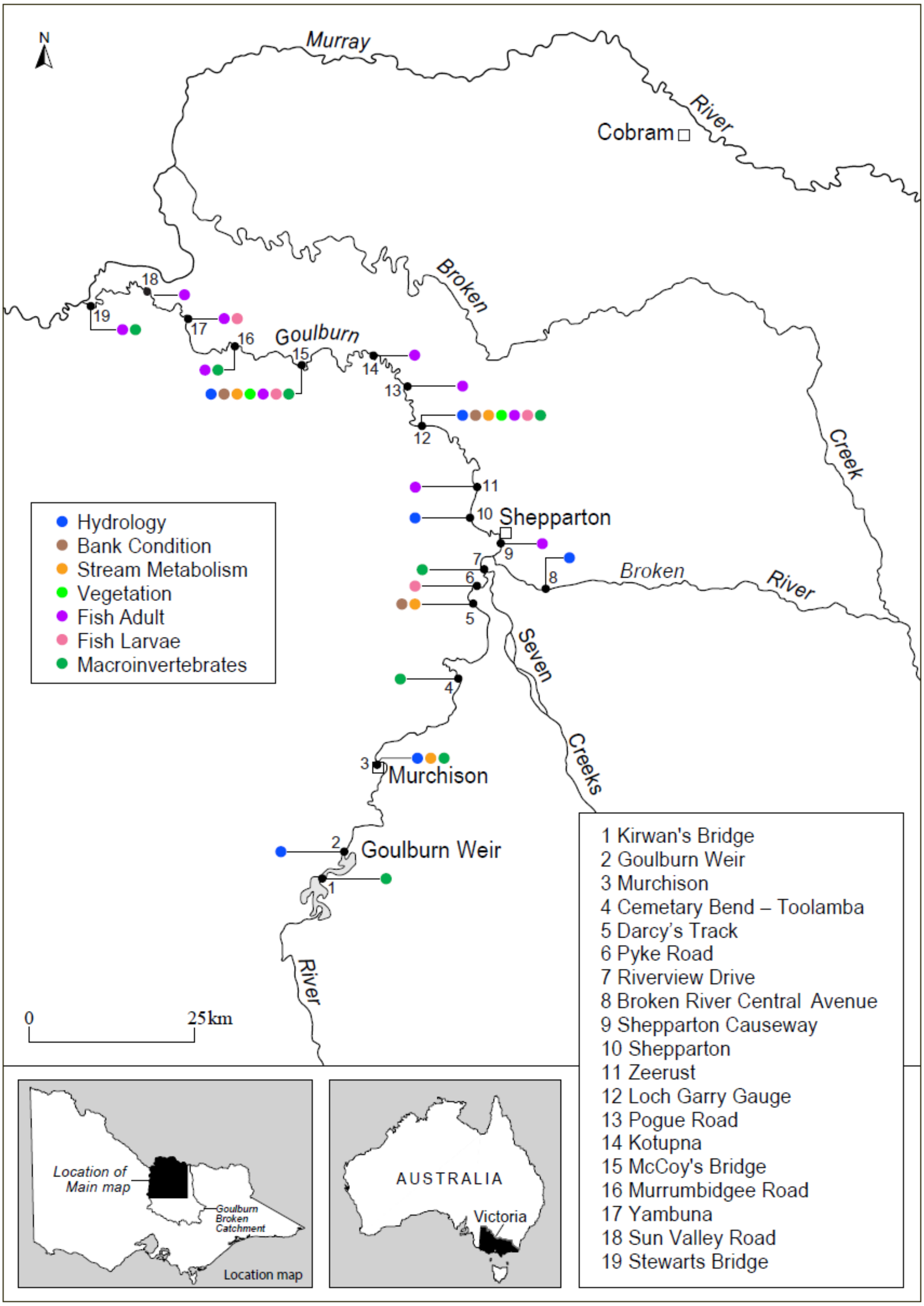


Figure 2-1 Map of the lower Goulburn River, with all core monitoring sites marked, along with flow gauges used to generate flow data to be used in the MER Program. Some sites extend into the Broken River. Colours denote different monitoring activities, with some sites being used for multiple activities. 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.

Table 2-1 Goulburn MER monitoring sites in each zone and the monitoring activities undertaken at each site.

Site No.	Site Name	Hydrology	Adult Fish	Larval Fish	Bank Condition	Turf Mats*	Vegetation Diversity	Stream Metabolism	Macro-invertebrates	Research Project	Pelagic Metabolism*	Murray Larval Monitoring*
	Zone 1 – Goulburn Weir to Broken River											
2	Goulburn Weir	■								■		
3	Salas Rd, Murchison	■						■	■			
4	Toolamba/Cemetery Bend								■			
5	Darcy's Track				■	■		■		■	■	
6	Pyke Road			■								
7	Riverview Drive								■			
	Zone 2 – Broken River to Murray River											
9	Shepparton Causeway		■									
10	Shepparton	■										
11	Zeerust		■									
12	Loch Garry Gauge	■	■	■	■	■	■	■	■	■	■	
13	Pogue Road		■									
14	Kotpuna		■									
15	McCoy's Bridge	■	■	■	■	■	■	■	■	■	■	
16	Murrumbidgee Road		■						■			
17	Yambuna		■	■								
18	Sun Valley Road		■									
19	Stewarts Bridge		■						■			
NA	Goulburn upstream Murray											■
	Outside of Zones 1 & 2											
1	Kirwans Bridge, Goulburn River								■			
8	Central Avenue, Broken River	■										
NA	Murray upstream Goulburn											■
NA	Murray downstream Goulburn											■

* Note: Contingency monitoring

2.2.2. Monitoring in 2020-21

Monitoring in 2020-21 proceeded in line with the original MER plan (Webb et al. 2019b), but with some modifications to account for natural flood events and restrictions associated with COVID-19 requirements (Table 2-2). Core monitoring activities took place according to plan except for adult fish surveys that were originally scheduled for April/May 2021 but were delayed until May/June 2021 because of high flows in late April/early May due to significant rainfall in the catchment. Detailed discussions of monitoring activities, how they differed from planned activities, results and discussion, are presented separately for each discipline in the following chapters.

A feature of the 2020-21 monitoring was the continuation of turf mat monitoring for sediment deposition rates and seed growth. Turf mat monitoring was introduced in the 5th year of the Goulburn LTIM (2018-19) and is continuing under the MER as a Contingency Monitoring activity. Two other contingency monitoring activities were also undertaken in 2020-21. These included:

- Larval fish surveys in the Murray River upstream and downstream of the Goulburn River to determine the contribution that larval drift from the Goulburn River was making to the Murray River population (see Section 11 for more details)

- Pelagic metabolism using light / dark bottles to determine the relative contributions of benthic versus water column metabolism to whole stream metabolism (see Section 10 for more details).

We also commenced an integrated research project to 1), identify types of slackwaters and habitat characteristics of slackwaters that are important for biota and ecological processes occurring in the lower Goulburn River and 2), identify the distribution of important habitat types and management actions (e.g. required flows) to optimise these habitat types (see Section 12 for more details).

Table 2-2 Schedule of planned and actual monitoring activities by month for 2020-21.

Monitoring activity	Number of sites per Zone		Planned / Actual	Schedule of planned and actual activities in 2020-21											
	Zone 1	Zone 2		J	A	S	O	N	D	J	F	M	A	M	J
Core Monitoring															
Adult Fish		10	Planned										✓	✓	
			Actual											✓	✓
Fish Larvae	1	3	Planned				✓	✓	✓						
			Actual				✓	✓	✓						
Vegetation Diversity		2	Planned			✓			✓			✓			
			Actual					✓	✓			✓			
Macroinvertebrate Abundance, Diversity and Biomass	3*	4	Planned			✓		✓		✓	✓	✓			
			Actual					✓	✓	✓	✓		✓		
Stream Metabolism	2	3	Planned	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Actual	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bank Condition	2	2	Planned			✓	✓					✓	✓		
			Actual					✓	✓				✓	✓	
Contingency Monitoring															
Murray Fish Larvae	0	1**	Planned				✓	✓							
			Actual				✓	✓							
Turf Mats: Sediment and Seed Deposition	1	2	Planned					✓	✓			✓		✓	✓
			Actual					✓	✓			✓	✓	✓	
Pelagic Metabolism	1	2	Planned					✓	✓	✓	✓	✓			
			Actual						✓	✓	✓	✓	✓		
Research Project															
Research Project	2	2	Planned				✓		✓		✓		✓		✓
			Actual						✓		✓		✓		✓

* + 1 site u/s of Goulburn Weir

** + 2 sites in the Murray River – 1 upstream of the Goulburn River confluence and one downstream

3. Commonwealth Environmental Watering

3.1. Overview of Commonwealth environmental watering

As of 31 August 2021, the Commonwealth held 360 GL of environmental water entitlements in the Goulburn River (http://www.environment.gov.au/water/cewo/about/water-holdings and see Table 3-1). The Goulburn River receives other environmental flows including from the Victorian Environmental Water Holder and The Living Murray 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. Inter-Valley Transfers have also previously been used to meet environmental flow targets when possible. Commonwealth environmental water 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.

Table 3-1 Commonwealth environmental water entitlements as of 31 August 2021.

Entitlement type	Registered entitlements (GL)	Long term average annual yield (GL)
Goulburn (high reliability)	318.6	308.0
Goulburn (low reliability)	42.5	24.8

3.2. Environmental water delivered in 2020-21

High priority watering actions planned for 2020–21 in the lower Goulburn (Reaches 4 and 5) 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 (CEWO 2020a, GBCMA 2021).

During 2020–21 around 239 GL of environmental water was delivered in the lower Goulburn River; the CEWO contributed 151 GL to this total (CEWO 2020b) (Figure 3-1). Interim operating arrangements introduced by the Victorian Water Minister limited IVT delivery volumes to around 40 GL/month over the 2020-21 summer and planned for delivery as an average baseflow around 1,300ML/day. IVTs also contributed to the late spring fresh for golden perch spawning and the Autumn fresh. Total IVT flows of 216 GL were released, more than the 162 GL delivered in 2019-20, but less than the 387 delivered in 2018-19 and 258 GL in 2017–18. Apart from a minor contribution to the spring and autumn freshes IVT prevented the delivery of environmental water over the period between November and May, but were released in a pulsed way to reduce the amount of damage caused to lower banks and riparian vegetation (VEWH 2020). Unregulated high flow events in winter and early spring provided greater than normal flow volumes in the lower Goulburn River over this period. Environmental water was used to slow the recession of an event in September and then deliver an early spring fresh (Figure 3-1).

The planned delivery for environmental water in 2020-21 is summarised in Table 3-2. Information on planned delivery and expected outcomes from (CEWO 2020a) and GBCMA (2021), which also outlines the actual deliveries and the conditions that influenced use decisions during the year. Appendix A provides a detailed breakdown of volumes used to deliver each planned event.

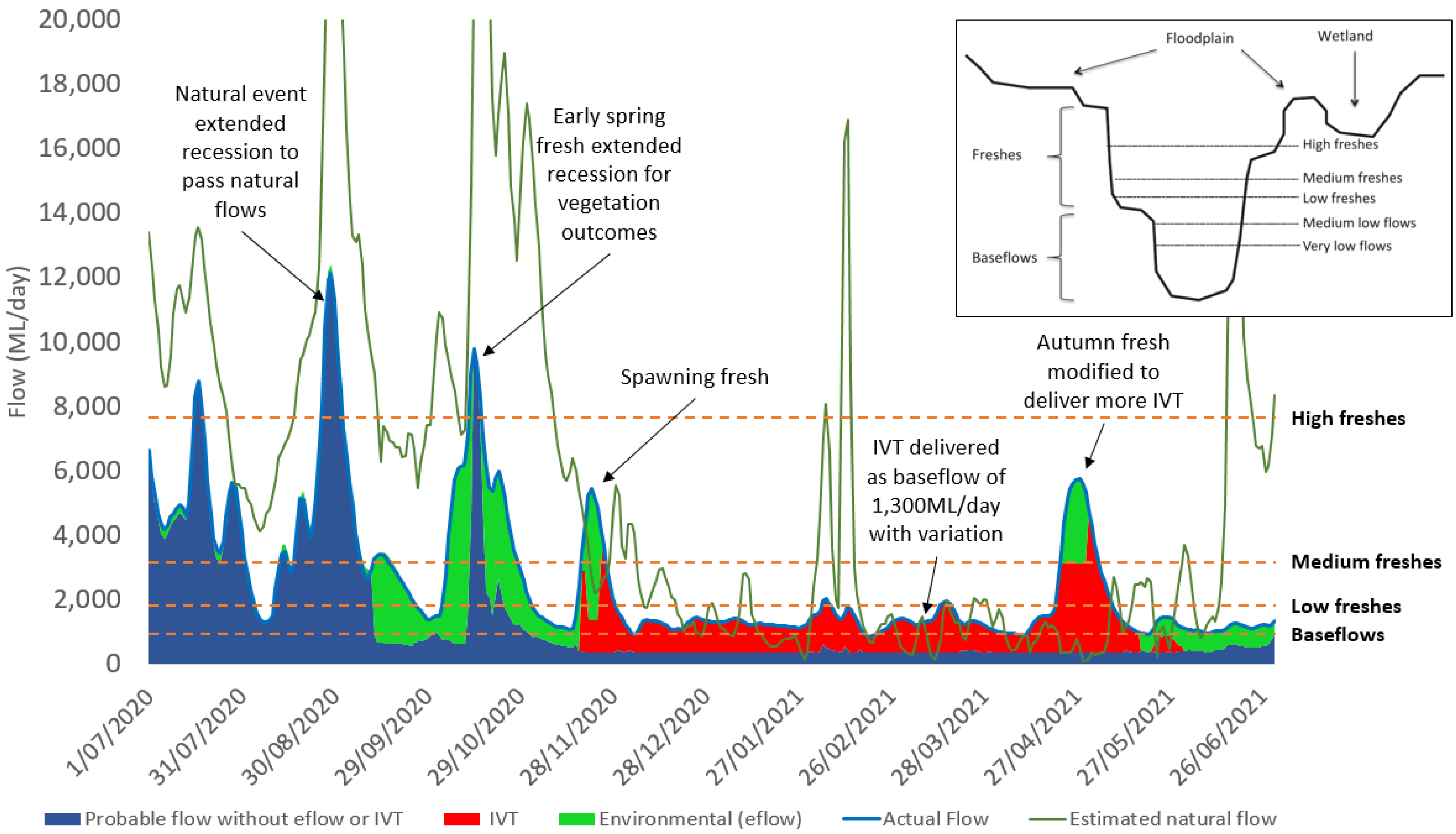


Figure 3-1 Relative sources of water contributing to total Goulburn River flows in 2020-21 at McCoy's Bridge (https://fchMcCoy's.hydronet.com/).

Table 3-2 Summary of planned and actual environmental flows for the lower Goulburn River 2020–21. Information on planned delivery and expected outcomes from (CEWO 2020a) and (GBCMA 2021). Information on actual delivery provided by CEWO (2020b). More details on specific volumes delivered from various sources is provided in Appendix A.

Flow component type and planned magnitude, duration, timing	Expected outcomes (primary and secondary as at delivery)	Actual delivery details and any operational issues that may have affected expected outcomes Comments
Provide a minimum baseflow of 500/540 ML/day at Murchison/McCoy's	Provide baseflows all year: to maintain water quality and provide minimum recommended habitat and food resources for native fish and macroinvertebrate and to water bank vegetation.	Minimum baseflow targets were met all year either by unregulated flows, environmental water or IVT delivery. Average flow conditions led to sufficient volumes of environmental water to target the higher baseflow levels.
Provide at least one winter/spring fresh (July-Oct) **>6,600 ML for 14 days** **Deliver using tributary flows where possible, rather than releases from Eildon.** **If there is no natural event then deliver as a managed event in Sept/Oct 2020.**	Contribute to long-duration freshes in winter/spring: to inundate vegetation on benches and the lower banks to facilitate recruitment, sustain growth, and encourage flowering, seed development and distribution. Stimulate golden perch spawning if also delivered in Nov-Dec.	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. Environmental water was used to slow the recession of the August event to meet the recommendations of bank inundation time for the winter fresh. A spring fresh was delivered in September and October. Due to wet conditions a natural flow event occurred during delivery of this fresh with an unregulated spill at Goulburn Weir, combined with tributary flow in the lower Goulburn leading to a higher natural peak of approximately 10,700 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 6,000 ML/day.
Higher Baseflow (April-Jun) 830/940 ML/day at Murchison / McCoy's	Contribute to higher baseflows: to maintain water quality and provide suitable habitat and food resources for native fish and macroinvertebrate and to water bank vegetation higher on the bank.	Due to the planned delivery of a native fish spawning event in November, environmental water delivery was intentionally used to inundate the lower bank to delay vegetation germination until after the fresh. Unregulated water or delivery of freshes led to flows exceeding 1,100 ML/day until the 6th December. Flows dropped below 1,000 ML/day for one week and then delivery of IVTs led to flows exceeding baseflow recommendation for the remainder of summer. Interim operating arrangements introduced by the Victorian Water Minister limited IVT delivery volumes to around 40 GL/month over the 2020-21 summer and Autumn period. In an attempt 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. This also allowed flows to drop below 1000ML/day briefly to allow monitoring to occur. Following the Autumn fresh, environmental water and IVT was delivered to meet the higher baseflow recommendation of 830 ML/day at Murchison. Flow from the lower Goulburn tributaries led to higher flow at McCoy's bridge.
Following natural flows (all year) **Provide water for a slower recession or add pulses**	Provide water for a slower recession or add pulses following natural cues/unregulated flows to minimise	Environmental water was used to slow the recession of a natural event in August to meet the recommendations of bank inundation time for the winter fresh. Most of the water came from tributary flows in the Mid Goulburn. This

Flow component type and planned magnitude, duration, timing	Expected outcomes (primary and secondary as at delivery)	Actual delivery details and any operational issues that may have affected expected outcomes Comments
following natural cues/unregulated flows.	the risk of bank erosion and hypoxic blackwater.	delivered sediment and seeds as well as delaying germination of vegetation on the lower banks so that it would not be affected by subsequent spring freshes.
Spring/summer low flow (after a spring fresh) <1000 ML/day for 5–6 weeks.	Contribute to flows <1000 ML/day for 5–6 weeks: to allow newly grown plants to establish, provide bank stability, and provide habitat for small-bodied fish and waterbugs.	This objective was deliberately not met this year to enable delivery of the late spring fresh for golden perch spawning. Environmental deliveries for the winter recession and early spring fresh were designed to delay germination of vegetation on the lower banks so that it would not be affected by delivery of the late spring freshes for native fish spawning.
Spring/summer fresh (Nov/Dec) **When possible, >6 600 for 1 day** **This will not be delivered if the spring/summer 5-6 weeks low flow for vegetation has not been achieved.**	Stimulate the spawning of golden and silver perch between October and December.	In November, a fresh was delivered to stimulate golden perch spawning. Due to Covid lockdown being removed and a request from the Victorian Fishing Authority to provide better fishing conditions for Melbourne residents, the fresh was delayed and shortened by two days to ensure it finished by Cod opening on 1 December. Part of the spawning fresh was delivered using IVT and at the end of this fresh, IVT delivery began to deliver baseflows in the lower Goulburn River.
Autumn fresh (Mar to April) **When possible >5 600 ML/day for 2 days. Note that delivery of the summer/autumn low flows between pulses is a trigger for this action.**	Contribute to an autumn fresh: to 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.	An Autumn fresh was delivered in late April and designed to achieve flows over 5,600 ML/day for 2 days at Murchison. The event was delivered using primarily IVT. 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. Peak flow for the event was 6,295 ML/day at Murchison and 5,739 ML/day at McCoy's bridge.

4. Physical Habitat

4.1. Introduction

Bank condition is explicitly linked to Commonwealth Environmental Water (CEW) delivery and other variable flows. The risk to plants and animals from changes in bank morphology and sediment liberated from erosion make bank condition an important, and explanatory variable for assessing the value of these water delivery patterns for achieving ecosystem objectives.

Riverbanks influence the velocity of flow, depth of water, and provide the sediment conditions for a range of plants and animals (biota). Riverbank condition can alter conditions for biota, and this is often related to the extent of bank activity and river flow. For example, appropriate levels of erosion provide niches for vegetation establishment, but excessive erosion can lead to sediment smothering of bed habitat (as well as concerns for riparian infrastructure such as bridges and property).

Riverbank vegetation richness and diversity are also impacted by flows, through flow characteristics such as prolonged inundation, high velocities, and smothering. These vegetation changes can be independent of bank condition, or inextricably linked. There are considerable advantages to monitoring bank condition in concert with riverbank vegetation condition.

Quantifying the relationship between CEW delivery and bank condition can assist with identifying critical flow ranges to support specific aquatic biota and ecological processes, vegetation density and resilience and the long-term condition of channel physical form.

Physical habitat monitoring, including hydraulic habitat (hydraulic modelling) and bank condition monitoring (including erosion pins) was undertaken as part of the Goulburn River LTIM Project over 2014-2019. This is continuing for the Goulburn MER Program but with a change in some approaches, including using Unmanned Aerial Vehicle (UAV) technology and photogrammetry methods to generate Digital Elevation Models of Difference (DEMODs). These are produced by comparing two 3D models of bank condition at two different points in time. The output of these models enables highly accurate (<1 cm^3) analysis of patterns of erosion and deposition on the riverbank.

4.2. Area specific evaluation questions

The key basin and area-scale evaluation questions and relevant indicators for physical habitat are listed in Table 4-1.

Table 4-1 Physical habitat key evaluation questions for the Goulburn selected area and associated indicators and evaluation approaches.

Key Evaluation Questions	Indicator	Evaluation Approaches
Basin Scale evaluation Questions		
There are no basin-scale evaluation questions for physical habitat		
Area-Specific evaluation questions		
How do CEWH environmental/variable flows contribute to sustaining bank condition?	• Increased deposition at a bank level across the system • Visual evidence of repair to historic damage due to sediment deposition	• Visual interpretation of change using DEMOD outputs from drone surveys
Are CEWH environmental/variable flows adversely impacting the banks of the rivers?	• High erosion volume to lower bank zones • Indication of notching and mass-failure (wide-spread bank erosion/slumping) events	• Visual interpretation of change using DEMOD outputs from drone surveys
How do timing and delivery of CEWH environmental/variable flows affect bank condition of rivers?	• Increased erosion/deposition in response to particular rates of rise and fall. • Increased erosion/deposition in response to flow delivery following different events of interest	• Expression of change analysis on flows using different rates of rise and fall and in different sequences of delivery

What timing and delivery of CEWH environmental/variable flows best sustain or improve bank condition for vegetation growth?	• Increased/decreased vegetation cover following particular flow events • Increased/decreased density/health of existing vegetation • Increased/decreased bank steepness following flow events	• Expression of change analysis on particular bank zones, considering bank profile and revegetation potential following flow events
How do vegetation responses to CEWH environmental/variable flows vary between sites with different channel features and different bank condition?	• Increased/decreased vegetation cover on benches and bars • Increased/decreased vegetation cover on outside banks/inside banks • Increased/decreased vegetation cover on steep/gentle banks	• Vegetation cover analysis on different banks throughout the system
Are bank erosion rates and processes impacting macroinvertebrate communities?	• Increased/decreased macroinvertebrate volumes in response to banks experiencing net a) erosion b) deposition	• Macroinvertebrate sampling in close proximity to different bank types

4.3. Main findings from monitoring program

The following sections provides a high-level summary of the outcomes of the 2020-21 monitoring and the implications of these findings to previous years outcomes.

4.3.1. 2020/21 findings

The findings of the monitoring of the effects of environmental flows are discussed along with the results of the IVT flow monitoring program as both flow delivery types can have impacts on the banks and the sequencing of these different flows can be important for erosion processes.

- Environmental Flows continue to contribute to erosion, this is however inevitable with any large flow delivery within a regulated system. The location (to areas of mid and upper bank), pattern (variable with lack of linear definition) and depth (shallow rather than deep) supports the contention that these flows are not causing damage to the long-term physical form of the Goulburn River but rather, in the majority of cases resulting in positive outcomes to the channel form through the *resetting* of lower bank steepening, which is a result of historic (and more recent) erosion from prolonged and invariable irrigation deliveries.

- Major drivers of erosion are duration of inundation (modelling and histograms show a clear link in cases), the duration of maximum flow (longer duration above 5,000 ML/d for example leads to more change to upper bank zones) and the daily rate of rise and fall (which as demonstrated during the IVT, impacts the pattern of erosion). Both the Spring and Autumn Freshes resulted in flows above >5,000 ML/d and thus influenced the upper bank, the Autumn Fresh however resulted in more prolonged time above this range and also was managed with a slower rate of fall, that may have helped minimise any instances of major erosion in sensitive areas of the lower bank related to erosion from the prior summer IVT deliveries.

- Flow sequence plays an important part in erosion response and thus bank condition cannot be assessed accurately through a single flow event, and prior events must be considered. This is particularly true when considering the impact of flow events that follow summer irrigation periods (in this case the Autumn Fresh) as defined erosion on the lower bank prepares the riverbanks for future erosion events. Additionally, flows that follow large natural events (i.e., Spring Fresh) are more likely to result in more erosion across the bank face as fresh deposits from the prior event have not been given time to set/consolidate to/with the bank face.

- Prolonged dry periods to bank zones, such as those experienced with the mid/upper bank (i.e. above the ~4,000 ML/d bank height) during the summer IVT period give time for prior deposits in this zone to consolidate and thus the expectation should be that erosion across this zone should be less (relative to similar events delivered in Spring).

- Flow delivery that results in minor fluctuations to water level over an extended period of time results in a wetting/drying effect that interrupts the deposition - erosion cycle on riverbanks, expediting erosion events in these zones. This process can lead to notch development and over time mass-failure events as evident in the data relating to the 2020-21 IVT delivery. Additionally, processes like this, which occur to the lower bank zone, can prepare the channel for future erosion events.

- Increased deposition directly corresponds to the source and timing of the water delivery (i.e., dam versus tributary delivered water percentage). The Spring Fresh had an estimated 37% tributary flow contribution which was significantly higher than the 9% experienced during the Autumn Fresh. The deposition data clearly highlights the correlation between increased tributary flow contribution and the depth of deposition.
- There is a positive feedback loop between vegetation density/cover and riverbank resilience. Banks which showed the greatest erosion volumes lacked vegetation cover and as a result the vegetation that remains will arguably continue to recede as this erosion process continues. Riverbanks with more cover gather more sediment which, if given time to consolidate to the bank face, will lead to more resilience over the longer term.
- The increased vertical variability of sediment change, in addition to the lack of mass-failure events resulting from the two monitored environmental watering events, supports the hypothesis that flows with the appropriate rise and fall, which reach the upper bank zones and which consider prior events, will lead to positive long term results. Considerations for flow management remain the same as 2019-20 with the additional consideration that the duration of the period above 5,000 ML/d should be maximised within the recommended daily rates of rise and fall.

4.3.2. Summary of previous findings and implications for any new finding

Previous findings

- In the majority of cases, increased bank erosion correlated with increased inundation duration. However, the pattern of a flow delivery (regarding the sequence of daily discharge volumes) is arguably a more critical factor when considering long-term bank condition.
- Current environmental flow management practices in the Goulburn River result in minor erosion, this erosion however is relatively (to IVT deliveries) shallow in depth (<3 cm) and is expressed more evenly (on the vertical axis) across the bank face. With respect to the Spring Fresh, this erosion is located primarily within the upper half of the bank (correlating to flows above 3,000 ML/d) and at depths of less than 3 cm on average.
- Deposition volume did not correspond directly with inundation duration and appears more closely related to a) bank erosion (where deposition is located beneath) and, b) seasonal variables, such as % of tributary flow contribution and sediment input resulting from rain events etc. (more apparent during Autumn Recession flow event), and c) the vegetation cover at a bank level. Vegetation cover appeared to play a major role at inside banks at Darcy's Track and Loch Garry.
- Although IVT flows resulted in extensive areas (laterally) of deep, defined erosion, mass-failure events were isolated to one bank at Darcy's Track (Bank D), there was no evidence of widespread mass-failure events across the system as was identified in 2018-19. Erosion was deep (up to 20 cm) and in some cases there was evidence of the formation of notching at bank zones corresponding to the upper quartile of IVT deliveries (2,000-3,000 ML/d). This was more apparent on inside banks where vegetation had receded over the years. Erosion on outside banks was expressed with greater vertical variability in zones correlating to flows.
- Sequencing of flow events played a key role for some banks. Clearly in some cases, deposition from previous events increased the erosion recorded during the following events. Additionally, the stress put on banks during the prolonged IVT period arguably enhanced the erosion volumes recorded from the final Recession flow event.
- The benefits of environmental flows may be offset by operational flows such as the IVT. The impact of the previous year IVT delivery (2019-20) was evident across banks monitored for all three events (Spring Fresh, IVT and Autumn Fresh), it can be assumed that this year's IVT will also contribute to future erosion events in 2021 and 2022 within the system due to the defined nature of IVT related erosion and its position on the lower bank. These processes are resulting in the continued retreat of the lower bank from 2019 to 2021.
- Considerations for flow management (as noted in MER 2018-19 report) should include:
  - Maintaining variability in flows and water levels to maintain bank wetting at varying levels to avoid bank notching. It was confirmed that notching occurred during the IVT flows, including lower bank recession
  - Maintain 'piggy backing' on tributary inflows to draw upon sediment and seed supplies from tributaries. The role of tributary flows needs further analysis, but it is clear that increases in tributary percentage of flow lead to greater volumes of deposition (the data from 2019-20 supports conclusions from 2018-19)

- Manage maximum rates of flow recession within current levels to avoid bank surcharging and erosion and to allow mud drapes to develop. Mud drapes on banks have been associated with vegetation growth.
- Design environmental flows that follow the IVT period (i.e., the Autumn Fresh) to target the upper bank zone, avoid long duration within IVT zones, and to align to the daily drawdown guidelines discussed between DELWP and the CMA.
- Continue the modification of flow management as a collaborative effort between researchers and water managers.

Implications for new findings

- All of these findings were supported in the data collected from the 2020-21 program; the only major differences were (1) the increased impact of preparation resulting from the IVT event to erosion to the lower bank (Darcy's Track Bank D), and (2), the clear impact of the increased tributary flow during the Spring Fresh event of 2020 on deposition depth (being greater than found in response to the Autumn Fresh, which had a lower tributary contribution).
- 2020-21 monitoring supports the findings from prior years that large *freshes* if delivered as advised can lead to positive results regarding channel form.

4.3.3. Summary of findings relevant to evaluation questions

Table 4-2 provides a summary of the physical habitat findings relevant to the evaluation questions. A more detailed examination of each evaluation question is provided in section 4.5.

Table 4-2 Summary of physical habitat findings relevant to evaluation questions.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
How do CEWH environmental/variable flows contribute to sustaining (or adversely impacting) bank condition?	Spring freshes were appropriate but a longer duration for the Recession flow in April was needed to reduce the impact of the falling limb of this event on bank condition	Spring freshes resulted in an acceptable amount of erosion and deposition across a wide area of the vertical bank zone. Erosion to the upper bank zone is natural and helps to reset erosion (and notching) in the lower bank zone caused by irrigation flows. However, the April Recession flow led to increased erosion due to its sequential position (directly after the IVT period).	Visual expressions of change through DEMODs Statistical analysis of data
How do timing and delivery of CEWH environmental/variable flows affect bank condition of rivers?	The Recession Flow, which followed the IVT flow period, could have been increased to peak above 3,000 ML/d rather than mirroring the IVT flows of the summer months	As mentioned above, the Recession flows led to increased erosion (due to the preparation from the IVT flow period), but also more deposition arguably due to increased tributary flow contribution.	Visual expressions of change through DEMODs
What timing and delivery of CEWH environmental/variable flows best sustain or improve bank condition for vegetation growth?	To support vegetation growth flows should be delivered prior to, during, and after the prolonged summer irrigation period	Prolonged inundation to the lower-mid bank during the IVT flow period is detrimental to vegetation growth during the hot dry months. The Spring Fresh was well timed to aid vegetation health prior to summer IVT period.	Visual expressions of change through DEMODs On-ground observations during field visits
How do vegetation responses to CEWH environmental/variable flows vary between sites with different channel features and different bank condition?	NA	Inside banks collect more sediment due to reduced fluvial stresses and increased deposition. Areas of bank with existing vegetation have more resilience to the stresses of flow and conversely bare banks have less resilience. This highlights the positive feedback loop between vegetation cover and condition.	Visual expressions of change through DEMODs On-ground observations during field visits

4.4. Monitoring methods and analytical techniques

4.4.1. Sites

The following figures describe the location of the banks of interest at each of the Goulburn River physical habitat monitoring sites: Darcy's Track (Figure 4-1), Loch Garry (Figure 4-2) and McCoy's Bridge (Figure 4-3). Banks are referenced with letters, such as "Bank D" and these names are used throughout the report in partnership with the site names, for example Bank D, Darcy's Track.

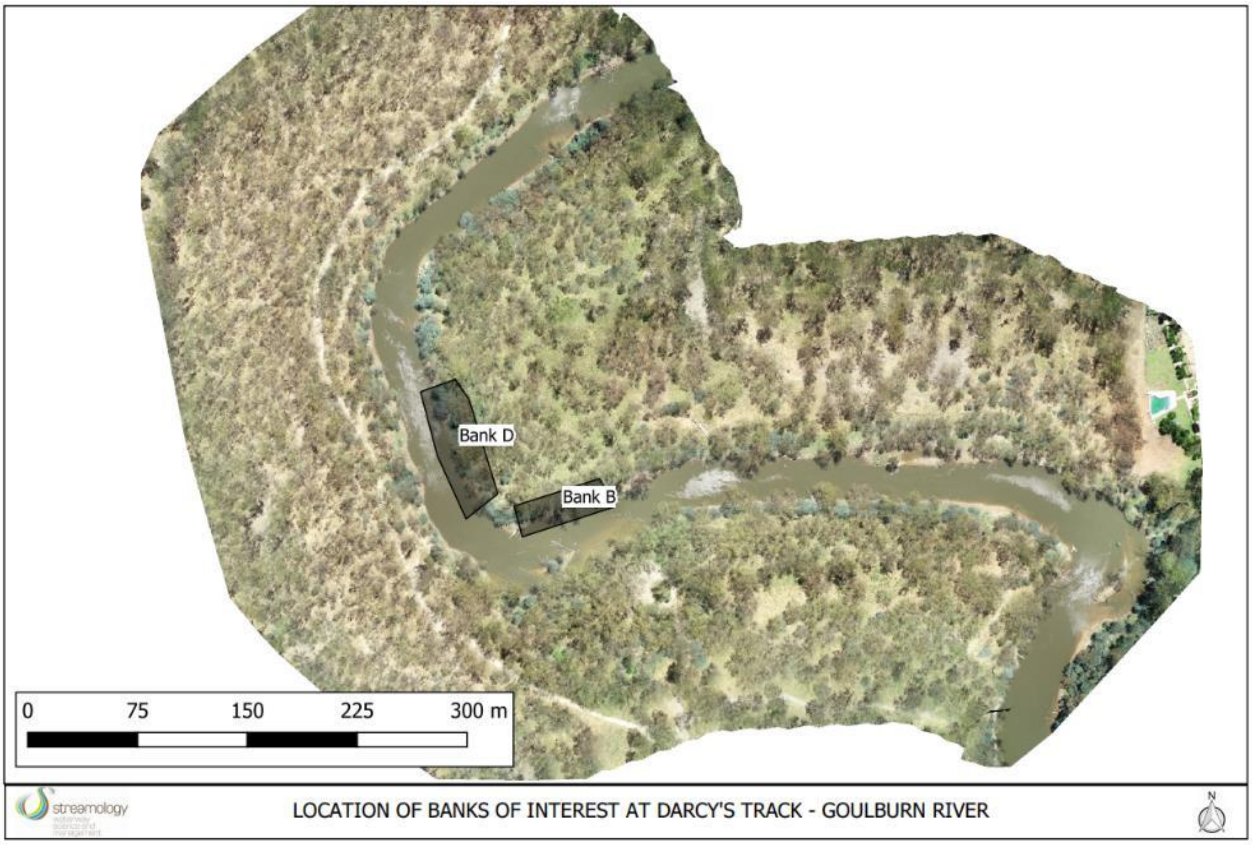


Figure 4-1 Location of Banks of Interest at Darcy's Track – Goulburn River.

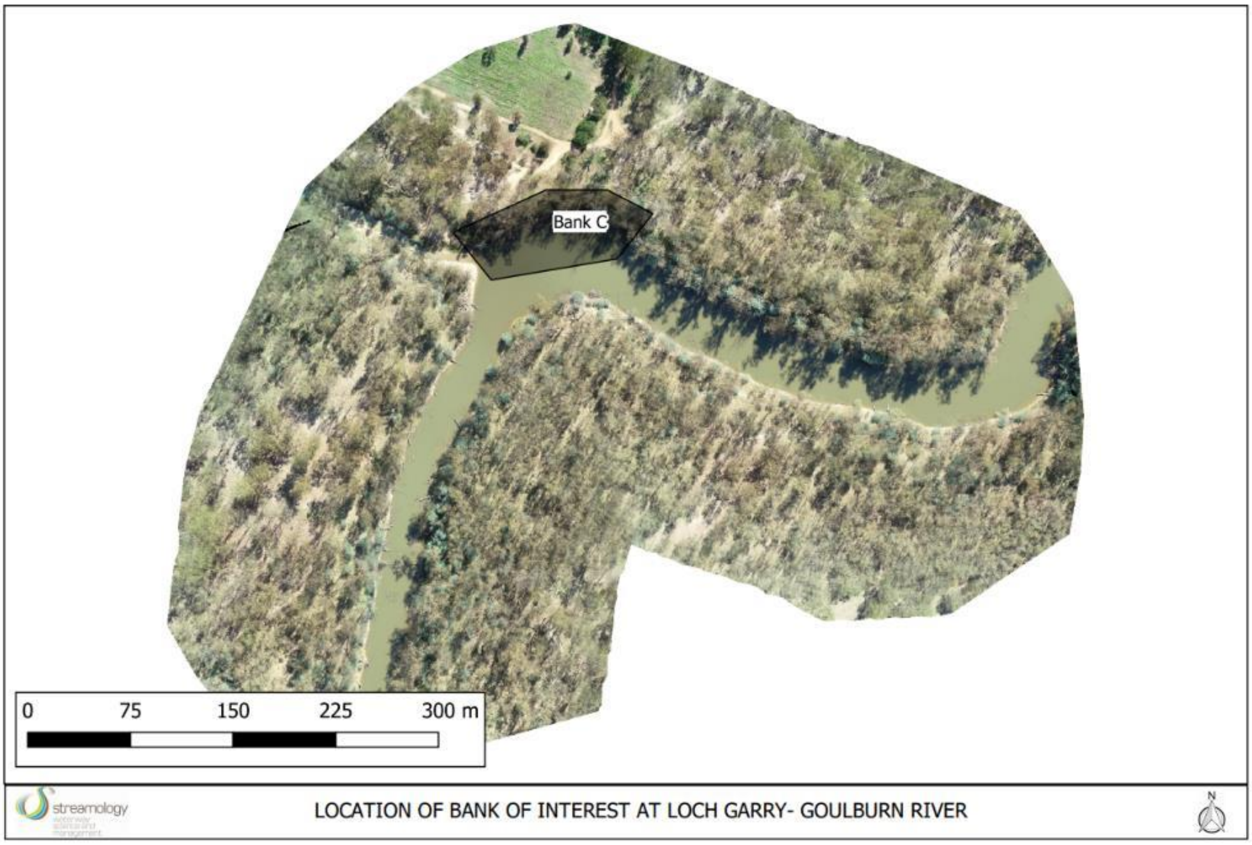


Figure 4-2 Location of Bank of Interest at Loch Garry – Goulburn River.

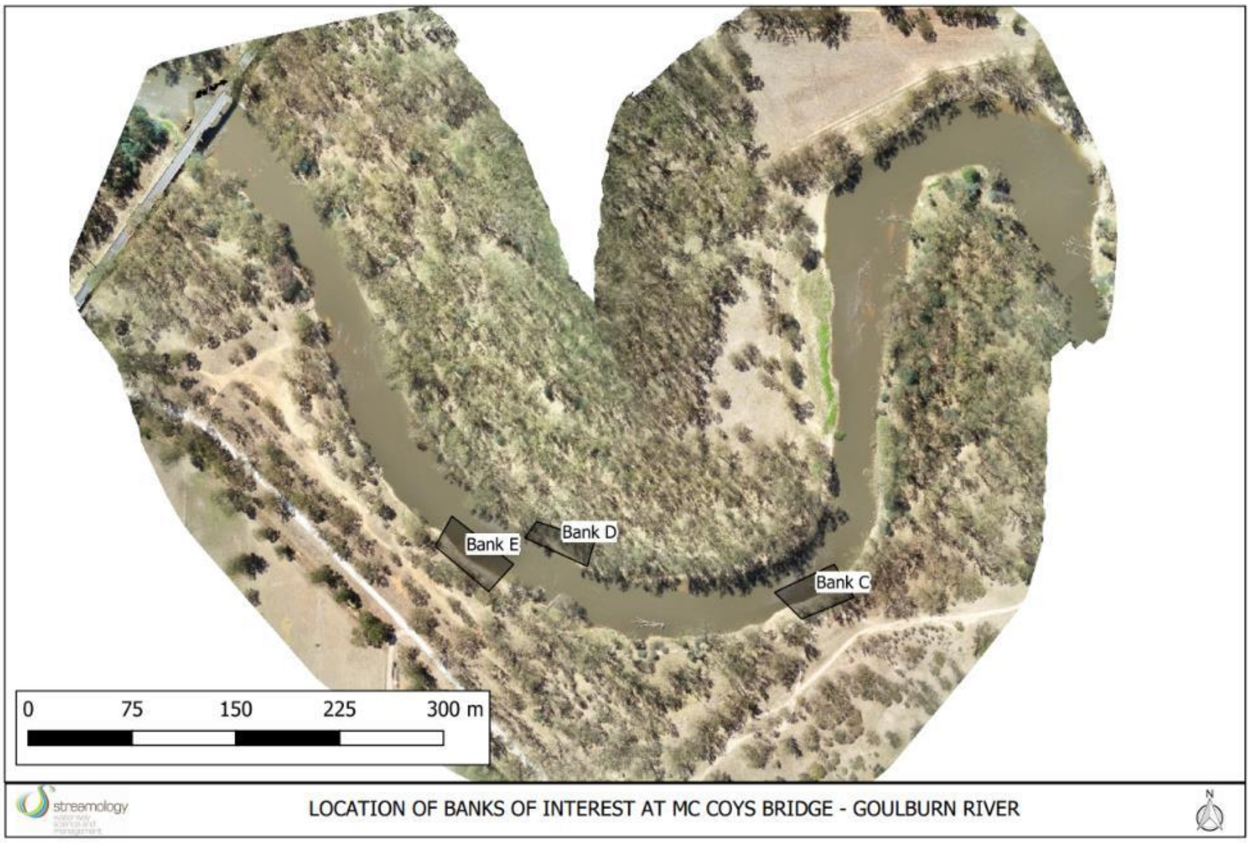


Figure 4-3 Location of Banks of Interest at McCoy's Bridge – Goulburn River.

4.4.2. Methods

Outcomes of environmental water use were based on periodic monitoring and the resulting quantitative data combined with observations in the field, historic research, and findings from past projects on the Goulburn.

Bank erosion was assessed in the LTIM Project using erosion pins and measurements of erosion and deposition. In 2019-20 the method was updated to use an Unmanned Aerial Vehicle (UAV) – this method was continued in 2020-21. Specifically, UAV flights are made before and after a flow event to create a Digital Elevation Model of Difference (DEMOD), which is the comparison of two 3D models of the same bank, before and after a flow event. The output of this method is far superior to the erosion pins method used previously, as it a) creates a very high-resolution (tens of thousands of points per m²) model of bank form across the entire bank section being surveyed, and b) provides a visualisation of the change occurring on banks, therefore allowing the analysis of the geomorphic processes contributing to erosion and deposition in response to flow events.

The infographic below in Figure 4-4 provides an overview of the methodology used to monitor bank condition in response to hydrological events delivered within the Goulburn system during the last 12 months. For a more detailed description of these methods refer to the DEWLP IVT Monitoring report 2019/20 (Streamology & Arthur Rylah Institute 2020). A number of riverbanks were surveyed at the following sites along the Goulburn River: Darcy's Track, Loch Garry and McCoy's Bridge.

Figure 4-4 Infographic providing an over-view of the methodology applied to bank and vegetation condition analysis using UAV technology (Streamology & Arthur Rylah Institute 2020).

4.4.3. Bayesian analysis

In addition to the descriptive results below, erosion and deposition data were analysed with a hierarchical Bayesian model that related erosion or deposition to the duration of inundation experienced by a point on the bank. For these analyses, 1000 spatial points were selected at random from each bank in the analysis and changes over time from before to after flow events were assessed. The model is presented below.

$$y_{ijk} \sim Bern(p_{ijk}) \qquad \text{Equation 4-1}$$

$$logit(p_{ijk}) = int + eff.inund_k \times inund_{ijk} + eff.survey_j \qquad \text{Equation 4-2}$$

$$eff.inund_k \sim Normal(\mu\_inund_k, \sigma\_inund) \qquad \text{Equation 4-3a}$$

$$eff.survey_j \sim Normal(0, \sigma\_survey) \quad \text{Equation 4-3c}$$

The occurrence of erosion or deposition (*y*) for observation *i* at site *k* during survey *j* is a Bernoulli-distributed event with probability *p*. This is driven by a global average erosion/deposition across all sites in the absence of inundation (*int*), plus the effect of inundation duration (*eff.inund*) for each site, which was modelled hierarchically, multiplied by the duration of inundation (*inund*). There is a random effect of survey (*eff.survey*) to capture any seasonal or other systematic differences among survey periods in erosion/deposition.

Effect of inundation is drawn from individual distribution for each site (Equation 4-3a). Inundation duration (i.e. the number of days a point is underwater between the surveys) is adopted as the model predictor (*inund* in Equation 4-2).

Two sets of analyses were carried out. The first assessed the effect of the duration of inundation for any individual point in the bank. The second aimed to investigate notching. For this model, the data were prepared differently. Instead of calculating the inundation duration, we calculated the number of days the water surface was within a small distance (±10 cm) of the point's elevation at the start of the survey (*inund* in Equation 4-2).

We assessed three endpoints: Severe erosion was defined as erosion of greater than 30 mm from the beginning to the end of the survey. Minor erosion was defined as erosion <30 mm. Deposition was defined as deposition greater than 5 mm.

4.5. Results

Bank condition was assessed by looking at change (erosion and deposition) in response to the three flow events captured throughout the 2020-21 monitoring period (Figure 4-5). The three flow events were the Spring Fresh, IVT Period and Autumn Fresh.

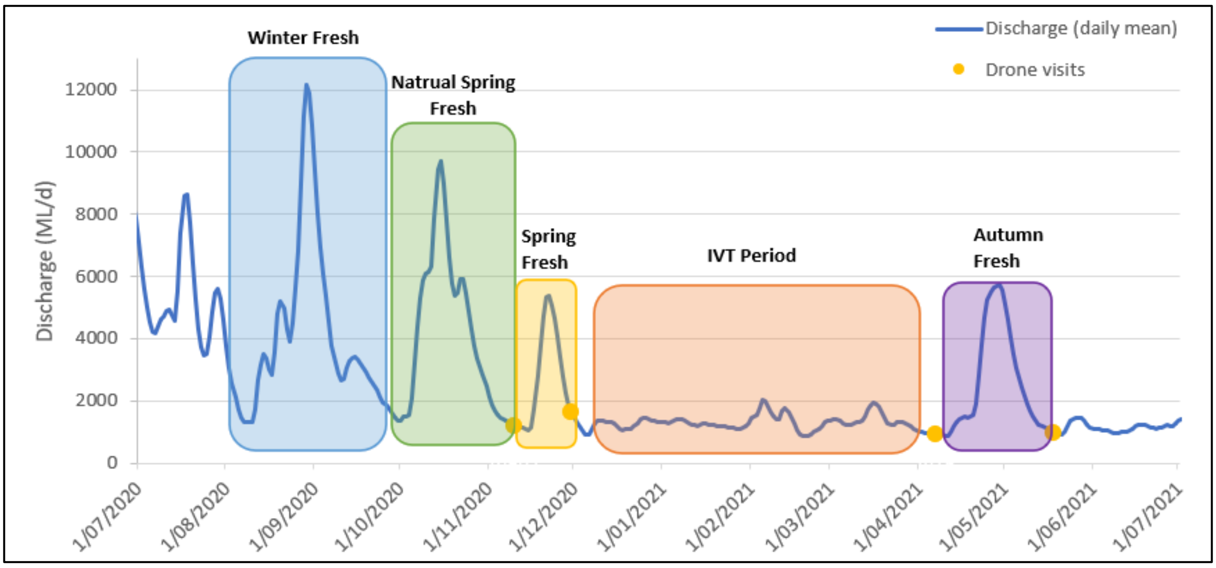


Figure 4-5 Bank survey visits during the monitoring period in relation to daily mean discharge at McCoy's Bridge (405232).

4.5.1. Initial hypothesis linked to hydrology

The major differences between the flow deliveries across the monitoring period are their duration, range of flows, and peak magnitude. Both freshes had similar range and magnitude of flows at 921 – 5,376 ML/d for the Spring Fresh and 982 – 5,723 ML/d for the Autumn Fresh. The IVT flows were overall lower at 851 – 2,013 ML/d, however the duration was much longer. The Spring and Autumn Freshes lasted 22 days and 37 days, respectively, compared with 126 days for the IVT period. Flow duration histograms for each period are provided in Figure 4-6.

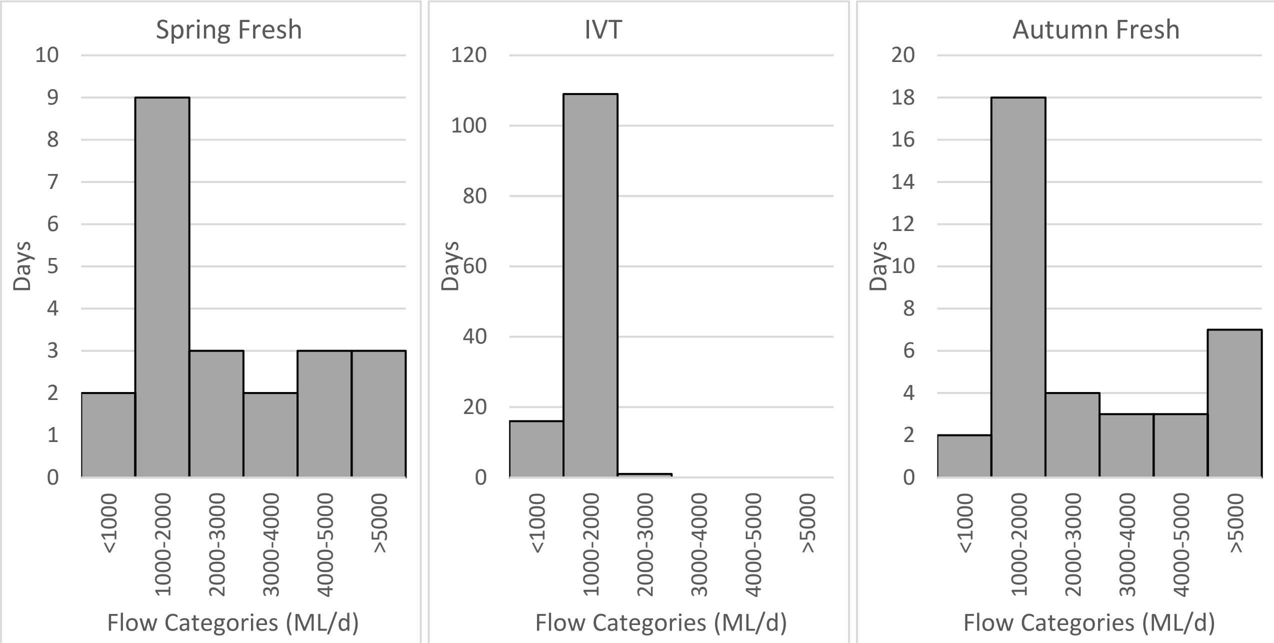


Figure 4-6 Histograms of flow duration for the three different flow delivery periods. Note the different vertical axis scales.

Bank zones of inundation

Both freshes reached maximum discharges of close to 6,000 ML/d which is high enough to reach the mid/upper bank zone at most banks monitored. The main exceptions would be large banks such as McCoy's Bridge bank C and the Loch Garry bank C where maximum flow events would have reached what could be referred to as mid rather than mid/upper banks zones. For simplicity's sake in the results section, we discuss bank zones which equate to flows >3,000 ML/d as mid/upper bank zone.

Tributary flow and flow Sequence

Tributary flow and the preceding flow events are both important variables to consider when analysing riverbank response to flow events. High contribution of tributary flow, as seen during the Spring Fresh (Table 4-3), can contribute significantly to deposition events due to the increased suspended sediment load carried by these flows. Prior flow events contribute primarily to erosion events through *preparation.* This was found in 2019/20, where the IVT period prepared the riverbanks for erosion events during the *Recession Flow* (or Autumn Fresh). The same order of flows was delivered this year (2020/21) with the order of delivery being (1) Spring Fresh, (2) IVT and (3) Autumn Fresh (Figure 4-5).

Table 4-3 Percentage of the total flow contributed by the tributary flow by site on the Goulburn River for each flow period.

Monitoring Window and corresponding flow event	% Tributary Flow at Darcy's track	% Tributary Flow at Loch Garry & McCoy's Bridge
Spring Fresh (v1 – v2)	38%	35%
IVT Period (v2 – v3)	30%	29%
Autumn Fresh (v3 – v4)	9%	9%

Previous results have shown that the long duration IVT flows result in more severe erosion to the lower bank, versus shorter, higher magnitude freshes. The outcome is that IVT flows lead to steeper and less stable bank profiles. Shorter duration, higher peak flow freshes vary over a wider swath of bank and have, in the past, resulted in erosion of the upper bank and deposition on the lower bank, working to counteract the steepening effect of IVT flows on the bank. Our hypotheses for the 2020-21 monitoring are based on these observations, and consideration of historic results. These hypotheses are detailed in Table 4-4.

Table 4-4 Hypotheses relating to hydrology summarised.

Monitoring window and corresponding flow event	Hypothesis
Spring Fresh (v1 – v2)	Relatively high flows (50% of days >2,200 ML/d) will lead to a pattern of change in which erosion dominates higher on the bank, with deposition across the mid/lower bank being extensive as a result of high percentage contribution from tributary flows (38% & 35%).
IVT Period (v2 – v3)	Long duration of relatively low flows (126 days in total, all below 2,200 ML/d) will result in both more severe erosion and less deposition on the lower bank. Minimal change will occur on the upper bank. Where historic notching in the system is present, this will result in a large amount of erosion and low deposition (due to cyclical nature of delivery).
Autumn Fresh (v3 – v4)	Similar flow pattern to Spring Fresh (43% of days >2,200 ML/d) therefore hypothesis is the same: erosion dominating on the upper bank, deposition on the mid/lower bank but to a lesser extent due to the reduced tributary flow contribution (9%).

4.5.2. Bank condition modelling

The probability of erosion or deposition occurring at each site was modelled using subsampled data from the bank condition DEMODs for the last two years of drone monitoring (2019-21). The modelling calculated the probability of erosion or deposition as a result of either the absolute duration of inundation or the duration of the period where the point on the bank was within ± 10 cm of the water surface (aimed at assessing notching). The probability of erosion (or deposition) and notching was also modelled under a counterfactual scenario, in which environmental flows did not occur. The key insights can be found in the sections below, for additional supporting information for the modelling of bank change related to Environmental Flows and notching analysis go to the Appendix B.

With environmental flows

<u>Inundation duration impact on probability of erosion or deposition</u>

The probabilities of severe erosion, minor erosion and deposition are all increased with an increasing duration of inundation (Figure 4-7), although the effect was not 'significant' (95% credible intervals of the regression slope estimates crossed zero) for severe erosion at McCoy's Bridge and minor erosion at Darcy's Track. The magnitude of the effect was largest at Loch Garry for all three endpoints

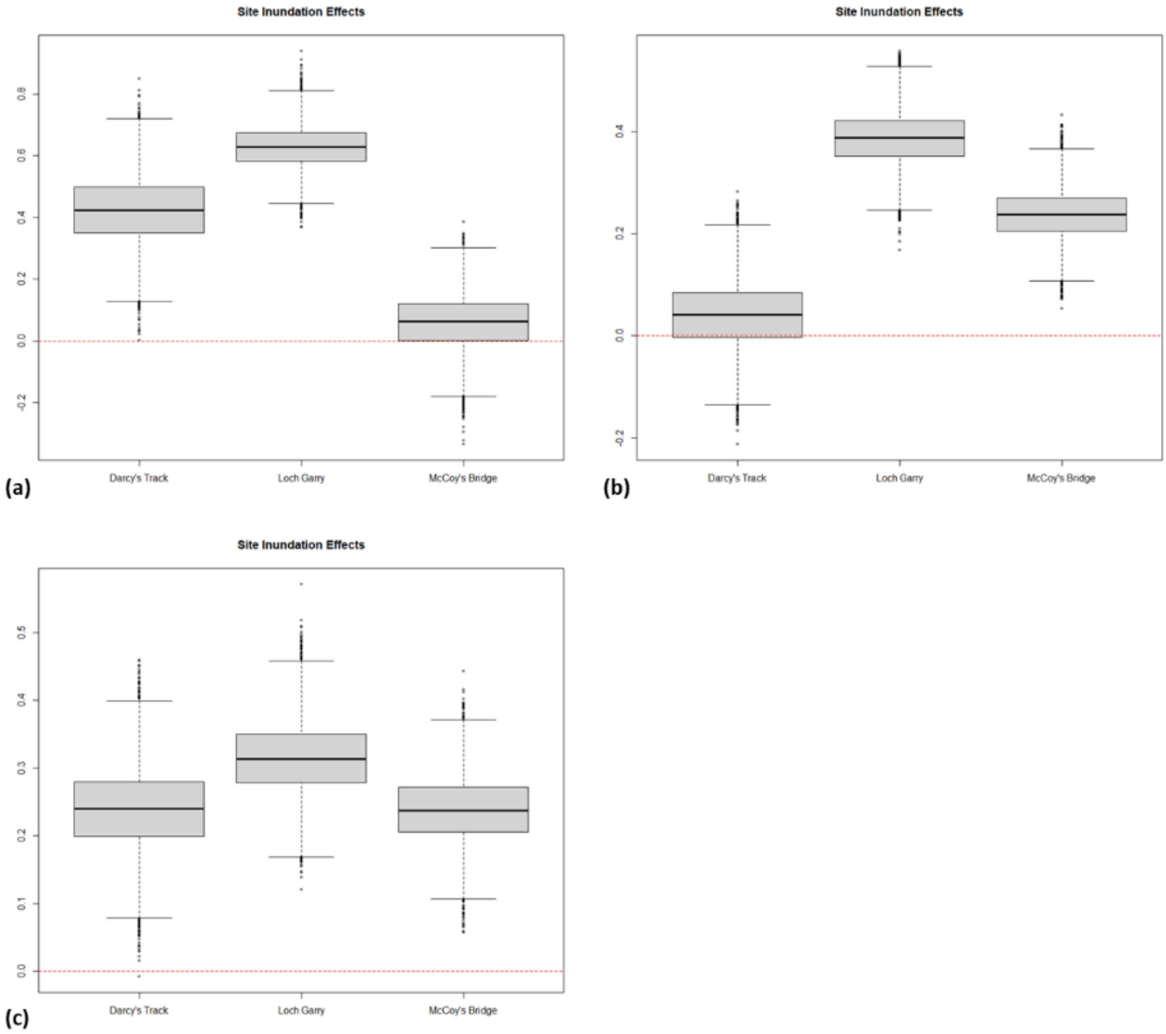


Figure 4-7 Site inundation effects on the probability of erosion. (a) significant erosion: > 30 mm; (b) erosion: > 5 mm; (c) deposition: > 5 mm. For each erosion level, results are shown for three sites (Darcy's Track, Loch Garry, and McCoy's Bridge). Note that the results for deposition (c) have been 'inverted' relative to model output. Deposition data are recorded as negative numbers in the data set, and so an increase in deposition associated with an increase in inundation is manifested as a negative parameter estimate. By inverting the result, the output is more intuitive (i.e. more inundation leads to more deposition).

Inundation duration impact on probability of notching

Regarding notching analysis, the results were more variable. The probability of significant erosion increases with longer duration of the water surface being within ± 10 cm of the measured point on the bank at Darcy's Track and Loch Garry, but decreases at McCoy's Bridge (Figure 4-8a). For minor erosion and deposition, increases are observed at Loch Garry and McCoy's Bridge, but a decrease at Darcy's Track (Figure 4-8b, c).

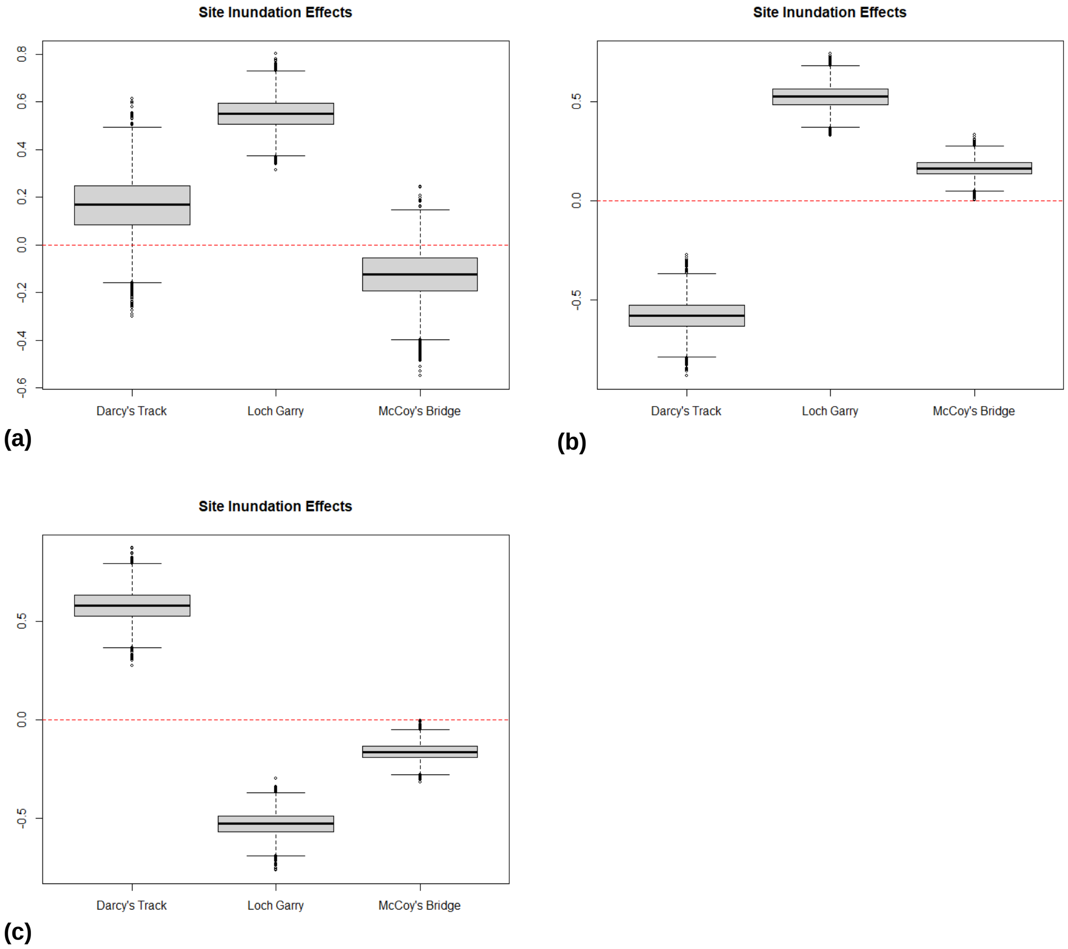


Figure 4-8 Site inundation effects on the probability of notching. (a) significant erosion: > 30 mm; (b) erosion: > 5 mm; (c) deposition: < 5 mm. For each erosion level, results are shown for three sites (Darcy's Track, Loch Garry, and McCoy's Bridge). As with Figure 1c, panel (c) is inverted relative to analysis output.

Without environmental flows (counterfactual)

By running the models with and without the environmental flows delivered from 2019 to 2021, we can see the predicted difference in probability of erosion at different points on the bank.

With a reduction in flows, we expect to see less erosion and deposition, and this is borne out in the results (Figure C-2, Appendix C). However, the variable effects of inundation seen at the three different sites on erosion lead to varying results when models are run with and without environmental flows; almost no difference at McCoy's Bridge for severe erosion and only small differences at Darcy's Track for minor erosion. We can see that the major changes are seen low on the bank. This makes sense because it is these areas that would see the greatest changes in flow regimes with the removal of environmental flows.

The change in the probability of notching-related erosion and deposition with and without environmental flows shows that increases in erosion are confined to the lower levels of the banks, to elevations inundated by baseflows and the higher baseflows of IVT season (Figure C-4, Appendix C). There is less sign of enhanced deposition, with the exception of Loch Garry. The presence of negative changes in probabilities for erosion and deposition reflect the fact that removal of environmental flows will expose some portions of the bank to longer durations of 'near surface' inundation, but probably lower on the bank. It is also worth noting that the removal of environmental flows does not affect the delivery of IVT flows. In future it would be possible to run a counterfactual version of this analysis that removes IVTs from the hydrograph rather than environmental water.

4.5.3. Analysis of geomorphic processes relating to flow events

Digital Elevation Models of Difference (DEMODs) were used to assess the magnitude of erosion and deposition in response to freshes and IVT flows. Detailed analytical results are present in Appendix C and summarised below. Sites are presented from upstream to downstream (Darcy's Track, Loch Garry and McCoy's Bridge). A summary of key patterns of change revealed by the DEMODs for each bank period is provided in Table 4-5, with further detail for the different flow types provided below.

Table 4-5 Summary of results from DEMODs.

Site and Bank	Spring Fresh	IVT	Autumn Fresh
Darcy's Track Bank B	No data	No data	• Erosion dominates lower bank upstream. • Deposition dominates lower bank downstream. **Hypothesis supported: Partly**
Darcy's Track Bank D	• Erosion dominates across whole bank but more severe on lower bank. • Minimal deposition **Hypothesis supported: No**	• Erosion dominates, including severe erosion on the lower bank. • Deposition more common on the upper bank. **Hypothesis supported: Yes**	• Erosion widespread but more severe on lower-mid bank. • Deposition widespread but more severe on mid-upper bank. **Hypothesis supported: No**
Loch Garry Bank C	• Deposition dominates across upper and lower bank. • Minimal erosion. **Hypothesis supported: Partly**	• Erosion dominates, especially on lower bank. • Minimal deposition. **Hypothesis supported: Yes**	• Minor deposition dominates on lower bank. • Minor erosion on upper bank. **Hypothesis supported: Yes**
McCoy's Bridge Bank C	No data	• Erosion dominates lower bank. • Deposition dominates upper bank (due to accumulated debris). **Hypothesis supported: Yes**	• Minimal erosion or deposition. • No discernible pattern. **Hypothesis supported: Unknown**
McCoy's Bridge Bank D	No data	• Deposition dominates lower-mid and is more severe on lower bank. • Some erosion on lower bank but mostly mid-upper bank. **Hypothesis supported: No**	• Deposition dominates, mostly on lower-mid bank. • Erosion worse on upper bank. **Hypothesis supported: Yes**
McCoy's Bridge Bank E	• Deposition dominates upstream and on the lower bank. • Erosion dominated upstream and on the mid bank. **Hypothesis supported: Yes**	• Both erosion and deposition on lower bank. • Negligible change on upper bank. **Hypothesis supported: Partly**	• Deposition dominates, mostly on the upper bank. • Erosion mostly on lower bank. **Hypothesis supported: No**

Summary of observations from DEMODs & histogram analysis

Spring Fresh

- Erosion was apparent on the mid/upper bank zones and zones relating to historic IVT erosion events. Deposition was primarily more apparent on the lower banks and of greater depths compared to other events.
- Erosion was generally minor for the Spring Fresh at Loch Garry Bank C, and was roughly balanced with deposition at McCoy's Bridge Bank E, both of which showed minimal erosion on the lower bank, providing partial support for the hypothesis. Erosion was the dominant process at one site (Darcy's Track Bank D), where it was more severe on the lower bank, thereby partially supporting the hypothesis in that historic IVT zones are likely to be eroded by freshes.
- Deposition dominated at one site, Loch Garry Bank C, and covered the entire bank. At McCoy's Bridge Bank E, there was a greater magnitude of deposition on the lower bank, which is in line with the hypothesis. At Darcy's Track Bank D, deposition was low in volume and concentrated around areas with increased roughness (roots or vegetation) across a broad range of vertical bank – partially supporting the hypothesis related to deposition range.
- Histograms illustrate that the Spring fresh resulted in higher volumes of deeper deposition than the other flow events (see Section 4.5.4).

Autumn Fresh

- Minor erosion and deposition (<30 mm) were more dominant in response to the Autumn fresh than the Spring Fresh and in some cases even the IVT period. Both were found at an extensive vertical range of bank, linking to flow.
- Erosion was minor overall for the Autumn Fresh but dominated the upper bank at two sites (Loch Garry Bank C and McCoy's Bridge Bank D), supporting the hypothesis. However, at two other sites (Darcy's Track Bank D and McCoy's Bridge Bank E) erosion was more severe on the lower bank, linking to preceding IVT erosion zones. At the remaining two sites the pattern of change was ambiguous, with Darcy's Track Bank B displaying minor erosion at one end (but deposition at the other) and McCoy's Bridge Bank C showing negligible change of any sort.
- Deposition dominated the lower bank at two sites (Loch Garry Bank C and McCoy's Bridge Bank D) and was shallower in depth than change linked to the Spring Fresh. Darcy's Track Bank D and McCoy's Bridge Bank E, deposition was more common on the upper bank, both findings support the hypotheses relating to deposition depth and location. At one site (McCoy's Bridge – Bank E) deposition was concentrated around areas of roughness.
- Histograms illustrate that deep deposition was greater at Darcy's Track Bank D than other time periods and fine deposition (on the majority of banks) was greater than seen related to other flow events (see Section 4.5.4).

IVT

- Defined erosion to lower bank at varying depths was the primary process visible across banks. This was apparent at all banks except McCoy's Bank E where there is more vegetation.
- Erosion overall was more severe during the IVT period compared with the Spring and Autumn Freshes. At three sites (Darcy's Track Bank D, Loch Garry Bank C, and McCoy's Bridge Bank C) it was the dominant process on the lower bank, supporting the hypothesis for IVT flows. Deep, defined and extensive erosion at Darcy's Track Bank D appears to be leading to minor notching and mass-failure with depths of erosion up to 0.2m in depth, extensively across the lower bank face. For one site (McCoy's Bridge Bank D), the pattern of erosion was diverse with erosion apparent at the lower/mid and mid-bank zone, with deposition above and below, illustrating dynamic sediment movement related to flow at this inside bank. At McCoy's Bridge Bank E there was similar amounts of erosion and deposition on the lower bank, and minimal change on the upper bank, providing partial support for the hypothesis.
- Deposition was generally minor during the IVT period. It was minimal on the upper bank for three sites (Darcy's Track Bank D, Loch Garry Bank C, and McCoy's Bridge Bank E), as hypothesised for this flow type. Despite relatively low peak flows for the IVT (87% of days <2,000 ML/d), McCoy's Bridge Bank C showed greater than expected deposition on the upper bank, where flows would not have reached. This apparent deposition is explained by an accumulation of leaf litter and other organic debris. In some cases apparent deposition also appears to link to erosion locations higher on the bank face.
- Histograms showed both minor and severe (>30 mm) erosion was more apparent on banks related to the IVT flow period in all cases but McCoy's Bridge Bank E (see Section 4.5.4).

4.5.4. Histogram analysis of different flow periods

Histograms of change were computed for the three banks where all flow periods were captured (Darcy's Track Bank D, Loch Garry Bank C, and McCoy's Bridge Bank E). The plots below display the prevalence of erosion and deposition for each flow event and period (vertical axis) and the severity of that change (horizontal axis). The prevalence represents the percentage of points in the DEMOD point cloud where change of a given magnitude (up to a maximum of 0.1m erosion or deposition).

Darcy's Track Bank D

The curves for the two freshes have similar shape, but the Spring Fresh is shifted to the right, indicating that erosion was the dominant process during that period, and that there was a greater prevalence of higher magnitude erosion (Figure 4-9). In contrast, the Autumn Fresh curve reveals change that is more balanced between erosion and deposition. The higher peak of the IVT curve indicates a greater prevalence of low magnitude changes than for the freshes. However, the second small peak to the right represents severe erosion was more common during the IVT period, compared with the freshes.

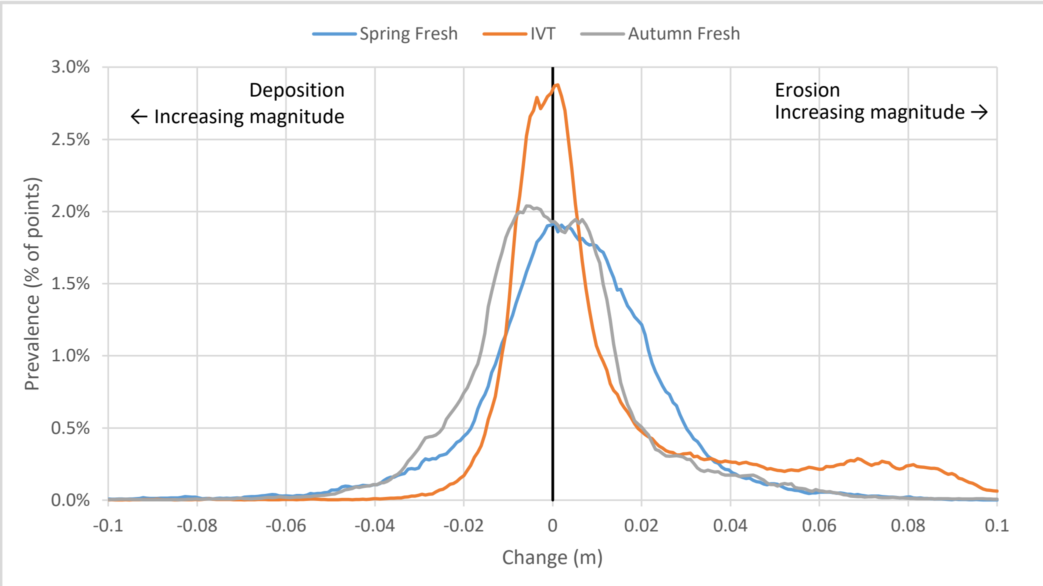


Figure 4-9 Histogram showing prevalence and magnitude of change at Darcy's Track Bank D for the three flow periods.

Loch Garry Bank C

The three flow periods resulted in more marked differences in change at Loch Garry Bank C (Figure 4-10). Both freshes are shifted left, indicating a general dominance by deposition, especially the Spring Fresh where the vast majority of change was deposition, and it was of higher magnitude. The Autumn Fresh resulted in overall deposition dominated change, and a higher prevalence of minor change (both erosion and deposition). In contrast, compared to the freshes, the IVT period caused a higher frequency (area) of both severe and minor erosion events.

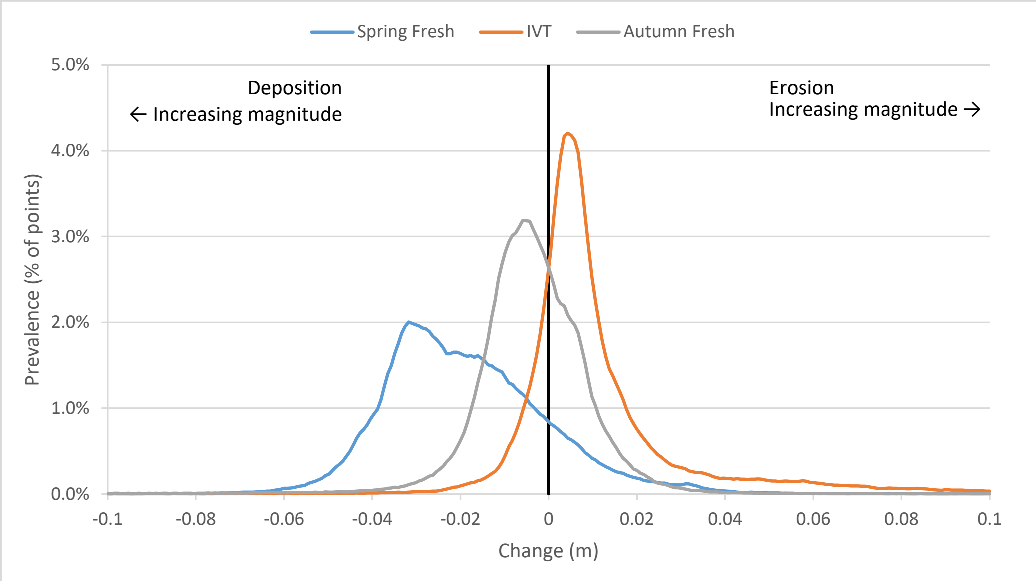


Figure 4-10 Histogram showing prevalence and magnitude of change at Loch Garry Bank C for the three flow periods.

McCoy's Bridge Bank E

At McCoy's Bridge Bank E (Figure 4-11), the Spring Fresh resulted in a greater prevalence of major magnitude change, both erosion and deposition, than the other two flow events, and a slight overall dominance by deposition. The Autumn Fresh was also slightly shifted towards deposition but with more change of a low magnitude. The IVT event resulted in more deposition than erosion overall, but with a greater prevalence of minor change than for the Spring Fresh.

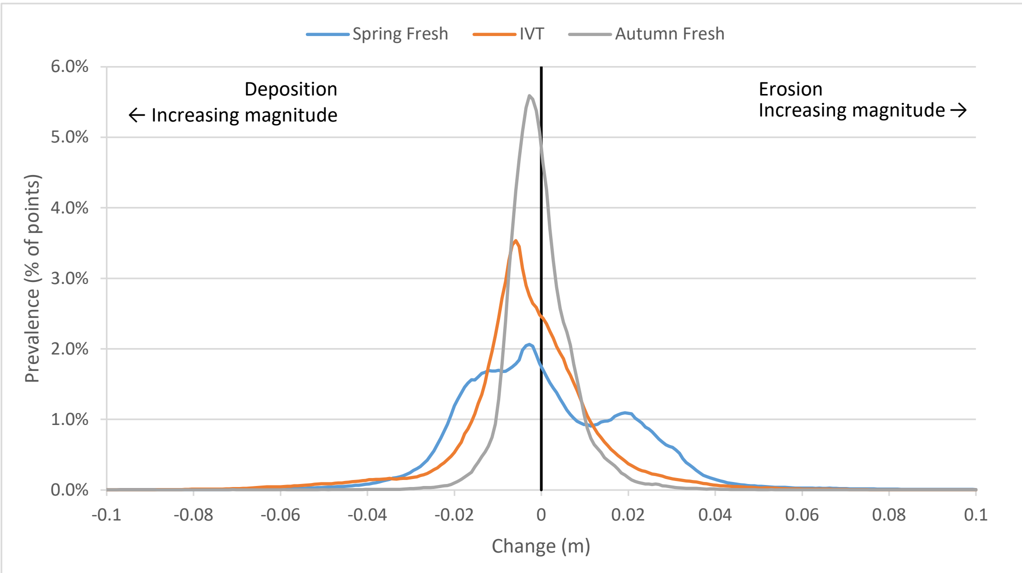


Figure 4-11 Histogram showing prevalence and magnitude of change at McCoy's Bridge Bank E for the three flow periods.

4.6. Discussion

4.6.1. Summary of 2020/21 results

How are the two freshes producing different results?

Both freshes resulted in similar patterns of change regarding the dominance of deposition. The main differences between the Autumn Fresh and the Spring Fresh were, (1) the location of deposition after the Autumn Fresh, in most cases, was higher on the bank resulting, and (2) the depth the deposition after the Autumn Fresh was shallower (less than 30mm). In some cases, the depth of deposition was considerably greater in response to the Spring Fresh (Loch Garry Bank C, McCoy's Bridge Bank E) this links to the increased tributary flow contribution.

The flow duration histograms illustrate that the riverbanks were inundated for considerably more time during the Autumn Fresh than the Spring Fresh, which would counter the findings, however the increased tributary flow percentage experienced during the Spring Fresh supports the idea that the deposition volumes would be greater due to increased suspended sediment in flows.

Is the order of flow events playing a role in terms of preparation?

The large natural flow events which occurred prior to the Spring Fresh appear to have prepared some banks for large erosion events due to the ease of removal of fresh deposits (from prior events) in vulnerable bank zones. This would explain the erosion across mid/upper bank zones seen at the majority of banks.

The IVT event appears to have – as was seen last year – prepared areas of the lower bank zone at sites for increased erosion. This is mainly apparent at McCoy's Bank E and Darcy's Bank D. Historic findings would support that the Spring/Summer IVT period, with its lack of inundation above bank zones relating to >3,000 ML/d, led to the drying of previous deposits across the upper area of the bank, and thus there was less malleable sediment (from recent deposits) in this zone and thus the erosion measured was shallower in depth.

How does this compare to findings from IVT flows?

In general, the IVT flows resulted in a greater prevalence of erosion, and more severe erosion to the lower bank relating to the flow period (flow primarily related to the band 1,000 – 2,000 ML/d), compared with the freshes. This erosion was more defined and thus deeper (up to 0.2 m in one case) and there are signs of notch development and minor mass-failure events at Darcy's Track Bank D. The following factors are contributing to these processes: (1) prolonged, relatively consistent flows impacting the same lower part of the bank, (2) the longer time period over which change was able to occur (from December 2020 to March 2021), and (3) the hot summer weather (leading to the rapid wetting and drying of clay-rich sediment, which can lead to cracking and rapid destabilisation of bank material).

Table 4-6 provides a summary of outcomes associated with each event in relation to stated hypotheses.

Table 4-6 Response to initial hypotheses.

Flow event	Hypothesis	Supported or rejected
Spring Fresh (v1 – v2)	Relatively high flows (50% of days >2,200 ML/d) will lead to a pattern of change in which erosion dominates higher on the bank, with deposition on the lower/mid bank. Increased % tributary flows (35% & 38%) encourage increased sediment deposit volume.	**Partly Supported.** Deposition dominated across the whole bank at 2/3 sites and was primarily deep/thick versus shallow/thin, with one displaying a greater magnitude on the lower bank. Erosion was minimal at the same sites, including on the upper bank. The third site displayed an opposite pattern (erosion dominating lower bank).
IVT Period (v2 – v3)	1.Long duration of relatively low flows (126 days in total, all below 2,200 ML/d) will result in both more severe erosion and less deposition on the lower bank. Minimal change will occur on the upper bank. 2. Where historic notching in the system is present, this will result in a large amount of erosion and low deposition (due to cyclical nature of delivery).	**1. Supported**. Erosion was generally more severe, including on the lower bank at 3/5 sites. Deposition was generally minimal, including on the upper bank of the same three sites. At another site similar amounts of erosion and deposition occurred on the lower bank, with negligible change to the upper bank. A single site displayed a pattern of change which displayed layers of erosion and deposition, with deposition at the toe of bank. This partly supports the hypothesis with erosion lower and deposition higher, but it is not clear-cut. **2. Supported.** Erosion was most severe at locations which relate to IVT erosion events from 2019-2020 IVTs at 3 banks.
Autumn Fresh (v3 – v4)	Similar flow pattern to Spring Fresh (43% of days >2,200 ML/d), however longer total flow period, and more time > 5,000 ML/d, prior flow event was IVT. Expectation is that erosion is greater than Spring Fresh due to extended flow period,	**Partly supported**. Erosion was high on the bank at 2/6 sites and was found to be deeper in IVT erosion locations at 2/6 sites. The other sites showed mixtures of the two and in one case very little sign of erosion. Deposition was located across a broad range of vertical bank including the low/mid zone as hypothesised on 4/6 banks.

Flow event	Hypothesis	Supported or rejected
	dominating on upper bank AND in areas of existing IVT erosion. Deposition on lower/mid bank is the same as Spring Fresh despite increased flow duration due to decreased tributary flow contribution percentage was lower (9% vs 35% & 38%).	The remaining two sites produced ambiguous results (negligible change or opposite patterns upstream vs. downstream). Deposition was not the same depth as seen in Spring Fresh, it was shallower/finer, but spread with more vertical range on the banks.

Comparison of bank condition modelling with histogram analysis

The findings from of the bank condition modelling are partially supported by the histogram analysis in the following ways:

- Duration of inundation is a strong predictor of change, especially for minor erosion and deposition. This is in line with the histogram analysis where there was a greater prevalence of low magnitude erosion and deposition as a result of the longer IVT period, than for the shorter Spring Fresh at all three sites, and Autumn Fresh at two sites (Darcy's Track and Loch Garry).
- Inundation duration was also a predictor of significant erosion (>30 mm) at Loch Garry, which aligns with the histogram results that show a clear increase in the prevalence of high magnitude erosion as a result of the longer duration IVT, versus both freshes.
- At McCoy's Bridge the probability of significant erosion was only weakly predicted by increased inundation. This may be explained by the greater prevalence of high magnitude erosion at that site during the Spring Fresh (the shortest flow period), which was greater than the longer IVT period or Autumn Fresh.
- Inundation duration was a good predictor of significant erosion at Darcy's Track, which aligns with the histogram analysis that shows a greater prevalence of high magnitude erosion during the longer duration IVT compared with either of the shorter freshes.
- The statistical modelling does not consider tributary flow in analysis of deposition volume, this is an important variable that could be considered during the modelling process next year. Nonetheless, deposition was strongly predicted by duration of inundation at all three sites.

4.6.2. Response to evaluation questions

The following section provides a summary of specific responses to evaluation questions.

How do CEWH environmental/variable flows contribute to sustaining bank condition?

This year's hypothesis (based on last year's findings) was supported in the majority of cases, highlighting that freshes result in (1) erosion that is lower impact (less defined and deep) compared to IVT events, (2) erosion is more common to mid and upper bank zones rather than low zones (which IVT deliveries affect), and (3) result in considerable sediment deposits across the bank face, which are more substantial across the mid/lower bank zone (and which can work to repair damage from IVTs).

Results this year, again support that both tributary flow contribution and prior flow events play a critical role in bank repair, and preparing banks for future erosion/deposition events, respectively. Thus both erosion and deposition volumes relating to freshes must continue to be considered when attributing changes in bank condition to isolated flow events (such as independent environmental flows).

The sediment within the system (driven partly by the water source) plays a key role in providing mud-drapes, which help to (a) repair riverbanks and, (b) introduce seeds on riverbanks for potential vegetation regeneration.

Although the environmental flows monitored resulted in some areas of significant erosion (at some banks the highest across all events), this erosion was expressed with large vertical variability across banks, with primary areas located above the bank zone corresponding to 3,000 ML/d. Minor erosion to upper banks like this results in the resetting of steepening and in-filling of notches at the lower bank level and thus results in long term benefits to the physical form of the channel by stabilising the processes of notching and reducing future mass failure events.

The deposition recorded in response to environmental flows ranged from extensive and shallow to extensive/variable deep (with the Spring Fresh contributing the deepest deposition and the Autumn Fresh resulting in the shallowest deposition). In both cases this process of draping deposits over the bank face during the receding limb of the flow event works to repair areas of past erosion on lower/mid-level banks and introduces seed to areas which aid the process of vegetation regeneration.

Are CEWH environmental/variable flows adversely impacting the banks of the rivers?

The majority of the data would support the contention that, environmental flows are not adversely impacting riverbanks. On the contrary the mud-drapes occurring across riverbanks with the sediment and seeds they carry are contributing to bank repair. The positive impact of these events is largely down to (1) the source of water and corresponding sediment content, and (2) the delivery of the fresh. The latter relates to the scale of the event and the rate of fall, and was more favourable during the Autumn Fresh due to the longer period above 5,000 ML/d and the slower rate of fall as the water level receded post-event.

In two cases, there is evidence that the Autumn Fresh has triggered some erosion events to areas of the lower bank which link to areas of considerable erosion responding to IVT deliveries (e.g. Darcys Track Bank D). These events can be explained by the positioning of the Autumn Fresh delivery (directly after the IVT period), these events cannot be attributed directly or solely to the delivery of the Autumn fresh. Considerations in how freshes following the IVT period are addressed in the following sections.

And*, *how do timing and delivery of CEWH environmental/variable flows affect bank condition of rivers?

Environmental flows that piggy-back upon natural events are much more effective as they provide more sediment and seeds to the riverbanks for repair. This is most important after the IVT period as this is where damage is being done to the lower bank, but is also critical prior to the IVT as there is an opportunity for (1) the recent deposits to the mid/upper bank zones to consolidate, and (2) introduced seedlings to these mid/upper zones to establish. Both of these processes improve bank resilience.

Erosion events resulting from Environmental Flows that are delivered after the IVT flow period must be interpreted with respect to *IVT-driven bank preparation*. This is where IVT erosion events prepare the riverbanks for further erosion during subsequent events (either environmental or natural) in the same locations. Therefore, erosion events that occur in response to flow events delivered after the IVT period (Autumn Fresh 2021) need to consider the IVT period as a contributing factor and cannot be analysed independently.

The delivery of flows impact erosion and deposition in two major ways, (1) the scale of the flow determines the area of riverbank that can benefit from introduced sediment, and (2) the shape of the flow – with regard to the number of days at each bank zone (low/medium/high), in combination with the rate of fall, impacts the potential for erosion as the event is delivered. Rapid rates of fall result in erosion to vulnerable areas of bank. This is particularly relevant for the Autumn Fresh that followed the IVT flow (where erosion is most defined and severe). Hence, when planning environmental flow events environmental water managers need to:

1. 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 impact of preparation on riverbanks.
2. Deliver flows which gradually rise (to the upper bank zone related to flows >5,000 ML/d as a minimum but ideally >7,000ML/d) and gradually fall (to the lower bank zone related to flows <900 ML/d) 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.
3. Attempt to increase sediment and seed content within flows by maximising natural flow events where possible.

What timing and delivery of CEWH environmental/variable flows best sustain or improve bank condition for vegetation growth?

The Spring Fresh is critical as it provides the sediment and seeds to riverbanks at a period when the majority of plants are in their regeneration cycle. Introduced sediment and seeds during this time period enable the consolidation of sediment and the bedding of seeds to areas of vulnerable bank prior to the dry summer.

The Autumn Fresh period is also important as there is the potential for this event to repair some of the damage done to the lower banks through erosion from prolonged invariable flows during hot summer months from the IVT.

A mid-summer (IVT) flow event designed to inundate the upper bank zones may provide some benefit with regard to *vegetation values* within the system as this would provide more opportunity for seed establishment. If flows were dropped to below 900 ML/d after the event, this would provide the opportunity for germinants to become established.

In all cases these deliveries should result in hydrographs which gradually increase and decrease across the delivery period to reduce the hydrological stresses exerted upon riverbanks at concentrated locations and through rapid changes in discharge.

How do vegetation responses to CEWH environmental/variable flows vary between sites with different channel features and different bank condition?

Considering that the drone monitoring did not focus on vegetation analysis the following insights are more general observations from the DEMODS:

- Banks with a higher percentage of existing vegetation cover generally exhibit more stable bank conditions with the lowest magnitudes of erosion in response to environmental flows. Recent findings show that there is less evidence that managed (IVTs) and environmental flows are removing vegetation on the apex of outer bends (where fluvial stresses are generally highest); rather it is the cyclical nature of rising and falling water levels, during managed flows on inside bank sections that is eroding sediment across the lower/mid bank zone and adversely impacting vegetation cover in these areas.
- Areas of riverbank that experienced large erosion events during the IVT season of 2018/2019 and earlier have not recovered and still are devoid of vegetation.

4.6.3. Key takeaways and implications on future flow management

Environmental flows appear to benefit the long-term physical form of the channel, due to the vertical variability in erosion higher on the bank face. This works to counter the steepening effect that occurs in response to consistent low invariable flows (i.e., IVTs). This is particularly true where the fresh-driven erosion occurs on the mid and upper bank zones at levels equivalent to >3,000 ML/d and >5,000 ML/d flows, respectively. As such, it is important that flow occurs for a significant duration above these thresholds during environmental flows on the Goulburn. Two weeks would be a good initial target (based on sediment saturation rates explored on different systems) as a threshold, however further investigation needs to be undertaken to establish a suitable timeframe for the Goulburn River specifically.

The rate of rise and fall is of equal importance as this determines the stress applied to riverbanks. When considering the environmental deliveries studied in this report, both the deliveries reached flows greater than the 5,000 ML/d day threshold and both aligned to the recommended rates of fall. The Autumn Fresh however, provided more favourable conditions in both of these areas due to its greater peak discharge rate (>8,000 ML/d) and its more prolonged receding limb resulting in a slower rate of fall. The GBCMA are aware of specific guidelines related to both of these categories which were part of another investigation.

Flow Sequence

Flow sequence plays an important part in erosion response, and thus prior events must be considered to understand bank condition response to a flow event. This is particularly true when considering the impact of flow events that follow summer irrigation periods (in this case the Autumn Fresh), as defined erosion on the lower bank prepares the riverbanks for future erosion events. Prolonged dry periods to bank zones, such as those experienced with the mid/upper (>4,000 ML/d) and upper (>5,000 ML/d) bank during the summer IVT period will consolidate Spring deposits across these zones, reducing their propensity for erosion by subsequent flows compared to (for example) an event that follows winter flows.

Flow Variability

Non variable flow deliveries, which sit around a daily discharge level for a prolonged period of time (as seen during periods of summer low flows during the 2020-21 IVT), can be detrimental to the physical form of a channel.

The IVT delivery of 2020-21 illustrates that flow deliveries that result in minor fluctuations in water level over a long period of time can lead to defined and deep erosion (in one case >0.2 m). This process can lead to notching and over time mass-failure events as subsequent large flow events saturate the upper bank and destabilise this sediment on drawdown (Figure 4-12). Extended durations of similar daily flow volumes and quick drawdown events must be avoided, if possible, to minimise the rate of channel widening.

Repairing Riverbanks

Increased deposition directly corresponds to the source and timing of the water delivery (e.g. dam versus tributary derived water). The comparison of Spring and Autumn Fresh data clearly highlights the influence of increased tributary flow contribution with the Spring fresh being comprised a greater proportion of tributary flow and resulting in a greater depth of deposition compared to the Autumn fresh. This highlights that piggybacking natural flow events, where possible, is a positive strategy to assist in repairing riverbanks. This strategy would be particularly effective during the period following the IVT; this could be a repair phase where sediment can be returned to the lower bank.

There is a positive feedback loop between vegetation density/cover and riverbank resilience. Banks experiencing the greatest erosion volumes lacked vegetation. As a result, the vegetation that remains will probably continue to recede as this erosion process continues. This is a clear challenge for the GBCMA as these sensitive areas of bank are in the lower zone that gets impacted by prolonged invariable flows during the IVT period, year after year.

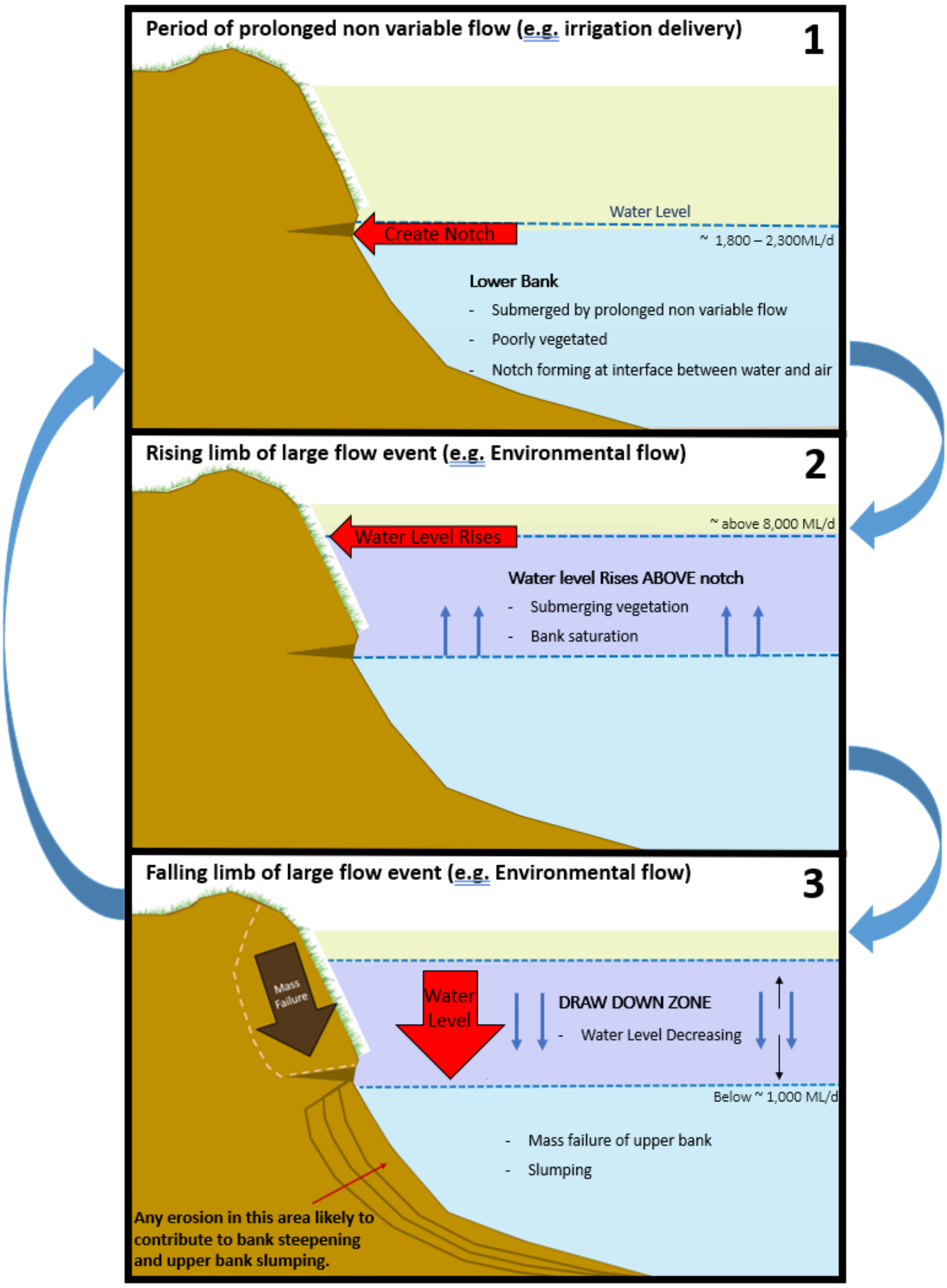


Figure 4-12 Three step process of notching resulting from sustained inundation period with limited variability.

5. Metabolism

5.1. Introduction

Whole stream metabolism measures the production and consumption of dissolved oxygen gas (DO) by the key ecological processes of photosynthesis and respiration (Odum 1956). Healthy aquatic ecosystems need both processes to generate new biomass (which becomes food for organisms higher up the food chain) and to break down plant and animal detritus to recycle nutrients to enable growth to occur. Hence metabolism assesses the energy base underpinning aquatic food webs. The relationships between these processes are shown in Figure 5-1.

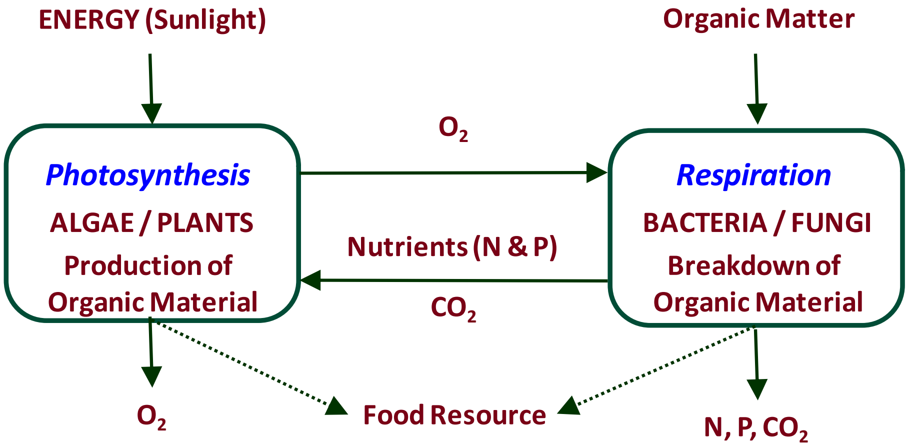


Figure 5-1 Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients.

Metabolism is expressed as the increase (photosynthesis) or decrease (respiration) of DO concentration over a given time frame; most commonly expressed as (change in) milligrams of dissolved oxygen per Litre per day (mg O_2/L/Day). Typical rates of primary production and ecosystem respiration range over two orders of magnitude, from around 0.2 to 20 mg O_2/L/Day with most measurements falling between 0.5 and 10 mg O_2/L/Day.

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

In general, there is concern when process rates are too high. Greatly elevated primary production rates usually equate to algal bloom conditions (or excessive growth of plants, including duckweed and *Azolla*), which may block sunlight penetration, killing other submerged plants, produce algal toxins and large diel DO swings - overnight, elevated respiration rates can drive the DO to the point of anoxia (no dissolved oxygen in the water). *Such conditions have been observed in several sites in the Goulburn River in previous years of the Long Term Intervention Monitoring (LTIM) project*. When an algal bloom collapses, the large biomass of labile organic material is respired, often resulting in extended anoxia. Very low (or no) DO in the water can result in fish kills and unpleasant odors. Bloom collapse often coincides with release of algal toxins; hence the water becomes unusable for stock and domestic purposes as well.

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

Some but not all of the organic carbon created through gross primary production is respired within the first 24 hours. Such respiration is performed by the autotrophs (primary producers) themselves and closely associated heterotrophic communities. Although there is a large amount of variability in the proportion respired 'immediately', Hall & Beaulieu (2013) estimate that on average 44% of new organic carbon created is respired before it can move into higher trophic levels.

5.2. Area specific evaluation questions

The key basin and area-scale evaluation questions and relevant indicators for metabolism are listed in Table 5-1.

Table 5-1 Metabolism key evaluation questions for the Goulburn selected area and associated indicators and evaluation approaches.

Key Evaluation Questions	Indicator	Evaluation Approaches
Basin Scale evaluation Questions		
What did CEW contribute to patterns and rates of decomposition?	• Dissolved oxygen, light and water temperature measurements taken at 15-minute intervals every day over the year	• Estimation of Ecosystem Respiration using the BASEv2 Bayesian Model
What did CEW contribute to patterns and rates of primary productivity?	• Dissolved oxygen, light and water temperature measurements taken at 15-minute intervals every day over the year	• Estimation of Gross Primary Production using the BASEv2 Bayesian Model
Area Scale evaluation questions		
How does the timing and magnitude of CEW delivery affect rates of Gross Primary Productivity and Ecosystem Respiration in the lower Goulburn River?	• Dissolved oxygen, light and water temperature measurements taken at 15-minute intervals every day over the year • Daily Discharge including CEW contribution	• Estimation of Gross Primary Production and Ecosystem Respiration using the BASEv2 Bayesian Model • Inclusion of Organic Loads and relationship with putative flow categories
How do stream metabolism responses to CEW in the lower Goulburn River differ from CEW responses in the Edward Wakool system where the likelihood of overbank flows is higher and nutrient concentrations are generally much lower?	• Similar methods and analysis performed in both the Goulburn and Edward-Wakool Selected Areas. Comparison including nutrient contrasts to be performed by the Basin Level Evaluation	• Estimation of Gross Primary Production and Ecosystem Respiration using the BASEv2 Bayesian Model

5.3. Main findings from monitoring program

5.3.1. 2020/21 findings

The main findings from both MER in 2020-21 and consideration of the entire 2014–21 data set can be summarised as:

- All rates found in the Goulburn Selected Area were typical of those in the southern Murray-Darling Basin, where usually low bioavailable nutrient concentrations constrained GPP. The rates are at the lower end of the 'normal' range found in global comparisons, but such comparisons are fraught due to the preponderance of clear water streams measured elsewhere. Reduced light availability due to turbidity is definitely also a major factor constraining GPP in the Goulburn and the MDB in general.

- Contrary to the prevailing thought at the start of the LTIM project that water needed to reach backwaters, flood-runners and even the floodplain before any positive outcome would be seen in metabolism, by considering the amount of organic carbon created by GPP (and consumed by ER), this report again shows that even small increases in discharge that remain within channel can still have substantial positive benefits for the energy ('food') underpinning aquatic foodwebs.

- This year produced the clearest evidence yet seen that even though flow pulses dilute GPP, when the hydrograph falls again, GPP and ER increase in response, suggesting that the higher flow event has brought in more nutrients and organic carbon to stimulate these higher rates.

- Categorization of flows into 'bands' allowed the pooling of metabolism data, thereby averaging out variation due to season and daily weather conditions and hence provided an excellent way of comparing metabolism in different flow regimes. Data from seven years is also sufficient to enable assessment of site-specific effects and inter-site differences.

- The effect of increased flow on organic carbon load creation through GPP was strongly seasonally dependent:
    - During winter, increasing flow from low flow to moderate flow, then up to low and medium freshes had no discernible effect on the amount (load) or organic carbon produced. Relatively small increases in discharge within the low flow band (312-960 ML at McCoy's Bridge) during winter will create the same amount of 'food' as much higher flow increases. *This result suggests that during winter, large volumes of additional water (from CEW) specifically targeting enhanced food production at the base of the aquatic foodweb is not necessary, as much smaller additions produce the same extra food*. Some caution is required concerning this finding as there is still a relatively small wintertime data set in all flow categories except 'moderately low'.
    - For spring, summer and autumn there was a substantial increase in organic carbon ('fish food') as the daily discharge moved up through the flow categories. The only 'category changes' not showing a statistically significant increase in organic carbon production were the very low to moderately low and low fresh to medium fresh transitions in summer. *This result strongly suggests that water addition specifically targeting enhanced food production at the base of the aquatic foodweb is not necessary in wintertime*. Timing of water delivery to boost organic carbon loads should be managed to coincide with other objectives, including food resource peaks for sustaining native fish populations.

- Using the comprehensive set of data from McCoy's Bridge, it was estimated that Commonwealth environmental water produced 21% of the organic carbon created by GPP over the seven-year period (454 of 2156 Tonnes). From an ecological perspective, CEW-enhanced GPP was perhaps most important in springtime when 36 – 59% (38% in 2020-21) of all GPP was associated with the extra CEW (with the exception of 2016 when there was large flooding and CEW was only 2% of all flow). CEW also contributed around half (44-52%) of wintertime organic carbon creation over 2017-2019 but only 4% in 2020. As noted above, this winter increase was independent of the flow category. The best outcomes for CEW-assisted creation of organic carbon are found in the 'Medium Fresh' flow category in spring and autumn where an average additional 800-1100 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.

- It is still suggested that larger flow increases that do move the water out of channel and then back again will provide even greater benefit due to the introduction of higher organic carbon and bioavailable nutrient concentrations.

5.3.2. Summary of previous findings and implications for any new finding

Previous findings:

The following findings are key aspects reported in previous reports (including MER Year 1) but don't appear in this report. They are more specific in nature and were not relevant in 2020-21 due to the change in sampling sites and the water quality conditions measured throughout this year:

- Dissolved Oxygen concentrations in 2017-18, as in 2015-16 and 2016-17, but not 2014-15, 2018-19 and 2019-20 dropped to very low levels that raise concerns about the immediate effects on aquatic biota, but anoxia only occurred in 2016-17. The origin of the low DO regime is clearly water entering the Goulburn River from the tributaries downstream from Goulburn Weir (Seven Creeks system). These poor water quality events were of moderate duration (typically 1-2 weeks before DO levels reverted to 'normal') and appeared to be stochastic, arising from intense summer storms in the northern half of the Goulburn Catchment.
- The apparent 'Goulburn Weir' effect on stream metabolism (much higher metabolic rates, especially for ER) observed previously at the LTIM project's Day Road site was not observed at the Murchison site in 2019-20. It is likely this enhancement effect is due to the export of nutrients and organic carbon from the Nagambie Lakes, although this is not definitive as there are no metabolism measurements further upstream. Clearly, any additional

nutrients including organic carbon from the Lakes are consumed in-river before Murchison as rates from this site in 2019-20 were extremely similar to the other four sites further downstream.

Implications for new findings:

One of the important new insights gained during the 2020-21 MER study was the appreciation of the importance of *some* CEW during winter. The volume delivered does not need to be large (e.g. under 1000 ML/Day) but this CEW can substantially enhance the amount of organic carbon created by GPP. Higher flows do not produce even more organic carbon, but rather, it seems that dilution becomes very important i.e. the same amount of organic carbon is produced irrespective of how much flow there is above the low flow category.

As noted above, there was clear evidence that a flow pulse during spring will stimulate both gross primary production and ecosystem respiration when the hydrograph falls. Hence targeted pulses during this period for other (non-metabolism) objectives, may have additional benefits in terms of organic carbon (food resource) production.

If possible, timing of spring flow events should be such that the rise and fall of the hydrograph occurs over many days to one-two weeks to facilitate this organic carbon creation. Elevated and relatively constant spring flows will be far less beneficial.

5.3.3. Summary of findings relevant to evaluation questions

The findings relevant to the evaluation questions are presented above in Section 5.3.1 and summarized here in Table 5-2.

Table 5-2 Summary of Metabolism findings relevant to evaluation questions.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
		Basin scale evaluation questions	
What did CEW contribute to patterns and rates of decomposition?	Yes, with the exception of the highest flow categories	Apart from the initial dilution effect (as seen in all previous years), there was no consistent effect of flow increases (including those from CEW delivery) across the 5 sites on ER (mg O_2/L/Day). There was a marked positive effect of flow increases, even those constrained within channel, on total amounts of ER expressed as mass (load) of organic carbon consumed per day. As there is no change in water source, the major effect of CEW is to augment flow.	Consideration of daily and seasonal trends in Ecosystem Respiration, expressed in both volumetric (mg O_2/L/Day) and load (kg organic C/Day) units versus discharge in both flow category based on stage height and also nominal bins of equal numbers of points. This approach minimizes the effects of daily variability resulting from meteorological conditions. CEW flow contributions are a component of total flow in these analyses. Mean ER rates are determined by site, season and flow category for these analyses.
What did CEW contribute to patterns and rates of primary productivity?	Yes, with the exception of the highest flow categories	As with ER in the previous line item, across all 5 sites there was a decrease in GPP (mg O_2/L/Day) with flow increases (including those from CEW delivery) arising from dilution, as seen in all previous years). It was also shown that after the hydrograph fell, there was an increase in GPP (and ER) in the subsequent days and weeks, due to the entrainment of nutrients and organic carbon during that event. Importantly, there was a marked positive effect of flow increases, even those constrained within channel, on total amounts of GPP expressed as mass (load) of organic carbon produced per day. As there is no change in water source (tributary flow is not a significant water source in this section of the Goulburn River), the major effect of CEW is to augment flow.	Consideration of daily and seasonal trends in Gross Primary Production, expressed in both volumetric (mg O_2/L/Day) and load (kg organic C/Day) units versus discharge in both flow category based on stage height and also nominal bins of equal numbers of points. This approach minimizes the effects of daily variability resulting from meteorological conditions. CEW flow contributions are a component of total flow in these analyses. Mean GPP rates are determined by site, season and flow category for these analyses.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
		Area Scale evaluation questions	
How does the timing and magnitude of CEW delivery affect rates of Gross Primary Productivity and Ecosystem Respiration in the lower Goulburn River?	Yes, with the exception of the highest flow categories	The findings in this, and earlier reports, show that augmenting natural flows with CEW (or using CEW to create flow events) has a positive benefit in terms of the amount of organic carbon created via GPP (and the mass of organic carbon consumed each day via ER). Analysis of the magnitude of organic carbon load enhancements shows that the biggest impact of CEW is found in the 'Medium Fresh' flow category in spring and autumn where an average additional 800-1100 kg organic carbon per day is created. Increasing flows from one flow band to a higher one enhances organic carbon production in all seasons except winter. It is important to note that it is likely that the reason for higher organic carbon loads with higher flow categories is that more nutrients and organic carbon are made available from rewetting banks, resuspending sediments and from upstream sources. Hence variation in flow, rather than maintaining constant flows, is extremely important.	Based on regression of daily discharge versus rates of GPP and ER, and on calculated loads of organic carbon. Flow was categorized according to Section 5.4.3. Data analysis showed statistically significant increases in organic carbon loads with flow categories in all seasons except winter, where no differences were detected. There was sufficient variability of flow levels (except < Very Low Flow, High Freshes and Overbank Flows) to detect any significant effects.
How do stream metabolism responses to CEW in the lower Goulburn River differ from CEW responses in the Edward Wakool system where the likelihood of overbank flows is higher and nutrient concentrations are generally much lower?	Yes, with the exception of the highest flow categories in the Goulburn River. Basin Level analysis will describe the flow regime in the Edward-Wakool system.	It is expected that patterns in the Edward-Wakool will mimic those in the Goulburn River (based on the findings of the Basin Level Evaluation by Grace (2020). However, analysis of the 2020-21 results is the responsibility of the MER Basin Level Evaluation team.	This is the responsibility of the Basin Level Evaluation Team where the Edward-Wakool results (not available here) can be compared and contrasted with the Goulburn River findings and those of other Selected Areas.

5.4. Monitoring methods and analytical techniques

The stream metabolism and water quality measurements were performed in accordance with the LTIM Standard Operating Procedure (Hale et al. 2014), which has remained essentially unchanged for the MER program (Webb et al. 2019b).

Water temperature and dissolved oxygen were logged every fifteen minutes with a DO logger placed in each of the five sites in zones 1 (Murchison[1], Arcadia Downs) and 2 (, Shepparton Golf Club, McCoy's Bridge, Loch Garry). Data were downloaded and loggers calibrated approximately once per month depending on access by staff from Australian Laboratory

[1] The site at Day Rd chosen in 2015-16 to replace the Moss Rd site used in 2014-15, was in turn replaced by the site at Murchison for MER. Similarly, the Darcy's Track site used throughout the LTIM program was replaced by the nearby Arcadia Downs site for MER. These changes were brought about due to better infrastructure and accessibility of the 'new' sites. As DO and temperature data were already being recorded at the Shepparton Golf Club site, this site was added to the program for MER.

Services (ALS). ALS is contracted via the Regional Water Monitoring Partnerships program to undertake water quality monitoring across Victoria. Light (PAR) loggers were also deployed in open fields at Shepparton Drain 12 and Nagambie (Tahbilk); these data were downloaded every few months.

Water samples were collected from the same two sites within each zone used for the metabolism measurements, to measure:

- Dissolved Organic Carbon (DOC)
- Water column Chlorophyll-a
- Nutrients (Ammonia (NH_4^+), Filtered Reactive Phosphorus (FRP), Dissolved Nitrate and Nitrite (NOx), Total Nitrogen (TN) and Total Phosphorus (TP))

In accord with the MER Standard Protocol, water quality parameters (temperature (°C), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were measured fortnightly.

After discussions at the annual LTIM forum in Sydney in July 2016, it was decided that an updated version of the BASE model (BASEv2) would be used for analysing the 2015-16 metabolism data and all data sets from that time onwards, including MER this year. This change was a result of the paper published by Song et al. (2016), which showed that our BASE model could be improved by changing from stepwise progression and fitting using each data point to integrated (whole data set) fitting and progression using modelled data.

The BASEv2 model (Grace et al. 2015) has been used since 2015-16 for analysing the stream metabolism data. Acceptance criteria remained unchanged: the fitted model for a day must have an r2 value of at least 0.90 and a coefficient of variation for GPP, ER and K parameters of < 50%; the convergence measure for parameter estimation, PPP, must lie between 0.1 and 0.9 and the reaeration coefficient, K, must be in the range 0.1 < K < 15 /Day. The rationale for these criteria has been explained in earlier annual reports while the fundamental model explaining how dissolved oxygen changes as a function of time due to primary production, respiration and reaeration has remained constant throughout (see the Stream Metabolism Foundation Report, (Grace 2015), which was slightly modified in 2019 (Grace 2019) for further details).

Many data in this report are presented as boxplots. These provide a convenient and simple visual means of comparing the spread of data.

5.4.1. Daily environmental water volumes at each site

The volume of environmental water at each of the 5 stream metabolism monitoring sites was determined in reference to McCoy's Bridge data (Webb et al. 2018).

- Loch Garry was considered one day's water travel time upstream from McCoy's Bridge
- Shepparton Golf Club was considered two day's water travel time upstream from McCoy's Bridge
- Arcadia Downs was considered three day's water travel time upstream from McCoy's Bridge, and
- Murchison was considered four day's water travel time upstream from McCoy's Bridge

5.4.2. Derived stream metabolism metrics

GPP and ER continue to be reported in the units from the BASEv2 modelling, namely mg O_2/L/Day. In addition, in this report a derived unit has also been calculated and forms the basis for investigating flow effects:

- The mass of oxygen (or organic carbon, see above) produced per day, which is effectively the ***daily load of organic carbon***. This is calculated by multiplying the GPP or ER in mg O_2/L/Day by the daily discharge. Conversion from oxygen-based units to organic carbon involves a factor of 12/32 (ratio of atomic mass of C and molecular mass of O_2). This factor does not include any physiological efficiency factor for converting oxygen to organic carbon which typically is in the range 0.8-1. Given the exploratory use of this metric, concern over conversion efficiency at this stage is unwarranted. As has been noted in previous LTIM Basin-scale Evaluation Reports (e.g. Grace 2020), the most notable effect of increased discharge on metabolism is an immediate reduction due to the dilution effect of the additional water. However, the fact there is now more water may mean that the overall amount of oxygen (hence organic carbon) produced or consumed that day may increase.

This unit is intended to relate to the amount of organic carbon required by the food web in that stream reach each day, and eventually to the sustainable stocking capacity for native fish in that reach, on the assumption that this capacity is resource (food) limited. There is much to be done in the future to quantitatively establish this link between primary production and the energetic needs of fish.

One common question is "How much of the stream is involved in creating these x kg of organic carbon each day?". It is the organic carbon created by all the water flowing past a fixed point or site e.g. the dissolved oxygen logger, or a stream gauging station in that 24-hour period. Hence the volume of water depends on the flow that day.

5.4.3. Flow 'Categories'

As part of the ongoing development of hydrological descriptors of flow regimes undertaken in LTIM, discharge can be grouped according to the flow stages developed by Stewardson & Guarino (2018) (Figure 5-2). The various flow levels are established as:

- Very low flows: flows less than the lowest flow in the unimpacted monthly flow series or 2% of mean unimpacted flow, whichever is greater.
- Medium low flows: flows that fall below the 95th percentile exceedance flow in the unimpacted monthly flow series or 10% of the mean unimpacted flow, whichever is greater.
- Low freshes: flow spells that raise water levels at least 1/8th of the height of the bank above the medium low flow level.
- Medium freshes: flow spells that raise water levels at least 1/4 of the height of the bank above the medium low flow level
- High freshes flow spells that raise water levels at least 1/2 of the height of the bank above the medium low flow level.

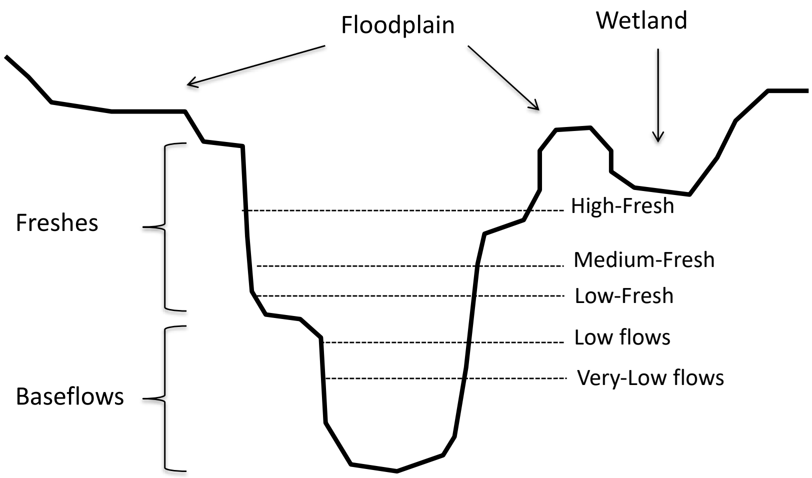


Figure 5-2 Flow stages according to Stewardson & Guarino (2018).

The flow thresholds associated with these stages was provide by Guarino (2019) – the data relevant to the Goulburn River metabolism sites are presented in Table 5-3. No specific threshold data are available for Arcadia Downs, so the Murchison thresholds were applied. No thresholds (or appropriate approximations thereof) are available for Loch Garry or Shepparton Golf Club sites.

Table 5-3 Flow Thresholds (ML/Day) for Goulburn River stream metabolism monitoring sites.

Site Name	MER Site	Modelled Natural Flow Site Name	Very Low	Moderate Low	Low Fresh	Medium Fresh	High Fresh	Finalised Bankfull
Murchison	Murchison	405200 – Goulburn River @ Murchison	252	868	1772	3211	8347	33000
McCoy's	McCoy's Bridge	405232 – Goulburn @D/S McCoy's Bridge	312	960	1822	3135	7613	28000

5.4.4. Statistical modelling

Relationships between discharge and gross primary production (GPP) and ecosystem respiration (ER) were analysed using a hierarchical Bayesian linear regression of the metabolism endpoint against discharge and temperature. Detailed statistical modelling descriptions are provided in Webb et al. (2019a).

We have explored the following model predictands:

- GPP
- ER

The models were also used to simulate the corresponding rates of metabolism without environmental flow, and the results were then compared with those from the original models to assess the effects of environmental water on GPP and ER rates.

Note that over all the LTIM reports e.g. Webb et al. (2019a), this Bayesian modelling found no evidence for lag effects (increased metabolic rates from 1-15 days after the onset of the event) when metabolism was expressed as mg O_2/L/Day, hence it was not repeated this year.

5.5. Results

In this report, results are presented and analysed over two timeframes: the 2020-21 sampling year and where appropriate, the entire seven-year period of record. Due to the change in the period used for the nominal year moving from LTIM (July 1 – June 30) to MER (May 1 – April 30), in most instances May and June 2019 are included in the MER year 1 data compilation and analysis rather than the LTIM data even though these two months were formally part of the LTIM project.

The periods of data logger deployments are listed in Table 5-4 along with the number of days' data that meet the acceptance criteria ($r^2 > 0.90$, coefficient of variation for all of GPP, ER and K < 50%, 0.1 < PPP < 0.9, 0.1 < K < 15). The % compliance data for the six previous years are included for comparison.

There was a minimum of 308 days data collected at Loch Garry and a full year of data at all other sites. There was an increase in the number of compliant days when compared to 2019-20 for three of the sites (Murchison, Shepparton Golf Club and Loch Garry), while there were fewer 'acceptable' days at McCoy's Bridge (41% down from 67%) and Arcadia Downs (23% down from 38%). The decline at McCoy's Bridge is even more significant when compared to earlier years where the acceptance rate as high as 81%. As is shown below in the plot of GPP, ER and flow versus date in 2020-21 for McCoy's Bridge, there were only a handful of acceptable data days during the extended high flows from May until mid-September. As mentioned in previous reports, BASEv2, like all equivalent stream metabolism models assumes that flow changes will be small during the course of a day. When the relative proportions of benthic and pelagic metabolism change within a day due to rapidly rising or falling water levels, the resultant model fits are often very poor. As will be shown below, the DO loggers at all sites other than McCoy's Bridge had periods of poor DO measurements from November 2020 onwards. *This may be a result of servicing and maintenance that is too infrequent. This aspect will be carefully monitored in 2021-22*.

Table 5-4 Summary of Data Collection and Acceptance Rates for BASE Results. MER (in light blue) & LTIM (dark blue).

	First Date	Last Date	Number of Days with data	Compliant Days using BASEv2	2020-21 % of total days in compliance	2019-20 % of total days in compliance	2018-19 % of total days in compliance	2017-18 % of total days in compliance	2016-17 % of total days in compliance	2015-16 % of total days in compliance	2014-15 % of total days in compliance
Loch Garry	1st May 2020	30th April 2021	308	61	20	16	23	46	51	33	38
McCoy's Bridge	1st May 2020	30th April 2021	365	151	41	67	79	81	56	48	66
Arcadia Downs	1st May 2020	30th April 2021	365	85	23	38					
Shepparton Golf Club	1st May 2020	30th April 2021	365	117	32	19					
Murchison	1st May 2020	30th April 2021	365	118	32	25					
Day Road					n/a	n/a	44	46	54	27	n/a
Darcy's Track					n/a	n/a	53	52	53	28	72

Notes: For MER, Murchison is a replacement for Day Rd, Arcadia Downs is a replacement for Darcy's Track, Shepparton Golf Club is an additional site for MER

5.5.1. Water temperature and dissolved oxygen

Figure 5-3 displays the mean daily water temperature and mean daily dissolved oxygen concentrations, collected from the DO loggers, at all five sites over the 2020-21 deployment period. The temperature profiles shown in Figure 5-3 conform to expected behaviour with the warmest average daily temperatures occurring in mid-late summer. There were relatively small but consistent differences among the loggers during the warmer months, but these may reflect local stream shading and water depth and are not considered ecologically important differences.

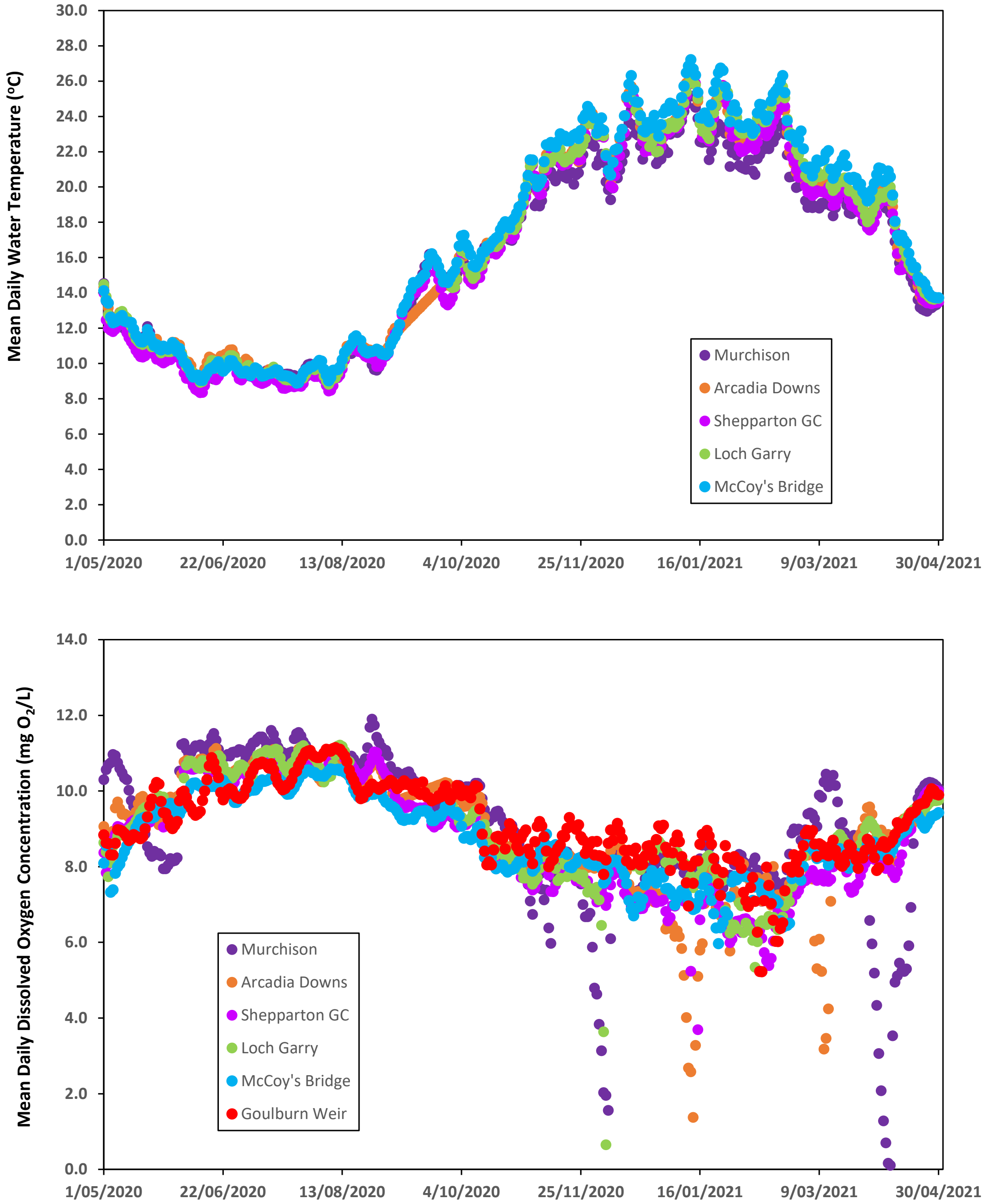


Figure 5-3 Mean Daily Water Temperature and Dissolved Oxygen Concentration for the five study sites 2020-21. A sixth data set, from the outflow from Goulburn Weir, was added to help determine the origin of the anomalies.

The overall seasonal pattern of DO concentrations depicted in Figure 5-3 is also expected as oxygen solubility decreases with increasing water temperature, hence an 'inverse' relationship is expected – and was observed - in the two panels of this figure. As noted above, this figure also clearly demonstrates that there are some problems with many of the DO data loggers at various points throughout the year. Clearly, poor DO data will result in the lack of acceptable model fits and is definitely a matter for ongoing concern. The logger at Murchison not only recorded unusually low DO on four occasions, three of these from November 2020 onwards, but also had unusually high readings in May 2020. One possibility is that there is water of unusual DO concentrations coming from Goulburn Weir. To examine this explanation, the DO logger data from Goulburn Weir was added to this plot and clearly showed no unusual divergences from the expected concentrations. As there are no significant tributaries entering the Goulburn River between the weir and the Murchison site, it is therefore most probable that these anomalous readings are artefacts of a malfunctioning logger. Similarly, the two "low" excursions for the Arcadia Downs logger are attributed to poor logger performance as there are also no significant tributaries entering the Goulburn River in the reach from Murchison to Arcadia Downs. In addition, any low DO water passing the Murchison logger should reach the Arcadia Downs logger a day later, but the timings for low DO at these two loggers were not matched. The DO readings at the Shepparton Golf Club logger fell below 4 mg O_2/L in January 2021. These 'low' readings may be valid as there are two significant tributaries that enter the Goulburn not far upstream from this logger: Seven Creeks and the Broken River. While there are no DO loggers on the Broken River close to Shepparton, the closest logger at Gowangardie (Station 404224) showed that DO was below 4 mg O_2/L only briefly on two occasions in January and February 2021. Conversely, the DO logger in Seven Creeks at Kialla West (Station 405269, very close to the confluence with the Goulburn River) had extended periods of very low DO and even anoxia from mid-November 2020 through to mid-March 2021. If these readings are correct (and not due to a faulty logger), then this would be expected to cause Goulburn River DO to fall. This has been seen in 2016-17 and 2017-18 following very large summer storms. The apparent low DO at the Loch Garry logger in December 2020 is again attributed to logger performance rather than any real major decrease in the riverine concentration. Whilst this paragraph highlights a litany of poor logger performance, it also demonstrates the huge benefit in having a network of loggers on a major stream such as the Goulburn River. This network allows monitoring of 'parcels' of low DO water as they transit down the river.

These logger issues are a major reason for the relatively low number of data days that met acceptance criteria compared to 2017-2019 for example.

5.5.2. Seasonal dependence of flows and flow categorization

In order to examine the role of flow (and additional CEW) on metabolism, and in particular loads of organic carbon being created and consumed each day by GPP and ER respectively, it is first necessary to categorize the flows themselves according to the thresholds in Table 5-3. Table 5-5 presents this data for the four flow categories used in the subsequent loads analysis and these are stratified by site and season. There were no flows over the entire seven-year period of record lower than the 'Very Low' flow threshold, but there were some 'High Fresh' and 'Overbank' flows (the latter in Spring 2016) but these are not included in this table due to the lack of corresponding metabolic rate data that met the acceptance criteria. Throughout this report, no summary statistics are presented for categories with fewer than 5 data points.

Table 5-5 Summary Statistics for Daily Flow (ML/Day), stratified by Season, Site and Flow Category. All data from 2014-2021.

Season	Site	Flow Cat	n	Mean	Std Dev	Min	Max	Median	25%	75%	Season	n	Mean	Std Dev	Min	Max	Median	25%	75%
Spring	Arcadia Downs / Darcy's Track	Very Low	37	729	132	514	902	758	558	828	Summer	38	774	112	568	904	808	689	881
		Mod Low	79	1234	232	918	1764	1185	1074	1374		152	1256	221	912	1770	1260	1053	1408
		Low Fresh	29	2527	434	1773	3179	2535	2085	2922		93	2459	414	1787	3193	2437	2102	2820
		Med Fresh	30	5127	1280	3312	7754	4793	3919	6198		19	3519	393	3255	5080	3431	3348	3508
	McCoy's Bridge	Very Low	97	813	125	504	958	860	724	915		97	856	114	551	960	903	836	929
		Mod Low	120	1305	241	964	1797	1275	1098	1516		226	1291	208	962	1805	1271	1118	1416
		Low Fresh	49	2495	412	1877	3126	2469	2061	2928		169	2512	367	1830	3062	2580	2168	2848
		Med Fresh	85	5228	1225	3137	7452	5290	4071	6292		2							
	Moss Rd / Day Rd / Murchison	Very Low	42	695	146	469	868	683	545	844		30	778	62	702	861	791	710	840
		Mod Low	33	1109	231	876	1698	976	949	1255		164	1240	210	870	1747	1257	1095	1380
		Low Fresh	29	2418	451	1775	3196	2283	2028	2833		84	2580	424	1785	3150	2640	2259	2985
		Med Fresh	22	5576	1461	3272	8071	5716	4505	6789		9	3238	19	3211	3261	3234	3223	3260
Autumn	Arcadia Downs / Darcy's Track	Very Low	1								Winter	1							
		Mod Low	69	1187	211	917	1689	1105	1048	1328		13	1313	198	1099	1676	1218	1164	1493
		Low Fresh	14	2266	386	1775	2957	2198	1948	2715		12	2301	463	1794	3183	2258	1833	2708
		Med Fresh	18	4288	888	3215	6997	4188	3754	4417		8	5133	1732	3565	7998	4775	3592	6438
	McCoy's Bridge	Very Low	100	872	78	684	958	893	830	936		10	803	124	632	960	818	669	930
		Mod Low	188	1238	241	963	1809	1169	1023	1412		100	1167	195	965	1732	1093	1024	1262
		Low Fresh	121	2461	327	1824	3128	2480	2189	2736		8	2241	303	1856	2746	2245	1948	2462
		Med Fresh	29	3920	477	3162	5615	3904	3594	4180		5	4513	1636	3331	7188	3537	3428	6086
	Moss Rd / Day Rd / Murchison	Very Low	12	763	127	539	866	842	635	849		6	825	31	783	853	828	800	852
		Mod Low	53	1058	225	895	1707	978	929	1039		15	1150	259	880	1651	1038	963	1353
		Low Fresh	24	2690	422	1817	3187	2831	2319	3035		7	2180	282	1801	2516	2244	1821	2420
		Med Fresh	15	4162	346	3554	4587	4253	3778	4474		4							

5.5.3. Metabolic parameters

MER 2020-21

From the results of modelling using BASEv2, the parameter estimates for GPP, ER, the reaeration coefficient K and the ratio of Gross Primary Production to Ecosystem Respiration ratio (P / R) for all 5 sites monitored, derived from all days meeting the acceptance criteria, are presented in Table 5-6.

Table 5-6 Summary of primary production (GPP) and ecosystem respiration (ER) rates, P/R ratios and reaeration coefficients for the five study sites, 2020-21.

Parameter	Murchison (n = 118)			Arcadia Downs (n = 85)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.05	0.02	7.42	1.40	0.02	9.47
ER (mg O_2/L/Day)	2.94	0.14	38.9	2.46	0.12	30.5
P / R	0.39	0.02	1.35	0.43	0.01	1.24
K (/Day)	2.66	0.14	13.9	1.76	0.37	10.3
Parameter	**Shepparton GC (n = 117)**			**Loch Garry (n = 61)**		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	0.99	0.02	9.93	1.35	0.05	8.31
ER (mg O_2/L/Day)	3.78	0.20	24.8	2.97	0.22	14.1
P / R	0.26	0.01	1.03	0.47	0.04	0.93
K (/Day)	2.09	0.15	11.4	2.90	0.32	10.4
Parameter	**McCoy's Bridge (n = 151)**			**All Combined (n = 531)**		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.46	0.06	11.62	1.23	0.02	11.6
ER (mg O_2/L/Day)	3.02	0.32	28.43	3.01	0.12	38.9
P / R	0.46	0.03	1.20	0.39	0.01	1.35
K (/Day)	2.52	0.23	13.85	2.40	0.14	13.9

Each metabolic parameter in Table 5-6 is expressed as a median with minimum and maximum values also included. The median provides a more representative estimate without the bias in the mean arising from a relatively few much higher values. As previously found with the combined 2014-20 LTIM/MER data set, the median GPP values from all five sites fall within a very narrow range of 0.99 (Shepparton Golf Club) to 1.46 (McCoy's Bridge) mg O_2/L/Day. The range of median ER values for the five sites is also relatively constrained, varying from 2.46 mg O_2/L/Day (Arcadia Downs) up to 3.78 mg O_2/L/Day at the Shepparton Golf Club site.

The P/R ratios (medians 0.26 to 0.47) are similar to those found in 2017-20 (LTIM/MER). The first three years of LTIM data have been excluded from this comparison as there was no winter-time data until the 2017-18 sampling year. GPP rates are constrained much more by season than ER rates. The median values indicate that, in general and on a daily basis, significantly more oxygen is consumed in these reaches than is produced. The maximum P/R ratios in Table 5-6 indicate that on some occasions, oxygen production is as high or slightly higher than consumption via ecosystem respiration. In most cases, as observed in previous years, these high P/R readings are typically due to lower ER rates than significantly increased GPP.

To put these metabolic rates into a global context, a summary of world-wide stream metabolism data (mostly from the USA) shows that GPP and ER values are each typically in the range 2-20 mg O_2/L/day (Bernot et al. 2010, Marcarelli et al. 2011) based on an assumption that the average water depth of 1 m (to convert the areal units of many reports to the volumetric units used in LTIM). Hence these Goulburn River data fall towards the bottom end of this global range. Whether these low rates, mirrored across the southern Basin, reflect a system under stress or are indicative of 'normal' rates for Australian lowland rivers should become more apparent as MER evolves, and is discussed further below. Publication of a significantly more extensive data set (from the USGS) covering many more biomes in the USA is (still!) imminent and will show that the Basin metabolic rates are low but *not* unusually low.

Figure 5-4 displays the daily rates of GPP and ER at McCoy's Bridge – the site with the most data days in 2020-21 (Table 5-4). The daily flow data are also plotted in this figure.

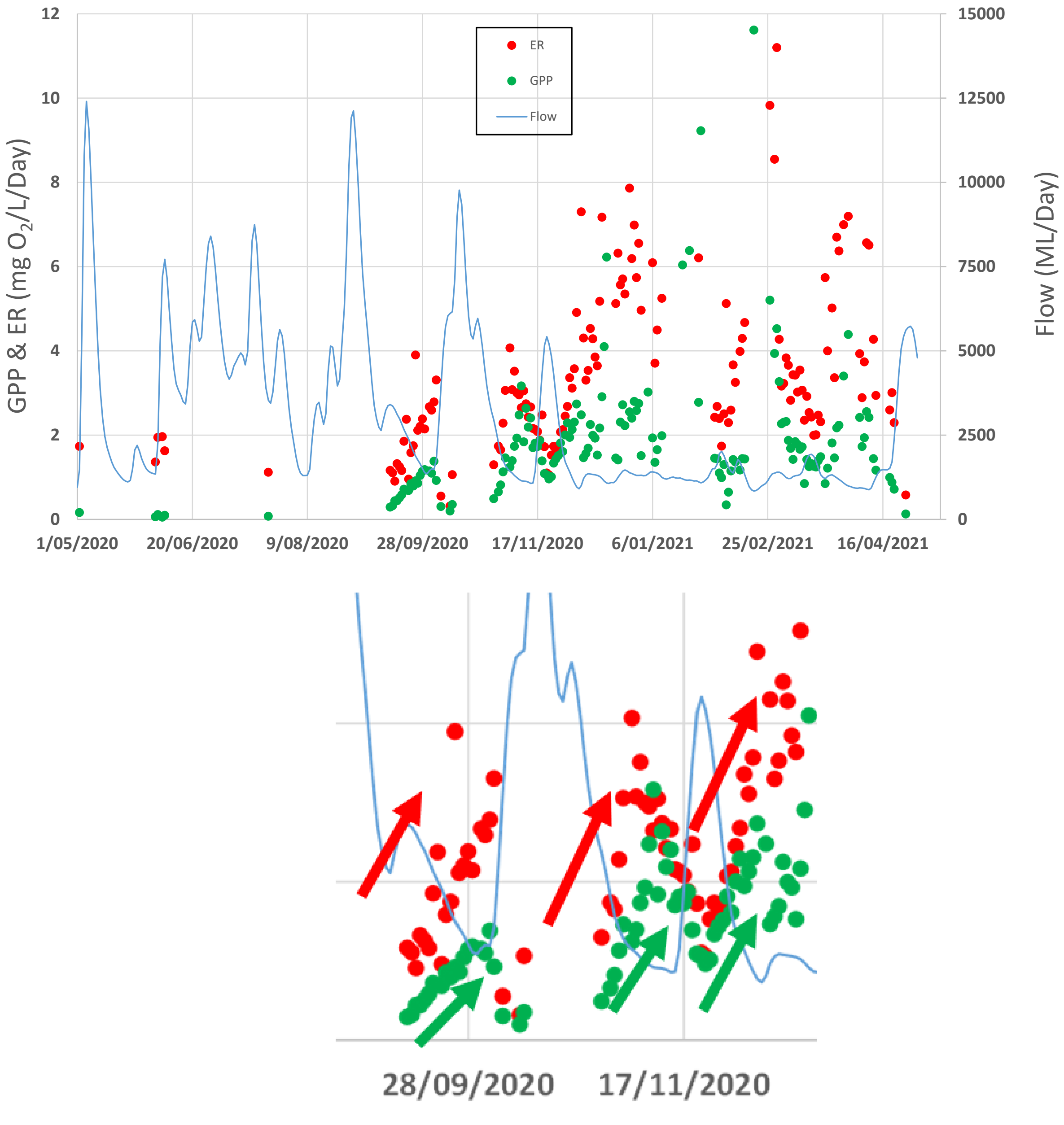


Figure 5-4 a) Stream Metabolism-Flow Relationships for McCoy's Bridge (Zone 2) from May 2019 to April 2020: Gross Primary Production and Ecosystem Respiration; b) Magnified view of September-November 2020.

Figure 5-4a highlights one of the difficulties of establishing relationships between high flow events and stream metabolism. As noted above and is very evident from this figure, the extended period of elevated and varying flows from June to September 2020 meant that almost no data days that met the acceptance criteria were found. The three largest flow events in May 2020 (peak flow 12403 ML/Day on 5/5), late August (peak flow 12127 ML/Day on 5/5) and mid- October (peak flow 9768 ML/Day on 14/10) are all in the high fresh category (Table 5-3). The underlying model used by BASEv2 and other stream metabolism models, including the USGS "streamMetabolizer" (Appling et al. 2018), assumes that flow in any one day remains "relatively constant". Hence for days with rapidly changing, large flows, model fits are poor and do not meet the acceptance criteria, with r^2 typically much less than the 0.9 criterion.

The magnified view of one section of Figure 5-4 clearly shows the remarkable consistency of increasing GPP values (also shown with green arrows) following the flow recessions, most notably in mid-September - early October 2020, early November 2020 and late November-early December 2020. Conversely, the rising limb of the hydrograph tends to dampen GPP probably due to simple dilution as noted later. This effect is evident with the declines seen with the rapidly rising daily flows in early October 2020 and mid-November 2020. These rising hydrographs also dramatically lower ER rates, again due to dilution. The red arrows in the magnified view show that ER (just like GPP) increases significantly in the days following the recession of the flow peak. Quantitative relationships between discharge and metabolism are explored in the statistical modelling results (Section 5.5.5).

Goulburn River stream metabolism across the years, 2014-2021

It is interesting to compare the metabolic data for 2020-21 with that found during the LTIM project and year 1 of MER. This allows consideration of this year's stream metabolism in the context of the larger data set available to help address the question "Was 2020-21 a 'typical' year or unusual in any way?" Note that all data presented in Table 5-7 which examines the annual variation in metabolism at the McCoy's Bridge site has been calculated using the BASEv2 model, and with the current acceptance criteria; hence comparison is not confounded by use of different models. McCoy's Bridge is chosen as the exemplar site as it has the highest number of data days meeting acceptance criteria (see Table 5-4) and also the most winter-time data. Seasonal effects on rates are explored later in this section. For that reason, the best years for comparison are those with full year data sets (2017-18 onwards).

Table 5-7 Comparison across seven years of median primary production (GPP) and ecosystem respiration (ER) rates, P/R ratios and reaeration coefficients at the McCoy's Bridge site.

Site	McCoy's Bridge						
Year	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20***	**20-21**
n	141	134	210	264	272	244	151
GPP (mg O_2/L/Day)	1.53	1.09	1.12	0.97	1.18	1.22	1.46
ER (mg O_2/L/Day)	3.06	1.75	2.19	2.74	2.24	2.37	3.02
K (/Day)	3.44	1.90	1.77	1.32	1.87	2.03	2.52
P/R	0.55	0.65	0.45	0.37	0.54	0.49	0.46

*Data set includes May 2019 & June 2019 which are also included in the 2018-19 year just for this comparison

Metabolic rates in the Goulburn River at McCoy's Bridge are remarkably consistent. Median GPP has only varied from 0.97 (2017-18) to 1.46 and 1.57 mg O_2/L/Day (in 2020-21 and 2014-15 respectively), while ER varied more but still by less than a factor of two across the five years (1.75-3.06 mg O_2/L/Day). Unsurprisingly, the reaeration coefficient was also relatively constant (1.32 – 3.44 /Day). Such behaviour in K is expected if similar flow regimes occur at the same site with no events that change the river topography. There was also a small amount of variability in the median P to R ratio, ranging from 0.37 to 0.65; all values that indicate a heterotrophic dominance in metabolism. The higher values in 2014-15 are largely attributed to the shorter data collection period which did not included winter 2014 or late autumn 2015 and also missed the coolest of the spring months (September); hence data was heavily biased towards the warmer months, thus producing higher rates.

Figure 5-5 and Figure 5-6 use this most comprehensive site data (McCoy's Bridge) to illustrate the variability in seasonal metabolism rates over the final two years of LTIM and both years of MER; the LTIM years were chosen as there was sufficient winter data for inclusion and comparison.

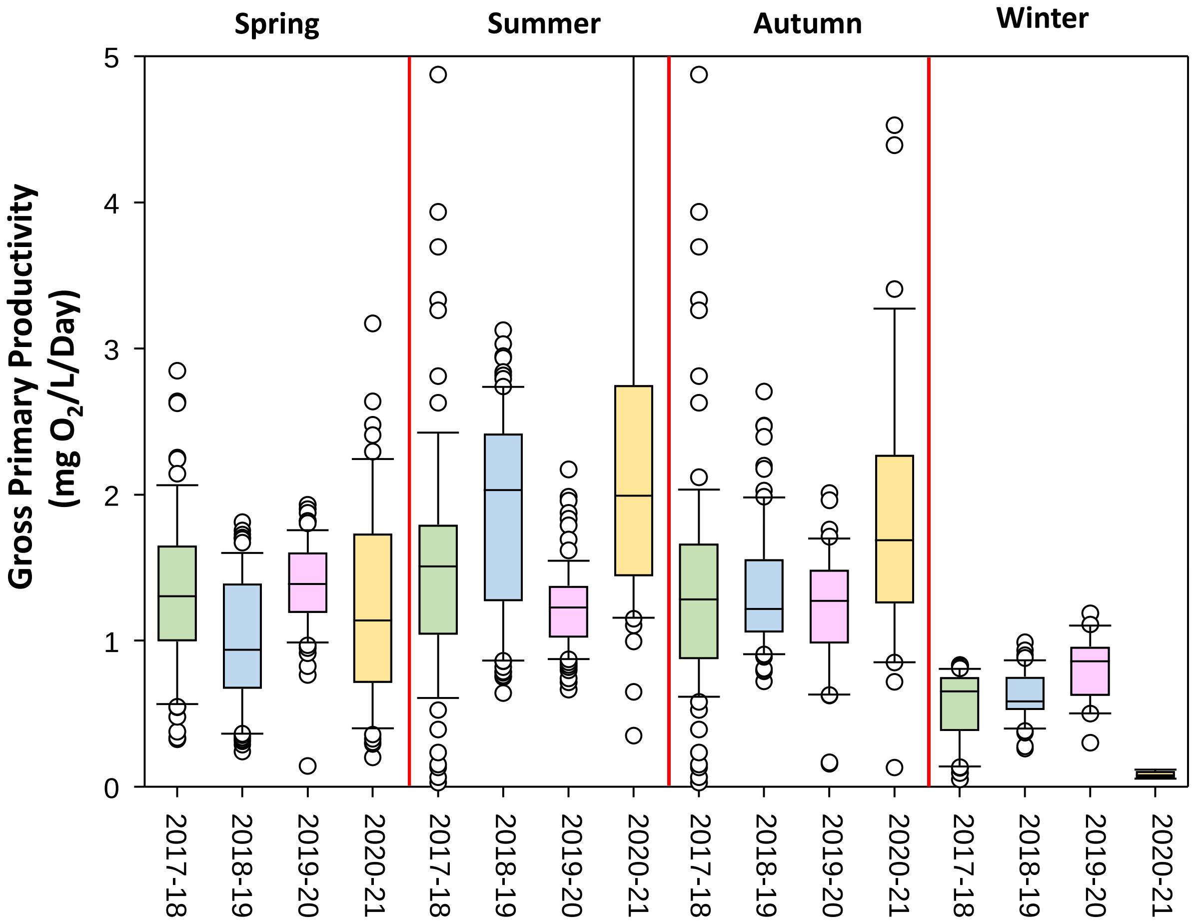


Figure 5-5 Annual variation in GPP stratified by season at the McCoy's Bridge site, 2014-21.

Although there initially appears to be a lot of inter-annual variability within each season, this figure actually shows that median daily GPP remains remarkably constrained within the range of 0.5 - 2.0 mg O_2/L/Day across all seasons with even a narrower range (1 – 2 mg O_2/L/Day) when discounting the winter time data. The origins of the extremely low winter-time data in 2020 are still under investigation. All of these rates are towards the lower end of 'normal' by world standards. Hence, they are not remarkably unusual nor cause for great concern. As will be shown later, this constraint to a relatively narrow range is attributed to the chronic low nutrient concentrations (especially bioavailable phosphorus) within the river channel. Hall et al. (2016) found that 14 larger rivers in the western USA had a wide range of GPP rates (0.2–26.2 mg O_2/L/Day). However, for 10 of these 14 rivers, rates were < 5 mg O_2/L/Day, putting them in the same range as the rates displayed in Figure 5-5 above. Hall et al. (2016) suggested that the rates at the lower end of this range were in most cases constrained by low bioavailable[2] nutrient concentrations (and in one case, the Colorado River, by extremely high turbidity).

[2] 'Bioavailable' refers to those forms of nitrogen (N), carbon and phosphorus (P) most readily taken up by organisms. This typically equates to 'dissolved' or 'filterable' phosphate for P and the combination of ammonia, nitrate and nitrite for N.

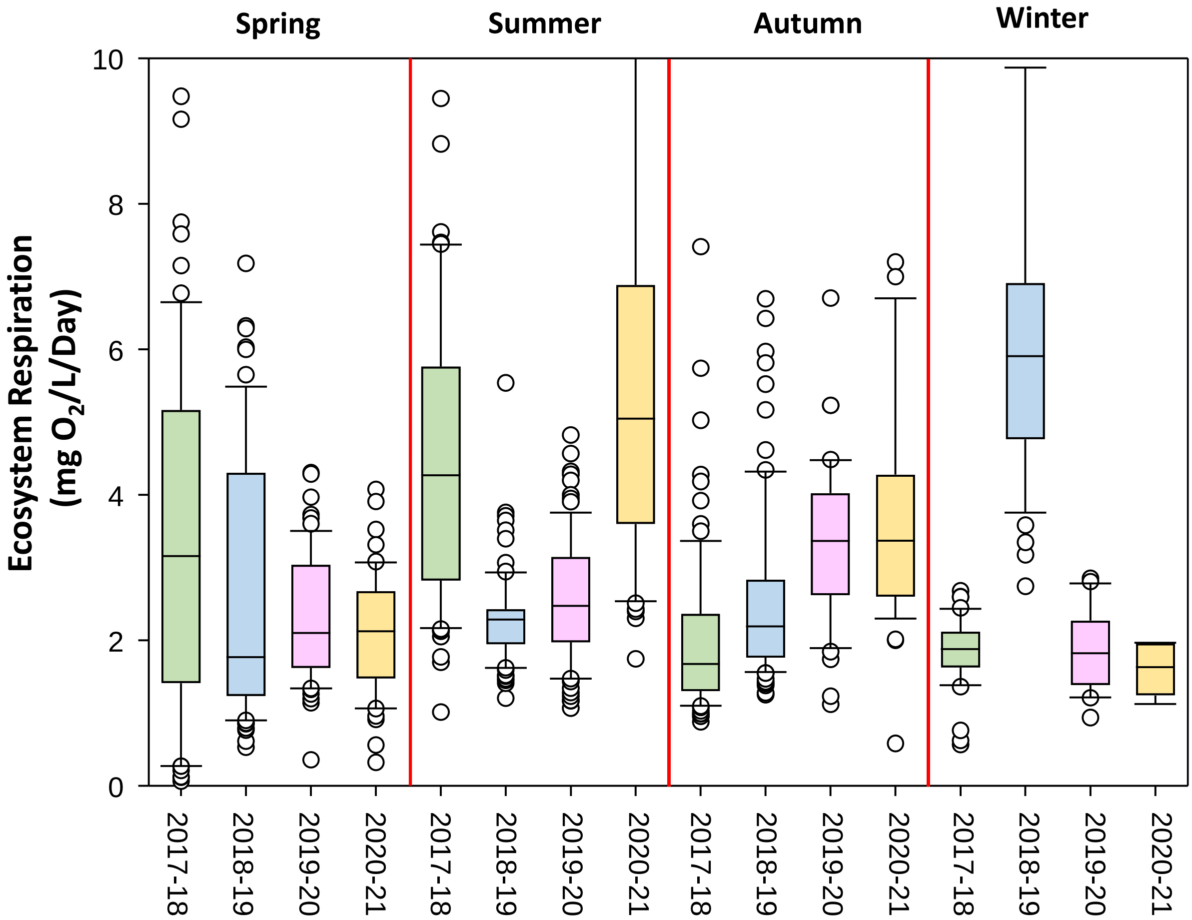


Figure 5-6 Annual variation in ER stratified by season at the McCoy's Bridge site, 2014-21.

There is considerably more interannual and inter-seasonal difference in Ecosystem Respiration rates (Figure 5-6). In general, summer time rates were higher than the other seasons although rates were suppressed in 2018-19 and 2019-2020 compared to the other two years (and lower than the other three years of LTIM data as well – see earlier reports). Not only were the median values lower (the 'middle line' in each box) but the range of values was also more constrained. As noted for GPP however, the appearance of a large degree of inter-seasonal and inter-annual variability is an artefact of the Y-axis scale. If the 'common' (world-wide) range of ER values (0.2 – 20 mg O_2/L/Day) was used as the Y axis, these apparent differences would appear to be smaller. Consequently, we are looking for more subtle explanations for differences which include basal metabolic rates of microbes which increase with temperature and organic carbon availability and lability (reactiveness) both in dissolved form and as water-born and benthic particulate matter. Flows will increase accessible organic carbon supplies by inundating new areas as water levels rise; the amount of organic carbon introduced to the aquatic environment will also depend on antecedent flow conditions – when was this area last connected to the river. The effect of temperature and flow on ER is investigated further using the Bayesian modelling approach in Section 5.5.5.

Metabolism across sites, 2014-2020

The relatively small amount of inter-seasonal and inter-annual variability in stream metabolism shown above (Table 5-7) for McCoy's Bridge, has been removed by pooling all the data for each site over its period of record. This overall site-specific summary is presented below as Table 5-8. This table also includes a summary line 'ALL' for pooled data from all sites.

Table 5-8 Summary LTIM Stream Metabolism Statistics for all Goulburn Sites in LTIM & MER, combined and individually, 2014-2021.

Parameter	Site	n	Mean	Std Dev	Min	Max	Median	25%	75%
GPP	**ALL**	3238	1.66	1.74	0.01	25.7	1.28	0.86	1.88
	Day Rd / Moss Rd*	369	3.42	3.61	0.15	22.9	2.17	1.11	4.06
	Murchison	185	1.09	0.82	0.02	7.42	0.96	0.49	1.53
	Darcy's Track*	464	1.53	1.15	0.03	7.15	1.30	0.75	1.92
	Arcadia Downs	186	1.57	1.51	0.02	10.9	1.37	0.85	1.80
	Shepparton GC	182	1.27	1.30	0.02	9.93	1.03	0.68	1.43
	Loch Garry	473	1.60	1.61	0.05	25.73	1.28	0.86	2.02
	McCoy's Bridge	1379	1.40	0.86	0.01	11.62	1.26	0.88	1.72
ER	**ALL**	3238	3.61	3.72	0.03	48.1	2.56	1.60	4.28
	Day Rd / Moss Rd*	369	7.04	6.40	0.21	40.7	5.31	2.49	9.35
	Murchison	185	3.72	4.19	0.13	38.9	2.86	1.55	4.25
	Darcy's Track*	464	2.91	2.65	0.03	18.1	2.09	1.25	3.48
	Arcadia Downs	186	3.21	3.03	0.12	30.5	2.59	1.80	3.68
	Shepparton GC	182	4.50	3.68	0.20	24.8	3.61	2.42	5.28
	Loch Garry	473	3.13	3.59	0.12	48.1	2.36	1.26	3.67
	McCoy's Bridge	1379	3.01	2.34	0.06	28.43	2.36	1.66	3.74

* LTIM Site Only.

As noted, when looking at individual years, the pooled data in Table 5-8 highlights the significantly higher median and mean daily GPP and ER rates found at the Day Road site compared to the other six sites where differences are generally extremely small. This difference is attributed to the immediate impact of water from the Nagambie Lakes affecting the Day Road site. For example, the median GPP of 1.98 mg O_2/L/Day is around 50% higher than the other three sites. Within an ecological context though, this difference in rates is still quite small and the drivers must be relatively subtle as there are no significant differences in the bioavailable nutrients from each site (see below).

To place the summary results from Table 5-8 into the context of the Murray-Darling Basin, Table 5-9 contains the statistics for GPP and ER from the five Selected Areas in the southern Murray-Darling Basin (Goulburn, Edward-Wakool, Lachlan, Murrumbidgee, Lower Murray) over the LTIM period 2014-2019. The one northern MDB Selected Area (Warrego-Darling) is excluded from this analysis due to both the much smaller data set and the different constraint on metabolism – light availability instead of nutrient limitation.

Table 5-9 Summary LTIM Stream Metabolism Statistics for the five Southern MDB Selected Areas, 2014-19.

	n	Median	Mean	Std Dev	Std Error	25th Percentile	75th Percentile
GPP (mg O_2/L/Day)	10577	1.6	2.2	2.0	0.02	1.0	2.6
ER (mg O_2/L/Day)	10577	3.1	4.0	3.8	0.04	1.6	5.2
K (/Day)	10577	1.8	2.3	2.1	0.02	1.1	2.8
P/R	10577	0.6	0.8	1.2	0.01	0.4	0.9

In comparing results, it is important to note that Goulburn results make up around 21% of the overall database used to generate Table 5-9. Nevertheless, the range in median GPP over all Goulburn sites and the six years of data is slightly lower than the overall LTIM result (1.3 *c.f.* 1.6 mg O_2/L/Day). However, the LTIM data are skewed by the fact that along with the Goulburn, only the Lachlan Selected Area had a significant amount of winter time data. For a similar reason the median Goulburn ER rate for all sites (2.56 mg O_2/L/Day) is slightly lower that the median value for all five selected areas (3.1 mg O_2/L/Day). Nevertheless, it is highly likely that the same factors constraining primary production (mainly nutrients) and ecosystem respiration (organic carbon supply) are important in all the southern Basin as well as specifically in the Goulburn River.

Metabolism across seasons, 2014-2021

The box plots in the composite Figure 5-7 portray the seasonal dependence of GPP, ER, P/R and NEP (Net Ecosystem Production = GPP – ER) using the full seven-year data set from all sites. The summary statistics for all of these parameters are presented in Table 5-10.

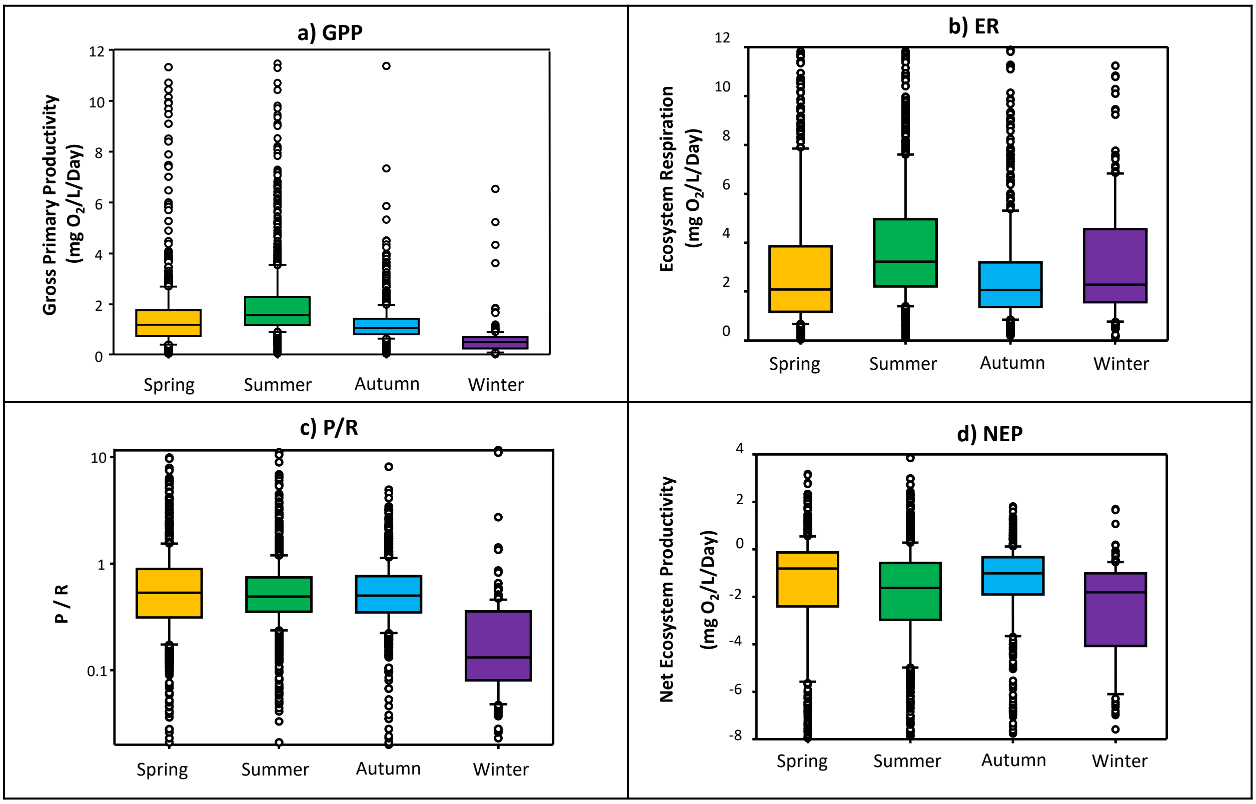


Figure 5-7 Seasonal dependence of GPP, ER, P/R and NEP for all sites combined, with data from 2014-21.

Table 5-10 Seasonal Dependence of GPP, ER, P/R and NEP – all sites combined. Data from 2014-2021.

Parameter	Season	n	Mean	Std Dev	Min	Max	Median	25%	75%
GPP	Spring	822	1.50	1.43	0.02	11.5	1.18	0.72	1.78
	Summer	1420	2.12	2.05	0.03	22.9	1.57	1.16	2.31
	Autumn	819	1.31	1.58	0.02	25.7	1.06	0.79	1.45
	Winter	218	0.57	0.70	0.01	6.60	0.49	0.22	0.71
ER	Spring	822	3.25	3.48	0.03	24.3	2.08	1.16	3.87
	Summer	1420	4.26	3.94	0.11	40.7	3.22	2.19	4.98
	Autumn	819	2.98	3.77	0.20	48.1	2.07	1.36	3.22
	Winter	218	3.44	3.59	0.13	25.7	2.28	1.55	4.58
P/R	Spring	822	0.83	1.07	0.01	9.87	0.53	0.31	0.90
	Summer	1420	0.69	0.93	0.01	16.9	0.49	0.35	0.75
	Autumn	819	0.65	0.59	0.01	8.10	0.50	0.35	0.77
	Winter	218	0.33	1.09	0.01	11.6	0.13	0.08	0.36
NEP	Spring	822	-1.75	2.94	-21.6	3.17	-0.81	-2.42	-0.11
	Summer	1420	-2.13	2.89	-21.7	12.1	-1.63	-2.99	-0.56
	Autumn	819	-1.67	2.96	-37.5	7.15	-1.01	-1.91	-0.32
	Winter	218	-2.88	3.32	-25.2	1.69	-1.81	-4.09	-0.99

This table shows that across the entire seven-year data set, the highest GPP rates were found, unsurprisingly, during the summertime. Median GPP rates were similar in spring and autumn and much lower during winter. The explanation for these findings is that the highest rates are found during the warmest temperatures (the cellular metabolism of the primary producers – phytoplankton, benthic, epiphytic and epilithic algae and macrophytes, increases with temperature), with the highest photosynthetically active radiation (sunlight) and the most hours of this sunshine. As shown in the Section 5.5.5 below, GPP is positively correlated with both mean daily water temperature and the amount of PAR each day.

Unlike GPP, wintertime ER rates were not lower than spring and autumn. Wintertime showed the largest (most negative) values of NEP due to the decline of GPP in the colder, darker months whereas ER remained constant. As noted earlier in this report, the actual magnitudes of these parameters (now including NEP) are on the lower end of the 'normal' range found elsewhere in the world.

In 2018, the concept of metabolic fingerprinting was introduced by Bernhardt and co-workers (Bernhardt et al. 2018). It highlights the relationship between GPP and ER, so in a sense is closely related to the P/R ratio. The benefit is that changes in the relative importance of these two metabolic parameters are easily visualized. An example of such fingerprinting is shown in Figure 5-8 which draws upon the MER Year 2 data from McCoy's Bridge. Such fingerprinting is also a focal point of the basin-level interpretations.

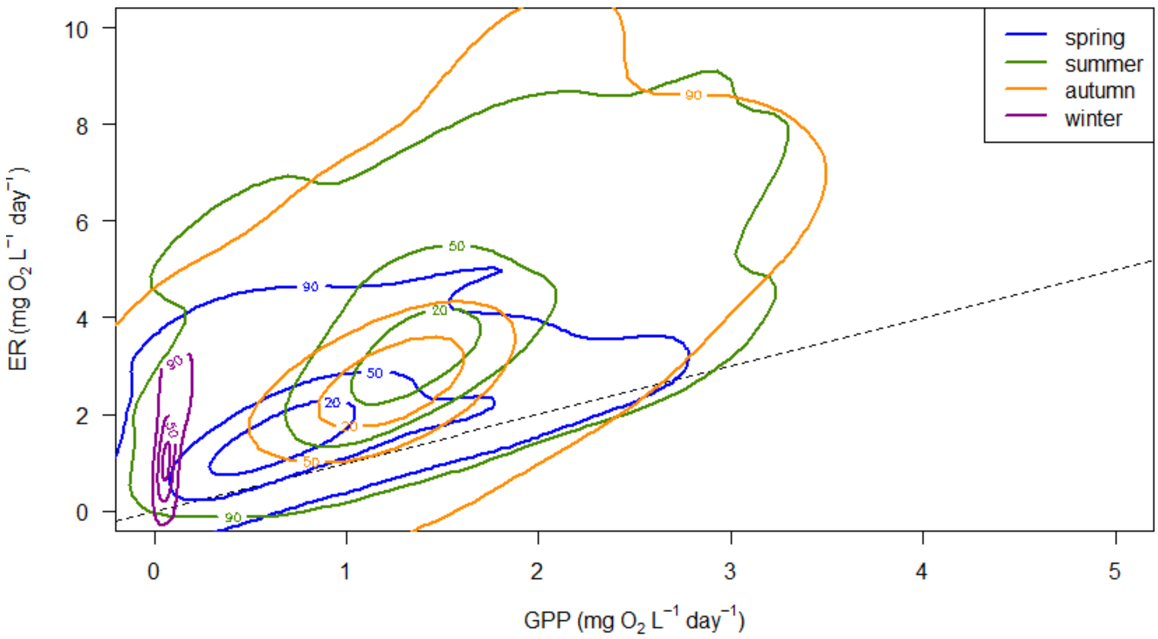


Figure 5-8 Seasonal dependence of the metabolic fingerprint at McCoy's Bridge for the Year 2 MER data set.

As this is the first time such a fingerprint has been presented in these reports, a few key features are explained. Firstly, the dashed line represents a 1:1 ratio of GPP and ER rates i.e. P/R=1. Above this line represents a net heterotrophic system where ER > GPP; conversely below this line indicates a net autotrophic system where GPP > ER. Each season is displayed as contour plots (in differing colours). The '50' contour line means half of all daily GPP&ER pairs lie within this contour. The '90' contour contains 90% of all GG&ER pairs and hence covers a wider area than the '50' contour. Similarly, the '20' contour is the smallest area and encloses the region where the most tightly packed GPP&ER pairs are found.

Even though there are some seasonal differences, the key feature of the figure is that almost all of the '90' contour lies above the 1:1 line, again consistent with the net heterotrophy indicated by NEP and P/R values. The '50' and '20' contours are above this line as well. It is also apparent that the range of spring time GPP&ER pairs is much more constrained in both GPP and ER than either summer or autumn (which are very close to equivalent). However, when comparing the '50' contours of summer and autumn, the summer time range reaches higher GPP and ER values. Winter results are extremely constrained with a very narrow range of GPP, as shown earlier in Figure 5-5. These winter time results are reflective though of the extremely low and narrow GPP results found in 2020. Further comparisons and insights will be made as this technique and its utility are expanded in future reports.

Metabolism across seasons and flow categories, 2014-2020

Consideration is now given to stratifying the same seasonal data by site and flow category (Table 5-3). Table 5-11 presents data for GPP and Table 5-12 for ER.

Table 5-11 Summary Statistics for Gross Primary Productivity (mg O2/L/Day), stratified by Season, Site and Flow Category. All data from 2014-2021.

Season	Site	Flow Cat	n	Mean	Std Dev	Min	Max	Median	25%	75%	Season	n	Mean	Std Dev	Min	Max	Median	25%	75%
Spring	Arcadia Downs / Darcy's Track	Very Low	37	1.62	0.64	0.6	4.04	1.54	1.24	1.91	Summer	38	3.58	1.93	1.3	7.15	3.14	1.87	5.56
		Mod Low	79	1.99	1.62	0.2	10.9	1.70	1.12	2.34		152	2.16	1.10	0.2	9.47	2.02	1.49	2.57
		Low Fresh	29	0.63	0.34	0.1	1.65	0.56	0.40	0.85		93	1.25	0.40	0.06	2.29	1.23	0.99	1.52
		Med Fresh	30	0.48	0.34	0.03	1.23	0.41	0.22	0.65		19	1.50	0.66	0.76	3.97	1.41	1.35	1.57
	McCoy's Bridge	Very Low	97	1.56	0.71	0.7	5.98	1.43	1.23	1.71		97	2.15	1.38	0.7	11.6	1.70	1.36	2.82
		Mod Low	120	1.64	0.76	0.4	4.09	1.46	1.13	1.93		226	1.65	1.02	0.2	9.23	1.42	1.14	1.83
		Low Fresh	49	1.27	0.55	0.4	2.65	1.18	0.81	1.65		169	1.59	0.67	0.1	3.13	1.40	1.00	2.12
		Med Fresh	85	0.76	0.39	0.14	2.00	0.73	0.46	0.99		2							
	Moss Rd / Day Rd / Murchison	Very Low	42	3.73	3.38	0.7	11.5	2.04	1.12	6.05		30	7.04	5.02	0.4	20.8	6.55	2.54	9.6
		Mod Low	33	3.00	2.52	0.6	10.3	2.19	0.94	3.80		164	3.38	3.81	0.3	22.9	1.87	1.26	3.94
		Low Fresh	29	0.93	0.65	0.1	2.89	0.84	0.43	1.29		84	2.14	1.63	0.2	11.4	1.90	1.10	2.69
		Med Fresh	22	0.64	0.32	0.09	1.28	0.62	0.44	0.83		9	2.27	0.67	1.47	3.64	2.04	1.81	2.71
Autumn	Arcadia Downs / Darcy's Track	Very Low	1								Winter	1							
		Mod Low	69	1.13	0.86	0.02	5.4	0.96	0.69	1.26		13	0.35	0.15	0.19	0.66	0.32	0.23	0.40
		Low Fresh	14	0.84	0.46	0.3	1.62	0.67	0.48	1.20		12	0.23	0.12	0.07	0.47	0.21	0.13	0.34
		Med Fresh	18	0.68	0.29	0.04	1.08	0.73	0.54	0.90		8	0.13	0.08	0.03	0.24	0.14	0.06	0.19
	McCoy's Bridge	Very Low	100	1.30	0.48	0.4	2.56	1.19	0.94	1.64		10	0.83	0.16	0.5	1.02	0.85	0.73	0.95
		Mod Low	188	1.25	0.66	0.2	4.53	1.10	0.83	1.48		100	0.66	0.29	0.06	1.85	0.65	0.50	0.77
		Low Fresh	121	1.06	0.35	0.6	2.10	1.03	0.77	1.25		8	0.19	0.12	0.04	0.38	0.14	0.12	0.32
		Med Fresh	29	1.22	0.35	0.13	1.60	1.36	0.98	1.46		5	0.10	0.09	0.01	0.26	0.08	0.03	0.18
	Moss Rd / Day Rd / Murchison	Very Low	12	2.36	3.35	0.1	11.5	0.96	0.57	3.30		6	0.76	0.50	0.2	1.7	0.68	0.42	1.1
		Mod Low	53	1.82	2.17	0.1	14.3	1.04	0.93	1.86		15	0.39	0.16	0.0	0.7	0.39	0.30	0.51
		Low Fresh	24	1.81	0.71	0.9	3.48	1.77	1.06	2.33		7	0.33	0.35	0.0	0.96	0.18	0.05	0.59
		Med Fresh	15	1.00	0.32	0.19	1.35	1.11	0.94	1.17		4							

Table 5-12 Summary Statistics for Ecosystem Respiration (mg O2/L/Day), stratified by Season, Site and Flow Category. All data from 2014-2021.

Season	Site	Flow Cat	n	Mean	Std Dev	Min	Max	Median	25%	75%	Season	n	Mean	Std Dev	Min	Max	Median	25%	75%
Spring	Arcadia Downs / Darcy's Track	Very Low	37	4.17	2.76	1.2	10.7	2.81	2.25	6.16	Summer	38	6.38	4.36	1.8	18.1	5.34	2.67	8.21
		Mod Low	79	3.26	2.89	0.4	12.3	2.26	1.50	3.59		152	4.11	3.18	0.9	30.5	3.46	2.51	4.68
		Low Fresh	29	1.52	0.65	0.2	3.10	1.45	1.02	1.94		93	2.11	1.16	0.7	6.4	1.81	1.26	2.61
		Med Fresh	30	1.09	0.78	0.03	3.19	0.98	0.46	1.77		19	2.82	2.28	1.21	11.8	2.37	1.75	2.92
	McCoy's Bridge	Very Low	97	4.22	2.59	0.7	17.7	3.68	2.57	5.27		97	5.06	3.29	1.5	25.2	4.27	2.74	6.70
		Mod Low	120	2.19	1.21	0.06	6.02	2.08	1.47	2.70		226	4.49	3.03	1.2	28.4	3.84	2.96	5.14
		Low Fresh	49	1.67	1.01	0.14	4.72	1.41	1.17	2.08		169	2.29	0.89	0.1	5.22	2.26	1.75	2.72
		Med Fresh	85	1.14	0.79	0.21	5.75	1.02	0.59	1.49		2							
	Moss Rd / Day Rd / Murchison	Very Low	42	7.31	6.51	0.8	20.2	4.71	1.50	12.84		30	6.42	5.54	1.4	21.0	3.80	2.34	8.6
		Mod Low	33	6.96	5.34	1.1	24.3	5.49	2.95	10.38		164	6.61	7.19	0.7	40.7	4.22	2.95	6.51
		Low Fresh	29	5.32	4.49	0.15	13.5	5.03	0.88	9.59		84	4.45	4.01	0.2	17.3	2.94	1.18	7.38
		Med Fresh	22	11.0	5.45	1.01	22.2	10.4	8.47	14.37		9	1.05	0.81	0.21	2.88	0.82	0.51	1.45
Autumn	Arcadia Downs / Darcy's Track	Very Low	1								Winter	1							
		Mod Low	69	2.06	2.14	0.34	12.8	1.33	1.01	2.23		13	2.47	1.48	0.5	5.06	2.48	1.22	3.37
		Low Fresh	14	1.32	1.37	0.47	5.82	0.87	0.59	1.50		12	2.29	1.05	0.7	4.45	2.00	1.64	2.80
		Med Fresh	18	1.13	0.61	0.28	2.40	1.03	0.65	1.70		8	1.68	1.15	0.79	4.04	1.29	0.82	2.41
	McCoy's Bridge	Very Low	100	2.93	1.33	0.9	6.69	2.85	1.76	3.87		10	5.05	4.02	1.2	11.2	3.54	1.65	9.76
		Mod Low	188	2.80	1.61	0.34	11.2	2.46	1.79	3.37		100	3.39	2.30	0.2	10.8	2.32	1.78	5.07
		Low Fresh	121	1.69	0.56	0.32	3.00	1.64	1.24	2.16		8	2.49	1.83	0.6	6.46	1.89	1.44	3.33
		Med Fresh	29	1.41	0.51	0.51	2.31	1.58	0.85	1.79		5	1.90	1.02	0.76	3.35	1.97	0.94	2.82
	Moss Rd / Day Rd / Murchison	Very Low	12	9.01	7.02	2.8	25.0	6.40	4.35	10.67		6	5.62	2.44	2.8	9.2	5.30	3.66	7.7
		Mod Low	53	4.85	6.47	0.57	38.9	2.34	1.60	5.26		15	1.74	1.26	0.7	4.6	1.20	0.84	2.44
		Low Fresh	24	7.02	3.96	0.34	15.6	8.19	4.05	9.30		7	3.05	2.79	0.6	7.76	2.02	1.03	6.20
		Med Fresh	15	3.17	1.23	0.33	4.67	3.30	2.87	3.89		4							

The major feature of the data is that increasing flow categories generally leads to decreased rates of oxygen production or consumption per litre of water. Without specific data to quantify these observations, it is expected that much of the primary production and ecosystem respiration occurs on the sediment surface and on other hard substrates in the water columns (e.g. snags). Biofilms, especially in the littoral zone (shallow, near bank region), are typically very important contributors to overall primary production. A recent Masters degree research project at the University of Melbourne (supervised by Angus Webb and Mike Grace) examined the contribution of water column primary production and respiration to stream metabolism at several of the sites in the Goulburn River. The findings of this project are summarised in Section 10 and will be further integrated into the whole stream metabolism analysis in next year's report. The importance of the littoral zone sets the Goulburn (and Lachlan and Edward/Kolety-Wakool river systems) apart from the larger rivers (Murrumbidgee and Lower Murray) where water column primary production via phytoplankton is a more important contributor to overall GPP. These changes in oxygen concentration from GPP (& ER) arising from the sediment and other hard surfaces are then mixed through the water column. The shallower the overlying water, the more influence the sediment-based changes in DO will have on this overlying water. Hence when more water is added, this sediment-based signal is distributed into more water and hence is 'diluted'. Of course, adding more water to the existing water column will also 'dilute' the extant phytoplankton population, thus reducing volumetric GPP rates, assuming that the 'new' water has lower phytoplankton populations. Attempting to better identify the relative contributions of benthic and water-column metabolism will be the subject of a contingency monitoring project to be undertaken over summer 2020-21.

Consideration of the origins of the decrease in GPP and ER with flow is important when determining the effectiveness of environmental water additions, as at first glance it might be assumed that adding water is achieving poor ecological outcomes. However, as strongly argued later, it is the overall increase in organic carbon load that is the major consideration when the effects of watering actions are considered.

5.5.4. Investigating the basal drivers for metabolism

Previous reports have demonstrated for several years that GPP is positively correlated with daily light and temperature and that ER is correlated with temperature as well. Unsurprisingly daily light and average daily water temperature are correlated with each other. Solar irradiance provides both light and heat to the water surface, so days of higher and more intense sunshine result in warmer water temperatures. This finding does mean that subsequent data analysis must take this covariance into account. These dependencies are explored in the Bayesian modelling described in Section 5.5.5.

Nutrient concentrations from the five MER sites were determined from samples that were collected approximately monthly in 2019-2021. These data are presented in Table 5-13, along with turbidity. Pooled nutrient data from all sites and across the seven years of record (2014-2021) are presented in Table 5-14. Also included in this table are data from the LTIM program plus data from 2014-19 at Murchison and McCoy's Bridge (DELWP 2015).

The key finding is that, consistent with the six previous years, the concentrations of bioavailable nutrients in the Goulburn River at all sites were very low. In particular, the bioavailable phosphorus concentration FRP, was consistently below 0.01 mg P/L with a few exceptions. These higher concentrations occurred in mid-autumn through to winter, possibly arising from breakdown of organic matter, plant detritus etc from the summer growth period. Similar mid-late autumn 'peaks' in FRP have been observed previously at McCoy's Bridge. It is very difficult to draw any conclusions about the effects of flow events (including Commonwealth environmental water) on nutrient concentrations as monitoring does not occur over the changing hydrograph; instead it is performed when the DO loggers are downloaded and maintained.

Table 5-13 Summary of Nutrient (N, P & C) concentrations of water samples collected from all five MER study sites combined over the period May 2019 to April 2021. For comparison, the combined LTIM data (four sites, 2014-19) and separately measured data for the Murchison and McCoy's Bridge sites were downloaded from the (Victorian) DELWP Water Measurement Information System covering the period July 2004 to June 2019. The number of single measurements in the LTIM data set that were below the Limit of Detection (LoD, 0.001 mg/L for dissolved nutrients, variable for Chlorophyll-a) are also noted.

Program	Parameter	NO_x mg/L N	NH_3 mg/L N	Total N mg/L N	Total P mg/L P	FRP mg/L P	DOC (MER) / NPOC mg C/L	Chl-a ug/L
MER 2019-21	n	96	72	96	96	96	78	70
	Median	0.100	0.008	0.451	0.039	0.003	3.2	8.6
	Mean	0.168	0.018	0.603	0.049	0.007	4.2	9.2
	Std Dev	0.177	0.022	0.384	0.039	0.011	2.5	6.4
LTIM 2014-19	n	123	123	123	123	123	123	96
	n < LoD	34	13	0	0	0	0	54
	Median	0.029	0.004	0.33	0.030	0.003	4.2	8.5
	Mean	0.055	0.006	0.37	0.035	0.004	5.5	9.6
	Std Dev	0.070	0.009	0.18	0.019	0.004	4.1	4.5
DELWP	n	733			733	732	509	
July 2004 - June 2019	Median	0.077			0.049	0.003	5.0	
McCoy's Bridge	Mean	0.144			0.057	0.007	6.7	
Murchison	Std Dev	0.167			0.049	0.016	4.2	

One interesting aspect of the data in Appendix D, which is not evident in the summary of the pooled data (Table 5-13), is the seasonal variation in NOx (nitrate + nitrite concentrations). This is clearly seen in Figure 5-9, which combines both years of data using a day-month x-axis.

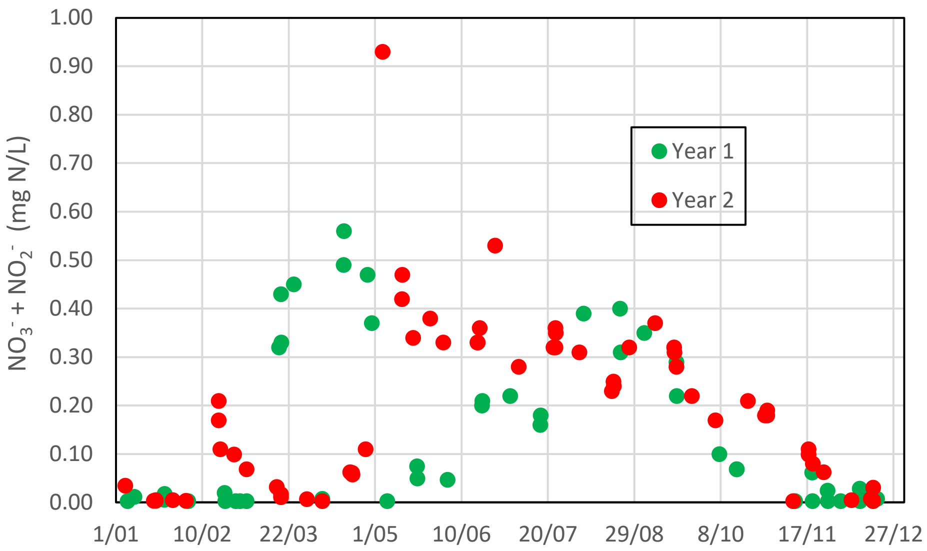


Figure 5-9 Variation in NOx concentrations in the Goulburn River, May 2019 – Apr 2021. Data combined from all 5 sites and taken from Table 5-13.

The key aspect of Figure 5-9 is the major drawdown of NOx concentrations during the warmer months (November – February). This is consistent with the period of more intense gross primary productivity, when the autotrophs require a source of bioavailable N. As can also be seen from Appendix D, the ammonia concentrations are extremely low (< 0.005 mg N/L) during this 'growing' time as well, before increasing in March and April due to lower growth rates plus decay of detrital material. In addition to bioavailable N, the autotrophs require a source of bioavailable phosphorus, which is measured here as Filterable Reactive Phosphorus (FRP). Throughout the late spring-early autumn period FRP concentrations were relatively constant at 0.003 mg P/L. These findings support the earlier conclusions from the LTIM project that primary production is constrained in the Goulburn River by bioavailable nutrient concentrations. There is no upstream-downstream trend in FRP; it is low throughout Zones 1 and 2, indicating that there is no significant continual input of this nutrient into the river. Any such inputs must be relatively transient as they are not evident in the monthly data. As noted elsewhere, it would be extremely insightful to follow nutrient concentrations across a flow event hydrograph, especially during the warmer months, but this is beyond the scope and budget of this project.

In addition to nutrients, there is sufficient data on turbidity and electrical conductivity to compare the results during the first two years of the MER project with longer term data sets collected at Murchison, Shepparton and McCoy's Bridge (Table 5-14).

Table 5-14 Summary of Turbidity and Electrical Conductivity pooled data from the 5 MER sites (2019-2021) and DELWP WMIS data covering the period 1990-2020.

	Site	n	Mean	Std Dev	Min	Max	Median	25%	75%
Turbidity (NTU)	**MER**	96	25	22	7	181	19	13	30
	Murchison	372	17	17	1	152	13	9	19
	Shepparton	366	32	20	4	139	26	18	38
	McCoy's Bridge	1297	42	21	8	257	38	28	52
EC (µs/cm)	**MER**	96	91	35	49	200	77	63	119
	Murchison	374	116	51	46	310	108	76	150
	Shepparton	368	143	56	49	320	139	100	180
	McCoy's Bridge	1311	168	68	53	470	160	120	210

EC and turbidity were generally lower in 2019-21 (Table 5-14) when compared with the long term (30 year) data sets from this region of the lower Goulburn River. While no great ecological significance is attached to the differences in electrical conductivity, it is interesting to explore the turbidity data a little further. Turbidity will affect light penetration into the water column, hence the smaller the turbidity value, the more of the water column and sediment surface receiving sufficient light to enable photosynthesis to occur. The turbidity attenuates the Photosynthetically Active Radiation (PAR) that has reached the water's surface and then moves down through the water. It is the PAR readings from light loggers in open fields that are investigated in the subsequent Bayesian modelling of metabolic drivers, as well as being the light term in BASEv2. Ideally, subsurface light would be measured and modelled but that is a very complex task due to how quickly it is attenuated. Thus, reliable turbidity measurements assist greatly in qualitative explanations of any changes in GPP-Surface Light relationships. As noted above with NO_x concentrations, annual summary statistics can sometimes hide patterns in the data; here in Figure 5-10, turbidity over the two years of the MER program (2019-2021) is plotted against the date of sampling.

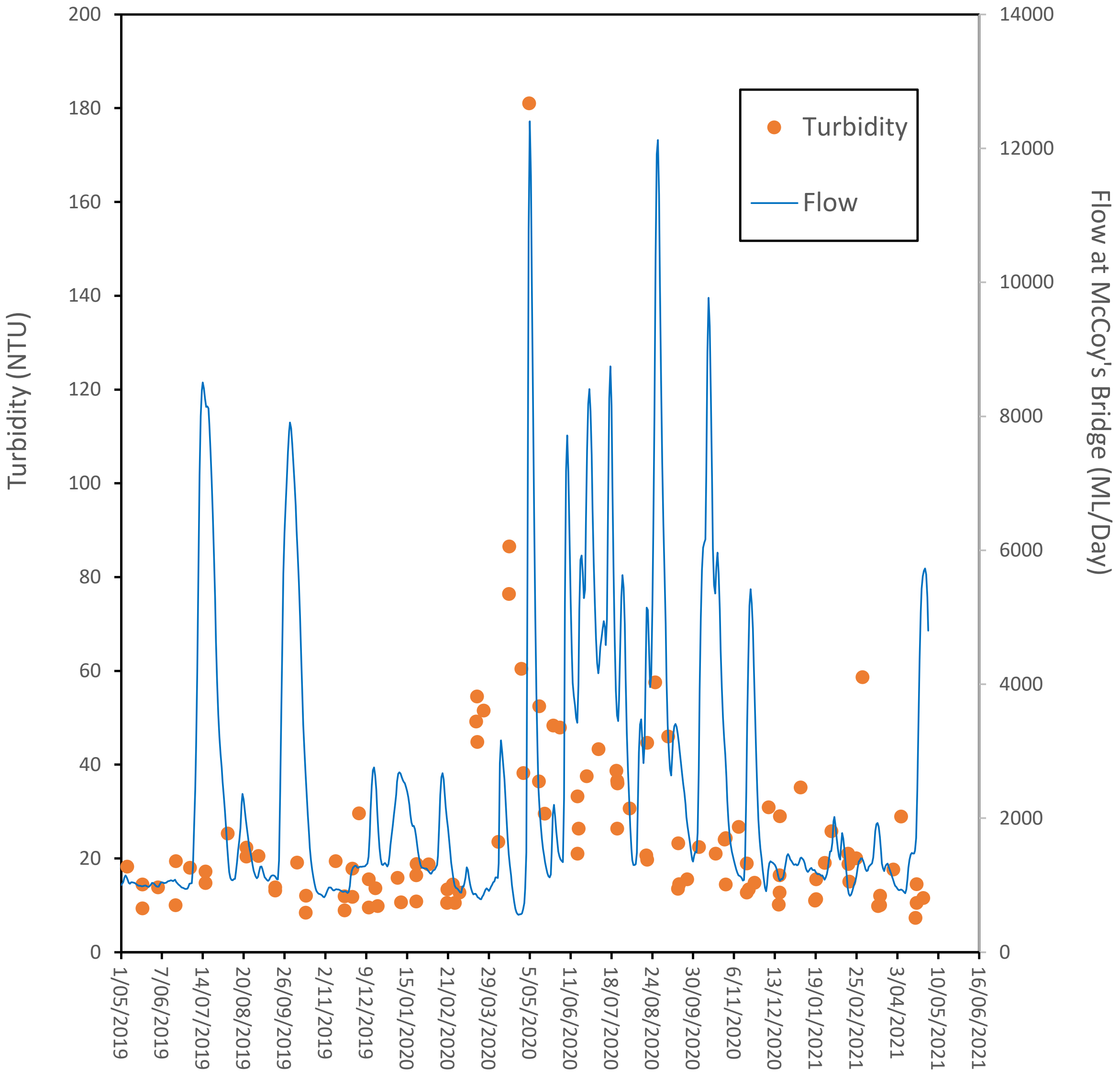


Figure 5-10 Variation in Turbidity (NTU) in the Goulburn River, May 2019 – Apr 2020. Data combined from all 5 sites and taken from Appendix D. Daily Flow data over this period is from McCoy's Bridge.

It is apparent from Figure 5-10 that there was a substantial peak in turbidity in March to May 2020 when this parameter increased substantially over the typical 10-30 NTU measured during the rest of this two-year period. It is difficult to attribute specific effects on GPP rates as rates would also be expected to fall due to the shorter number of hours and less intense sunlight during autumn compared to summertime. The origin of the turbidity increase is not definitive but is almost certainly emanating from further upstream as the turbidity at the Goulburn Weir Wall (Station 405259) jumped from 10-20 NTU to over 60-90 NTU in early March. The McCoy's Bridge discharge has been added to this figure and this data suggests that the origin of the higher turbidity is not the April 2020 higher flow event.

5.5.5. Statistical modelling

As described in Section 5.4.4, a hierarchical Bayesian linear regression model, incorporating first-order auto-regression, examined the relationship of each metabolism endpoint (GPP and ER) against daily discharge, light and temperature. The predictor variable was daily discharge. This analysis used data from 2020-21 (MER), and only included data that met the acceptance criteria.

Results of the regression analyses (Table 5-15) may be summarised as:

GPP

- Flow has a negative effect on rate of GPP at all sites when using both log-discharge and delta discharge as the flow indicator. The results with log-discharge as the flow indicator are more significant than those with delta discharge as the flow indicator.
- Both light and temperature have positive effects on GPP at all five sites, regardless of the flow indicator adopted.

ER

- When using log-discharge as the indicator, flow has a negative effect on ER at all five sites, with no positive effects observed. When using delta discharge as the indicator, flow has an on-average positive effect at Loch Garry but negative effects at the other four sites. However, the effect of flow on ER is not as large as that on GPP, with the only significant effect being observed at Murchison.
- Light has negative effects on ER at all five sites when using both log-discharge and delta discharge as the flow indicator, but the effects are not significant at McCoy's Bridge and Shepparton with log-discharge as the indicator, and at Murchison and Shepparton with delta discharge as the indicator.
- Temperature has positive effects at all five sites using both log-discharge and delta discharge as the flow indicator, but only the effects at Arcadia Downs and Murchison are significant.

These findings are largely consistent with previous years; in addition, modelling presented in the LTIM reports showed that no improvement to any model was achieved by adding in a lag period (in days) between flow and metabolic response, hence was not undertaken this year.

The finding that additional light stimulates GPP in all 5 sites is unsurprising given the essential role of sunlight in the photosynthetic process. Temperature shows a strong positive effect on GPP for 4 of the 5 sites – the result at Shepparton also indicates a positive, but not statistically significant, relationship as the lower (2.5%) credible interval is below zero.

Table 5-15 Regression coefficients from Bayesian modelling of relationships between discharge and GPP or ER based on Equation 2, directly using log(Q) as the discharge indicator for data from 2019-20. "ac" is the coefficient of the autocorrelation term. Coloured rows show 'significant' positive (blue) or negative (red) effects. Here significance is assigned for any distribution for which the entire 95% credible interval (2.5% to 97.5%) lies either above or below zero.

	Predictor	Site	Discharge (log(Q))			Delta discharge (diffQ)		
			2.5%	median	97.5%	2.5%	median	97.5%
GPP	Flow	Arcadia Downs	-0.129	-0.071	-0.009	-0.039	-0.003	0.028
		Murchison	-0.129	-0.070	-0.013	-0.042	-0.007	0.022
		Loch Garry	-0.143	-0.078	-0.021	-0.036	-0.002	0.030
		McCoy's Bridge	-0.143	-0.078	-0.014	-0.046	-0.005	0.031
		Shepparton	-0.137	-0.074	-0.007	-0.047	-0.004	0.029
	Light	Arcadia Downs	0.069	0.133	0.194	0.070	0.135	0.195
		Murchison	0.119	0.188	0.261	0.122	0.191	0.271
		Loch Garry	0.053	0.124	0.202	0.052	0.122	0.185
		McCoy's Bridge	0.057	0.109	0.164	0.053	0.106	0.163
		Shepparton	0.078	0.159	0.256	0.084	0.162	0.298
	Temperature	Arcadia Downs	0.050	0.156	0.281	0.051	0.155	0.278
		Murchison	0.053	0.163	0.305	0.049	0.158	0.300
		Loch Garry	0.023	0.141	0.253	0.028	0.137	0.264
		McCoy's Bridge	0.009	0.114	0.206	0.003	0.114	0.199
		Shepparton	-0.010	0.140	0.275	0.010	0.146	0.291
	ac	-	0.789	0.809	0.826	0.789	0.809	0.827
ER	Flow	Arcadia Downs	-0.168	-0.074	0.046	-0.060	-0.007	0.046
		Murchison	-0.347	-0.206	-0.064	-0.147	-0.085	-0.028
		Loch Garry	-0.194	-0.081	0.061	-0.026	0.029	0.085
		McCoy's Bridge	-0.159	-0.049	0.083	-0.125	-0.047	0.026
		Shepparton	-0.181	-0.056	0.118	-0.125	-0.064	-0.007
	Light	Arcadia Downs	-0.163	-0.084	-0.018	-0.160	-0.084	-0.017
		Murchison	-0.155	-0.081	-0.012	-0.155	-0.080	0.001
		Loch Garry	-0.172	-0.087	-0.021	-0.171	-0.088	-0.021
		McCoy's Bridge	-0.124	-0.066	0.002	-0.125	-0.068	-0.001
		Shepparton	-0.149	-0.070	0.035	-0.149	-0.069	0.039
	Temperature	Arcadia Downs	0.012	0.130	0.281	0.022	0.138	0.289
		Murchison	0.035	0.167	0.355	0.041	0.171	0.359
		Loch Garry	-0.174	0.008	0.147	-0.145	0.030	0.156
		McCoy's Bridge	-0.023	0.081	0.177	-0.027	0.082	0.175
		Shepparton	-0.125	0.061	0.213	-0.100	0.073	0.217
	ac	-	0.636	0.661	0.686	0.637	0.661	0.686

ER was negatively related to flow at all sites (Table 5-15) as expected due to the water dilution effect, however, was only statistically significant at Murchison, as at the other four sites, the upper (2.5%) credible interval is above zero. The presence of a statistically significant inhibitory effect of light on ER at all sites except McCoy's Bridge and Shepparton is surprising, and at this stage, unexplained. A stimulatory effect might be expected (as noted elsewhere) if there is sufficient light stimulated GPP that then measurably enhances ER through increased organic carbon exudate production. The positive effect of temperature on ER at all sites (statistically significant at Arcadia Downs and Murchison) is expected due to microbial metabolic rates increasing with temperature.

The counterfactual models (run without environmental flows) demonstrate minor effects of the flows on rates of GPP and ER (Figure 5-11). When using log-discharge as the predictor, almost all modelled differences for GPP and ER intercept the zero line, indicating no strong effect of environmental flows. This occurs even while medians are nearly all negative, reflecting the negative effects of flows seen in Table 5-15.

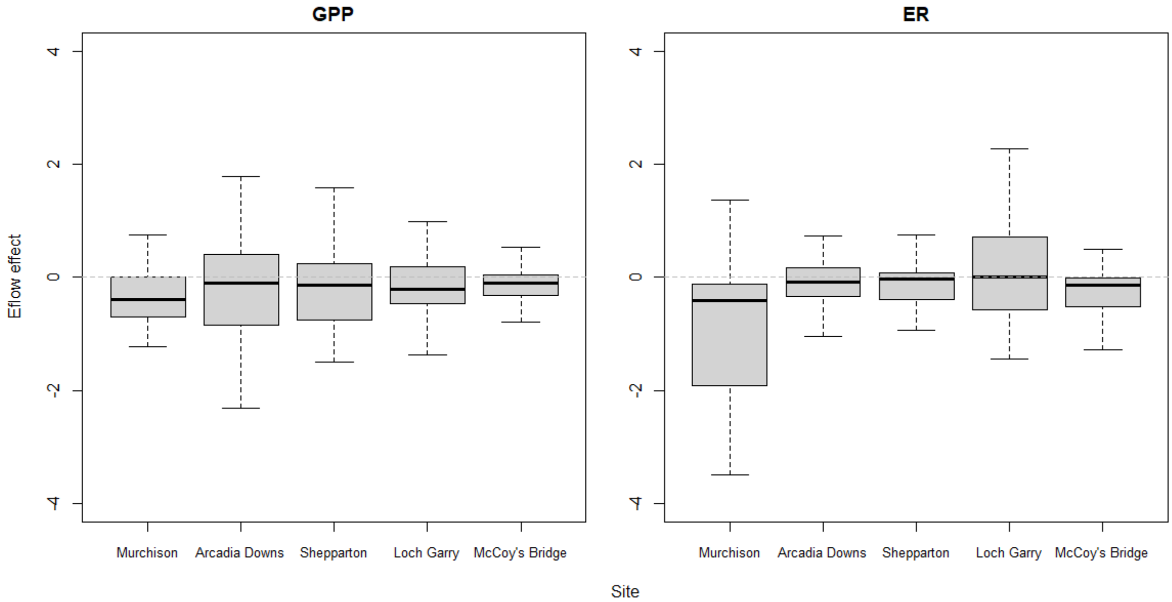


Figure 5-11 Effects of Environmental Flows (including watering actions) on rates of GPP and ER, using discharge (log(Q)) as the flow predictor. Y-axes show the differences in corresponding rates between with and without the environmental water delivered in 2019-20.

Higher flows suppress volumetric rates of GPP and ER (i.e. per litre of water, the amount of gross primary production and ecosystem respiration) decreases. Unlike some other river systems in the MDB, there is only one source of CEW water, so changes of CEW source affecting metabolic rates is not relevant to the Goulburn. For example, regulated water returning from the Chowilla Floodplains has a measurable impact on GPP and ER in the Lower Murray River. It has been noted in previous reports that inflows to the Goulburn River from anoxic summertime, storm event flows from Seven Creeks can adversely affect water quality (especially Dissolved Oxygen concentration) for as long as two weeks. Unfortunately, there are no nutrient data collected during such events so it is unclear whether such flows then induce greater metabolic rates through nutrient addition. Given the similarity in rates found upstream and downstream of Shepparton, it is extremely likely that the two tributaries entering the Goulburn (Seven Creeks and the Broken River) are not having any significant stimulatory or inhibitory impact on metabolism in the Goulburn River itself.

When using delta discharge as the flow indicator (Figure 5-12), the flow effect on GPP is very similar to the above results (Figure 5-11), while the effect on ER is not entirely consistent with the above results. Significant increases in ER with environmental flows are predicted in Murchison, Shepparton and McCoy's Bridge, while reductions in ER are predicted at Arcadia Downs and Loch Garry (Figure 5-12). The origins of increases in ER with change in flow are currently under investigation. The inconsistency between sites is also puzzling, but it is noted this is not a longitudinal trend downstream.

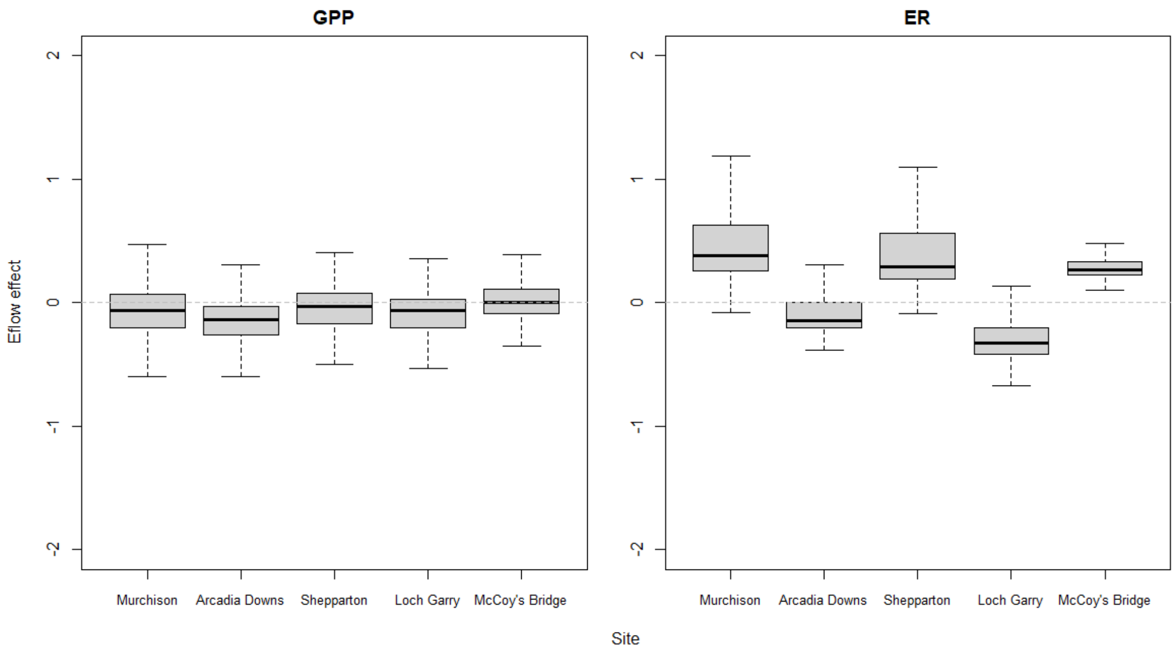


Figure 5-12 Effects of Environmental Flows (including watering actions) on rates of GPP and ER, using delta discharge (diffQ) as the flow predictor. Y-axes show the differences in corresponding rates between with and without environmental water, which are presented

5.5.6. Organic carbon loads and flow categories

For the three sites (Day Rd/Murchison, Darcy's Track/Arcadia Downs and McCoy's Bridge) where flow categorization is possible according to Table 5-3, daily loads of organic carbon created by GPP and consumed by ER have been stratified into these categories using all seven years of available data from the LTIM and MER programs. Almost all days (> 99%) with metabolic parameter estimates meeting acceptance criteria fall into four flow categories: Very Low Flow (VL), Moderately Low Flow (ML), Low Fresh Flow (LF) and Medium Fresh (MF). The summary statistics for these daily organic carbon load data are presented in Table 5-16 (GPP) and Table 5-17 (ER). The two respective box plots are Figure 5-13 (GPP) and Figure 5-14 (ER).

Table 5-16 Summary Statistics for Daily Organic Carbon Load (kg Org C/Day) created by GPP, stratified by Season, Site and Flow Category. All data from 2014-2021.

Season	Site	Flow Cat	n	Mean	Std Dev	Min	Max	Median	25%	75%	Season	n	Mean	Std Dev	Min	Max	Median	25%	75%
Spring	Arcadia Downs / Darcy's Track	Very Low	37	446	205	158	1228	417	268	569	Summer	38	1039	547	273	1889	872	563	1593
		Mod Low	79	894	662	145	3884	793	463	988		152	1006	566	122	5197	909	699	1206
		Low Fresh	29	588	327	144	1500	487	373	697		93	1142	394	47	2542	1113	895	1375
		Med Fresh	30	837	538	69	2017	745	475	1026		19	2068	1381	935	7558	1789	1730	2047
	McCoy's Bridge	Very Low	97	472	218	218	1615	426	335	516		97	679	436	239	3672	539	458	778
		Mod Low	120	819	464	197	2462	693	531	974		226	783	443	150	3751	676	536	889
		Low Fresh	49	1162	481	465	2567	1153	680	1532		169	1545	783	57	3334	1343	898	2201
		Med Fresh	85	1412	583	332	2723	1565	868	1827		2							
	Moss Rd / Day Rd / Murchison	Very Low	42	861	698	198	2357	564	307	1235		30	2076	1511	120	6192	1955	677	2954
		Mod Low	33	1199	989	290	3970	879	439	1687		164	1488	1551	87	7894	872	588	1667
		Low Fresh	29	835	559	160	2033	659	326	1257		84	2070	1458	106	7659	1836	1068	2738
		Med Fresh	22	1227	492	206	2159	1132	907	1640		9	2763	820	1773	4453	2468	2198	3296
Autumn	Arcadia Downs / Darcy's Track	Very Low	1								Winter	1							
		Mod Low	69	503	395	11	2246	401	295	643		13	170	66	97	272	144	112	239
		Low Fresh	14	705	377	198	1348	512	416	1025		12	184	78	74	313	168	116	248
		Med Fresh	18	1033	423	93	1592	1142	750	1355		8	244	205	62	711	219	94	272
	McCoy's Bridge	Very Low	100	421	155	141	859	406	293	494		10	245	44	163	295	250	208	294
		Mod Low	188	576	317	86	2378	502	362	732		100	277	109	32	735	276	228	320
		Low Fresh	121	989	378	440	2262	916	694	1153		8	155	92	29	313	137	104	235
		Med Fresh	29	1767	528	271	2345	1965	1397	2235		5	153	113	17	325	149	61	249
	Moss Rd / Day Rd / Murchison	Very Low	12	729	1064	40	3625	305	129	1047		6	233	153	56	500	211	124	331
		Mod Low	53	726	860	42	5239	380	330	784		15	173	102	17	430	156	115	250
		Low Fresh	24	1841	771	612	3829	2011	1166	2260		7	256	256	43	648	122	44	552
		Med Fresh	15	1571	511	265	1970	1794	1509	1894		4							

Table 5-17 Summary Statistics for Daily Organic Carbon Load (kg Org C/Day) consumed by ER, stratified by Season, Site and Flow Category. All data from 2014-2021.

Season	Site	Flow Cat	n	Mean	Std Dev	Min	Max	Median	25%	75%	Season	n	Mean	Std Dev	Min	Max	Median	25%	75%
Spring	Arcadia Downs / Darcy's Track	Very Low	37	1190	894	373	3009	740	548	1876	Summer	38	1889	1412	519	6009	1597	759	2301
		Mod Low	79	1420	1128	201	4772	1094	741	1702		152	1948	1659	355	16751	1670	1116	2337
		Low Fresh	29	1410	591	283	2536	1333	1031	1782		93	1875	990	715	6235	1564	1234	2174
		Med Fresh	30	1998	1551	78	7039	1575	883	3254		19	4011	4566	1547	22520	3170	2218	3739
	McCoy's Bridge	Very Low	97	1241	721	214	4774	1045	848	1470		97	1611	1061	475	7974	1323	879	2065
		Mod Low	120	1079	625	32	3000	1046	645	1410		226	2104	1276	534	11558	1845	1431	2394
		Low Fresh	49	1550	959	154	5419	1377	1075	1845		169	2135	854	99	5498	2111	1592	2570
		Med Fresh	85	2152	1332	316	7337	1902	1215	2756		2							
	Moss Rd / Day Rd / Murchison	Very Low	42	1681	1361	257	4558	1115	474	2912		30	1943	1785	445	6702	1060	649	2612
		Mod Low	33	2898	2326	377	9364	1945	1409	4618		164	2954	2990	379	18426	1970	1380	3112
		Low Fresh	29	4961	4466	173	12978	3786	642	8921		84	4289	4066	255	16357	2414	1126	5724
		Med Fresh	22	23662	14842	2279	49225	18860	12044	37715		9	1269	981	260	3466	990	616	1772
Autumn	Arcadia Downs / Darcy's Track	Very Low	1								Winter	1							
		Mod Low	69	928	1097	193	6984	570	412	991		13	1243	822	192	2805	1086	694	1743
		Low Fresh	14	1090	1048	389	4498	852	510	1253		12	2009	1215	759	5307	1525	1302	2596
		Med Fresh	18	1873	1226	441	5342	1648	1010	2466		8	2868	1404	1085	5586	2434	1911	3730
	McCoy's Bridge	Very Low	100	965	464	266	2325	828	587	1299		10	1525	1274	299	3727	991	565	3025
		Mod Low	188	1283	780	198	5883	1091	769	1573		100	1512	1079	63	4383	1028	693	2415
		Low Fresh	121	1538	506	361	2773	1384	1197	1935		8	2036	1475	638	5309	1490	1139	2538
		Med Fresh	29	2064	766	633	3271	2250	1219	2723		5	3086	1689	1421	5296	3045	1454	4738
	Moss Rd / Day Rd / Murchison	Very Low	12	2327	1384	888	5728	1982	1375	2678		6	1742	761	893	2793	1661	1092	2412
		Mod Low	53	2181	3694	343	22756	887	582	1863		15	737	487	266	1575	466	344	1112
		Low Fresh	24	7356	4300	271	17179	8778	4051	9770		7	2415	2181	567	5848	1601	863	5242
		Med Fresh	15	4991	1998	487	7453	5127	4722	6544		4							

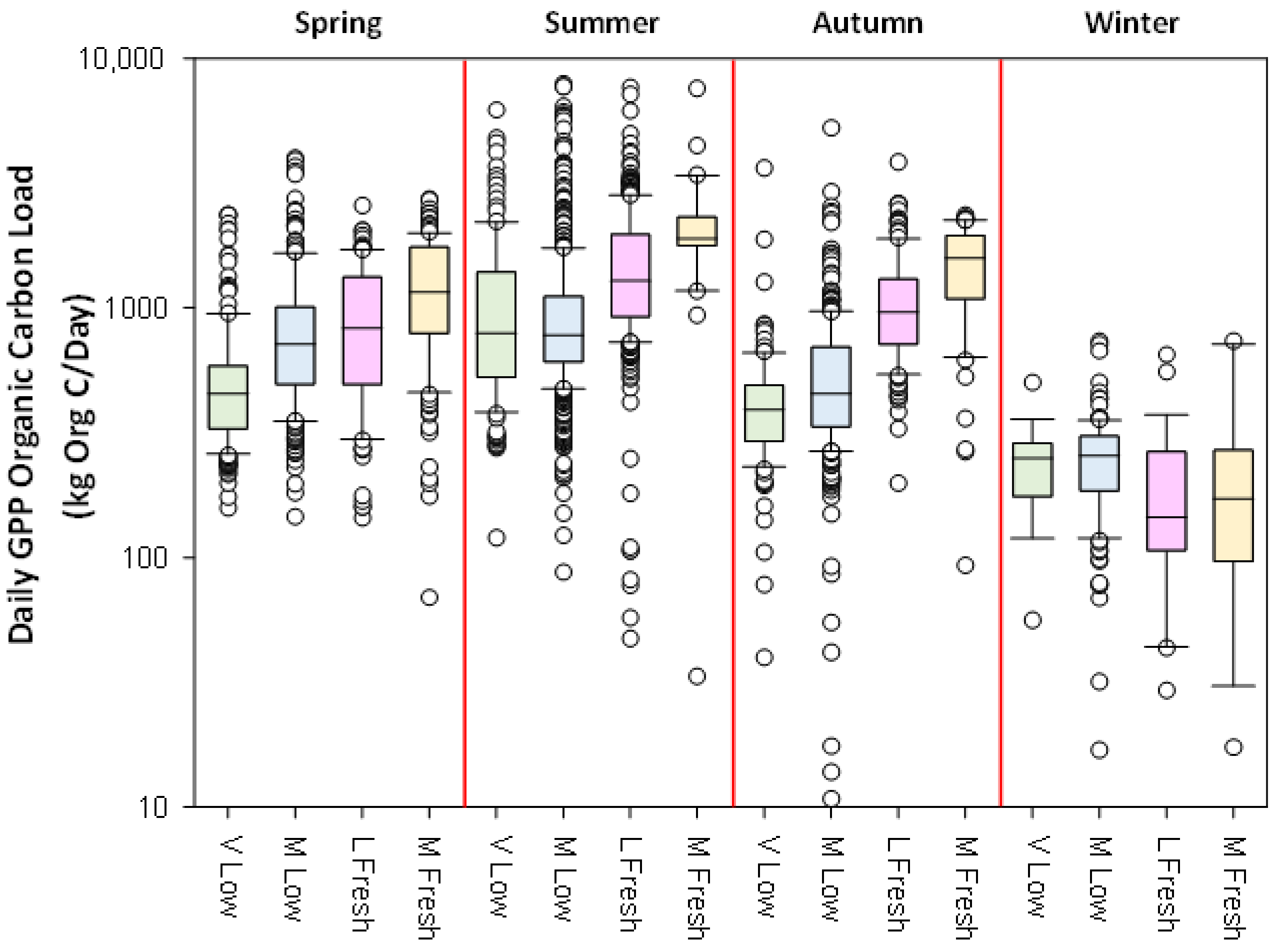


Figure 5-13 Box plot showing the Daily Organic Carbon Load (Tonnes/Day) created by GPP for the combined 7-year LTIM-MER data set, stratified by season and flow category: Very Low Flow, Moderately Low Flow, Low Fresh Flow and Medium Fresh Flow. Summary statistics are presented in Table 5-16. Note the log scale for the Y-axis.

Statistical analysis was preformed to determine the significance (at α = 0.05) of any differences in carbon load with flow category within each season. Differences between seasons were not examined as these would provide very little useful information for management. As a starting point, Wilks-Shapiro tests on both raw data and common transformations (square root, log) of the raw GPP load data indicated failure of normality. Consequently, Mann-Whitney Rank Sum tests were performed between each pair of flow categories (VL-ML, ML-LF, LF-MF) within each season. The results of all tests are summarized in Table 5-18. Bold text indicates a statistically significant increase in GPP load when moving from one flow category to the next higher category. A bold red text value indicates a statistically significant decrease in GPP load with increasing flow category.

Table 5-18 Results of Pair-wise Comparisons of GPP and ER Load Increases with increasing discharge categories, stratified by season. The data are pooled across the sites presented in Table 5-16 and Table 5-17. Statistically significant differences (based on α = 0.05) are shown in bold text. Red text indicates a significant decline in load on increasing discharge.

	GPP Load Comparisons			ER Load Comparisons		
Season	**VL - ML**	**ML - LF**	**LF - MF**	**VL - ML**	**ML - LF**	**LF - MF**
Spring	**< 0.001**	0.328	**< 0.001**	0.555	**0.001**	**< 0.001**
Summer	0.880	**< 0.001**	**< 0.001**	**0.004**	0.090	0.145
Autumn	**< 0.001**	**< 0.001**	**< 0.001**	0.634	**< 0.001**	**0.002**
Winter	0.531	**0.002**	0.754	0.421	**0.003**	0.311

These Mann-Whitney Rank Sum tests for GPP loads showed a very strong statistical difference ($p < 0.001$) for all spring, summer and autumn comparisons except for ML-LF in spring and VL-ML in summer. The winter-time comparisons were non-significant ($p > 0.05$) except for ML-LF where a significant decrease was found ($p = 0.002$). With the exception of this one winter-time instance, in each case of a statistically significant difference between the flow categories, the organic carbon load created from GPP increased with increased flow. All four of these flow categories represent flows that are well constrained within the stream channel. This very important point is developed further in the discussion below.

As with GPP, Wilks-Shapiro tests on both raw data and common transformations (square root, log) of the raw ER load data portrayed in Figure 5-14 indicated failure of normality, hence, Mann-Whitney Rank Sum tests were performed between each pair of flow categories at each site. Six of the twelve comparisons also showed an increase in load with increasing flow category (seen in Figure 5-14) although there was no season when all comparisons were significant. Only in summer was there a significant increase when moving from very low to moderately low flow.

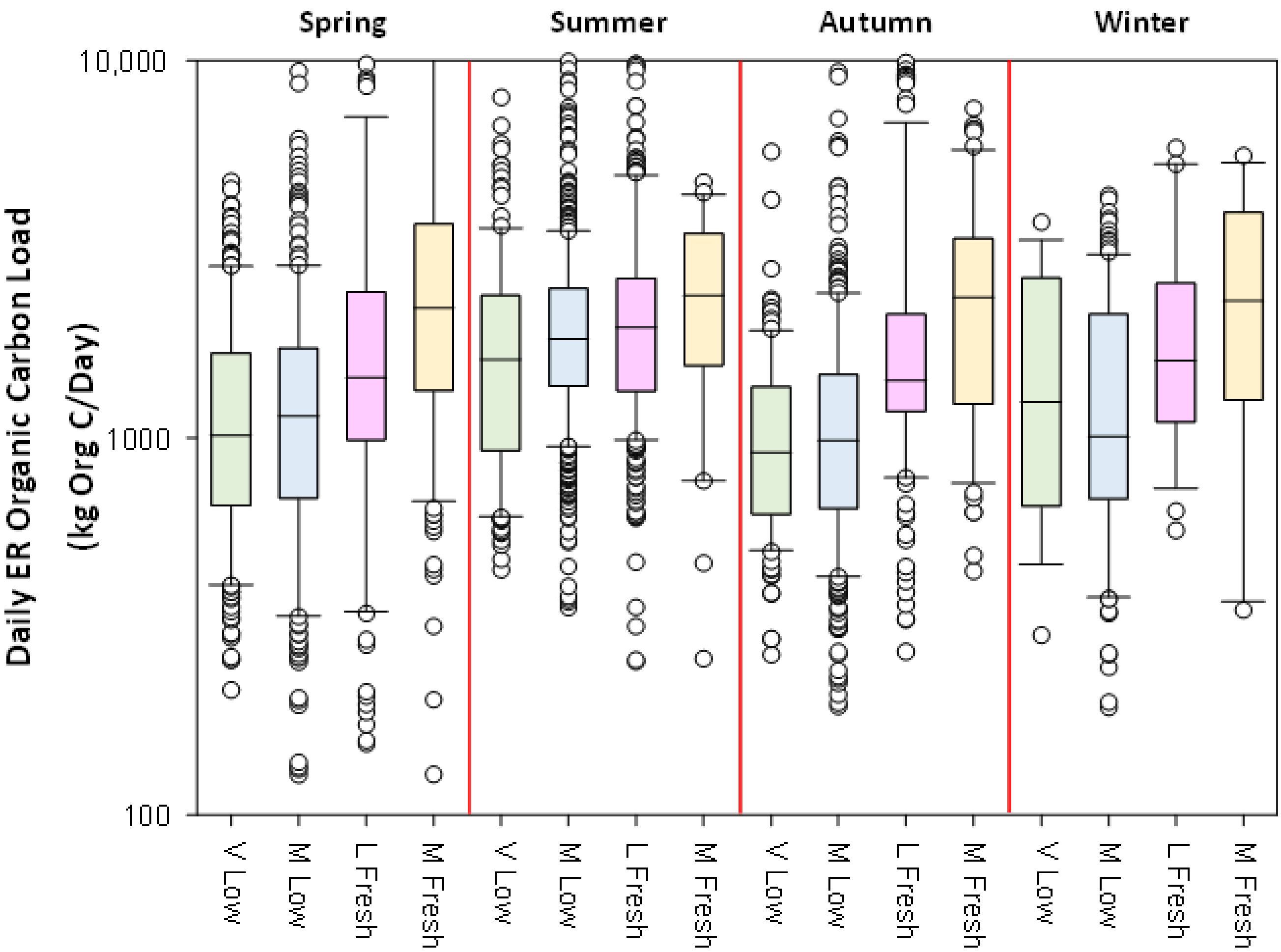


Figure 5-14 Box plot showing the Daily Organic Carbon Load (Tonnes/Day) consumed by ER for the combined 7-year LTIM-MER data set, stratified by season and flow category: Very Low Flow, Moderately Low Flow, Low Fresh Flow and Medium Fresh Flow. Summary statistics are presented in Table 5-17. Note the log scale for the Y-axis.

5.5.7. The contribution of CEW to organic carbon production in the Goulburn River

Using the complete seven-year data set at McCoy's Bridge, we are now in the position to determine how CEW has contributed to the creation of organic carbon through Gross Primary Production. The method is described in more detail below but essentially involves estimating the amount of organic carbon created each day and apportioning that to either CEW or non-CEW flow. This is not as straight-forward as apportioning the daily organic carbon load on the relative amounts of CEW and non-CEW flow as the GPP rate is very dependent upon the actual discharge, with increasing discharge decreasing the amount of GPP per litre due to dilution. Hence the following method uses the actual data set for each season (as seasonal effects are very important as shown in Figure 5-7) then divides each season up into 6 'bins' going from the lowest flow in that season to the highest, in all cases only using flows on days when the metabolism model results met the acceptance criteria. A summary of the McCoy's Bridge site data in each bin is presented in Appendix E. The McCoy's Bridge site was chosen as it was the only site with a significant number of winter days (125).

Briefly, using a method modified described in Watts et al. (2018), the calculations were performed using the following steps:

1. Every date with metabolism results that passed the model acceptance criteria was then stratified into a season (summer, autumn, winter, spring) and flow quantile (6 groups or 'bins'). Each of the six groups contained the same number of data days, or differed by one day based on the total number of acceptable data days in that season and whether that number divided exactly by six. The flow quantiles characterized data days by the daily discharge with the lowest quantile (bin) containing the lowest 1/6 of all data days, the second bin containing data days with flows from 1/6 to 2/6 etc.
2. For each season and bin the mean rate of organic carbon production per litre per day (g C/L/day) were calculated. These data are presented in Appendix E.
3. The mean rate of production for each day was estimated by multiplying this mean rate of production for that day's season and bin (in g C/L/day) by the observed discharge on that day (L). This provided an estimate of the total production on that day. This calculation was made for all days in that season.
4. To calculate the discharge estimated to have occurred in the absence of Commonwealth Environmental Water (CEW), firstly the non-CEW discharge (observed discharge – CEW) was determined.
5. The mean rate of production associated with that season and the bin in which the non-CEW discharge fell, was then used to determine the predicted rate of production (g C/L/day) for that day in the absence of CEW.
6. This alternative rate of production was then multiplied by the non-CEW discharge volume to determine the total production predicted to have occurred on that day in the absence of CEW. This then provided a time-series of daily production rates with and without CEW.
7. The daily estimates of CEW/non-CEW derived production were then summed to estimate the total additional production from CEW over each season for the full five years of this study.

Using the full 2019-21 MER data set, Figure 5-15 shows the GPP load from non-CEW water in blue and the visible orange colour indicates the additional organic carbon load emanating from the addition of CEW. The daily load for each day was calculated using the mean GPP rate for that flow bin and season. The binning and mean GPP rates were based on the full 7-year combined LTIM/MER data set. The resultant seasonal totals data are summarized in Table 5-19.

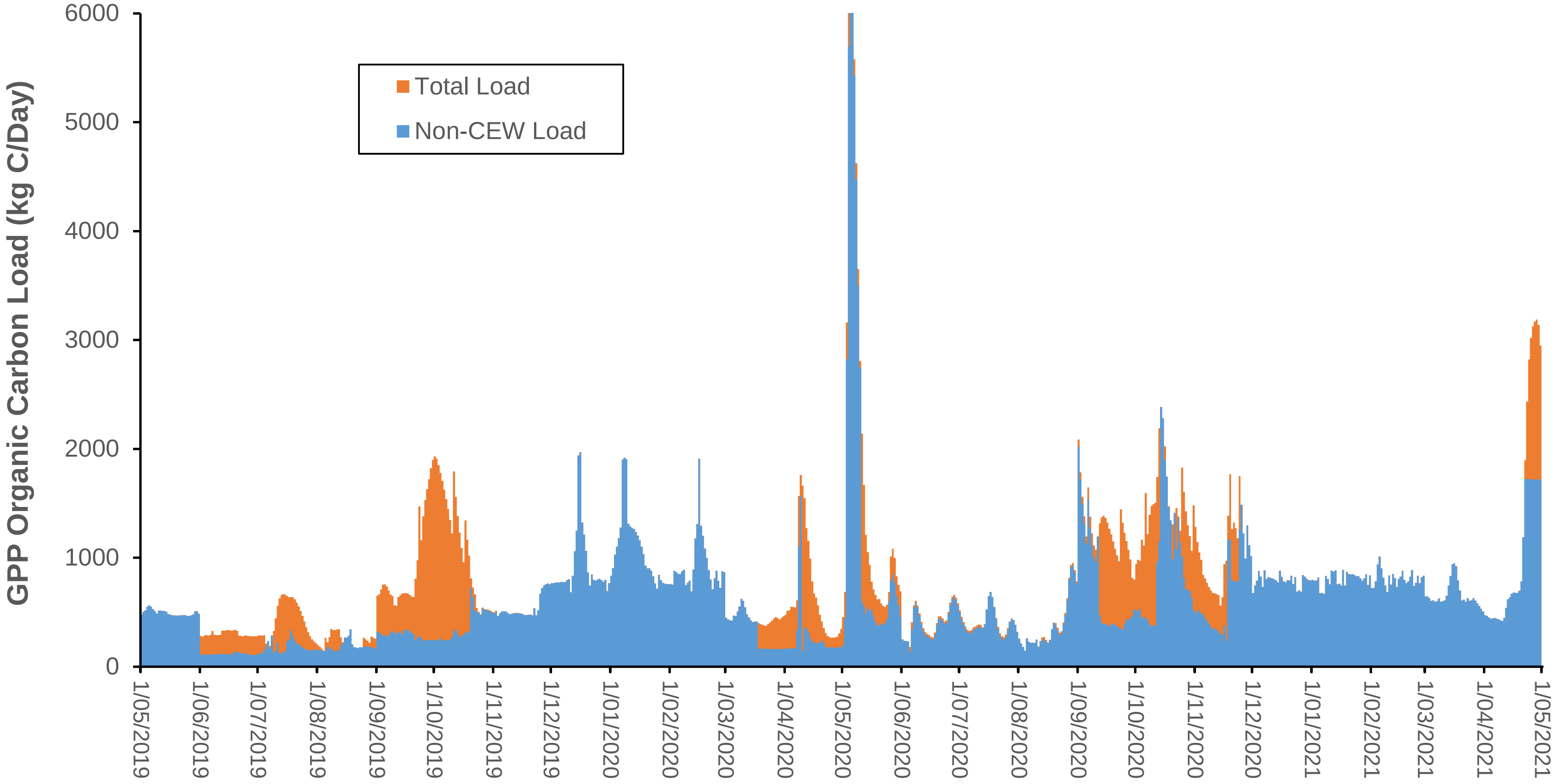


Figure 5-15 Estimated daily loads of organic carbon created by GPP at McCoy's Bridge showing the total load and the load without the contribution of CEW. The visible orange section of each bar represents the contribution of CEW. This plot estimates loads for every day over the MER period of record (May 2019 to April 2021).

Table 5-19 Seasonal Loads of Organic Carbon Produced by GPP at McCoy's Bridge showing total loads and the contribution made by Commonwealth environmental water (CEW) over the duration of this project (October 2014 to April 2021). The Seasonal Flows, including the CEW contribution are also shown.

Season	Seasonal Total Load (Tonnes Organic Carbon)	Seasonal Contribution from CEW (Tonnes Organic Carbon)	% Contribution from CEW	Total Flow (GL)	Total CEW Flow (GL)	% Contribution from CEW
Spring 2014*	73.4	26.6	36	218	114	52
Spring 2015	63.5	36.5	57	165	120	73
Spring 2016	268	11.6	4	1022	16	2
Spring 2017	80.7	46.6	58	190	133	70
Spring 2018	80.7	14.0	17	213	81	38
Spring 2019	77.9	42.1	54	208	146	70
Spring 2020	113.8	42.7	38	323	154	48
Summer 2014-15	96.9	16.1	17	145	18	12
Summer 2015-16	52.9	0.0	0	59	0	0
Summer 2016-17	86.8	14.8	17	138	23	17
Summer 2017-18	158.4	11.8	7	241	21	9
Summer 2018-19	136	0.0	0	205	0	0
Summer 2019-20	87.3	0.0	0	156	0	0
Summer 2020-21	71.3	0.0	0	114	0	0
Autumn 2015	63.7	17.0	27	127	34	26
Autumn 2016	55.5	32.0	58	111	62	56
Autumn 2017	88.8	56.9	64	173	105	61
Autumn 2018	100.5	0.0	0	196	0	0
Autumn 2019	64.1	0.0	0	131	0	0
Autumn 2020	92.4	24.4	26	179	48	27
Autumn 2021	58.1	10.3	18	115	18	16
Winter 2015	26.3	6.0	23	152	28	19
Winter 2016	34.8	2.1	6	393	9	2
Winter 2017	30.5	13.4	44	292	151	52
Winter 2018	28.2	12.6	45	262	148	56
Winter 2019	29.1	15.1	52	236	164	70
Winter 2020	36.3	1.3	4	447	9	2
Total	**2156**	**454**	**21**	**6210**	**1603**	**26**

* Autumn 2014 data was only from October and November of that year. Autumn 2020 was only from March and April.

Table 5-19 shows that overall, CEW contributes to the generation of 21% of all organic carbon created from Gross Primary Production in the Goulburn around the McCoy's Bridge site: 454 of 2156 Tonnes of organic carbon over the duration of the combined MER-LTIM monitoring (1st October 2014 to 30th April 2021). This table also includes the amount of CEW and non-CEW water and this shows that Commonwealth environmental water made up 26% of the total flow in the Goulburn River at McCoy's Bridge over the same time frame. This close congruence of load contribution and flow contribution is perhaps unsurprising because as shown in the binning data in Appendix E, there is generally only a small difference in GPP rates for the 6 bins, whereas the relative variation in flow is much greater.

From noting the position of the 'orange colour' in Figure 5-15 (corresponding to the CEW load contribution) and the data in Table 5-19 it is clear that CEW contributions in spring time are particularly important. With the exception of Spring 2016 when CEW only contributed 4% to flow due to the large flooding event, CEW contributed 36-59% of all organic carbon created by GPP in this season, including 38% in Spring 2020. This may be ecologically very significant as it will provide a food resource to support and perhaps sustain fish breeding.

CEW has also contributed around half (44-52%) of winter time organic carbon creation over 2017-2019 but only 4% in 2020. This much lower contribution in 2020 is likely to be a result of the higher non-CEW flows (447 GL, Table 5-19) compared to the 236-292 GL over the preceding three years. A similar scenario was found in Winter 2016 where the CEW contribution to organic carbon load was 6%, within the non-CEW seasonal flow of 393 GL.

Finally, Figure 5-16 illustrates how the seasonal partitioning in organic carbon load created by GPP between non-CEW and CEW water is affected by the nominal flow category (Table 5-3). The summary statistics used to create this plot are presented as Appendix F.

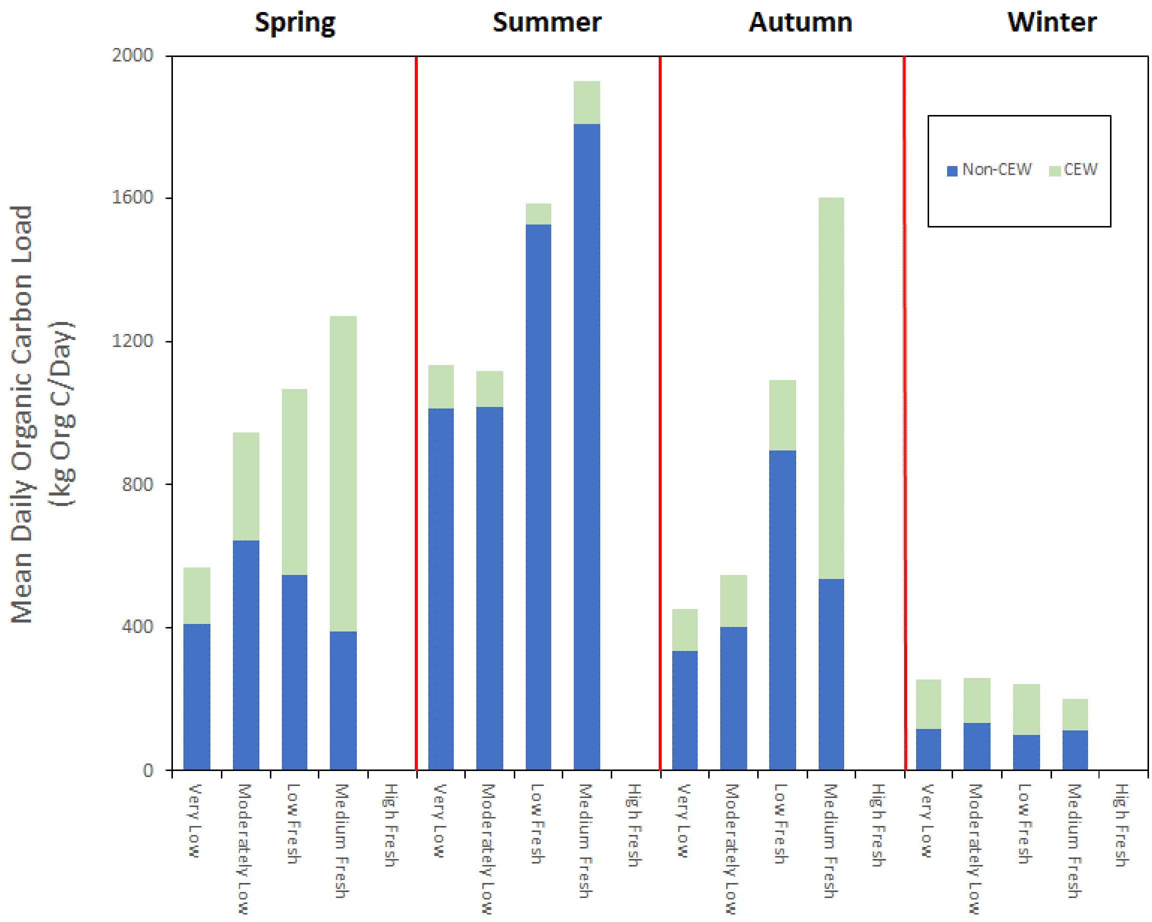


Figure 5-16 Estimated mean daily loads of organic carbon created by GPP, stratified by season and flow category. Data from 2014-20, pooled across the Moss/Rd/Day Rd/Murchison, Darcy's Track/Arcadia Downs and McCoy's Bridge sites.

There are several striking features shown in Figure 5-16:

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 by increasing flows above the very low category,
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' flow category in spring and autumn where an average additional 800-1100 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.

We stress that there are a lot of assumptions made to enable these calculations, most notably that the mean GPP for a particular flow band (bin) in any season is appropriate for any day in that season with a flow in that range. Daily variation in weather will ensure that the 'mean GPP' is not correct, but it will not be grossly wrong. Despite these caveats, the general conclusions drawn from this analysis should be robust and can certainly be validated with ongoing data collection.

5.6. Discussion

The statistical modelling found the (expected) positive relationships between GPP and light and temperature and there were significant relationships at some sites between ER and temperature. This modelling also demonstrated a predominantly negative i.e. suppressive, effect of increasing flow on rates of GPP and ER expressed on a per litre basis. This is consistent with findings from previous years. It is clear that the immediate effect of flow is to lower the extant GPP (and ER) rates, almost certainly by simple dilution with large amounts of water. Primary production is expected to respond to additional nutrients introduced via the higher flows on a perhaps 10-20 day time frame following flow events (this time frame is based on typical algal doubling rates of 1-2 days), as this corresponds to sufficient time post-nutrient addition to generate a significantly higher biomass of primary producers. The key assumption is that an increase in flow will introduce nutrients into the river channel which will then stimulate biomass growth and hence higher rates of GPP. This was demonstrated in Figure 5-4 when GPP rates increased significantly in the days to weeks after the hydrograph dropped after large flows. The influx of nutrients from the antecedent flow event is the most likely explanation for this observation. The origin of these nutrients is likely to be a combination of 'upstream sources' and within the reach from rewetting banks and mobilizing nutrients. Higher flows are also more likely to reconnect backwaters and flood-runners, which in turn are likely to be nutrient sources. It is extremely likely that the absence of significant growth during summer and into mid-autumn is due to the extremely low bioavailable nutrient concentrations, especially the extremely low levels of filterable reactive phosphorus (which essentially equates to bioavailable phosphate). Respiration rates also increased slightly in the days to weeks following discharge events. A flow-based influx of organic matter will enhance respiration although the quality/palatability of that organic matter is just as important as the increase in concentration.

Using the 'load approach' (Grace 2018), the mass of organic carbon created by GPP or consumed by ER per day in water flowing past the logger location, and incorporating the flow categorization of Stewardson & Guarino (2018), it has been clearly demonstrated that small increases in discharge introduce more organic carbon into the stream through photosynthetic production**.** As emphasized in the final LTIM report and the 2019-20 MER Report, this is a positive finding as the initial paradigm was that no benefit to metabolism would accrue unless the water levels were sufficient to reconnect flood runners, backwaters and even the floodplain. Hence increasing flow from the very low to moderately low category means more energy ('food') being created to support the aquatic foodweb. There is also an increase in respiration rate with flow category thus greater nutrient regeneration to sustain increased primary production.

Data from McCoy's Bridge (the site with the largest LTIM data record) showed that the organic load enhancements were similar in magnitude in spring, summer and autumn. Hence further work should be undertaken to match this extra organic carbon production to the times of the year where it is most needed by native fish and other biota. There was negligible benefit in greatly increasing discharge in winter from the perspective of organic carbon creation as the four flow categories all produced approximately the same amount of organic carbon (production is most likely constrained by low water temperatures, low sunlight intensity and the relatively short days (less overall sunshine to drive photosynthesis). Consequently, providing relatively small volumes of CEW in winter-time will significantly boost the energy (food) supply without the need to greatly elevate discharge. This may represent a significant beneficial flow intervention in dry climate years when winter base flows are very low due to low tributary inputs – CEW could provide supplementary base flow and contribute to maintenance of base load organic carbon production.

It was also estimated that CEW provided around 22% of all organic carbon created by GPP over the LTIM and first year of MER projects and this was closely related to the amount of CEW relative to non-CEW supply. The timing of the CEW delivery can be matched to ecological need (e.g. for fish) as well as operational constraints on such delivery.

From a management perspective, there is a positive benefit in increasing discharge, even by relatively small amounts when there are restrictions on the amount of water that can be delivered in watering actions. This is certainly the case for water delivery in winter when even small increases within the low flow category can create significant amounts of 'food'. Nevertheless, it is likely that such increases in metabolic rates are still constrained by resources (nutrients) and much greater increases would be possible with reconnection of backwaters, etc.

There remains an issue with the metabolism data whereby the BASE model assumes stationary flows for its calculations. When flows are changing rapidly, such as during environmental flow events, we are more likely to have data points rejected because of poor fits to the model. Direct analysis of dissolved oxygen levels may offer a way forward here, and this should be further investigated given the focus of this program on changes in flows.

6. Macroinvertebrates

6.1. Introduction

Macroinvertebrates 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. Macroinvertebrates are frequently monitored in aquatic ecosystem assessments to understand the health of those ecosystems. In large lowland rivers, such as the Goulburn River, the macroinvertebrate communities tend to be dominated by species that favour relatively simple habitats and are able to tolerate moderate to poor water quality. Environmental flows delivered to these rivers are more likely to influence macroinvertebrate abundance and biomass than diversity. Previous work from the Goulburn LTIM Project macroinvertebrate monitoring program has also shown that crustaceans seem to be particularly responsive to flows in the lower Goulburn River (e.g. Webb et al. 2019a). To have more of a focus on abundance and biomass of invertebrates, the MER Program differs from the LTIM monitoring to include a rapid bioassessment of macroinvertebrates (to look at key families/taxa) and edge sampling and bait trapping of crustaceans at a number of sites in the Lower Goulburn. There is also more of a focus in the MER Program on looking at how all freshes and water deliveries contribute to sustaining macroinvertebrate and crustacean populations rather than just the spring fresh.

The macroinvertebrate indicators measured at the area scale include:

- **Macroinvertebrate composition and abundance – Rapid Bioassessment Methodology (RBA)**. The taxonomic groups (family level) presence and abundance will provide information on how these potential key food sources for fish respond to environmental flows. In particular, it will be important to monitor macroinvertebrates such as chironomids and trichopterans that may be an important food source for young Golden Perch or other smaller fish.
- **Large-bodied crustacean (shrimp, prawns, yabbies) life history (size, abundance, reproductive capability) and biomass – Bait traps**. It is believed that crustaceans are an important food source for fish, including the Golden Perch (*Macquaria ambigua*), with literature confirming they may eat macroinvertebrates and large bodied crustaceans (Herbert 2005). The information specifically targeting large-bodied crustaceans will provide information on how these potential key food sources for fish respond to environmental flows.

These indicators will contribute to a better understanding of how environmental flow deliveries in the lower Goulburn River can affect the abundance and composition of macroinvertebrates and the lifecycle (reproduction and recruitment) of large-bodied crustaceans. This has important implications for the river in terms of the services and functions provided by macroinvertebrates. The role of bank vegetation, macrophytes and biofilms play an important role in sustaining these populations, while it is likely large-bodied crustaceans are likely to be an important food source for other riverine species, especially golden perch.

6.2. Area specific evaluation questions

The key basin and area-scale evaluation questions and relevant indicators for macroinvertebrates are listed in Table 6-1.

Table 6-1 Macroinvertebrate key evaluation questions for the Goulburn selected area and associated indicators and evaluation approaches.

Key Evaluation Questions	Indicator	Evaluation Approaches
Basin Scale evaluation Questions		
There are no basin-scale evaluation questions for macroinvertebrates		
Area Scale evaluation questions		
What did CEW contribute to the composition and abundance of macroinvertebrate groups in the lower Goulburn River? Specifically, what combination of freshes and low flows are required to maximise key macroinvertebrate groups in the river?	• Composition of families of macroinvertebrates • Abundance of total macroinvertebrates and key groups	• Examining relationships between composition and abundance of families of macroinvertebrates across multiple sites and freshes and flows.
What does CEW and other natural flow events contribute to crustacean growth, reproduction and biomass in the Goulburn Catchment and exploitation of novel habitats by these large-bodies crustaceans? Specifically, what combination of flows are required	• Crustacean abundance, biomass and reproduction caught in bait traps	• Examining relationships between abundance and biomass of crustaceans

to maximise large-bodied crustacean growth, reproduction and biomass in the river?	• Crustacean abundance, biomass and reproduction caught in sweep samples • Assessment of habitat cover for crustaceans in bait traps	across multiple sites and freshes and flows. • Examine relationships between crustaceans and habitat.

6.3. Main findings from monitoring program

The following sections provide a high-level summary of the outcomes of the 2020-21 monitoring and the implications of these findings to previous years outcomes.

6.3.1. 2020/2021 findings

The main findings from the 2020-21 monitoring are:

- Overall, the data showed total macroinvertebrate abundance and common taxa abundance increased after the CEW spring fresh event and remained high from December-February. The extent to which abundance increased in response to flow or temperature/seasonal changes remains unclear. An increase in some common taxa this year compared to last year does suggest that the higher unregulated flow in winter/spring 2020 may have contributed to the observed response.

- Crustaceans (shrimp - *Paratya australiensis* and prawns - *Macrobrachium australiense*) appear to be most abundant in the summer months, December – February after the CEW spring fresh. There is evidence of recruitment and breeding occurring in shrimps and prawns with a range of cohorts and females with eggs found across the sites within the lower Goulburn, particularly during the December – February sampling period. Biomass of both shrimp and prawns are generally highest in November and December, which is followed by an influx of immature crustaceans.

- Different crustacean species have a clear preference for sections of the Goulburn River, with shrimps more abundant in the upstream reaches and prawns absent at Kirwans Bridge and only occurring in low abundances at Salas Road (Murchison) the two most upstream reaches of the Goulburn River.

- Immature shrimps and prawns increased in abundance after the CEW spring fresh event in December and January. This was seen across all sites in December and at three sites in January. The increases in flow may have provided crustaceans with access to slower flowing areas of vegetation and snag habitats, which may have contributed to their abundance. The recruitment of crustaceans may provide an important food source for native fish, including golden perch.

- Both species of shrimps and prawns are more abundant where there is some complex habitat present. The shrimp showed a positive relationship with macrophyte cover (increasing abundance with increasing macrophyte cover). In comparison prawns did not show a relationship between abundance and complex habitat or snags.

- Shrimp captured in bait traps showed a significant increase in 2020-21 compared to 2019-20. We hypothesize that this difference was caused by large unregulated flows in winter and spring 2020 bringing large amounts of organic carbon into the river to fuel production.

6.3.2. Summary of previous findings and implications for any new finding

Previous findings:

- The findings from 2019-20 were broadly similar to the 2020-21 findings summarized above.

Implications for new findings:

- The 2021/21 findings have overall supported the findings from 2019-20, whereby spring freshes and other environmental water delivery appear to have small positive impacts on the macroinvertebrate fauna, particularly the large-bodied crustaceans in the Goulburn River.

- There is some evidence to suggest that the larger unregulated flows in 2020-21 have increased the abundance of some macroinvertebrate taxa and large bodied crustaceans, which may be due to an increase in food supply for macroinvertebrates (increased organic carbon).
- A change in the IVT delivery pattern over the summer months does not appear to have affected macroinvertebrate and crustacean abundance or biomass.

6.3.3. Summary of findings relevant to evaluation questions

Table 6-2 provide a summary of results with specific reference to the evaluation questions.

Table 6-2 Summary of macroinvertebrate findings relevant to evaluation questions.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did CEW contribute to the composition and abundance of macroinvertebrate groups in the lower Goulburn River? Specifically, what combination of freshes and low flows are required to maximise key macroinvertebrate groups in the river?	Yes	An increase in overall macroinvertebrate abundance after CEW delivery that continued to be high throughout December-February. This is likely to be a combination of a seasonal increase and flow contributions. Further data are needed to understand the best combinations of freshes and low flows to maximise key macroinvertebrate groups.	Qualitative observations of macroinvertebrate taxa sampled across sites along the lower Goulburn River during multiple time periods.
What does CEW and other natural flow events contribute to crustacean growth, reproduction and biomass in the Goulburn Catchment and exploitation of novel habitats by these large-bodies crustaceans? Specifically, what combination of flows are required to maximise large-bodied crustacean growth, reproduction and biomass in the river?	Yes	An increase in overall crustacean abundance and biomass after the CEW flow event that continued to be high throughout December-February. This is likely to be a combination of a seasonal increase and flow contributions. Evidence of reproduction and recruitment after the CEW spring fresh delivery with high numbers of immature crustaceans observed in December and January. Some taxa showed increased abundances in Year 2 compared to Year 1 following high unregulated flows in winter-spring 2020.	Qualitative observations of crustacean taxa (abundance, biomass, reproduction) sampled across a sites along the lower Goulburn River during multiple time periods. A paired t-test comparing Year 2 to Year 1 of various endpoints.

6.4. Monitoring methods and analytical techniques

6.4.1. Methods

The methods used for monitoring macroinvertebrates are given in the MER plan and the Standard Operating Procedures Macroinvertebrates v2.0 (The University of Melbourne 2019). Two methods were employed at eight sites along the Goulburn River; Rapid bioassessment edge sweep and Bait traps, as briefly described below. There are eight sites along the Lower Goulburn and the samples are collected on 5 sampling occasions. The timing of monitoring, along with significant catchment events is given in Figure 6-1 and Table 6-3.

The first method, Rapid Bioassessment edge sweep (RBA) samples, were conducted at all sites, following the methodology outlined in the EPA Victoria Rapid Bioassessment protocols (2003). Sampling involves taking 10 meters of sweep samples across a representative selection of the edge habitats at each site. The contents of the sample were placed in a sampling tray, and picked for 30 minutes, with an emphasis on targeting macroinvertebrates >5 mm. The live pick sample, and remaining bulk sample were preserved in separate jars of 100% ethanol for analysis in the laboratory.

The second method, Bait Traps, specifically targeted large-bodied crustaceans and was conducted at all sites. Five bait traps were deployed overnight at each site. The traps were placed among complex habitat, such as macrophytes or snags where possible. The surrounding habitat, depth and flow rate were recorded surrounding each bait trap. Upon retrieval, all crustaceans were removed from the bait traps and stored in 100% ethanol for analysis in the laboratory except for yabbies (*Cherax* species), which were counted, measured, weighed and released back into the river.

The RBA live pick macroinvertebrates were processed in the laboratory by sorting and identifying macroinvertebrates within the samples to family level where possible, with the exceptions of chironomids, which were identified to sub-family, and immature or damaged specimens, which were identified to the lowest taxonomic level possible. Crustaceans were identified from the live pick as well as from the bulk samples to measure biomass of each of the families present. The crustaceans from the bait trap samples were identified to species in the laboratory and had their carapace lengths measured (from the tip of the rostrum to the end of the carapace). These were air dried for 24 hours, dried in the oven at 60°C for a further 24 hours and weighed.

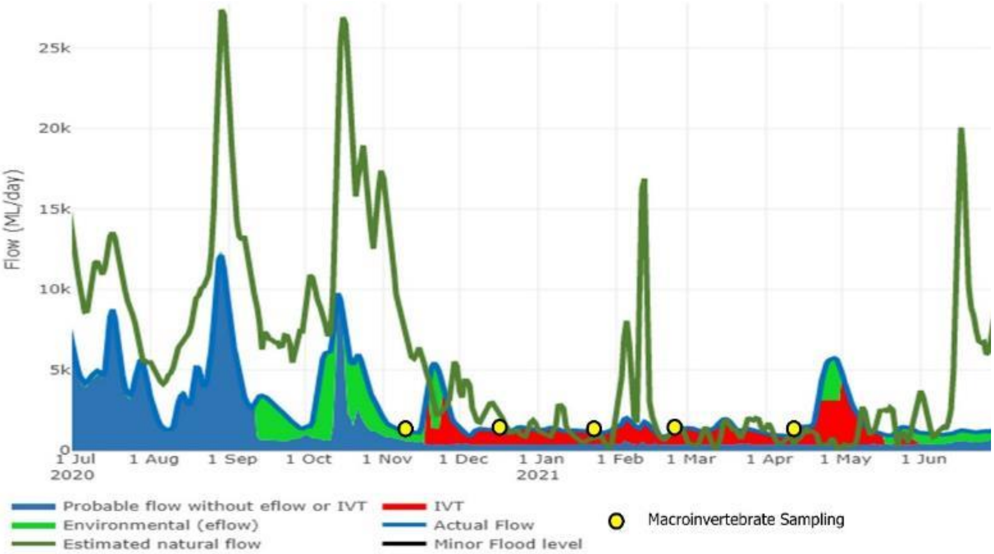


Figure 6-1 Macroinvertebrate sampling in 2020-2021 pre and post Commonwealth Environmental Water delivery and other flow events.

Table 6-3 Macroinvertebrate and crustacean sampling times and significant events on the Goulburn River during 2020-21. CEW = Commonwealth environmental water delivered as spring freshes. Pre-CEW = pre-Commonwealth environmental water delivery (before spring fresh); Post-CEW = post-Commonwealth environmental water delivery (after spring fresh).

		Sampling dates						
Activity / event	Site	September 2020	November 2020	December 2020	January 2021	February 2021	March 2021	April 2021
Events	Goulburn River	CEW start	CEW End; 2nd CEW Start (small flow)	2nd CEW End (small flow) Elevated flows for consumptive demand	Elevated flows for consumptive demand	Elevated flows for consumptive demand		Elevated flows for consumptive demand
RBA	Kirwans Bridge		Pre- 2nd CEW 10/11	Post-2nd CEW 16/12	26/1	22/2		13/4
	Salas Road (Murchison)		Pre-2nd CEW 10/11	Post-2nd CEW 16/12	27/1	23/2		13/4
	Cemetery Bend		Pre-2nd CEW 9/11	Post-2nd CEW 15/12	27/1	23/2		13/4
	Riverview Drive		Pre-2nd CEW 10/11	Post-2nd CEW 16/12	27/1	23/2		13/4
	Lord Road (nr Loch Garry)		Pre-2nd CEW 11/11	Post-2nd CEW 17/12	28/1	24/2		14/4
	McCoy's Bridge		Pre-2nd CEW 11/11	Post-CEW 17/12	28/1	24/2		14/4
	Murrumbidgee Road		Pre-2nd CEW 11/11	Post-CEW 18/12	28/1	24/2		14/4
	Stewarts Bridge		Pre-2nd CEW 11/11	Post-CEW 17/12	28/1	24/2		14/4
Bait traps	Kirwans Bridge		Pre-2nd CEW 9/11-10/11	Post-CEW 15/12-16/12	26/1-27/1	22/2-23/2		12/4-13/4
	Salas Road (Murchison)		Pre-2nd CEW 9/11-10/11	Post-CEW 15/12-16/12	26/1-27/1	22/2-23/2		12/4-13/4

Cemetery Bend	Pre-2nd CEW 9/11-10/11	Post-CEW 15/12-16/12	26/1-27/1	22/2-23/2	12/4-13/4
Riverview Drive	Pre-2nd CEW 2nd 9/11-10/11	Post-CEW 15/12-16/12	26/1-27/1	22/2-23/2	12/4-13/4
Lord Road (nr Loch Garry)	Pre-2nd CEW 11/11-12/11	Post-CEW 16/12-17/12	27/1-28/1	24/2-25/2	14/4-15/4
McCoy's Bridge	Pre-2nd CEW 11/11-12/11	Post-CEW 17/12-18/12	28/1-29/1	24/2-25/2	14/4-15/4
Murrumbidgee Road	Pre-2nd CEW 11/11-12/11	Post-CEW 17/12-18/12	28/1-29/1	24/2-25/2	14/4-15/4
Stewarts Bridge	Pre-2nd CEW 11/11-12/11	Post-CEW 17/12-18/12	28/1-29/1	24/2-25/2	14/4-15/4

6.4.2. Statistical Analysis

Total abundance of macroinvertebrate taxa and the most abundant taxa were plotted from the RBA data. Averages and standard deviations are presented for sampling months and sites, as well as raw data for all sites over the five months of sampling in 2019-20 and 2020-21. Similar bar graphs and line graphs were also plotted for RBA abundance and biomass of juvenile crustaceans, shrimps and prawns. Bait trap abundance and biomass of dominant crustaceans, shrimps and prawns were also plotted. The relationship between the mean value of abundance from bait traps and the percentages of complex habitat, macrophytes and snags were also respectively presented for crustaceans. For analysis of habitat data shrimp at the sites Cemetery Bend, Lord Road and Riverview Drive and prawns at Kirwans Bridge were excluded from the analysis as there were no individuals or few individuals caught.

A paired t-test comparing Year 2 to Year 1 was also conducted on each of the endpoints plotted to determine if there was an increase in abundance or biomass of macroinvertebrates as a result of higher unregulated flows in winter and spring in 2020-21 compared to 2019-20. The paired t-test was used because abundances and biomass typically vary substantially across the sampling season. A model structure with temporally autocorrelated errors was used to account for the repeated samples over time during each year.

6.5. Results

6.5.1. RBA Macroinvertebrate Taxa

In 2020-21, a total of 76,501 macroinvertebrates from 54 taxa were collected in live picks from RBA sweep samples across all sampling periods. The most common taxa, where >100 individuals were collected across all sampling periods, included: mites; the water bugs (Micronectidae, Gerridae, Notonectidae and Veliidae); the mayfly Baetidae; the caddisfly Leptoceridae; and the shrimp, Atyidae. All these taxa increased after the CEW spring fresh event with the highest abundances occurring in the summer months December-February.

Average total abundance across all sites was similar in November and December 2020 (after the CEW spring fresh event) with peak abundance occurring in January 2021 (Figure 6-2a). This pattern was largely driven by the highly abundant water bugs, Micronectidae (Appendix G). Overall, there was a significant increase in average total abundance across all sites this year (2020-21) compared to the previous year (2019-2020) (Figure 6-2a; Table 6-4). Total abundance was lowest at Kirwans Bridge, with the highest total abundance in December 2020. Most of the other sites increased in abundance in January, with a large increase observed at McCoy's Bridge and Lord Road, reaching about 15,000 and 10,000 individuals respectively (Figure 6-2b).

The abundance of common taxa and the number of individuals varied across the year and between sites. Many of the common taxa have the highest abundances in the summer months, between December 2020 and January 2021 (Appendix G; Table 6-4). At Kirwans Bridge, where there was little variation in flow, there was very little change in abundance across most of the common taxa throughout the year, in comparison to the rest of the sites that generally had an increase in abundance during the summer months after the CEW spring fresh event (Appendix G). In January 2021, the mayfly Baetidae, the chironomids, Chironominae, Orthocladiinae and Tanypodinae, and the water bugs Micronectidae and Notonectidae all increased in abundance at McCoys Bridge (Appendix G). Overall, there was a significant increase in average abundance of Micronectidae, Baetidae, Tanypodinae and Leptoceridae across all sites this year (2020-2021) compared to the previous year (2019-2020) (Appendix G; Table 6-4).

The results indicate that overall total abundance and common taxa abundance are generally higher following the spring fresh, although this also coincides with warmer conditions (moving from spring to summer), so it is as yet unclear the extent to which abundance increases in response to flow or temperature/seasonal changes. An increase in some common taxa this year compared to last year does suggest that the higher unregulated flow in winter/spring 2020 may have contributed to the observed response.

Table 6-4 Summary of total macroinvertebrates and common taxa abundance trends in 2020/2021 and a paired t-test comparison between years (2019-20 and 2020-21) on the Goulburn River.

Taxa	Abundance Trend 20/21	Comparison Between Years	P(T<=t) one-tail
Total Macroinvertebrates	Highest Jan & Feb	Increase in 20/21	0.02
Micronectidae	Highest Jan & Feb	Increase in 20/21	0.03
Baetidae	Highest Dec & Jan	No evidence of an increase	0.47
Notonectidae	Highest b/w Dec 20- Feb 21	No evidence of an increase	0.18
Chironominae	Highest b/w Nov 20- Jan 21	No evidence of an increase	0.18
Orthocladiinae	Highest b/w Nov 20- Jan 21	No evidence of an increase	0.49
Tanypodinae	Highest Jan & Feb	Increase 20/21	0.02
Leptoceridae	Highest Dec	Increase in 20/21	0.03
Gomphidae	Highest Jan & Feb	No evidence of an increase	0.33

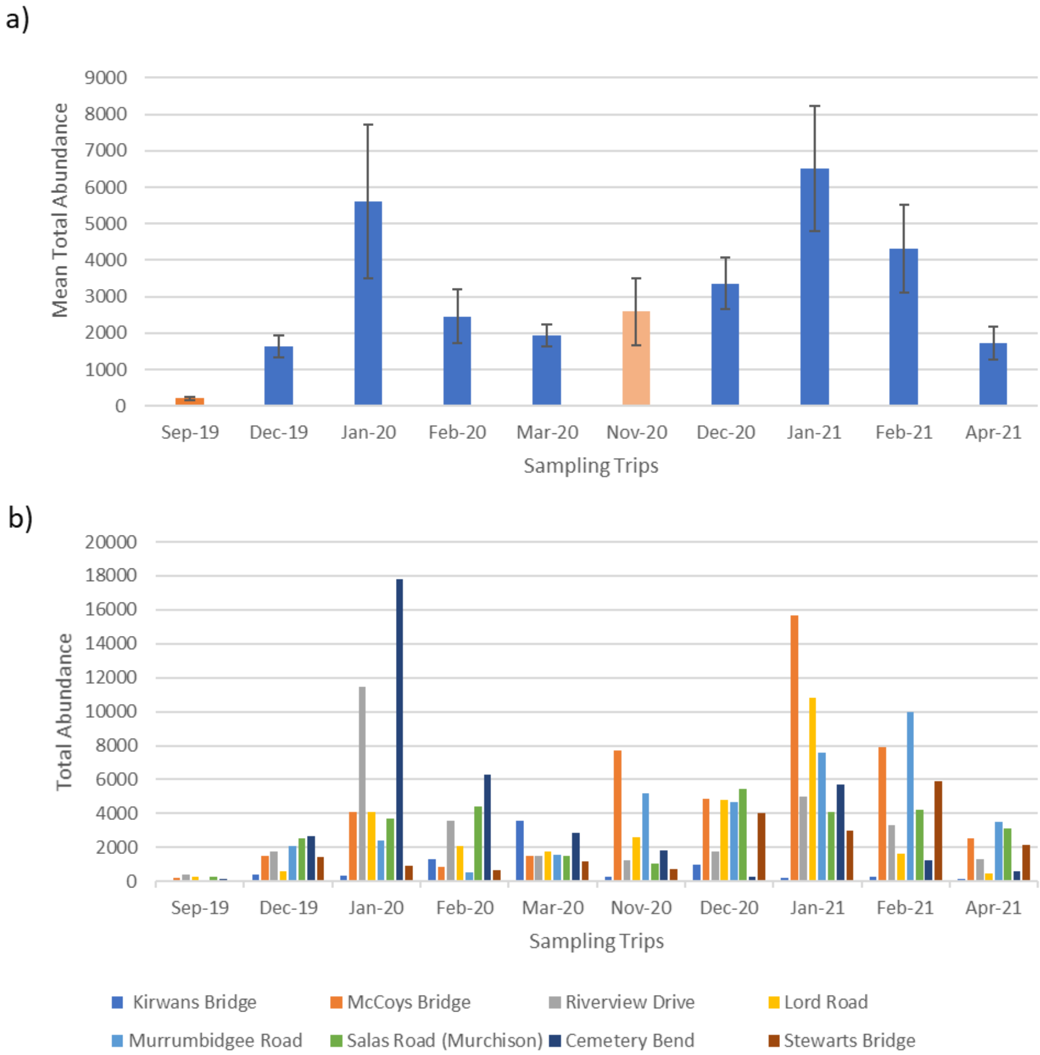


Figure 6-2 RBA macroinvertebrate sampling a) mean (± standard deviation) total abundance of all taxa caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. b) abundance (± standard deviation) of all taxa for all sites in different months.

6.5.2. RBA Crustaceans

A total of 2,512 crustacean individuals were collected in the RBA samples across all sampling periods. Three groups of crustaceans were collected (shrimps: *Paratya australiensis* and *Caridina* spp.; prawns: *Macrobrachium australiense*; yabbies: *Cherax* spp.), with the shrimp, *Paratya australiensis* the most abundant crustacean taxon, followed by the prawns, *Macrobrachium australiense* within the lower Goulburn. A large number of immature crustaceans were also collected across all sites.

The shrimp, *Paratya australiensis* had low mean abundances in November and December (post the delivery of the CEW Spring Fresh), increasing in January and February (Figure 6-3a), which is a similar trend to the previous year. The highest mean abundances occurred in January and February which was mainly driven by shrimp collected at Kirwans Bridge and Riverview Drive (February 2021) (Figure 6-3). Across all other sites, low mean abundances of shrimp were collected across all sampling times, with Stewarts Bridge containing the fewest shrimp (Figure 6-3b). Mean biomass (g/m^3) of the shrimp was highest in November 2020 and April 2021 and lowest in December 2021 (Figure 6-4a). Biomass was similar across most sites in November 2020 and was highest at Kirwans Bridge between January to April 2021 (Figure 6-4b). Overall, there was no significant increase in average abundance (p=0.35) or biomass (p=0.26) of shrimps this year compared to the previous year.

Between November 2020 to January 2021 there were low mean abundances of prawns across all sites, with increasing abundances in February and April 2021 (Figure 6-3c). While mean abundances of prawns increased in the summer months over both sampling years (2019-20 and 2020-21), prawn abundance increased earlier in 2019/20 compared to this year. No prawns were found at Kirwans bridge and very few were found at Salas Road (Murchison). Cemetery Bend had the highest mean abundances of prawns which was driven by a large increase in abundances in January and February. Apart from Salas Road (Murchison), more prawns were collected at the lower sites within the Goulburn (Lord Road (Loch Garry) to Stewarts Bridge) (Figure 6-3d). While prawn mean abundances were low in November, the mean biomass (g/m^3) was highest, suggesting that larger bodied prawns were caught during this time (Figure 6-4c, d). Mean biomass of prawns was similar across the other months, except in January 2021. Overall, there was no significant increase in average abundance (p=0.38) or biomass (p=0.49) of prawns this year compared to the previous year.

Very few immature crustaceans were collected in November. An increase in immature crustaceans was observed after the CEW spring fresh, increasing substantially in December and January before decreasing in February and April, suggesting reproduction is occurring during these months (Figure 6-5a). The increase in immature crustaceans was seen a month earlier this year compared to the previous year (2019-20). Immature crustaceans increased across all sites in December 2020 and increased in January at Riverview Drive, Lord Road and Cemetery Bend (Figure 6-5b). While there was no significant increase in immature crustaceans this year compared to the previous year (p=0.19), this would have been partly driven by the change in timing of peak increase described above and the fact that the paired t-test explicitly compares each visit. Overall, there is an increase in the abundance of immature crustaceans in 2020-21, suggesting the higher unregulated flows may be contributing to an increase in productivity of these crustaceans.

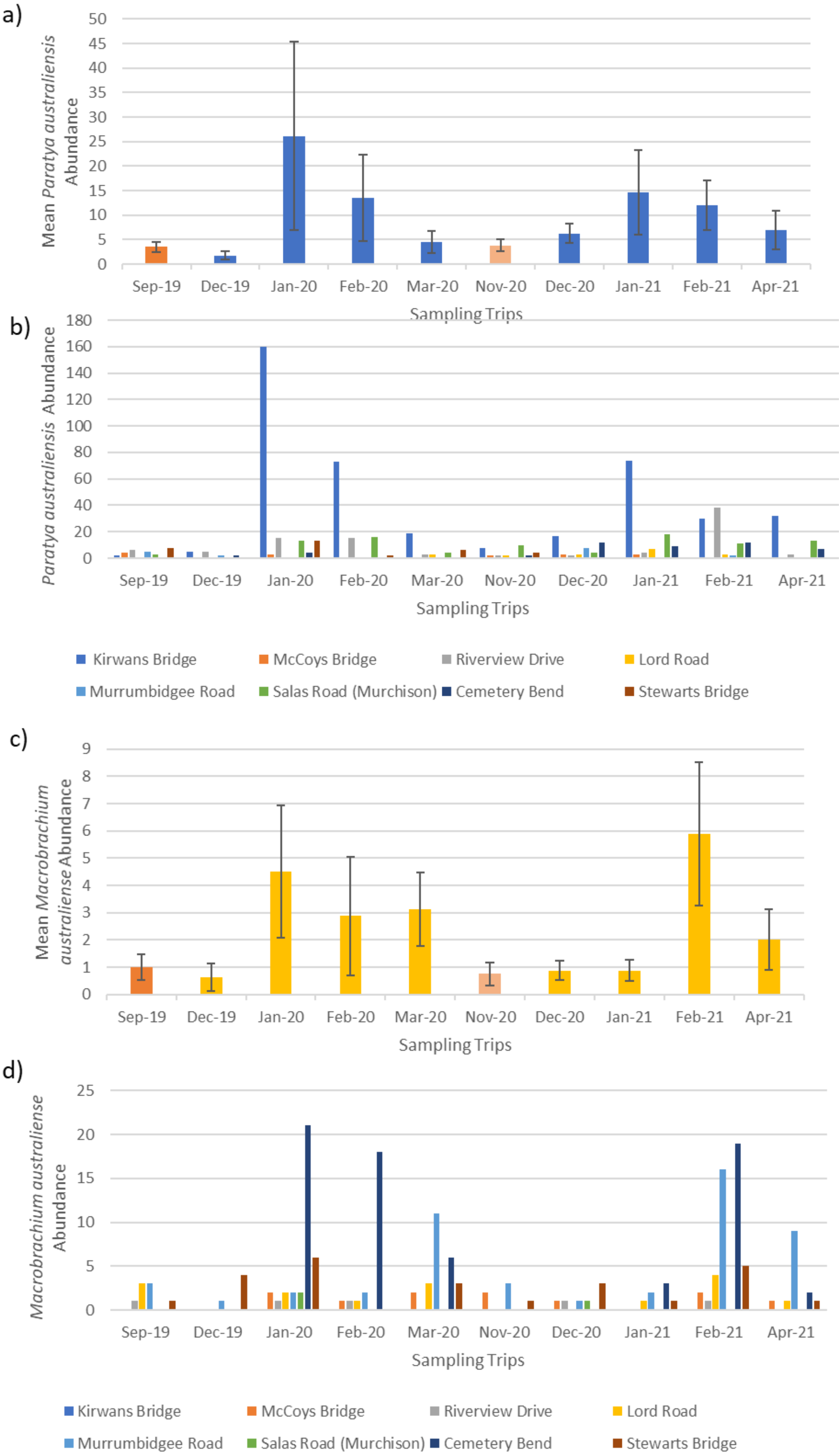


Figure 6-3 RBA crustacean sampling a) mean (± standard deviation) abundance of the shrimp *Paratya australiensis* per sample in different months. Orange colour: before spring fresh; light orange: before 2nd small spring fresh blue colour: after spring fresh. b) abundance of the shrimp *Paratya australiensis* for all sites in different months. c) mean (± standard deviation) abundance of the prawn, *Macrobrachium australiense* per sample in different months. Orange colour: before spring fresh; light orange: before 2nd small spring fresh blue colour: after spring fresh. d) abundance of the prawn, *Macrobrachium australiense* for all sites in different months.

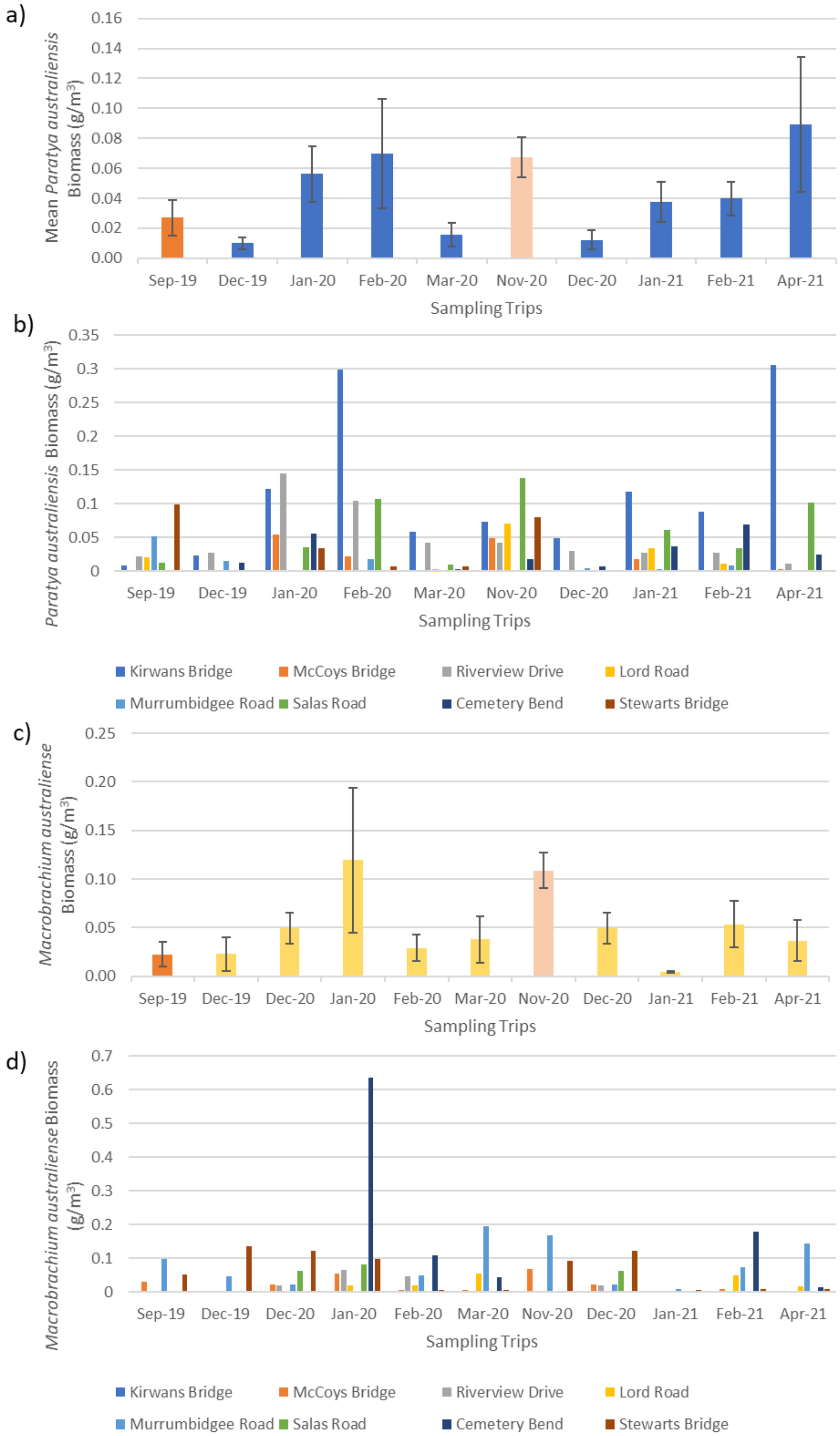


Figure 6-4 RBA crustacean sampling a) mean (± standard deviation) biomass (g/m^3) of the shrimp *Paratya australiensis* per sample in different months. Orange colour: before spring fresh; light orange: before 2nd small spring fresh blue colour: after spring fresh. b) biomass (g/m^3) of the shrimp *Paratya australiensis* for all sites in different months. c) mean (± standard deviation) biomass (g/m^3) of the prawn, *Macrobrachium australiense* per sample in different months.

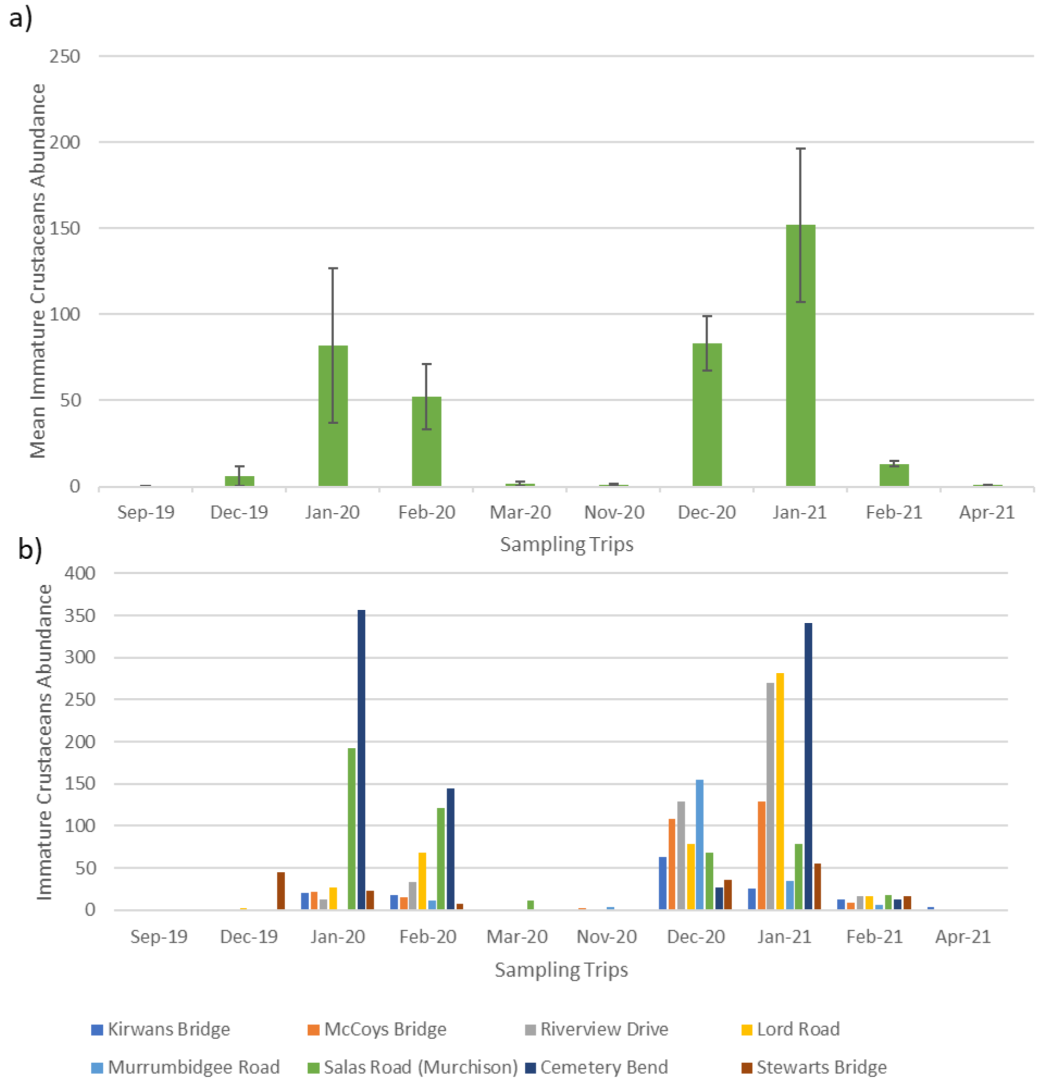


Figure 6-5 RBA crustacean sampling a) mean (± standard deviation) abundance of immature crustaceans per sample in different months. Orange colour: before spring fresh; light orange: before 2nd small spring fresh; green colour: after spring fresh. b) abundance of immature crustaceans for all sites in different months.

6.5.3. Crustaceans caught in bait traps

A total of 487 crustacean individuals were collected in the bait traps across all sampling periods. Three groups of crustaceans were collected (shrimps, prawns and yabbies). Prawns were the most abundant crustacean caught within the bait traps, while only four yabbies were caught during the sampling period. There is evidence of recruitment and breeding occurring of shrimps and prawns with a range of cohorts and females with eggs found across the sites within the lower Goulburn, particularly during the December – February sampling period.

Mean abundance of the shrimps across months and sites were highest between December 2020 and February 2021 after the CEW Spring Fresh (Figure 6-6a). The highest abundances of shrimps were at Kirwans Bridge, followed by McCoy's Bridge and Salas Road (Murchison) (Figure 6-6b). This was different to the previous year which had similar abundances across the sampling period. Mean biomass was similar across the sampling periods except for January 2021, which was slightly lower (Figure 6-7a). Kirwans Bridge, McCoy's Bridge, Salas Road (Murchison) and Stewards Bridge had the highest biomass of shrimp (Figure 6-7b). Overall, there was a significant increase in average abundance (p=0.01) and biomass (p=0.003) of shrimps this year compared to the previous year.

In comparison, the mean abundance of prawns was similar between the sampling months, highest in November 2020 after the CEW fresh delivery (Figure 6-6c). No prawns were collected in the bait traps at Kirwans Bridge (Figure 6-6d). Mean biomass of the prawns was also similar between sampling months, except in April where biomass was lower (Figure 6-7c). Biomass was highest at McCoy's Bridge in November 2020 and Riverview Drive in February 2021 (Figure 6-7d). Overall, there was no significant difference in average abundance (p=0.26) and biomass (p=0.29) of prawns this year compared to the previous year.

While the results show that shrimp and prawn abundance and biomass is generally higher following the Spring Fresh (from November onwards), this also coincides with warmer conditions, so it is unclear the extent to which abundance and biomass increases in response to flow or temperature / seasonal changes. An increase in the shrimp this year compared to last year does suggest that the higher unregulated flow in winter/spring 2020 may have contributed to the observed response.

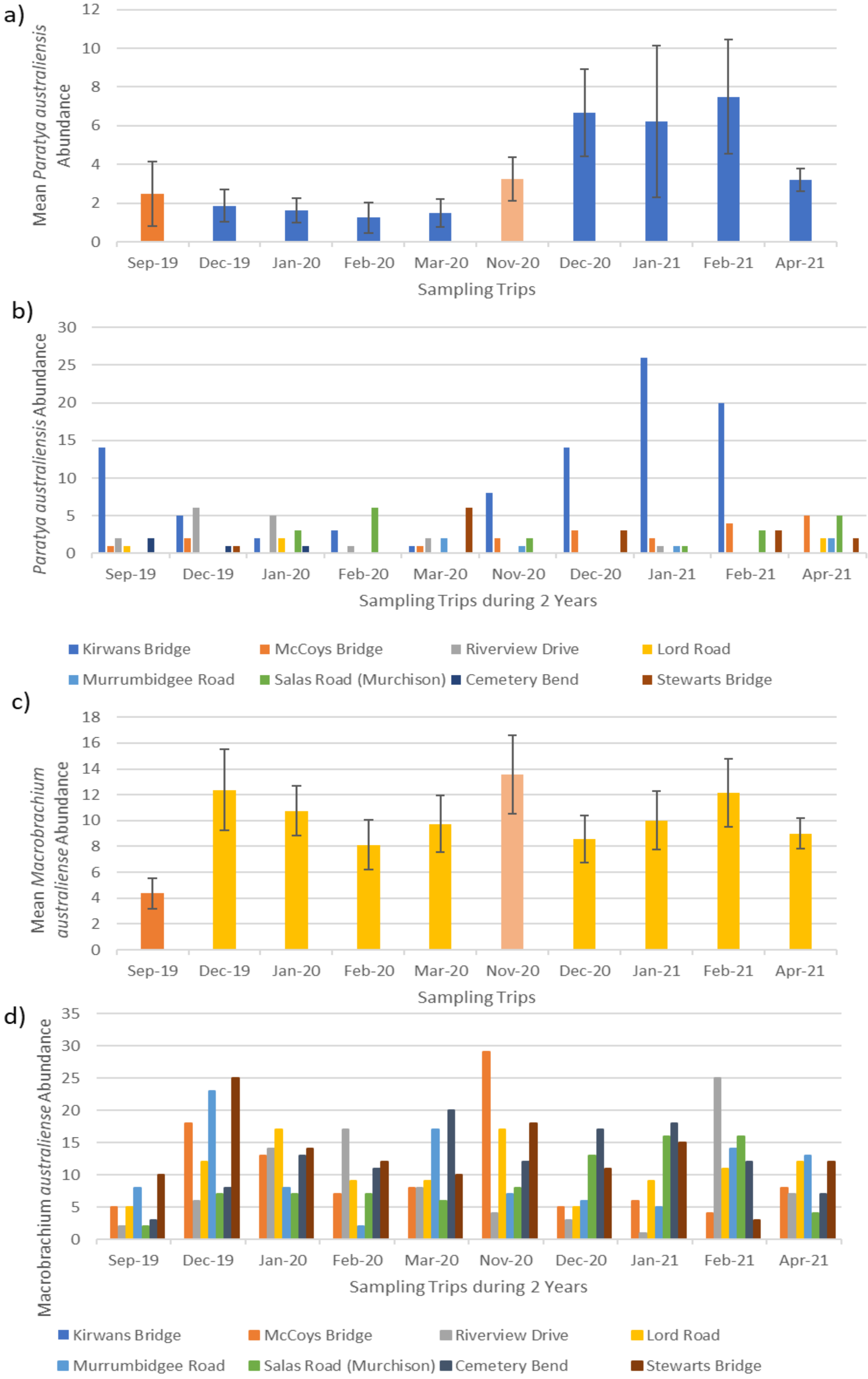


Figure 6-6 Crustacean Bait Trap sampling a) mean (± standard deviation) total abundance of shrimps (*Parataya australiensis*) caught per sample in different months. Orange colour: before spring fresh; light orange: before 2nd small spring fresh; blue colour: after spring fresh. b) abundance of all shrimps for all sites in different months. c) mean (± standard deviation) total abundance of prawns (*Macrobrachium australiense*) caught per sample in different months. Orange colour: before spring fresh; light orange: before 2nd small spring fresh; gold colour: after spring fresh. d) abundance of all prawns for all sites in different months.

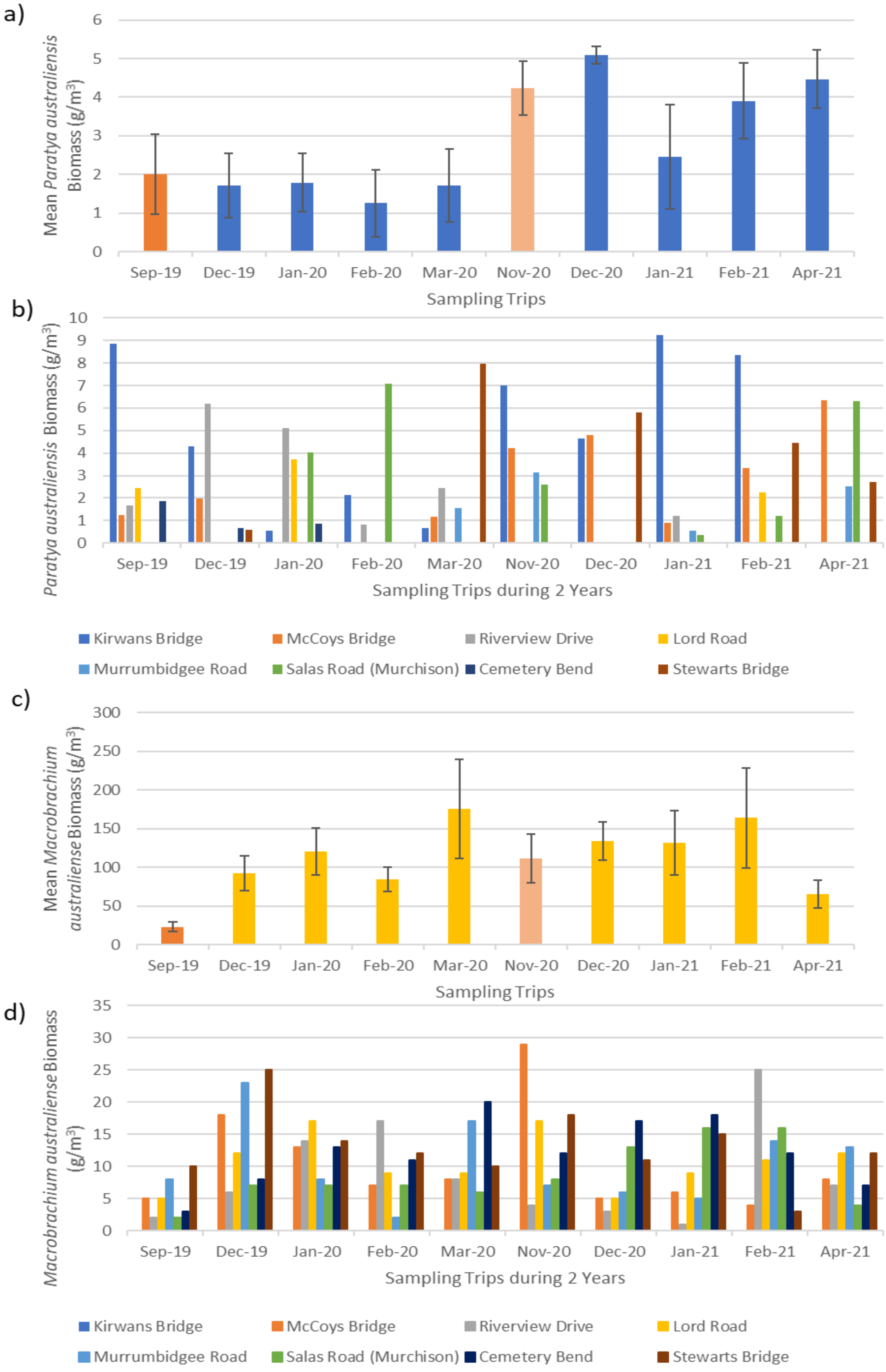


Figure 6-7 Crustacean Bait Trap sampling a) mean (± standard deviation) total biomass of shrimps (*Parataya australiensis*) caught per sample in different months. Orange colour: before spring fresh; light orange: before 2nd small spring fresh; blue colour: after spring fresh. b) Biomass of all shrimps for all sites in different months. c) mean (± standard deviation) total biomass of prawns (*Macrobrachium australiense*) caught per sample in different months. Orange colour: before spring fresh; light orange: before 2nd small spring fresh; gold colour: after spring fresh. d) Biomass of all prawns for all sites in different months.

Previous work in the LTIM Project has shown that crustaceans are more abundant in some type of complex habitat (e.g. macrophytes, snags, CPOM) compared to bare edges. The MER Program targets complex habitat to understand the preference of crustaceans to different types of habitats. Overall, the shrimp showed an increasing trend in abundance as percentage of complex habitat increased, which was driven by an increase in percentage of macrophyte cover rather than percentage of snags (Figure 6-8a, b, c). The majority of shrimp were found in bait traps in Kirwans Bridge which was dominated by macrophyte cover. Across all other sites there was little macrophyte cover. In comparison, prawns did not show an obvious increasing or decreasing trend of abundance as the percentage of complex habitat or percentage of snag cover changed (Figure 6-8d, e). Prawn abundance was not plotted against percentage of macrophyte cover as the majority of macrophytes present within the Lower Goulburn is at Kirwans Bridge, where prawns are not found. The lack of a relationship between complex habitat and snags maybe due to the bait trap appearing to be a safe 'habitat' to prawns in otherwise open areas.

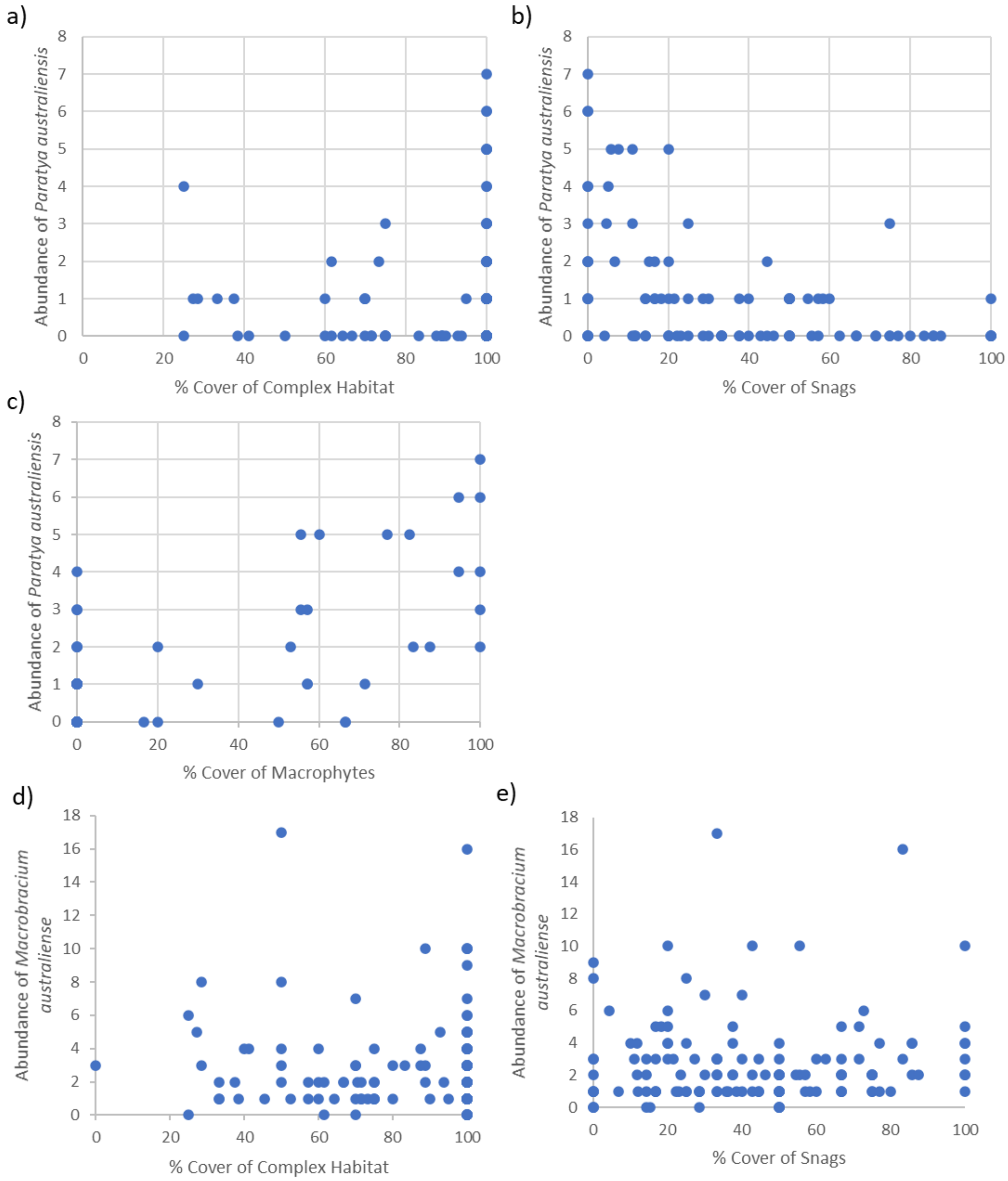


Figure 6-8 Crustacean Bait Trap sampling a) shrimp abundance vs percentage of complex habitat. b) shrimp abundance vs percentage of snag cover. c) shrimp abundance vs percentage of macrophyte cover. d) prawn abundance vs percentage of complex habitat. e) prawn abundance vs percentage of snag cover.

6.6. Discussion

Overall, the findings from the second year of the MER program were similar to those of the previous year, suggesting that overall macroinvertebrate abundance and common taxa increased after the CEW Spring Fresh event, with the highest abundances occurring in the summer months December-February. The abundance and biomass of the key crustacean species increase after the CEW Spring Fresh event, particularly from December through to February. The results also suggest that key crustaceans are utilising the edge habitats that contain some complex habitat (macrophytes, CPOM and or snags). After two years of sampling, we are still not able to determine how much of the increases are directly related to the flow events and how much is caused by seasonal changes, such as increased temperature. This is because spring freshes are being delivered every year in the system. However, there has been some evidence that flow events can have small positive impacts on macroinvertebrate fauna, particularly the large-bodied crustaceans probably through the inundation and maintenance of important habitats and increasing organic material. The higher unregulated flows over winter and spring this year may have also increased the abundance and recruitment of some macroinvertebrates and crustaceans, presumably driven by an increase in the organic matter entering the river channel.

There is evidence of crustaceans reproducing within the Goulburn River after the CEW Spring Fresh event, with large increases in immature crustaceans (shrimp and prawns) occurring in December and January. During these periods of sampling, the flows were higher, allowing crustaceans to access bank vegetation and snag habitats in areas of slower flow that provided a sheltered environment to support immature crustaceans (shrimps, prawns and yabbies). The increase in macroinvertebrates and crustaceans in December-February is likely to be beneficial to native fish which spawn around November-December, providing an abundant food source for larvae and juveniles.

Crustacean species have a clear preference for sections of the Goulburn River, with shrimp more abundant in the upstream reaches and prawns less so. It is still unclear as to why there are different distributions of crustacean species across the lower Goulburn. Previous work has demonstrated that both the shrimps and prawns were more abundant where there was some complex habitat present. This year's data demonstrates that shrimp abundance increases with increasing macrophyte cover, primarily at Kirwans Bridge, but not with increasing snag cover. We may hypothesize that snags are used as fish habitat, and thus there may be higher predation pressure. Macrophytes may offer better cover and perhaps fewer fish. The prawns did not have a clear relationship with increasing complex habitat or snag cover. More data are needed to understand the links between these crustacean species, habitat (vegetation/snags) and the food resources associated with each habitat to understand the drivers of abundance and biomass. It is still hypothesised that the link between habitat (vegetation), flow and crustaceans is important for maintaining these populations, and this question is being partly addressed in the integrated research project (Section 12).

Given that it is still unclear what proportion of macroinvertebrate abundance and biomass increase is driven by flows and what proportion is driven by seasonal changes, it is also unknown what combination of freshes and low flows are required to maximise production of these groups in the river. Continuing the monitoring of macroinvertebrates and crustaceans over the duration of the MER Program, it is expected that there will be a greater understanding of the types of flows that are needed to maximise macroinvertebrates.

7. Vegetation

7.1. Introduction

Riparian and aquatic vegetation communities hold intrinsic value and underpin aquatic systems by: (1) supplying energy to support food webs, (2) providing habitat and dispersal corridors for fauna, (3) reducing erosion and (4) enhancing water quality. In the Goulburn River, several factors have contributed to reducing the quantity, quality and diversity of riparian vegetation over the last 20 years. These include, the Millennium drought which was followed by large floods and more recently increased Intervalley Transfers (IVTs) to meet irrigation demand.

Minimum summer and winter low flows and periodic freshes are recommended to help rehabilitate and maintain riparian vegetation along the lower Goulburn River. The recommended flow components shape riparian and aquatic plant assemblages by influencing (1) inundation patterns in different elevation zones on the bank and hence which plants are promoted in each zone; (2) the abundance and diversity of plant propagules dispersing in water; and (3) where those propagules are deposited and germinate.

Vegetation diversity was monitored at four sites in the lower Goulburn River as part of the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP; Miller et al. 2015) and the Commonwealth Short Term Monitoring Projects (STIM; Stewardson et al. 2014, Webb et al. 2015). Vegetation diversity monitoring in the LTIM Project (2014/15-2018/19) and MER Program (2019/20-2021/22) and at two sites (Loch Garry and McCoy's Bridge) in the lower Goulburn River is extending those data sets and allowing the effect of different flow components to be assessed under a broader range of (i) climatic conditions, (ii) unregulated flows and (iii) Intervalley Transfers (IVTs) to meet irrigation demand. The results are being used to identify what flows are needed to maintain or rehabilitate riparian vegetation in the lower Goulburn River depending on its current condition and state of recovery. They can also be used to broadly inform appropriate water management in other systems recovering from extreme events.

7.2. Area specific evaluation questions

To determine the contribution of Commonwealth environmental water in selected areas, and to improve understanding of the relationship between specific watering actions and ecological objectives for assets, the following questions are being addressed in the Goulburn selected area. This information also contributes to broader Basin-scale evaluation – where area-level results are pooled to enable evaluation at a larger spatial scale.

The key area-scale evaluation questions and relevant indicators for vegetation are listed in Table 7-1.

Table 7-1 Vegetation key evaluation questions for the Goulburn selected area and associated indicators and evaluation approaches.

Key Evaluation Questions	Indicator	Evaluation Approaches
	Area Scale evaluation questions	
Does the CEW contribution to Spring Freshes increase the abundance of riparian vegetation on the bank face?	▪ Cover of all ground layer vegetation ▪ Cover of focal plant groups ▪ Cover of focal taxa	▪ Visual comparison of pre and post Spring Fresh data summary plots for vegetation cover ▪ Visual comparison of data summary plots for the cover of focal taxa and plant groups across bank zones
Do flows shift the distribution of riparian vegetation communities on the bank face	▪ Cover of all ground layer vegetation ▪ Cover of focal plant groups ▪ Cover of focal taxa	▪ Visual comparison of data summary plots for the cover of focal taxa and plant groups across bank zones
What influence do hydraulic variables have on the abundance of riparian vegetation communities?	▪ Cover of all ground layer vegetation ▪ Cover of focal plant groups ▪ Cover of focal taxa	▪ Bayesian models
Is there a positive trend in the abundance of riparian vegetation communities over the medium-long term?	▪ Cover of all ground layer vegetation ▪ Cover of focal plant groups ▪ Cover of focal taxa	▪ Visual and statistical examination of changes in cover of indicators

		over time characterised by regression lines.
How does the annual flow regime (natural, environmental or consumptive) influence the abundance of riparian vegetation communities at the end of the growth season?	▪ Cover of all ground layer vegetation ▪ Cover of focal plant groups ▪ Cover of focal taxa	▪ Visual examination of changes over time

7.3. Main findings from the vegetation monitoring program

The following sections provides a high-level summary of the outcomes and implications of the 2020-21 monitoring and comparison of these findings to previous years' outcomes.

7.3.1. 2020/21 findings

The main findings from the 2020-21 monitoring are:

- Spring Freshes appear to support water dependent (species that depend on inundation from the river for some or all of their life history requirements) species as their cover and occurrence on the bank continues to be greatest in bank zones inundated by Spring Freshes. Vegetation responses to the Spring Fresh could not be directly examined in 2020-21 as high natural flows prevented sampling prior to the Spring Fresh.

- Lower and more stable flows over summer in 2020-21 following the recession of the fish spawning fresh resulted in the establishment of narrow bands of water dependant vegetation along the river fringe (Zone 1b) in March 2021. These newly established bands were patchily distributed along the river and comprised mostly of sedges (mostly *Cyperus* spp.), water pepper *(Persicaria hydropiper)* and pale knotweed (*Persicaria lapathifolia*). Many plants along the fringing zone were setting seed in March 2021 after ~13 weeks of lower flows. Although some recovery of fringing vegetation has been achieved from the previous year, there was little to no response of vegetation in Zone 1a, the lowest elevation surveyed, and lower flows may be required for vegetation to establish in this zone.

- Environmental flows in 2020-21 were also used to prevent water levels dropping and triggering germination along the river fringe (Zone 1a and 1b) between the Spring Fresh and the fish spawning fresh when successful establishment of new germinants could be impacted by the fish spawning 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 vegetation along the river fringe (Zone 1a and 1b) was low, suggesting that recruitment was likely suppressed by this strategy. 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 and further research is needed.

- Since 2014 the summed cover of all ground layer plants over time has shown a small positive trend at both Loch Garry and McCoy's Bridge, but trends vary for different regions of the bank. Positive trends in the summed cover of ground layer plants are generally found at higher elevation, particularly in Zone 3. In contrast, the summed cover of fringing vegetation (Zone 1a and Zone 1b) has oscillated over time with no discernible trend. This is consistent with the vulnerability of this zone to unnatural high summer flows associated with IVT delivery.

- Models that examine responses of vegetation to inundation >25 cm found that water dependant species declined steadily after 40 days of inundation >25 cm over the IVT period although sensitivity varied among species with the group. It is uncertain how response differ if inundation is continuous or intermittent. Individual inundation however should be less than two weeks as currently recommended.

7.3.2. Summary of previous findings and implications for any new finding

Previous findings:

<u>*Spring Freshes*</u>

- The mean summed cover of water dependent vegetation across all sampling locations at both sites increased following Spring Freshes in 2014–15, 2015–16 and 2018-19. Increases were again observed at Loch Garry but not at McCoy's Bridge in 2019-20. This difference between Loch Gary and McCoy's Bridge may be because post Spring Fresh surveys occurred two weeks earlier than previous years and because responses at McCoy's Bridge may be slower than at Loch Garry. In 2020-21 natural high flows prevented an assessment of vegetation responses to the Spring Fresh. While increases in cover are positively correlated with Spring Freshes it is not known what portion of the increase can be attributed to seasonal patterns of plant growth that would have occurred without the delivery of Spring Freshes.

- The extent and duration of inundation provided by Spring Freshes is correlated with the distribution and cover of vegetation up the bank. Water dependent taxa have higher cover in regions of the bank inundated by Spring Freshes. In contrast, the perennial native common tussock grass (*Poa labillardierei*) is more restricted in its distribution to elevations at the upper margins or above the level inundated by Spring Freshes. This pattern has persisted over time. Similarly, the recruitment of silver wattle (*Acacia dealbata*) and river red gum (*Eucalyptus camaldulensis*) is restricted to higher areas of the bank that experience shallow and less frequent inundation.

<u>*Low summer flows and Inter-Valley Transfer (IVTs)*</u>

- Prolonged high river discharges delivered for consumptive use as IVTs in 2018-19 eliminated much of the fringing vegetation (Zone 1a and Zone 1b) that had established under low flows in 2015-16. In September prior to IVT delivery in 2019-20 there was no evidence that vegetation was re-establishing under the unnaturally high summer flow resulting from IVTs delivered in 2018-19, although some patches of germination were observed. Following IVT delivery in 2019-20 there were no further reductions in vegetation as most vegetation in this bank zone had already been lost in 2018-19. At higher elevations where IVT flows are likely to result in only very shallow inundation the cover of grasses increased. Suitable hydraulic habitat may be experienced for some plant taxa on low lying benches under higher summer flows associated with IVT delivery, but the spatial extent of these features is not well mapped.

- Lower and more stable flows over summer in 2020-21 resulted in the establishment of narrow bands of water dependant vegetation along the river fringe (Zone 1b). These newly established bands were patchily distributed along the river and comprised mostly of sedges (mostly *Cyperus* spp.), water pepper *(Persicaria hydropiper)* and pale knotweed (*Persicaria lapathifolia*). Many plants that had established were setting seed in March 2021 after ~13 weeks of lower flows. Although some recovery of fringing vegetation has been achieved there was little to no response of vegetation in Zone 1a, the lowest elevation surveyed, and lower flows may be required for vegetation to establish in this zone.
- The narrowing of the littoral band of vegetation due to higher IVT demand (and therefore larger/longer summer flows) is expected to reduce the resilience of vegetation by limiting propagule supply and reducing the buffering capacity that wider bands may offer against high flow velocities. This increases vulnerability to erosion and further loss of vegetation. The loss of vegetation at the toe of bank increases the risk of erosion and subsequent changes in channel geomorphology that are not easily reversed.

<u>*Autumn fresh*</u>

- There was no evidence that the delivery of a fresh in March 2017 had any immediate negative outcome on bank vegetation. There is some evidence that grasses at higher elevations benefited from this late season watering.

<u>*Differences between sites*</u>

- Vegetation cover is consistently lower at McCoy's Bridge compared with Loch Garry but responses of vegetation to environmental water and unregulated flows are generally similar. The reason for differences in vegetation cover between the two sites is not known but may reflect differences in channel shape, the aspect of sampled transects, or differences in subsurface water inflows. Loch Garry potentially receives higher subsurface water inflows from the closer proximity of large wetlands compared to McCoy's which experiences more human activity and livestock grazing (*pers*. *obs.* D. Lovell, GBCMA).

<u>*Temporal trends*</u>

- There has been a small increase in the summed cover of all ground layer plants between 2014 and 2021 at both Loch Garry and McCoys Bridge. Trends, however, vary for different zones of the bank. Positive trends in the summed cover of ground layer plants at both sites are found at higher elevations (Zone 3). Increases are largely due to increased cover of grasses, notably common tussock grass (*Poa labillardierei*). In contrast, the summed cover of vegetation in Zone 1a and Zone 1b (the lowest surveyed elevations at the toe/fringe) have oscillated over time, consistent with the vulnerability of this zone to unnatural high summer flows.

Influence of hydraulic variables

- Modelled relationships examine how the cover and occurrence of selected taxa and groups change as the duration of inundation in the year prior to sampling increases. These models again demonstrated differences in the hydraulic niche of the plant groups and taxa examined. The data collected in 2020-21 has contributed to refining these models.
- Modelled relationships of selected taxa and the duration of inundation over the IVT period generally show similar patterns as inundation over the year prior to sampling, but thresholds differ, reflecting the short temporal scale examined. Models that examine responses to inundation >0 cm and those that examine response to inundation >25 cm are similar but also reveal some differences in response thresholds.

  The model outputs suggest that the probability of emergent water dependent taxa occurring on the bank starts to steadily decline when the total duration of inundation >25 cm over the IVT period exceeds 40 days. In contrast, previous models considered inundation >0 cm and showed a lower sensitivity, with declines occurring after 55 days.

- It is not clear to what extent antecedent conditions contribute to the response to inundation, or how responses will differ if the days inundated are continuous or intermittent. Current recommendations are that individual inundation events should not be greater than two weeks (DELWP 2021, Roberts 2016, Vivian et al. 2020).

  Further data and modelling are needed to explore (1) the relative importance of antecedent conditions, (2) how the duration of individual inundation events influences vegetation responses and (3) how inundation in different seasons influence vegetation responses at the end of the growth season.

Influence of climate and non-regulated flow

- Climatic conditions and non-regulated flows can exert a strong influence on vegetation and potentially influence the outcomes of environmental watering actions. Prolonged natural flooding in 2016–17 caused a substantial decline in the cover and occurrence of sedges and rushes, but increased the cover and distribution of lesser joyweed (*Alternanthera denticulata*) and to a lesser extent common sneezeweed (*Centipeda cunninghamii*) which colonised the exposed bare mud following flood recession. Common tussock grass (*Poa labillardierei*) at elevations above the Spring Fresh appeared to benefit from natural floods in 2016-17.

Implications for new findings:

- Low summer flows are a feature of the natural flow regime and are needed to maintain fringing vegetation. Models of vegetation responses to inundation suggest that avoiding inundation >25 cm for more than 40 days over summer is needed to support the persistence of emergent water dependant plants. It is not known if antecedent conditions influence responses to inundation duration, or if responses differ if inundation is continuous or intermittent. Current recommendations are that individual inundation events over the summer IVT period should not be greater than two weeks (Roberts 2016, Vivian et al. 2020).
- Although some recovery of fringing vegetation has been achieved with lower summer flows in 2020-21 there was little to no response of vegetation in Zone 1a, the lowest elevation surveyed, and lower flows may be required for vegetation to establish in this zone.
- There is a strong capacity for recovery following plant losses incurred in years of high IVT demand. Initially recovery is patchy and successive years of low summer flows are likely to be needed to increase the distribution of fringing vegetation.
- Long periods of low flow over the growth season for around 13 weeks appears to allow fringing vegetation to mature and set seed. Providing these opportunities in some year will enhance resilience.

7.3.3. Summary of findings relevant to evaluation questions

Table 7-2 provides a summary of the vegetation findings relevant to the evaluation questions. A more detailed examination of each evaluation question is provided in Section 7.5.

Table 7-2 Summary of vegetation findings relevant to evaluation questions.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
Area scale evaluation questions			
Does the CEW contribution to Spring Freshes increase the abundance of riparian vegetation on the bank face?	Spring Freshes were appropriate. Prolonged summer inundation by IVT flows resulted in negative outcomes	Spring Freshes contribute to maintaining the cover of water dependent taxa. This is demonstrated by: Water dependent taxa generally increase in cover post Spring Freshes. This could not be tested this year due to natural high flows. The distribution of water dependent taxa is mostly limited to regions of the bank influenced by Spring Freshes.	• Visual comparison of summary data plots for the cover of focal taxa and plant groups across bank zones • Visual comparison of summary data plots for of pre and post Spring Fresh cover
Do flows shift the distribution of riparian vegetation communities on the bank face?	As above	The distribution of plant groups and species along the bank face reflects their hydraulic tolerances. The distribution of emergent water dependent taxa is limited to regions of the bank influenced by Spring Freshes and the distribution of common tussock grass is limited to higher elevation where it experiences shallow and brief inundation. Periods of unnatural high summer flows due to IVT demand eliminated emergent, water dependent species at the lowest elevations effectively narrowing the littoral zone and increasing the risk of erosion. In 2020-21 lower summer flows were associated with the establishment of emergent, water dependant taxa in a narrow band along the river fringe.	• Visual comparison of summary data plots for the cover of focal taxa and plant groups across bank zones
Do responses of bank vegetation differ among sites?	As above	Vegetation cover is consistently lower at McCoy's Bridge compared with Loch Garry but responses of vegetation to environmental water and unregulated flows are generally similar.	• Visual comparison summary data plots for the cover of focal taxa and plant groups across bank zones • Visual comparison summary data plots of pre and post Spring Fresh cover
What influence do hydraulic variables have on the abundance of riparian vegetation communities?	As above	The duration of inundation > 25 cm depth in the year prior to sampling and over the IVT period influence the abundance of plant groups and taxa differently and reflects their distribution on the bank. For emergent, water dependent taxa, > 40 days of inundation >25 cm depth over the summer IVT period is correlated with a steady decline in the probability of occurrence. Previous models that only	• Bayesian models

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
		assessed the duration of inundation >0cm found that sensitivity was lower, with a decline occurring after 55 days of inundation. This difference suggests that depth of inundation is influential as it determines if plants are completely submerged. It is not known if antecedent conditions influence responses to inundation duration, or if responses differ if inundation is continuous or intermittent. Current recommendations are that individual inundation events do not exceed two weeks over the summer IVT period.	
Is there a positive trend in the abundance of riparian vegetation communities over the medium-long term?	As above	The mean summed cover of ground layer vegetation averaged across all bank zones show a small positive trend at both sites, with similar rates of increase at both sites. The increase in cover is mostly due to increases in the cover of grasses at higher elevations. In contrast the cover of emergent water dependent vegetation at lower elevations has oscillated over time and doesn't show a trend of increasing. Unnatural high summer flows contribute to variability in cover of water dependant taxa in this zone.	▪ Visual examination of changes over time and trend lines
How does the annual flow regime (natural, environmental or consumptive) and weather conditions influence the abundance of riparian vegetation communities at the end of the growth season?	As above	The cover of vegetation at the end of the growing season reflects the cumulative response to the annual flow regime and weather conditions. Responses however vary across different zones of the bank. At elevations above the Spring Fresh the summed cover of ground layer herbs and grasses tended to decline between December 2020 and March 2021. In contrast, with low summer flows in 2020-21 water dependant vegetation including herbs and sedges in the fringing zone increased.	• Visual comparison of cover over time

7.4. Monitoring methods and analytical techniques

7.4.1. Sampling

Vegetation has been sampled on both banks at Loch Garry and McCoy's Bridge, before and after the delivery of Spring Freshes in 2014–15, 2015–16, 2017–18, 2018-19 and 2019-20 (Appendix H). In 2016 Spring Freshes were not delivered due to the large unregulated flows that persisted between June and November 2016, and vegetation was instead sampled in December 2016 after the recession of flood waters. Comparing vegetation cover measured in December 2016 with past surveys in December 2014 and 2015 provides insights into the influence of large natural flood events.

Vegetation was also sampled in February 2017 and April 2017, before and immediately after, a fresh delivered in March 2017 for instream vegetation and fish objectives. Vegetation monitoring was undertaken in this case to assess recovery of vegetation following the natural flooding and to assess responses of vegetation to the March fresh that could guide future flow planning. Vegetation sampling carried out in April 2017 was supported by the GBCMA with VEFMAP funds.

Due to increasing IVT demand, an additional survey was undertaken at McCoy's Bridge in March 2019 to evaluate the responses to IVT delivery and was funded by the VEWH and GBCMA.

In 2019-20 surveys were carried out before and after the Spring Fresh and again in March at both McCoy's Bridge and Loch Garry. Surveys in December 2019 allow an evaluation of the short-term responses to the Spring Fresh but also provide a baseline prior to higher IVT delivery. Surveys in March 2020 enable an evaluation of responses to IVT delivery as well as the end of growing season response to the annual flow regime.

In 2020-21 natural high flows prevented sampling prior to the Spring Fresh and instead surveys were carried out in November 2020 when flows had receded, prior to the fish spawning fresh. Surveys were also undertaken as part of the planned monitoring regime in December 2020 and March 2021.

At all sampling times vegetation was surveyed along transects that ran perpendicular to stream flow. Sampling was initially designed to survey regions of the bank that had previously been surveyed by other programs (i.e., VEFMAP and CEWO STIM). However, many quadrats sampled by these programs were at elevations well above the level expected to be inundated by Spring Freshes. As such, subsequent sampling did not attempt to match the spatial extent of these previous programs. Instead, surveys extended from around base flow to just above the level inundated by Spring Freshes (nominally a change in elevation of approximately 3 m). As transect elevation data were not available in the first year of sampling, a 3 m change in height from base flow was estimated visually.

Vegetation indicators were assessed using the line point intercept method at each sampling interval along the transect. This is done by placing a 2 m measuring tape perpendicular to the transect (i.e., parallel to streamflow) and recording every 10 cm along the tape all species that intercept a rod placed vertically through the vegetation. This gives a total of 20 sampling points at each sampling location. Foliage projected cover (%) for each species was then calculated by dividing the number hits per species by the total number of points sampled (see details in standard operating procedures - Webb et al. (2019b)).

7.4.2. Analyses

Monitoring data collected over the seven years of the LTIM and MER programs provides insights into the responses of vegetation to environmental flow events and to longer term hydrologic regimes. Qualitative and quantitative approaches have been applied to evaluate vegetation responses.

Qualitative approaches include the following:

- Examination of foliage projective cover of different taxa across all sampled locations at each site in relation to short and longer-term flow histories.
- Examination of the foliage projective cover of different taxa across the elevation gradient at each sample date at each site.

Temporal trends reported here excluded data collected at Loch Garry at elevations above 93 AHD m as these higher elevations were only surveyed in the early phase of the program and including them would confound temporal patterns of change.

Quantitative approaches were developed to identify relationships between hydrologic variables and vegetation cover and occurrence that is more transferrable to other sites and support a more predictive approach. Models have been developed for (1) vegetation presence/absence and number of days inundated and (2) vegetation abundance and number of days inundated. Models are described in detail in previous annual reports (e.g. Webb et al. 2019a).

The models were revised this year to assess responses of vegetation to number of days inundated >25 cm as it was expected that it would account for more variability in the response.

The evaluation has concentrated so far on various plant groups and focal species with high enough occurrences to reveal responses to inundation. Plant groups included water dependent taxa and different life form groups including, grasses, sedge, herb and rushes. Focal species including creeping knotweed (*Persicaria prostrata*), lesser joyweed (*Alternanthera denticulata*) and common tussock grass (*Poa labillardierei*) that are representative of ground-layer dominants of some Riverine floodplain Ecological Vegetation Classes (EVCs) relevant to the Goulburn River bankside assemblage (Cottingham et al. 2013). Drain flat-sedge (*Cyperus eragrostis*) is the only introduced sedge species found and was included in the analyses of sedges as it is representative of key ground-layer dominants of Ecological Vegetation Class (EVC) 962 (Riparian Wetland), which develops in a band along the lower banks. The group "all grasses" included all annual and perennial, native and introduced grasses, but only common tussock grass occurred with high enough frequency to warrant species level analyses. Water dependent species were classified as those tolerant of flooding (Leck & Brock 2000).

7.5. Results

7.5.1. Relevant flow components delivered to the lower Goulburn River in 2020–21

Commonwealth environmental water was used to slow the recession of natural high flows in September 2020. A Spring Fresh for vegetation and macroinvertebrates objectives was delivered in October 2020. Rainfall during the event led to high natural flows and the fresh being a combination of environmental and unregulated flows with a peak flow of 9768 ML/day at McCoy's Bridge on the 14 October 2020. A fish spawning fresh was also delivered in November 2020 with a peak flow of 4089 ML/day on the 21 November 2020 at McCoy's Bridge (Figure 3-1).

Environment flows were also used to prevent water levels dropping and triggering germination in the lower fringing zone prior to the fish spawning fresh in November which would likely have otherwise caused high mortality of any new germinants. This strategy would therefore optimise the germination response on the recession of the Spring Fresh when seedlings were more likely survive.

7.5.2. Response of bank vegetation

Responses of bank vegetation to flows are examined in relation to the evaluation questions outlined in Table 7-2. To inform this evaluation the cover of vegetation across different bank zones that are variously influenced by Spring Freshes and IVT flows are examined. The zones are described in Table 7-3 in terms of their elevation and whether they are inundated by IVTs or Spring Freshes based on the elevations reached by different discharge volumes at each site.

Table 7-3 Bank zone elevations and inundation of zone by Spring Freshes and Inter Valley Transfers at McCoy's Bridge and Loch Garry.

Site	Zone	Elevation AHD m	Spring Fresh	IVT
McCoy's Bridge	Zone 1a	>93.00-93.25	√	√
	Zone 1b	93.25-93.5	√	√
	Zone 2	93.5-94.0	√	√
	Zone 3	94.0-95.5	√	x
	Zone 4	>95.5	x	x
Loch Garry	Zone 1a	<98.3-98.6	√	√
	Zone 1b	98.6-99.05	√	√
	Zone 2	99.05-99.8	√	√
	Zone 3	99.8-101.6	√	x
	Zone 4	>101.6	x	x

Is there a positive trend in the abundance of riparian vegetation communities over the medium-long term?

There has been a small but statistically significant increase in the summed cover of all ground layer plants between 2014 and 2021 at both Loch Garry and McCoy's Bridge. Cover has increased by ~ 2% per year at both sites. Trends, however, vary for different regions of the bank due to differences in the flow regimes experienced at different elevations. The responses of different vegetation groups and taxa over time in each bank zone are summarised below with relevant graphical responses provided in Figure 7-1 and Appendix I.

The strongest positive trend in the summed cover of ground layer vegetation at both sites is found in Zone 3 followed by Zone 2. In Zone 3, cover increased by ~ 4% per year. This is largely due to increased cover of grasses, notably common tussock grass (*Poa labillardierei*).

In contrast to the observed increases in the cover of grasses at higher elevations, the cover of water dependent vegetation at lower elevations has not increased over time. Despite short-term increases following Spring Freshes, the cover of water dependent vegetation has oscillated over time. Although oscillations are expected, the cover of water dependent vegetation has not returned to levels observed in summer 2015-16. Unregulated flooding in 2016 followed by unseasonal prolonged high summer flows associated with high IVT demand eliminated most vegetation from Zone 1a and continuing unnatural high summer flows due to IVT in 2019-20 has prevented recovery.

Lower and more stable flows over summer in 2020-21 were correlated with the establishment of narrow bands of water dependant vegetation along the river fringe (Zone 1b). These newly established bands were patchily distributed along the river and comprised mostly of sedges (mostly *Cyperus spp*) water pepper *(Persicaria hydropiper)* and pale knotweed (*Persicaria lapathifolia*). Many plants that had established were setting seed in March 2021 after ~13 weeks of lower flows. Although some recovery of fringing vegetation had been achieved there was more limited response of vegetation in Zone 1a and lower flows may be required for vegetation to establish in this zone.

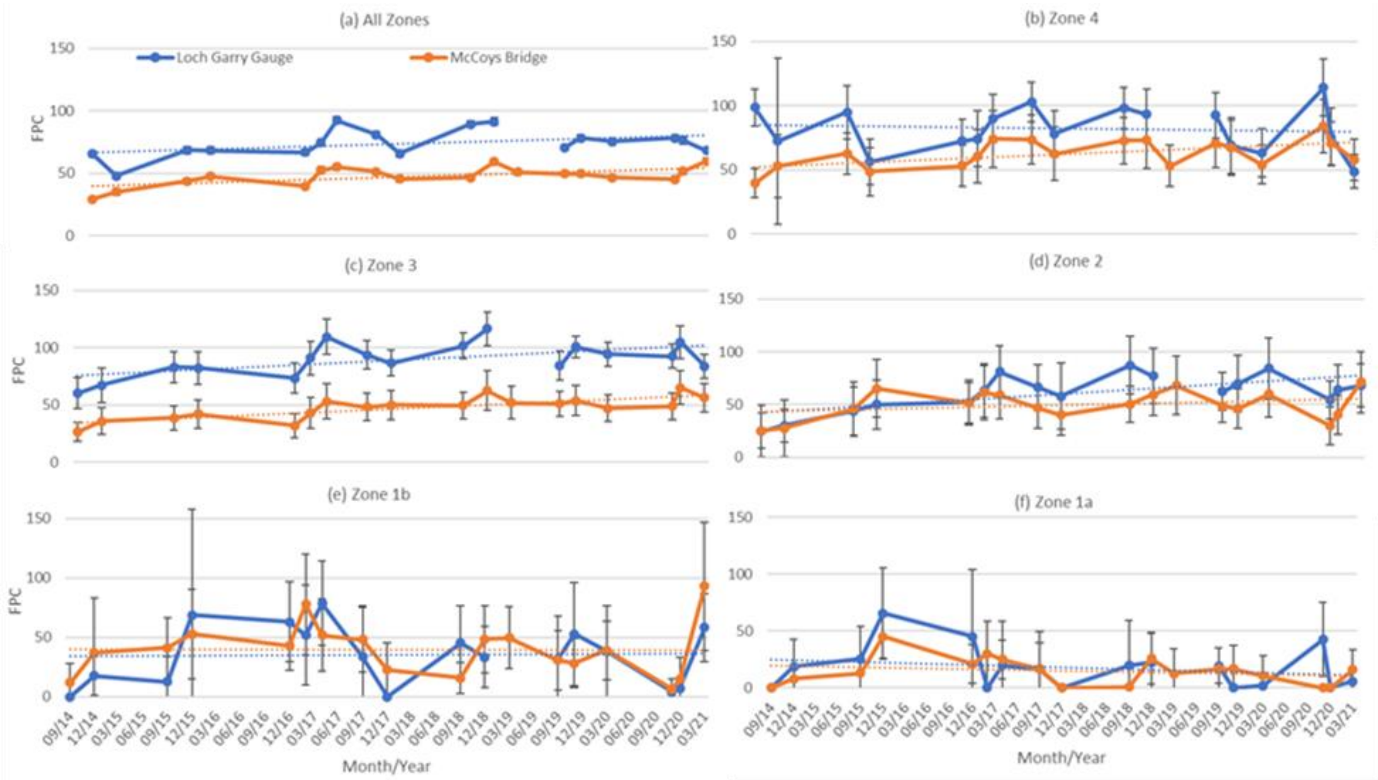


Figure 7-1 Mean (+/- 95% CI) foliage projected cover (FPC) of ground layer vegetation at McCoy's Bridge and Loch Garry at each survey averaged across all zones(a), Zone 4 (b) Zone 3 (c) Zone 2 (d) Zone 1a (e), and Zone 1a (f). Trend lines (dotted) are also shown for each site.

Does the CEW contribution to Spring Freshes increase the abundance of riparian vegetation on the bank face?

Spring Freshes contribute to maintaining the summed cover of water dependent species in the ground layer vegetation that are representative of relevant riparian EVCs of the Goulburn River. The mean summed cover of all water dependent taxa typically increases between September and December following the delivery of the Spring Fresh at McCoy's Bridge and Loch Garry. Spring Freshes may also contribute to maintaining the abundance of common tussock grass through the growing season by contributing to soil moisture stores. In 2020-21 responses of vegetation to the Spring Fresh could not be evaluated and high unregulated flows prevent monitoring prior to the Spring Fresh. However, water dependent taxa continue to maintain higher cover in regions of the bank inundated by Spring Freshes (Appendix I).

Environmental flows in 2020-21 were also used to prevent water levels dropping and triggering germination along the river fringe (Zone 1a and 1b) between the Spring Fresh and the fish spawning fresh. This was done because the fish spawning fresh could kill newly germinated plants and deplete the available seed supply without resulting in successful recruitment. As such, the strategy aimed to optimise the germination response on the recession of the fish spawning fresh, when low flows were likely to be sustained for longer and favour survival.

The cover of water dependant vegetation along the river fringe (Zone 1a and 1b) in November 2020 (after the October Spring Fresh) and again in December (after the November fish spawning fresh) was low, suggesting the recruitment was likely suppressed by this strategy, or that very young seedlings were killed by the November fresh. Following the recession of the fish spawning fresh, lower flows were maintained over summer and significant establishment of fringing vegetation in Zone 1b occurred at both sites in March 2021. It is unclear to what extent the strategy of suppressing germination along the fringing zone between the Spring Fresh and fish fresh contributed to this positive outcome and further research is needed.

Do responses of bank vegetation differ among sites?

Vegetation cover is consistently lower at McCoy's Bridge compared with Loch Garry but responses of vegetation to environmental water and unregulated flows are generally similar (Figure 7-1, Appendix I). The reason for differences in cover at the two sites is not known but may reflect differences in channel shape, the aspect of sampled transects, or differences in subsurface water inflows. Loch Garry potentially receives higher subsurface water inflows from the closer proximity of large wetlands compared to McCoy's Bridge, which also experiences more human activity and goat grazing on creeping knotweed (*pers*. *obs.* D. Lovell, GBCMA).

Do flows shift the distribution of riparian vegetation communities on the bank face?

The distribution of focal plant groups and taxa along the bank face reflects their hydraulic tolerances. The distribution of water dependent taxa is limited to regions of the bank influenced by Spring Freshes (Zone 1a-Zone 3) and the distribution of common tussock grass (*Poa labillardierei*) is constrained to elevations where it experiences only shallow and brief inundation (Zone 3 and Zone 4).

Creeping knotweed (*Alternanthera denticulata*) has a broad distribution across the bank face, but its cover is highest in Zone 3 (the upper limits of the Spring Freshes) and is lowest in Zone 1a, which experiences deeper and more prolonged inundation. Unregulated floods in 2016 increased the cover of creeping knotweed in Zone 4 at McCoy's Bridge (above the level reached by Spring Freshes) to match that achieved in Zone 3; cover has since decreased to below that in Zone 3.

Water dependent vegetation in Zone 1a was mostly eliminated by IVT delivery in 2018-19 and only tall established species such as common reed (*Phragmites australis*) and some sedges (*Cyperus* spp.) persisted. Common reed, which was only present at one location, made a significant contribution to the remaining vegetation cover in Zone 1a at McCoy's Bridge. Few plants had re-established by September 2019 prior to IVT delivery, although germination was triggered at some locations indicating the capacity to recover if suitable flows are provided. Further declines in mean cover were not observed following IVT delivery in 2019-20, possibly as only summer inundation tolerant plants remained.

The cover of sedges fell across all zones following natural flooding in 2016 but recovery under higher IVT delivery in subsequent years was limited and inconsistent. The cover of rushes (entirely composed of *Juncus* spp.) was reduced in Zone 1 following natural flooding in 2016 and recovery has been limited to higher elevations in Zone 2 where the influence of IVTs was less.

IVTs appear to have favoured the growth of grasses at higher elevations and of pale knotweed (*Persicaria lapathifolia*) on benches where only shallow flooding would have been experienced.

In 2020-21 low flows provided opportunities for water dependent vegetation to establish along the river fringe in Zone 1a, comprised of sedge (Cyperus spp.) and herbs (water pepper (Persicaria hydropiper), pale knotweed (Persicaria lapathifolia)). However, vegetation did not respond to lower flows in Zone 1b at Loch Garry and only a small increase occurred at McCoy's Bridge. Lower flows are likely to be needed to stimulate recruitment in Zone 1b (Figure 7-1, Figure 7-2, Appendix I).

Figure 7-2 Patch of plants re-establishing along the river fringe at McCoys Bridge in March 2021.

How does the annual flow regime (natural, environmental or consumptive) and weather conditions influence the abundance of riparian vegetation communities at the end of the growth season?

The abundance of vegetation in March, near the end of the growing season, reflects the cumulative response to the annual flow regime and weather conditions. Monitoring of vegetation in March at both sites has only occurred since 2018-19. Over this time vegetation foliage project cover (FPC) at higher elevations has tended to decline at both sites between December and March (Figure 7-1). These declines likely reflect the influence of decreased soil moisture and the seasonal senescence of annual terrestrial herbs at higher elevations (Figure 7-1, Appendix I).

At lower elevations FPC does not show a seasonal pattern of increase over the growing season in 2018-19 and 2019-20 as would be expected under a more natural flow regime, where low summer flows provide suitable conditions for water dependant plants to establish and grow at lower elevations. The failure of a strong seasonal growth response in 2018-19 and 2019-20 is likely due to elevated summer flows associated with IVT delivery. In 2020-21 IVT flows were lower and there was a strong seasonal increase in FPC in Zone 1b and to a lesser extent in Zone 2, highlighting the importance of low summer flows for fringing vegetation.

What influence do hydraulic variables have on the abundance of riparian vegetation communities?

The influence of two hydraulic variables on vegetation have been modelled: (1) the duration of inundation >25 cm depth in the year prior to sampling and (2) the duration of inundation >25 cm depth over the IVT period.

All model outputs for the duration of inundation the year prior to sampling are based on both MER (2 years) and LTIM (5 year) data as inputs and uses vegetation data for all sampling events. Model outputs for the duration of inundation in the IVT season only is calculated based in days inundated over the IVT period, and only uses vegetation data sampled in March and April.

The modelled outputs are show in Figure 7-3 to Figure 7-5 and demonstrate that the duration of inundation >25 cm depth, over the year prior to sampling, and over the IVT period, influence the cover and occurrence of focal plant groups and taxa differently.

Probability of occurrence in response to days inundated over the year prior to sampling

Model outputs for the probability of occurrence for different taxa and plant groups to the number of days inundated >25 cm depth in the year prior to sampling are shown in Figure 7-3 to Figure 7-5 and reveal differences across the taxa and groups examined.

- The occurrence responses of all vegetation groups are similar to the results from last year (using 5-year LTIM data and only 1-year MER data) which modelled response to inundation >0 cm, except the grass species, which has more obvious changes this year.
- The probability of occurrence for all ground layer vegetation generally decreases with increasing inundation, and there is higher uncertainty after about 300 days of inundation; this uncertainty stems from the fact that almost none of the surveyed vegetation was inundated for this length of time.
- There is little change in the probability of occurrence for water dependant vegetation during the first 100 days of inundation. After that, there is a decreasing trend as the inundation period increases.
- For grass species combined and common tussock grass (*Poa labillardierei*) individually, the probability of occurrence declines rapidly initially until approximately 130 days, after which the probability almost remains unchanged as inundation increases. However, as above, the uncertainty increases after about 300 days, especially for grass species.
- Rushes (composed entirely of *Juncus* spp.) and creeping knotweed (*Persicaria prostrata*) show mild declining responses to increasing inundation in previous year.
- There is an initial increase of probability for sedges as inundation period increases until around 40 days, which then keeps stable to about 100 days of inundation. After that, the probability of occurrence gradually decreases as inundation period increases.
- The probability of lesser joyweed (*Alternanthera denticulata*) occurrence shows an initial positive relationship with inundation period, which then changes to a negative relationship. This pattern may be the result of the fact that this species colonises exposed mud that becomes available after floods.

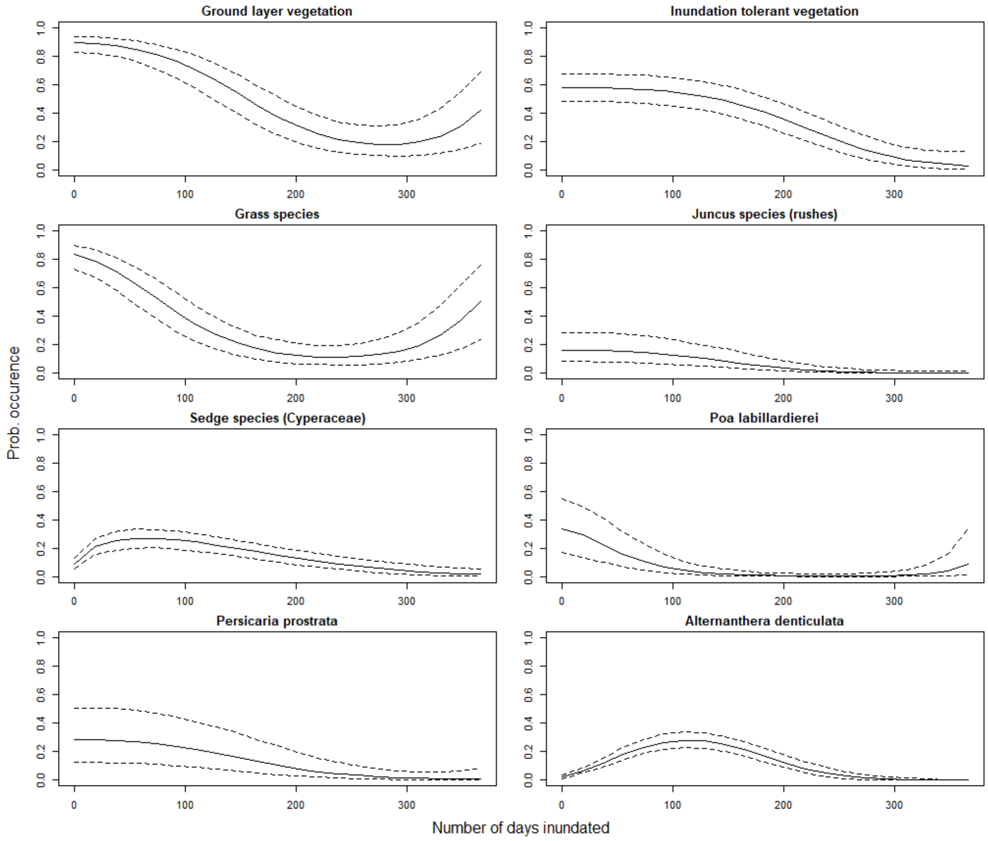


Figure 7-3 Modelled probability of occurrence for groups and species in response to number of days inundated at >25 cm in the previous year.

Probability of occurrence in response to days inundated over the IVT period

The probability of occurrence for different species to the duration of inundation >25 cm depth in the previous IVT season is show in Figure 7-4. Predictions beyond about 200 days are unreliable as there are insufficient data above this duration to calibrate the model reliably. Patterns are similar to those last year. Model responses reported here do not evaluate how responses change if inundation is continuous or intermittent. Current recommendations are that individual inundation events should not exceed two weeks (Roberts 2016; Vivian et al. 2020).

- Ground layer vegetation, rushes (entirely *Juncus* spp.) and creeping knotweed (*Persicaria prostrata*) demonstrate a declining trend as the inundation period increases, although the change for ground layer vegetation is much larger.
- Water dependant vegetation shows a similar changing pattern as to the inundation in previous year but the threshold before a decline in occurrence is lower than found last year. Last year models based on inundation >0 cm found occurrence declined after 55 day over the IVT season, but models this year based on inundation >25 cm (and additional data) indicate a decline after only 40 days.
- The occurrence probability of grass species decreases rapidly during the first 20 days of IVT inundation, and then remains stable, with the uncertainty increasing after 60 days.
- For common tussock grass (*Poa labillardierei*), the probability of occurrence decreases sharply to almost 0 during the first 5 days of inundation in IVT season. This high level of sensitivity is unexpected and probably reflects insufficient data for this species which occupies higher elevations and is rarely inundated by IVTs.
- There is no clear relationship between probability of occurrence and inundation in IVT season for sedge species, and there is slightly higher uncertainty after 60 days of inundation.
- In contrast, there is a significant increase in probability of occurrence for lesser joyweed (*Alternanthera denticulata*) within 5 days, which then gradually decreases within an increasing IVT inundation period. This pattern may result as this species colonises exposed mud that becomes available after floods.

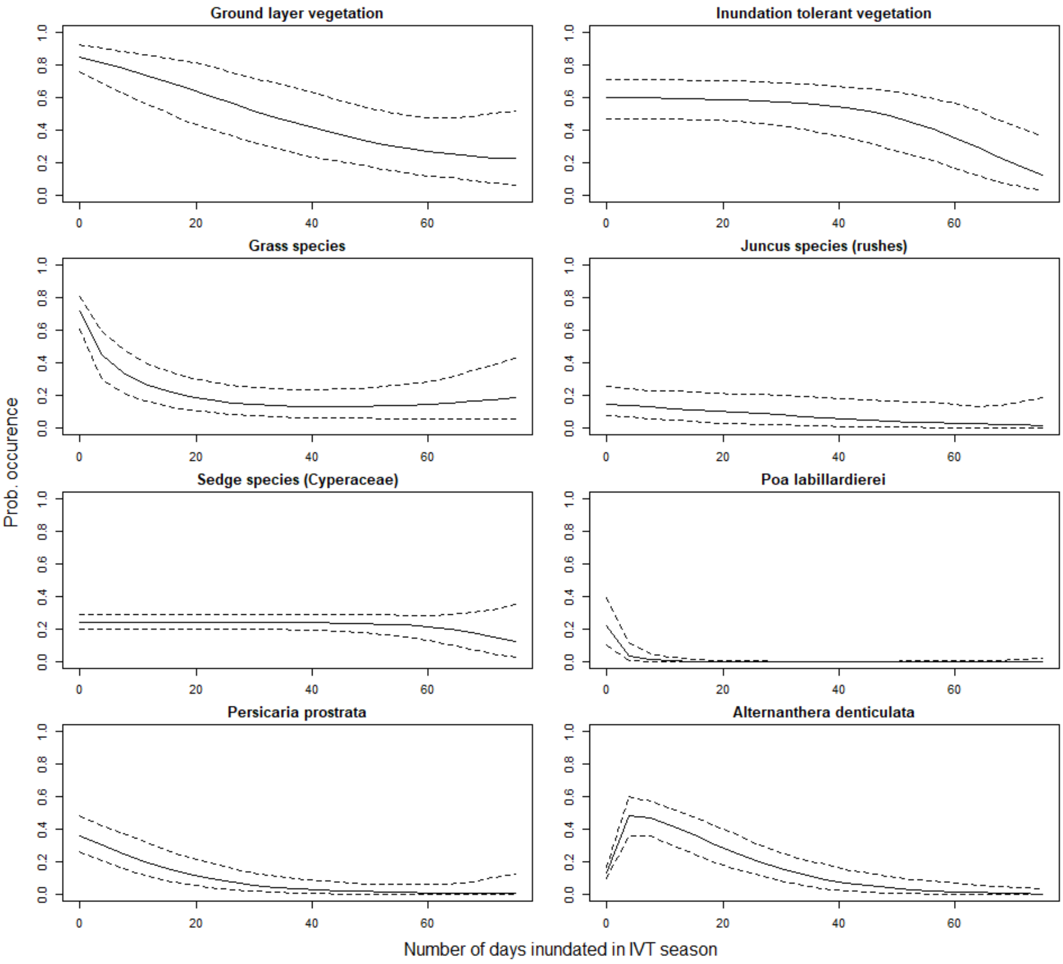


Figure 7-4 Modelled probability of occurrence for groups and species in response to number of days inundation >25cm in the previous IVT season.

Responses of plant foliage projected cover

Responses of precent foliage projected cover (FPC) to the period of inundation in the year prior to sampling is shown in Figure 7-5 and are similar to those obtained last year. Note that predictions beyond about 200 days are unreliable as there are insufficient data above this to calibrate the model reliably.

- For all ground layer vegetation, water dependant vegetation, rushes (entirely *Juncus* spp.), sedges and the herb creeping knotweed (*Persicaria prostrata*), FPC shows a general decreasing response within the inundation duration during the past year, with high uncertainty after 300 days for rushes and sedges, for the reasons described above.
- FPC of grass species has a negative relationship with inundation less than about 100 days, with almost complete exclusion for longer inundation periods.
- FPC of lesser joyweed (*Alternanthera denticulata)* demonstrates a similar response pattern to inundation as for its probability of occurrence, with the threshold being about 140 days.
- FPC of common tussock grass (*Poa labillardierei*) also presents similar decreasing pattern as its probability of occurrence.

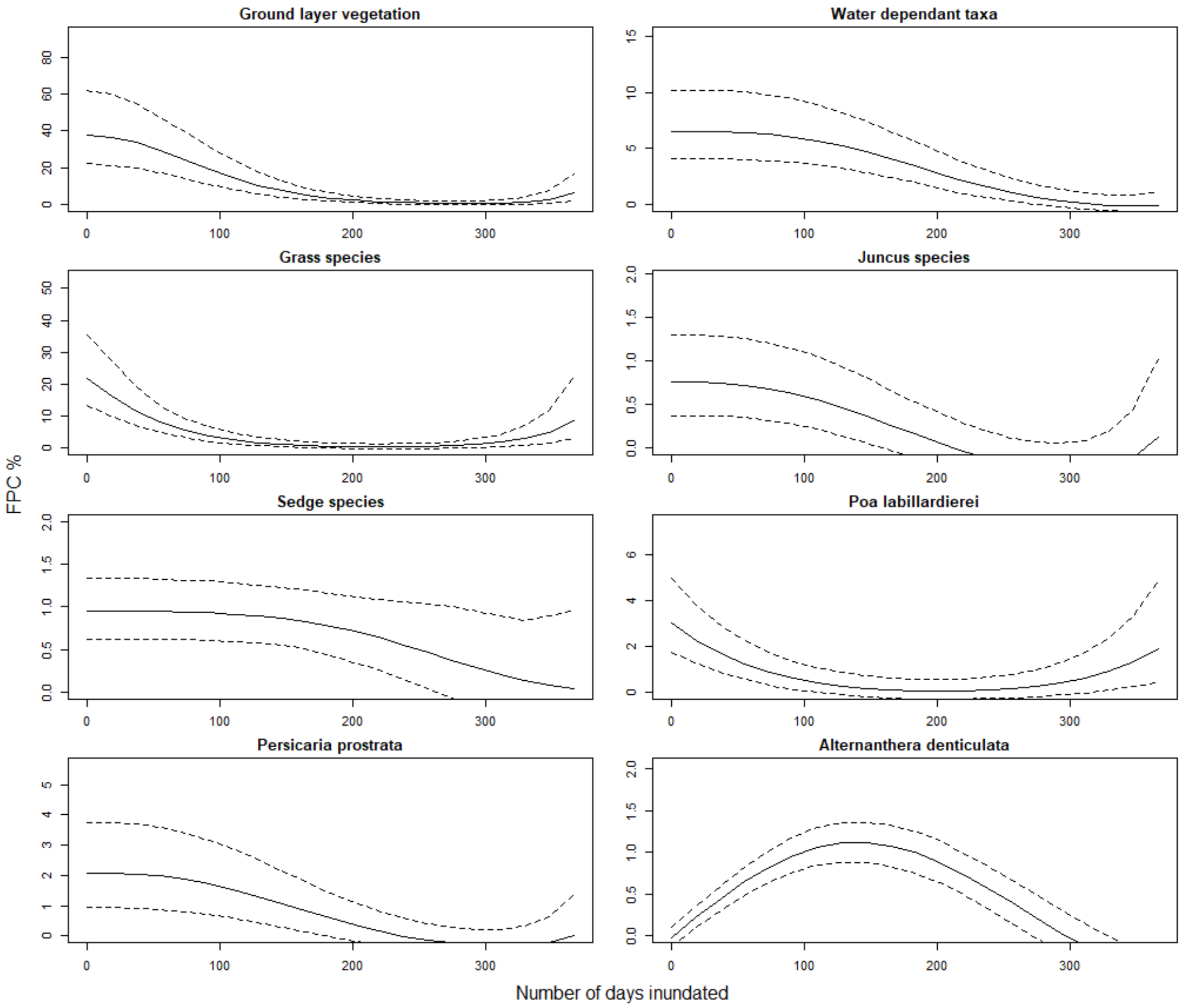


Figure 7-5 Modelled foliage projected cover (FPC %) for groups and species in response to number of days inundated >25 cm in the previous year.

7.6. Discussion

Over the five years of the LTIM Project and two years so far of the MER Program, environmental, natural and consumptive flows have all influenced the occurrence, cover and distribution of vegetation on the banks of the Goulburn River. Spring Freshes appear to support water dependent species as their distribution on the bank is greatest in areas inundated by Spring Freshes, and repeatedly increase in cover between pre and post Spring Fresh surveys. How seasonal patterns of plant growth contribute to this response is not known.

Medium-term trends show that while the summed cover of ground layer vegetation is increasing on the banks, responses vary between species and zones of the bank. For example, the overall increase in ground layer vegetation results from increases of vegetation at higher elevations, predominantly grasses, particularly common tussock grass (*Poa labillardierei*). In contrast, the cover of vegetation along the river fringe (Zone 1a and 1b), predominantly water dependant species has oscillated over time and does not show a medium-term increase despite increasing following Spring Freshes.

Restoring the abundance of vegetation along the river fringes has been limited by unnatural high summer flows from 2017-2019 associated with IVT delivery to meet consumptive demand. A reduction in IVT flows over summer in 2020-21 has resulted in the establishment of fringing vegetation in Zone 1b. Low summer flows are a feature of the natural flow regime and provide long periods over the growing season where the fringing zone experiences moist soil conditions to very shallow inundation. These conditions allow seeds of emergent plants to germinate and quickly extend their shoots above the water, improving gas exchange and access to light (Colmer et al. 2011). This enhances survival and more rapid progression to mature and more resilient life stages. Where inundation is deeper, germination may not be triggered and seeds that do germinate may lack sufficient energy reserves to extend their shoots through the water column, and consequently perish. Models of the probability of occurrence of water dependant species in response to inundation suggest a steep decline in occurrence once the duration of inundation >25 cm exceeds 40 days over the summer period.

As fringing vegetation matures, sets seed, and expands in extent, it is likely to show greater tolerance to unfavourable inundation events and to recover more rapidly following such events. Following the lower summer flows in 2020-21 many plants along the fringing zone were observed to be flowering and setting seeds in March. This suggests that 13 weeks of low summer flow allow plants to mature and reproduce. This is consistent with studies by Warwick & Brock (2003) that found most species that germinated in a soil seed bank study were flowering at 13 weeks under suitable inundation regimes.

Although lower summer flows in 2020-21 resulted in the re-establishment of narrow bands of vegetation from seeds and rhizomes along the lower banks, recruitment was patchy, and benches and bars were important locations for re-establishment. 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.

It is uncertain to what extent longitudinal expansion of vegetation will occur over time, or if other factors limit vegetation expansion along the river length. Some local factors that may constrain establishment of vegetation on the lower banks, even if suitable flows are provided include:

- depleted propagule sources at some locations
- steep banks that provide only very narrow bands of favourable hydraulic conditions for establishment
- absence of retentive features that slow flow and promote seed deposition and favour early establishment
- lack of shade that reduces thermal stress
- flow scour on outside bends.

Although flows suitable for the establishment of fringing vegetation can conflict with flows required to meet consumptive demand, vegetation in this region of the bank has intrinsic value as well as playing functional roles such as reducing bank erosion (O'donnell et al. 2015). The role vegetation plays in improving bank stability by stabilising and trapping sediment and slowing flows is well supported in the literature, with studies demonstrating that vegetated stream banks have lower rates or occurrence of erosion (Abt et al. 1994, Abernethy & Rutherfurd 1998, Harmel et al. 1999, Steiger et al. 2001, Rutherfurd 2007).

Adaptive management

To promote recovery of vegetation along the river fringe flow management should consider the following:

- Synchronise freshes with tributary flows where possible to enhance propagule supply.
- Provide low flows for 6-8 weeks following the recession of the Spring Fresh to promote recruitment of vegetation before delivering higher flow pulses for environmental or consumptive purposes. Further windows of low flows should be provided over the growth season to promote plant growth, flowering, seed set and vegetative expansion.
- 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.
- Provide adequate periods of low flows between inundation events to allow plants to recover.
- Avoid submergence of plants during flowering or seed set.
- 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.
- Provide successive years of low summer flows to increase the spatial extent and propagule supply of water dependant species in the fringing zone.

Analysis

Models of vegetation responses to inundation duration over the IVT period show similar patterns of responses to models of inundation over the year. This suggests that response over the growth season may exert the most influence on vegetation. To explore this, it would be useful to develop models that can assess the relative influence of inundation in different seasons on vegetation attributes at the end of the growth season (i.e., March surveys).

Current models do not assess if responses differ depending on whether inundation is intermittent or continuous and this warrants further attention given its relevance to flow management.

Research

Adaptive flow management to promote the establishment of vegetation would be supported by research to address the following knowledge gaps:

- How do fish spawning freshes delivered after the Spring Fresh influence the survival of young plants that have germinated along in the fringing zone following the recession of the Spring Fresh?
- Do low flow events that trigger germination deplete propagule availability and reduce the germination response to subsequent low flow events in the same season?
- Can impacts of high IVT demand on vegetation in the fringing zone be mitigated by delivering IVT flows as short pulses of higher volume to prevent prolonged inundation >25 cm over summer?
- How do elevated IVT flows impact on flowering and seed production of vegetation?
- As newly recruited vegetation matures, is it more tolerant to high summer flows?
- How do antecedent flow conditions and starting vegetation condition influence responses of vegetation to flow events?
- Do patches of fringing vegetation expand longitudinally under favourable flows and how quickly does this occur?
- What non-flow factors constrain recruitment of vegetation on the lower banks including:
    - propagule availability
    - bank slope
    - retentive features
    - shade
    - flow scour on outside bends
- What is the maximum portion of river length that fringing vegetation can establish on with optimal flows, given the non-flow constraints listed above? This can help to set realistic targets for what can be achieved under improved flow conditions.
- How much fringing vegetation is needed to ensure the persistence of plant populations and to support ecological functions such as bank protection and fauna habitat provision?

8. Fish

8.1. Introduction

Riverine ecosystems throughout the Murray-Darling Basin have been greatly modified by the construction of dams and weirs, and associated water regulation. These modifications are linked to major changes in river ecology, including reduced abundance and distribution of native fish populations. Water for the environment, complemented with additional recovery measures, are considered key to rehabilitating native fish populations in the Murray-Darling Basin. The MER Program 'Fish Theme', which continues the work undertaken through the LTIM Project, aims to evaluate the benefits of Commonwealth environmental water to native fish populations and improve understanding of flow-ecology and population dynamics of native fish to inform environmental water management for fish (https://flow-mer.org.au/basin-theme-fish/).

Two fish monitoring methods are employed in the core MER Program monitoring in the Lower Goulburn River Selected Area: 1) Annual population surveys using electrofishing and netting, and 2) Surveys of eggs and larvae using drift nets. The annual population surveys provide data to be integrated and analysed across all seven Selected Areas in relation to the benefits of water for the environment to native fish populations using statistical models (https://flow-mer.org.au/basin-theme-fish/). The annual population surveys in the lower Goulburn River build upon annual surveys conducted since 2003 and represent one of the longest continuous sets of fish monitoring data collected in the Murray Darling Basin. Moreover, this covers a wide range of climatic conditions including record drought, record floods, and a major blackwater event that contributed to widespread fish kills.

The drift net surveys in the lower Goulburn River collect eggs and larvae of a range of fish species, but specifically aim to examine the influence of flow on spawning of golden perch and silver perch. Environmental flows aimed specifically at initiating spawning in golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) have been introduced into the management of regulated rivers in the Murray-Darling Basin in recent years by the Commonwealth Environmental Water Office, with planning and delivery in partnership with Catchment Management Authorities. Spawning of both species has been linked to flows, but there is a need for a more detailed understanding of how components of the flow regime such as timing, duration, and magnitude affect spawning, in order to develop and refine environmental flow delivery strategies.

8.2. Basin and area specific evaluation questions

The key basin and area-scale evaluation questions and relevant indicators for fish are listed in Table 8-1.

Table 8-1 Fish key evaluation questions for the Goulburn selected area and associated indicators and evaluation approaches.

Key Evaluation Questions	Indicator	Evaluation Approaches
Basin Scale evaluation Questions		
What did CEW contribute to sustaining native fish populations?	Fish species occurrence and abundance (Specific indicators to be confirmed at Basin Scale)	Annual population surveys (electrofishing and netting), and surveys of eggs and larvae (drift nets). All data entered into the MDMS for use in statistical analysis at the Basin-Scale to examine relationships between fish population metrics and flow data.
What did CEW contribute to sustaining native fish reproduction?	Occurrence and counts of eggs and larval fish (Specific indicators to be confirmed at Basin Scale)	Observations based on surveys of eggs and larvae (drift nets). Statistical models predicting the likelihood of spawning.
What did CEW contribute to sustaining native fish survival?	Fish species occurrence and abundance (Specific indicators to be confirmed at Basin Scale)	Annual population surveys (electrofishing and netting). All data entered into the MDMS for use in statistical analysis at the Basin-Scale to examine relationships between fish survival metrics and flow data.
Area Scale evaluation questions		
What did CEW contribute to the recruitment of golden perch in the adult population in the lower Goulburn River?	Counts of young-of-year golden perch in annual surveys.	Annual population surveys (electrofishing and netting).

What did CEW contribute to golden perch or silver perch spawning?	Counts of eggs and larvae in drift net surveys.	Observations based on surveys of eggs and larvae (drift nets). Statistical models predicting the likelihood of spawning.

8.3. Main findings from monitoring program

The following sections provides a high-level summary of the outcomes of the 2020-21 monitoring and the implications of these findings to previous years outcomes.

8.3.1. 2020/21 findings

The main findings from the 2020-21 monitoring are:

- The nationally threatened trout cod was collected in low numbers in the 2021 annual population surveys. Evidence of spawning was also detected, with larvae of trout cod collected in the drift surveys in November 2020.
- A large proportion of the Murray cod population comprised young-of-year fish, likely spawned in spring-summer 2020.
- There was a considerable increase in the abundance of two small-bodied fish species, Murray River rainbowfish and Australian Smelt, in the 2021 annual population surveys.
- Low numbers of the nationally threatened silver perch were collected in the 2021 annual population surveys. Spawning of silver perch was also detected in drift sampling in late November 2020 coinciding with a targeted within-channel environmental flow pulse.
- Spawning of golden perch was detected in drift sampling in late October 2020 during a natural within-channel flow pulse, and in mid-November 2020 coinciding with a targeted within-channel environmental flow pulse. A single young-of-year golden perch was collected in the annual surveys in 2021.
- A single unspecked hardyhead was collected in the 2021 annual population surveys. This species had not been collected in the previous six years but is occasionally encountered in the Goulburn River (W.M. Koster, unpublished).

8.3.2. Summary of previous findings and implications for any new finding

- The nationally threatened trout cod has now been collected in low numbers in consecutive years (2020 and 2021) in the annual population surveys and four of the last seven years. Larvae of trout cod have been also collected for four consecutive years (2017-2020) in the drift surveys. Results from VEFMAP sampling conducted by ARI show trout cod are more common in the Goulburn River in upstream reaches near Murchison.
- Abundance of Murray cod remains lower than levels recorded prior to the 2017 blackwater event. Nevertheless, a considerable proportion of the population in the 2021 surveys was young-of-year fish. These individuals likely originated from recent natural spawning in the river, as the Murray cod population in the Goulburn River consists almost entirely of *in situ* recruits.
- A single young-of-year golden perch was collected in the annual population surveys in 2021. It is probable that this individual was stocked as the golden perch population in the Goulburn River consists mostly of stocked fish. Young-of-year golden perch are rarely collected in the annual population surveys, although this is likely because early life stages (eggs, larvae) drift downstream and into the Murray River.
- Only low numbers of silver perch were collected in the 2021 surveys. The silver perch population in the Goulburn River consists mostly of fish originating from the Murray River. Flows can be important in promoting immigration of silver perch into tributaries such as the Goulburn River (Koster et al. 2021), notwithstanding the outcome will be dependent on the abundance of fish in the Murray River.
- Abundances of Murray River rainbowfish in the 2021 population surveys were the highest recorded in the last seven years. Abundances of Australian smelt were also high relative to previous years. It is possible that a reduction in high flow conditions throughout summer 2021 relative to the previous few years may have been more favourable to recruitment.

- Spawning of golden perch and silver perch in the Goulburn River occurs during within-channel flow pulses or bankfull flows especially around November-December, including during periods of targeted managed environmental flow releases (i.e., 'freshes'). Environmental water allocation in the Goulburn River can effectively enhance or trigger spawning of golden perch and silver perch.

8.3.3. Summary of findings relevant to evaluation questions

Table 8-2 provides a summary of the findings relevant to basin and areas scale evaluation questions. Key points are outlined below:

- Spawning of golden perch was detected in drift sampling in late October 2020 during a natural within-channel flow pulse, and in mid-November 2020 coinciding with a targeted within-channel environmental flow pulse.
- Our analysis shows that the probability of spawning of golden perch in the Goulburn River was related to discharge, with greatly increased spawning probability at flows between about 3500–4000 ML/day when water temperature exceeded ~18.6°C.
- Our analysis also shows that increased flows prior to spawning were associated with increased spawning probability for golden perch.
- These results support previous findings linking prior flows and golden perch spawning and suggest that it is important to provide adequate flows not just to cue spawning but throughout the leadup to the reproductive season.
- To achieve the management objective of spawning of golden perch in the Goulburn River, elevated flows throughout spring, coupled with flow pulses of around at least 3500–4000 ML/day particularly around November, are needed.
- Spawning of silver perch was also detected in drift sampling in late November coinciding with a targeted within-channel environmental flow pulse.
- Similar to golden perch, spawning of silver perch in the Goulburn River appears dependent on elevated flows in late spring-summer coupled with appropriate water temperature.
- Measuring or reporting recruitment outcomes at a reach or river scale in this region may be unsuitable for species with early life stages that can drift or disperse long distances away from spawning locations.

Table 8-2 Summary of fish findings relevant to evaluation questions.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
Basin scale evaluation questions			
What did Commonwealth environmental water contribute to sustaining native fish populations?	Quantitative statistical analysis is needed to examine relationships between fish population metrics and flow data.	Key observations from surveys include: There was a large increase in abundances of Murray River rainbowfish and Australian smelt in 2021. One native (bony bream) and two exotic (redfin perch, oriental weatherloach) species collected in low numbers in previous surveys were not detected in 2021. Spawning of golden perch and silver perch was detected in the 2020 drift sampling.	Annual population surveys (electrofishing and netting), and surveys of eggs and larvae (drift nets). All data was entered into the MDMS for use in statistical analysis at the Basin-Scale to examine relationships between fish survival metrics and flow data.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did Commonwealth environmental water contribute to sustaining native fish reproduction?	Environmental water was delivered specifically for spawning of golden perch in November 2020.	Spawning of golden perch was detected in mid-October coinciding with a natural within-channel flow pulse. Spawning of golden perch and silver perch was also detected in mid and late November respectively coinciding with a within-channel environmental flow pulse.	Observations based on surveys of eggs and larvae (drift nets).
What did Commonwealth environmental water contribute to sustaining native fish survival?	Quantitative statistical analysis is needed to examine relationships between fish survival metrics and flow data.	Key observations from surveys include: Abundances of several small-bodied native species increased in 2021. One native and two exotic species collected in low numbers in previous surveys were not detected in 2021.	Annual population surveys (electrofishing and netting). All data was entered into the MDMS for use in statistical analysis at the Basin-Scale to examine relationships between fish survival metrics and flow data.
Area scale evaluation questions			
What did CEW contribute to the recruitment of golden perch in the adult population in the lower Goulburn River?	Environmental water was delivered specifically for spawning of golden perch in November 2020.	A single young-of-year golden perch was collected in the annual surveys in 2021. It is probable that this individual was stocked, as the golden perch population in the Goulburn River consists mostly of stocked fish.	Qualitative observations based on drift netting and electrofishing and fyke netting data. Previous monitoring shows that the Goulburn River supports spawning of golden perch if appropriate flows are provided. Young-of-year fish are rarely collected in the annual population surveys. This is likely because fish early life stages (eggs, larvae) drift downstream and into the Murray River. Otolith strontium analysis as part of other projects shows golden perch spawning in the Goulburn River acts as a source of fish to both the Goulburn and Murray rivers. Measuring or reporting 'recruitment' outcomes at a reach or river scale in this region may be unsuitable for species with early life stages that can drift or disperse long distances away from spawning locations.
What did CEW contribute to golden perch or silver perch spawning?	Environmental water was delivered specifically for spawning of golden perch in November 2020.	Spawning of golden perch and silver perch was detected in mid and late November respectively coinciding with a within-channel environmental flow pulse.	Observations based on surveys of eggs and larvae (drift nets). Statistical models predicting the likelihood of spawning.

8.4. Monitoring methods and analytical techniques

8.4.1. Annual population surveys (electrofishing and netting)

Electrofishing was conducted at 10 sites in the Goulburn River during May and June 2021 using the same methods as previous years of the study (2015-2019) and as documented in the Standard Operating Procedures included in the Goulburn River MER plan 2019-2022 (Webb et al. 2019b). Briefly, sampling was conducted at each site during daylight hours using a Smith–Root model 5 GPP boat–mounted electrofishing unit (Figure 8-1). At each site the total time during which electrical current was applied to the water was 2880 seconds. Ten fyke nets were also set at each site (Figure 8-1). Nets were set in late afternoon and retrieved the following morning.

Figure 8-1 Electrofishing and netting surveys on the Goulburn River.

8.4.2. Surveys of eggs and larvae (drift nets)

Fish eggs and larvae were sampled at four sites (Yambuna, McCoy's Bridge, Loch Garry, Pyke Road) on the Goulburn River using three drift nets at each site using the same methods as per previous years of the study (2014-2019) (Figure 8-2). Sampling was conducted once per week from October to December 2020. Drift nets were of 500-µm mesh, 150 cm long with a 50 cm mouth diameter, and had flow meters (General Oceanics, Florida, USA) fitted to the mouth of the net to measure the volume of water filtered. Nets were set in late afternoon (1500–1800 hours) and retrieved the following morning (0800–1000 hours). Drift samples were inspected briefly in the field to obtain fertilised eggs so that these could be taken to the laboratory for hatching to assist identification. The remainder of the samples preserved in 90% ethanol and taken to the laboratory for processing and identification.

Figure 8-2 Golden perch eggs collected in drift netting surveys on the Goulburn River.

8.5. Results

8.5.1. Annual population surveys (electrofishing and netting)

Nine native and three exotic species were collected from the ten survey sites in the Goulburn River in 2021. The nationally threatened trout cod was collected for the second consecutive year (2020 and 2021) and has been collected in four of the last seven years. Other species of conservation significance collected were silver perch, Murray cod 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.

Similar to the results of previous surveys, the small-bodied Australian smelt was the most abundant species collected, and the exotic carp was the most abundant large-bodied species collected. Abundances (mean number per site) of Murray River rainbowfish were considerably higher in 2021 compared to the previous six years. Abundances of Australian smelt were also high relative to previous years. One native (bony bream) and two exotic (redfin perch, oriental weatherloach) species collected in low numbers in previous surveys were not detected in 2021.

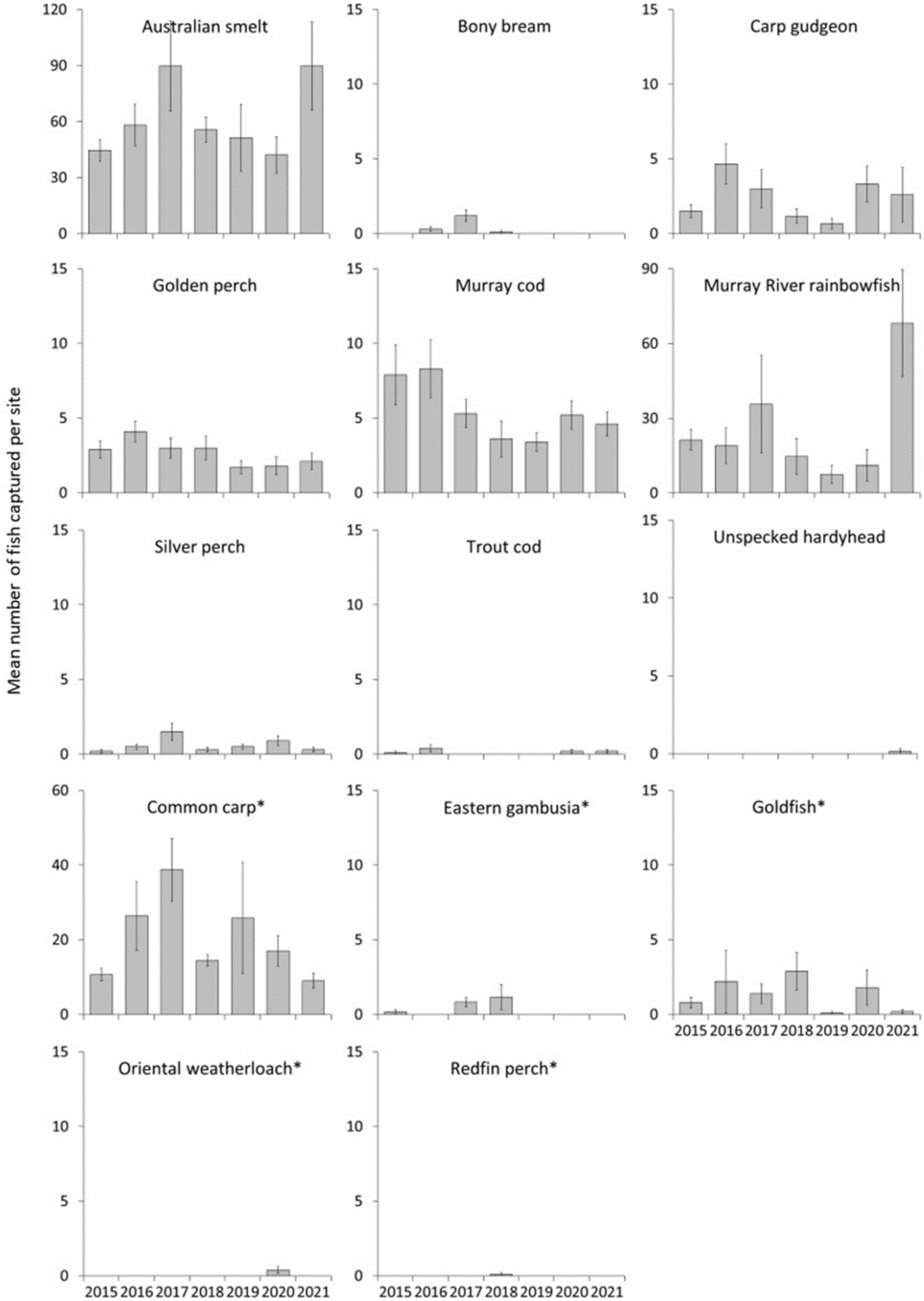


Figure 8-3 Mean number (±se) per site of fish species collected during electrofishing surveys 2015 to 2021. * denotes exotic species.

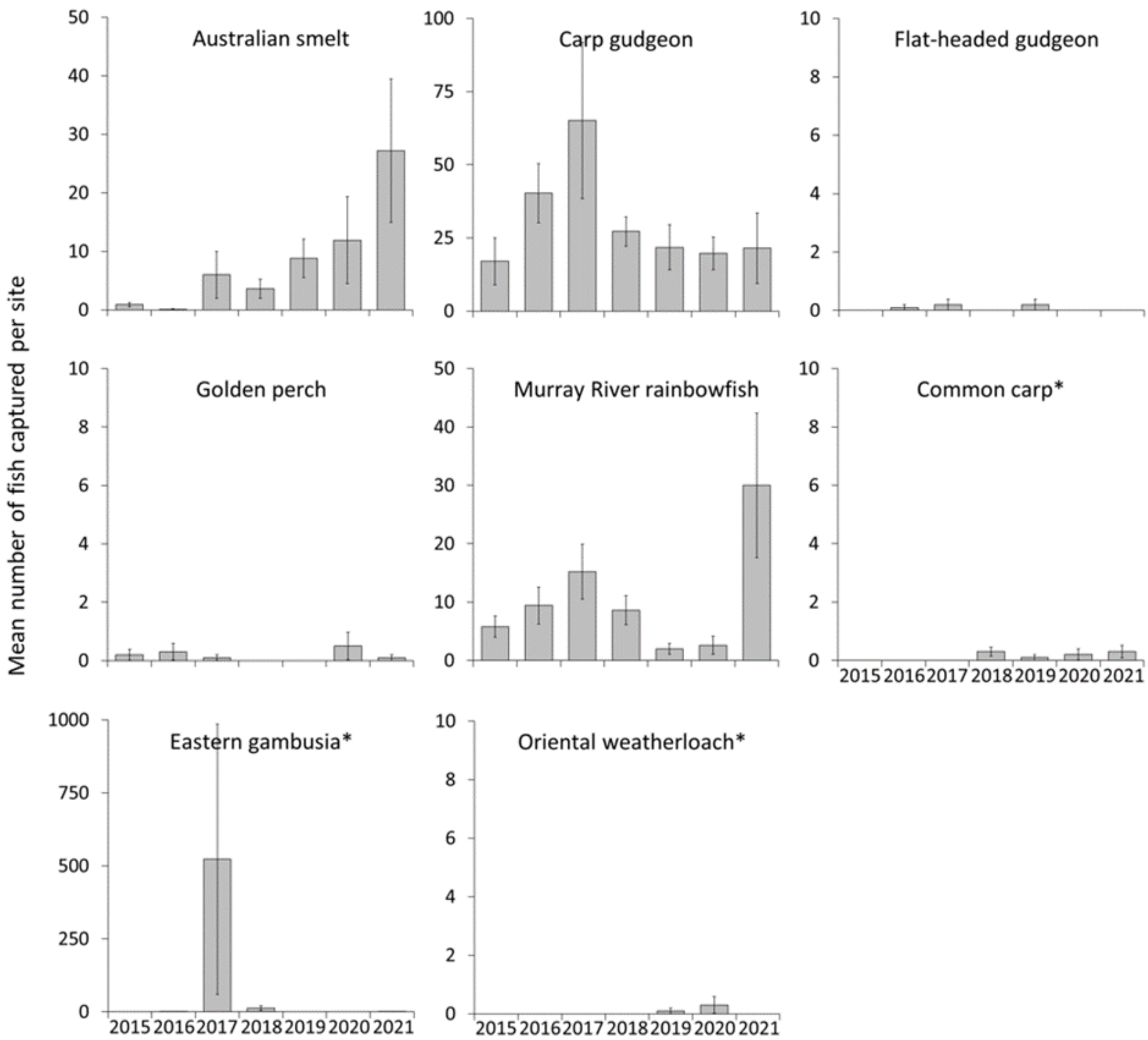


Figure 8-4 Mean number (±se) per site of fish species collected during fyke netting surveys 2015 to 2021. * denotes exotic species.

Length frequency histograms are presented below for four of the large-bodied species collected: Murray cod, trout cod, golden perch and silver perch (Figure 8-5).

The population structure of Murray cod collected in the 2021 surveys consisted of several cohorts, with young-of-year (YOY) fish (i.e. <100 mm in length) comprising the largest cohort. The majority of the population were below the minimum legal angling size (550 mm) for Murray cod. The population structure of golden perch in 2021 consisted mostly of large (>300 mm in length) adult fish similar to previous years. One juvenile golden perch (37 mm in length) was collected. Three silver perch were collected in 2021 ranging in length from 124 to 310 mm which represent immature and mature individuals. Two juvenile trout cod were collected in 2021 (142 and 147 mm in length).

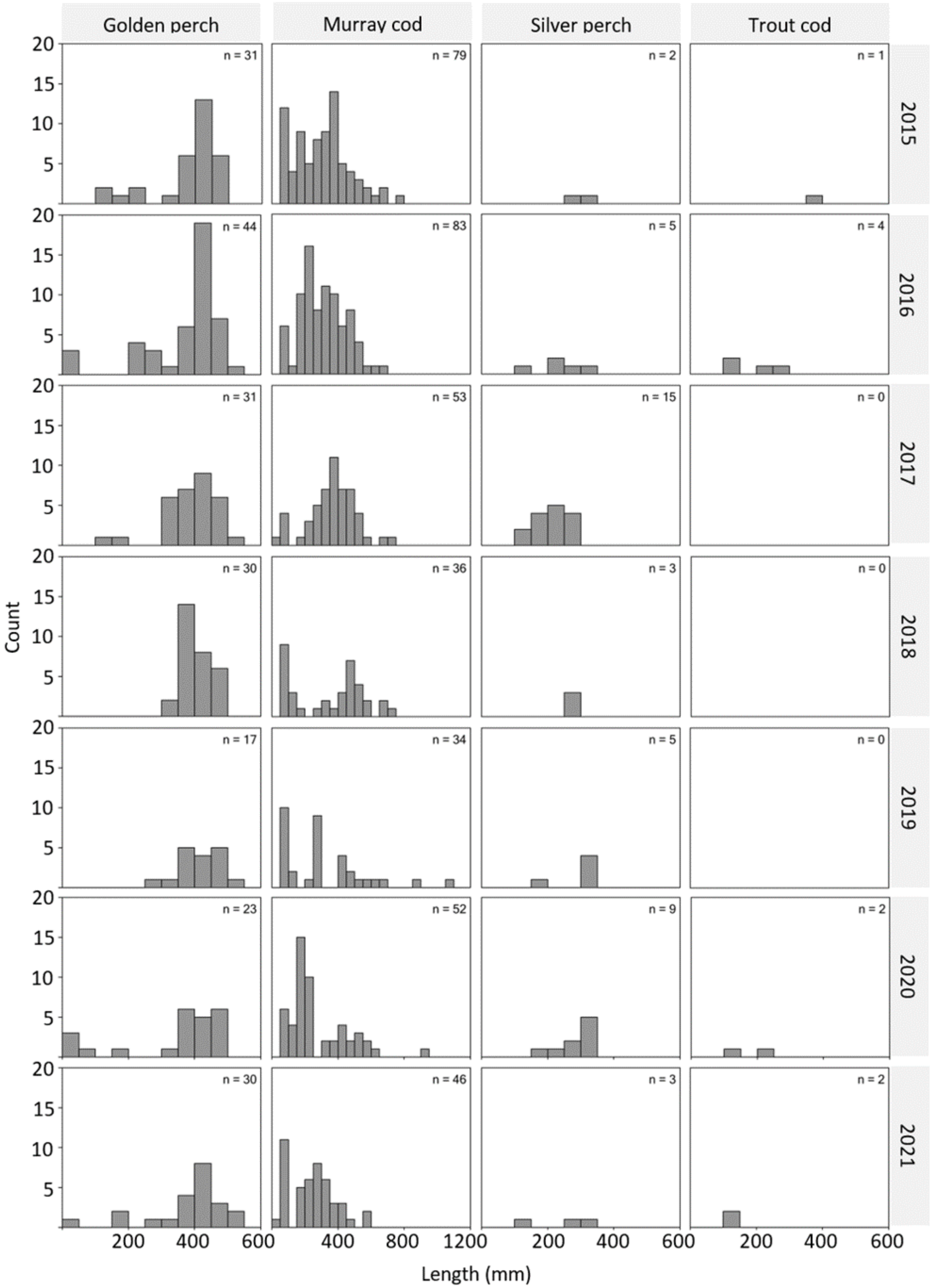


Figure 8-5 Length frequency of golden perch, Murray cod, silver perch and trout cod collected in the Goulburn River 2015-2020.

8.5.2. Surveys of eggs and larvae (drift nets)

Over 2800 individuals (eggs and larvae) representing seven native and one exotic species were collected from the four drift sampling sites in the Goulburn River in 2020 (Table 8-3). Murray cod was the most abundant species collected, comprising 58% of the total abundance for all species, similar to the results of previous surveys. Spawning by trout cod was detected in 2020 with a single larva collected in late November.

Spawning of golden perch was detected in mid-October (8 eggs) coinciding with an unregulated within-channel flow pulse (Figure 8-6). 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.

Using data collected during LTIM (2014-2018) and MER (2019-2020) monitoring as well as earlier sampling (2010-2014) (Koster unpublished data) our analyses show that the probability of spawning of golden perch was related to discharge, with greatly increased spawning probability at flows between about 3500–4000 ML/day when water temperature exceeded ~18.6°C. Using water velocity, as the descriptor of flow, result in a similar pattern, with the peak probability of spawning at velocity >0.2-0.3 m s^{-1} when temperature was >18.6°C (Figure 8-7; Figure 8-8). Increased flows prior to spawning were also associated with increased spawning probability, more so at the three sites in Reach 2.

Table 8-3 Numbers of eggs (E) and larvae (L) of fish species collected in drift net surveys from the Goulburn River 2014-2020. Species with asterisk are exotic species.

Species	2014	2015	2016	2017	2018	2019	2020	Total
Silver perch	47E		34E	37E	67E	7E	18E	210
Murray cod	942L	355L	892L	2007L	1939L	1046L	1659L	8840
Trout cod				15L	25L	13L	1L	54
Unidentified cod sp.					349L	159L	113L	621
Golden perch	1628E, 1L		47E	289E, 11L	18E		826E, 14L	2834
Common carp*		15L	19L	16L	5L		2L	57
Australian smelt	204E, 9L	81E, 7L	32E, 1L	177E, 16L	122E, 3L	119E, 18L	129E, 4L	922
Flathead gudgeon	8L	11L	18L	48L	85L	65L	64L	299
Carp gudgeon		11L	1L	37L	5L	2L	5L	61
Gudgeon sp.				4L	16L	27L	19L	66
Goldfish*				1L				1
Unidentified perch					1E		11E	12
Total	**2839**	**480**	**1044**	**2658**	**2635**	**1456**	**2865**	**13977**

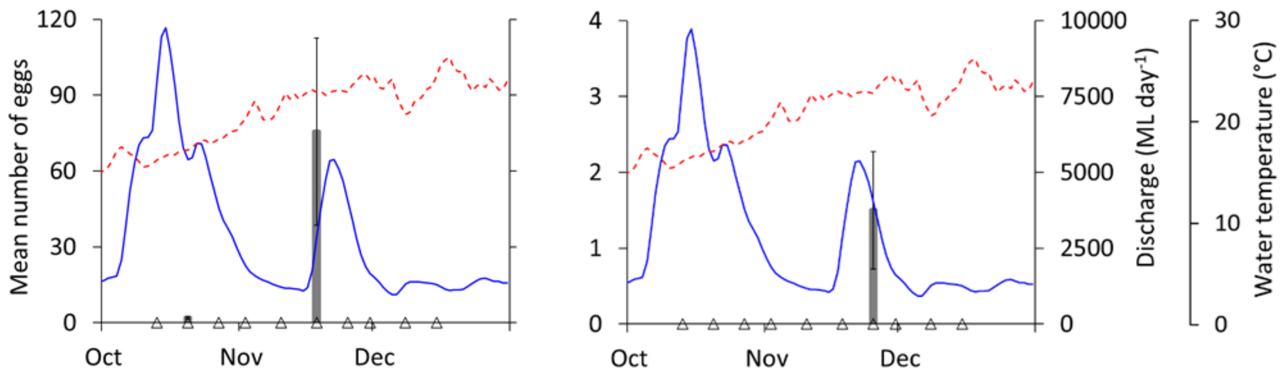


Figure 8-6 Mean (±se) number of golden perch (left panel) and silver perch (right panel) eggs/larvae per drift net collected in the Goulburn River in 2020. Mean daily discharge (blue line) and water temperature (broken red line) of the Goulburn River at McCoy Bridge. Triangles denote sampling trips.

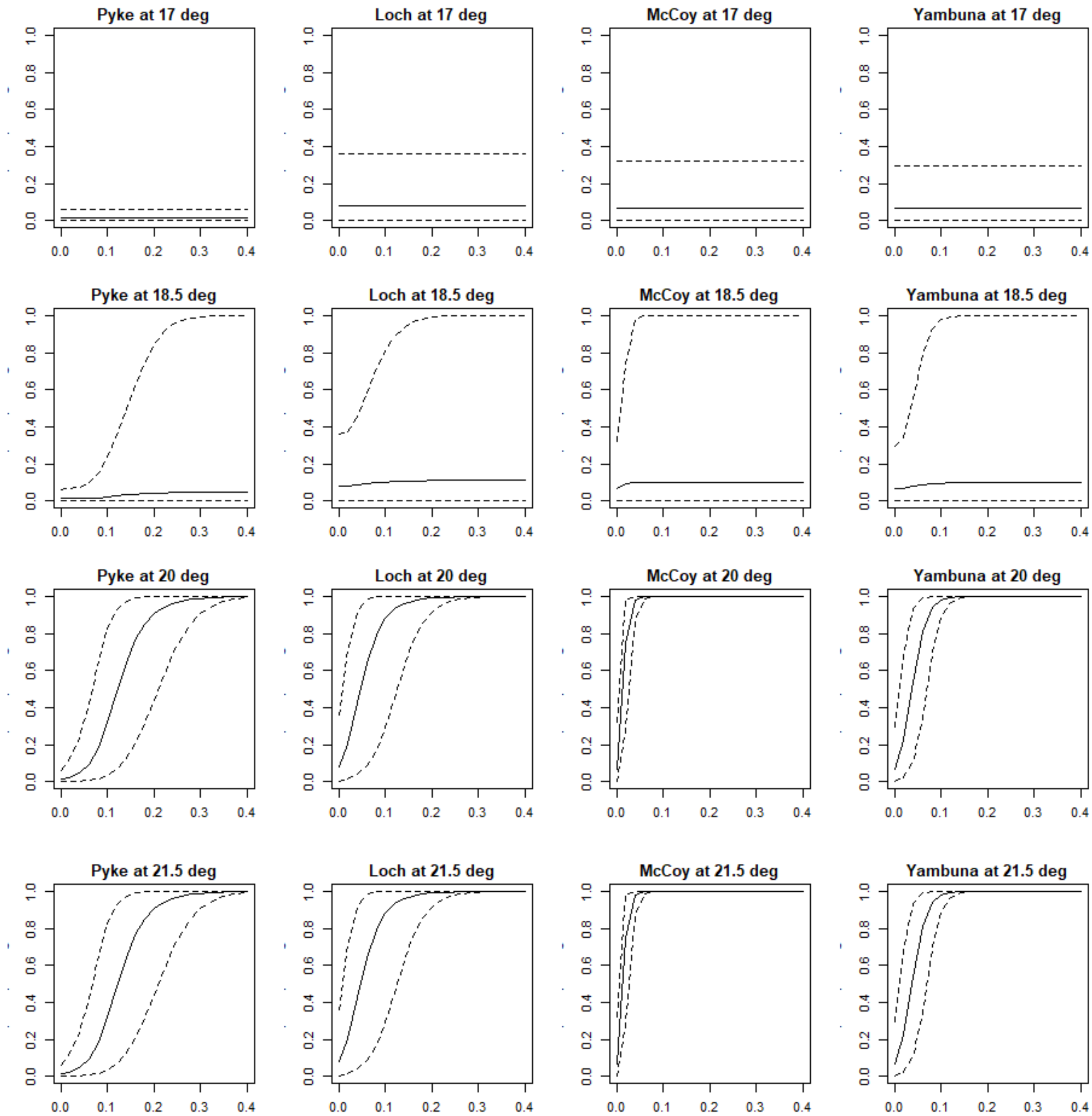


Figure 8-7 Relationship between the probability of spawning (y-axis, 0-1) and velocity (x-axis, m/s). Rows correspond to results modelled at different temperatures. Results are based on the occurrence model that uses velocity as the main predictor and includes the 5-week antecedent flow effect.

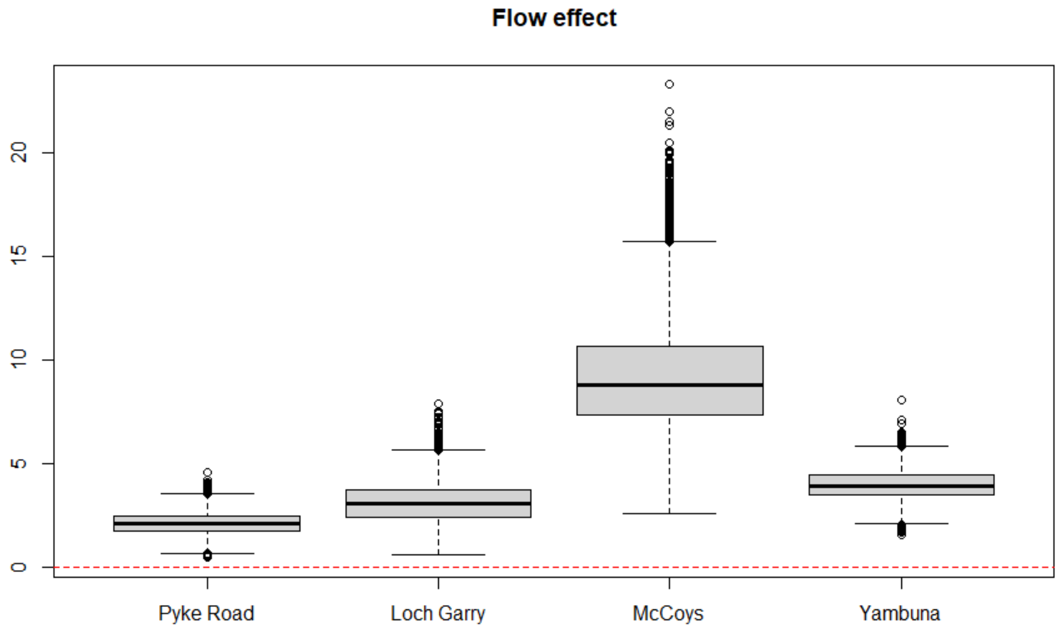


Figure 8-8 Flow effect in four sites, based on the model of occurrence of spawning with 5-week antecedent flow effect, using velocity as the main predictor. Plots above the 0 line indicate that spawning is more likely to occur in response to a high flow.

8.6. Discussion

8.6.1. Annual population surveys (electrofishing and netting)

The nationally threatened trout cod was collected in low numbers for the second consecutive year (2020 and 2021) in the annual surveys and has now been collected in four of the last seven years. Larvae of trout cod were also collected for the fourth consecutive year (2017-2020) in the drift surveys. Results from VEFMAP sampling conducted by ARI show trout cod are more common in the Goulburn River in upstream reaches near Murchison.

Abundance of Murray cod at our sampling sites in 2021 was similar to last year. Abundance in this reach remains lower than levels recorded prior to the 2017 blackwater event. Nevertheless, a considerable proportion of the population in the 2021 surveys was young-of-year fish. These individuals likely originated from recent natural spawning in the river, as otolith analysis indicates that the Murray cod population in the Goulburn River consists almost entirely of in situ recruitment.

A single young-of-year golden perch was collected in the annual surveys in 2021. It is probable that this individual was stocked. Otolith analysis indicates that the golden perch population in the Goulburn River consists mostly of stocked fish, although there is some *in situ* recruitment, and immigration into the Goulburn River by fish originating from locations such as the Murray River. Young-of-year golden perch are rarely collected in the annual population surveys, although this is likely because early life stages (eggs, larvae) drift downstream and into the Murray River. Measuring or reporting recruitment outcomes at a reach or river scale in this region may be unsuitable for species such as golden perch with early life stages that can drift or disperse long distances away from spawning locations.

Only low numbers of silver perch were collected in the 2021 surveys. This result possibly reflects numbers of silver perch migrating upstream in the mid-Murray River. Otolith analysis indicates that the silver perch population in the Goulburn River consists mostly of fish originating from the Murray River. Flows can be important in promoting immigration of silver perch into tributaries such as the Goulburn River (Koster et al. 2021), notwithstanding the outcome will be dependent on the abundance of fish in the Murray River.

There was a considerable increase in abundance of Murray River rainbowfish in 2021, following a decrease in abundance from 2017 to 2019. Abundances recorded in 2021 were the highest recorded in the last seven years. Abundances of another native small-bodied fish, Australian smelt, were also high relative to previous years. The causes of these fluctuations are unclear, but it is possible that a reduction in high flow conditions throughout summer 2021 relative to the previous few years (2018-2020) might have been more favourable to recruitment.

8.6.2. Spawning of golden perch and silver perch

In 2020, spawning of golden perch was detected in drift sampling in late October during a natural within-channel flow pulse, and in mid-November coinciding with a targeted within-channel environmental flow pulse. Much greater numbers of eggs were collected in late November. This result is possibly related to factors such as warmer water temperatures in November compared to October (King et al. 2016). High flows that occurred earlier in the spawning season in October might also have improved reproductive condition and subsequent spawning output in November. Our analysis shows that the probability of spawning of golden perch in the Goulburn River was related to discharge, with greatly increased spawning probability at flows between about 3500–4000 ML/day when water temperature exceeded ~18.6°C. Our analysis also shows that increased flows prior to spawning were associated with increased spawning probability. To achieve the management objective of spawning of golden perch in the Goulburn River (GBCMA 2021), elevated flows throughout spring, coupled with flow pulses around at least 3500–4000 ML/day particularly around November, are needed. Spawning of silver perch was also detected in drift sampling in late November coinciding with a targeted within-channel environmental flow pulse. Similar to golden perch, spawning of silver perch in the Goulburn River appears dependent on elevated flows in late spring-summer coupled with appropriate water temperature (>~20°C).

9. Contingency Monitoring – Turf Mats

The main contingency monitoring activity across 2019-21 has been the assessment of sediment and seed deposition under flows comparing CEW and natural high flow events. The assessment utilises turf mats, squares of artificial turf affixed on targeted sections of the riverbank, that are inundated by flows. The sediment and seeds are subsequently analysed within the laboratory and linked to characteristics of flow inundation. The outcomes of the turf mat monitoring are described in more detail below.

9.1. Introduction

Maintaining a healthy Goulburn River to support ecological and social values requires ensuring that the system is adequately resilient to changes in flows. Part of this resilience is related to the riverbank condition which can experience erosion and changes in vegetation. An important part of resilience is the recovery of the system, and for riverbanks this includes how a river might reduce excessive erosion through vegetation coverage. This requires seed deposition and regeneration of bank vegetation following flow events, plus riverbank repair through sediment drapes. Understanding these sediment and seed dynamics has been the focus of this study which commenced initially in 2018 to understand sediment and seed response to flows for the Long Term Intervention Monitoring (LTIM) Project.

The sediment and seed monitoring program requires a considerable timeframe for propagation, before data can be provided. This results in a lag to presentation of results. As a result, the seed data in this annual report focusses on findings from turf mat retrievals across the 2019 to early 2020 monitoring periods.

9.2. Main findings from monitoring program

The main findings from the turf mat monitoring are:

- In general, greater peak flow height and longer inundation duration results in the deposition of more sediment and greater seed abundance and species richness. These results support the role for greater magnitude and longer duration freshes to support the recovery of banks affected by IVT flows.
- Increased sediment mass (deposition) is linked to increased seed abundance. Seed diversity, however, is not always related. This depends on the location of the habitat feature. Relative to riverbanks, bars attracted more diversity in seeds in the majority of cases, and benches in some isolated cases.
- The deposition on bars and benches highlights the important role of shallow profile features on lower banks for vegetation recruitment.
- Tributary flow contributions (sediment and seeds) are difficult to discern from event size. The role that tributary flow percentage made could not be isolated from the influence of increased flow magnitude (i.e. when tributaries were flowing the event contributions from storages were also larger). This analysis will be more robust with the analysis of all retrievals (R5 – R9) at the end of the full study period. It also highlights the importance of providing a variety of sources flow (i.e. including tributary inflows without operational contributions).
- Over 60 plant species were identified in turf mat deposits. Increased seed taxonomic richness correlated well with inundation duration and mass of sediment deposited. Thus, longer duration freshes will promote sediment deposits with greater species diversity.
- While more species were typically deposited on bars, some species were preferentially deposited on higher bank features, such as Eucalyptus camaldulensis (River Red Gum), and at different times of year. This 'directed' dispersal results from different propagule characteristics and phenologies and highlights the importance of hydrogeomophological variability for maintaining diverse riverine vegetation communities.

Previous turf mat monitoring showed:

- Environmental flows (the winter and spring freshes) provided around half of the sediment and seeds deposited on inundated features at sites in the lower Goulburn River. The environmental flows were the primary contributor of sediment and seeds to riverbanks, providing three-quarters of sediment and seed deposition on banks.
- Deposition has been identified as more prevalent during the colder months. The 2018-19 findings reinforced this, highlighting deposition of sediments on higher bank levels being common due to high flows during winter and spring freshes. This may be linked to the role of tributary flows, though this hypothesis needs to be verified.

Implications for new findings/investigation:

- There is a direct link between flow magnitude (in addition to duration) between seed abundance and richness.
- Longer inundation generally increases the diversity of propagules (both floating and non-floating), particularly for the important lower bank.
- The role that dry periods play, in both propagation and sediment consolidation, at this stage is unclear.
- The data suggest that increased tributary flow proportion is leading to increased seed abundance and richness, but additional datasets are needed to confirm this hypothesis.
- Bars in general are attracting a higher diversity of seeds (more richness), correlated with common species with buoyant seeds (e.g. *Cyperus* and *Juncus* spp.), suggesting that channel complexity (in an otherwise homogenous channel) is important.
- Some anomalies exist and highlight external factors. For example, the Loch Garry bench habitat feature appears to be influenced by other factors (isolated tributary flows or overhanging trees perhaps) as seed abundance and richness increased with diminishing flow duration and magnitude.
- There was a significant reduction in river red gum seeds present in response to the 2020 spring fresh versus prior freshes. This will be monitored over the coming events.

Table 9-1 Summary of physical habitat findings relevant to evaluation questions.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did CEW contribute to riverbank sediment and seeds?	Varied. All freshes provided sediment and seeds, with bank and bench vegetation being best served by winter and spring freshes with high peak flow volumes. The lower magnitude flow during the 2020 spring fresh reduced the abundance and richness of sediment and seeds; this flow could have been larger ideally for this purpose.	For all environmental flows (the winter and spring freshes) there was a strong correlation between inundation duration and magnitude of seed abundance and taxonomic richness at all sites (the exception being Loch Garry where the *bench* habitat feature had varying results). Inundation duration/magnitude also directly correlated to sediment mass volume across all habitat types and sites monitored. Conversely, maximum dry period, showed inconsistencies for seed data but generally a negative effect on sediment mass. Seed taxonomic diversity was relatively similar across the winter and spring freshes of 2019 with 42, and 47 different species recorded respectively. This reduced in response to the 2020 Spring fresh, this event however was lower in magnitude (6,000 ML/d vs. 8,000 ML/d) and had a lower tributary flow contribution. No comparison of these results relative to IVT flow events was possible due to travel restrictions in place due to COVID-19.	Artificial turf mats and analysis of deposited sediment and seeds under laboratory conditions

9.3. Methods

Field and laboratory protocol

From 2018 onwards, turf mats have been used to quantify sediment transport and propagule assemblages dispersed by flow events in the lower Goulburn River. Small synthetic turf mats (36 x 24cm) are fixed to the banks in groups of four (six during the 2018 monitoring) replicates per feature (Figure 9-1). Features were selected to capture a variety of geomorphic forms, including bars, banks, benches, and ledges. Mats were periodically retrieved during periods of low flow with seeds transported directly to the University of Melbourne, Burnley Campus nursery for germination and identification, and sediments assessed in the laboratory for dry mass and sediment size.

Figure 9-1 a) Sediment mats on low-level bars prior to inundation, b) mat collection following inundation, c) seedling growth in the nursery following collection, and d) sediment analysis.

Modelling Overview

The turf mat monitoring and modelling aims to test the following hypothesis:

The transport of seeds/sediments in waterway is affected by streamflow, which differs by habitat type (bank, bar, bench or ledge) and time of the year. The time of year also affects the percentage of tributary contribution to flow at the sampling point. This corresponds to a hierarchical model described as:

$$y_t \sim Normal(mu_{ijs}, \sigma) \quad \text{Equation 9-1}$$

$$mu_{ijs} = int + eff.Q_{is} \times Q_{ij} \quad \text{Equation 9-2}$$

$$eff.Q_{is} \sim Normal(\mu\_effQ_{is},\ \sigma\_effQ) \quad \text{Equation 9-3}$$

$$\mu\_effQ_{is} = int_{effQ} + eff.trib * trib_i + eff.habitat_s \quad \text{Equation 9-4}$$

Where *i, j* and *s* represent survey event (retrieval), site and habitat type, respectively.

For the seed analysis, y_t represents the individual samples of seeds abundance captured by turf mats.

The mean seed abundance (log-transformed) for a particular combination of survey, site and habitat type, mu_{ijs}, is affected by flow condition (*Q*) represented by one of a) **peak inundation height** over sampling point, b) **number of days inundated**, and c) **maximum dry period**, during the sampling period (i.e. between deployment and retrieval of each sample). Flow effects ($eff.Q_{is}$) are modelled with the percentage tributary contribution corresponding to the particular survey event (*trib*), with *eff.trib* representing the tributary contribution effects. *eff.habitat* is a random effect to represent the influence of habitat type on the flow effects.

During the seed abundance sampling, some samples were taken at high elevations at McCoy's Bridge, which were never inundated during the sampling period. The habitat type of these samples was thus denoted as 'air samples'. Preliminary analysis indicated that very few seeds were deposited on these mats, highlighting the importance of hydrochory (flow dispersal) for seeds deposited on other lower elevation mats. These air samples were not included for further analyses which focused on flow effects.

The sediment analysis was conducted focusing on impacts of the above mentioned three flow indicators on the total mass of sediments deposited (y_t in Equation 9-1).

9.4. Sites and sample dates

Turf mats have been deployed at three sites: Darcy's Track, Loch Garry and McCoy's Bridge (Figure 2-1). Five visits, capturing three events, were undertaken in 2019-20 (Figure 9-2) and 2020-21 (Figure 9-3).

Following on from four retrievals in 2018-19, turf mats were re-deployed in mid-winter on the 27/6/2019. These mats were retrieved in early spring on the 12/9/2019 (retrieval event 5), after a period of 77 days, predominantly a winter fresh and small rise, and another set of mats deployed (Figure 9-2).

Mats were again retrieved and replaced later in spring on the 30/10/2019 after a period of 48 days, predominantly a spring fresh (retrieval event 6). Between deployment and retrievals, similar flow peaks of ~8,000 ML/day occurred, labelled here as winter fresh and spring fresh, respectively (Figure 9-2).

An intended retrieval and redeployment in March 2020 was cancelled due to COVID-19 restrictions placed on fieldwork activities by The University of Melbourne. Due to these restrictions, the mats were not redeployed until November 2020, and thereafter retrieved/deployed in December 2020 (retrieval event 7) (Figure 9-3).

Subsequent field work retrievals in April 2021 (retrieval event 8) and May 2021 (retrieval event 9), are still in the propagation phase and thus are not analysed in this report. Likewise, processing of the soil samples collected from the mats for the winter and spring freshes of 2019 and subsequent events has been delayed due to restrictions on access to labs at the University of Melbourne. Thus, only data relating to retrieval 5 (Winter fresh, 2019, R5), retrieval 6 (Spring fresh, 2019, R6) and retrieval 7 (Spring fresh 2020, R7) are reported here. This includes propagule abundance, taxa richness and sediment mass for each flow event.

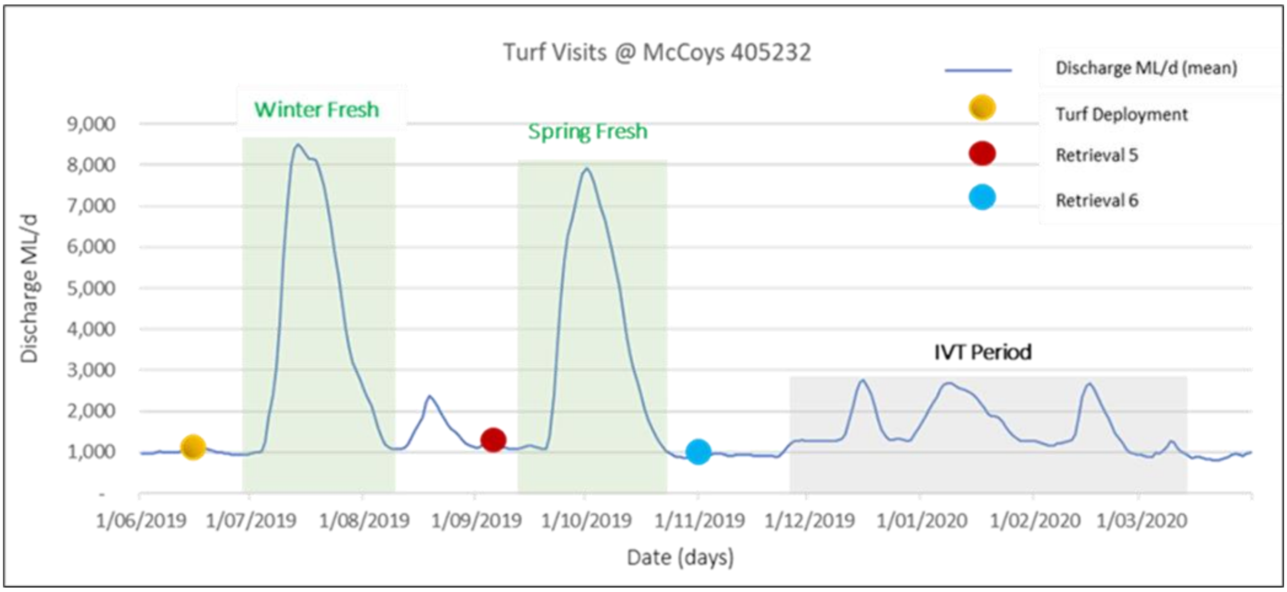


Figure 9-2 Hydrograph of flows in the Goulburn River at McCoy's Bridge with dates of mat deployment (yellow circle) and retrieval/deployment (red circles) indicated. Date range 2019-20.

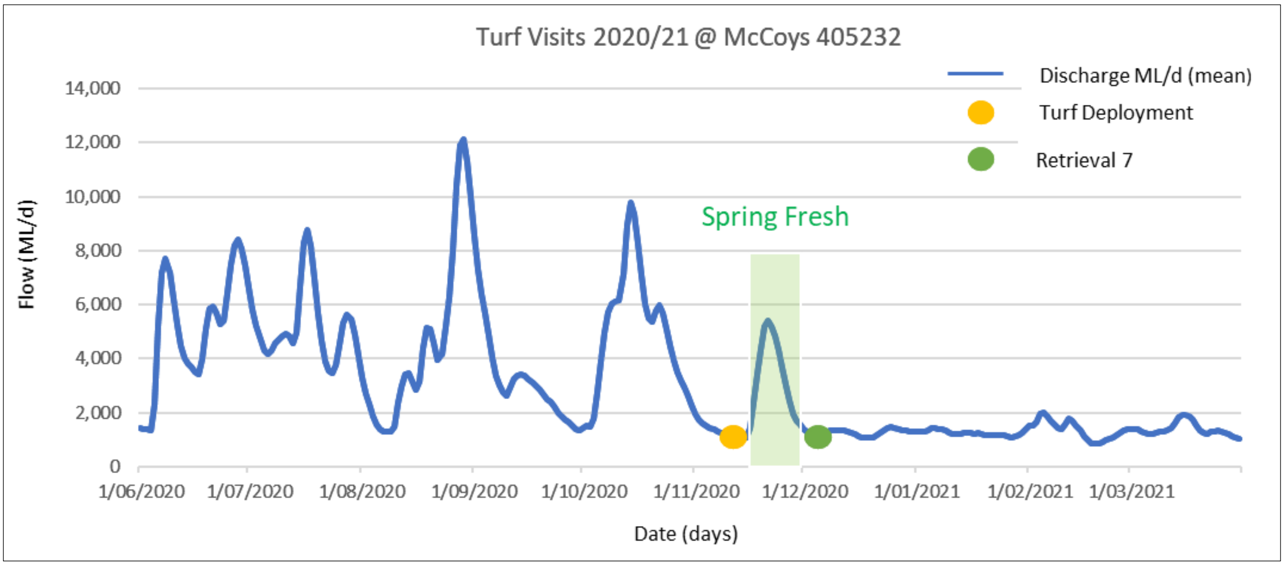


Figure 9-3 Hydrograph of flows in the Goulburn River at McCoy's Bridge with dates of mat deployment (yellow circle) and retrieval/deployment (green circle) indicated. Date range 2020-21.

Lower bank features were notably devoid of vegetation at the time of the winter fresh retrieval (Figure 9-4). During the retrieval following the spring fresh, several mats were missing, clearly due to theft (the tent pegs had been removed), as a result no samples were able to be collected for Bench and Bank features at Darcy's Track for that retrieval.

Figure 9-4 Mats redeployed on the bench (left) and bank (right) at Darcy's Track after the winter fresh that were not present for retrieval after the spring fresh. Note these features were largely devoid of vegetation at the time of mat collection.

9.5. Results and discussion

9.5.1. Seed and sediment mass

The following provides a summary of results related to seed and sediment outcomes:

Seed Abundance

- An increase in peak inundation height generally leads to increasing seed abundance at all habitat types including bar, bench, bank and ledge in Darcy's Track and Loch Garry. Similar changing patterns can also be observed at bench and ledge habitat at McCoy's Bridge. However, for bar and bank habitat at McCoy's Bridge, peak height over sampling point has little effect on the total seed abundance (Figure 9-5).

- The influence of number of days inundated on total seed abundance is similar to that of peak inundation height, with an increasing trend of seed abundance observed across all habitat types at all sites. At McCoy's Bridge, there is no obvious relationship with the number of inundation days and seed abundance on bars, and only a slight positive relationship for banks (Figure 9-6).

Sediments

- Increases in both peak height and number of days inundated show consistent increasing effects on sediment mass across all habitat types in all three sites (Figure 9-7 & Figure 9-8). By contrast, maximum dry period has a consistent decreasing effect on sediment mass in all sites, except that sediment mass increases as maximum dry period increases on bars at Darcy's Track and Loch Garry for Retrieval 5.

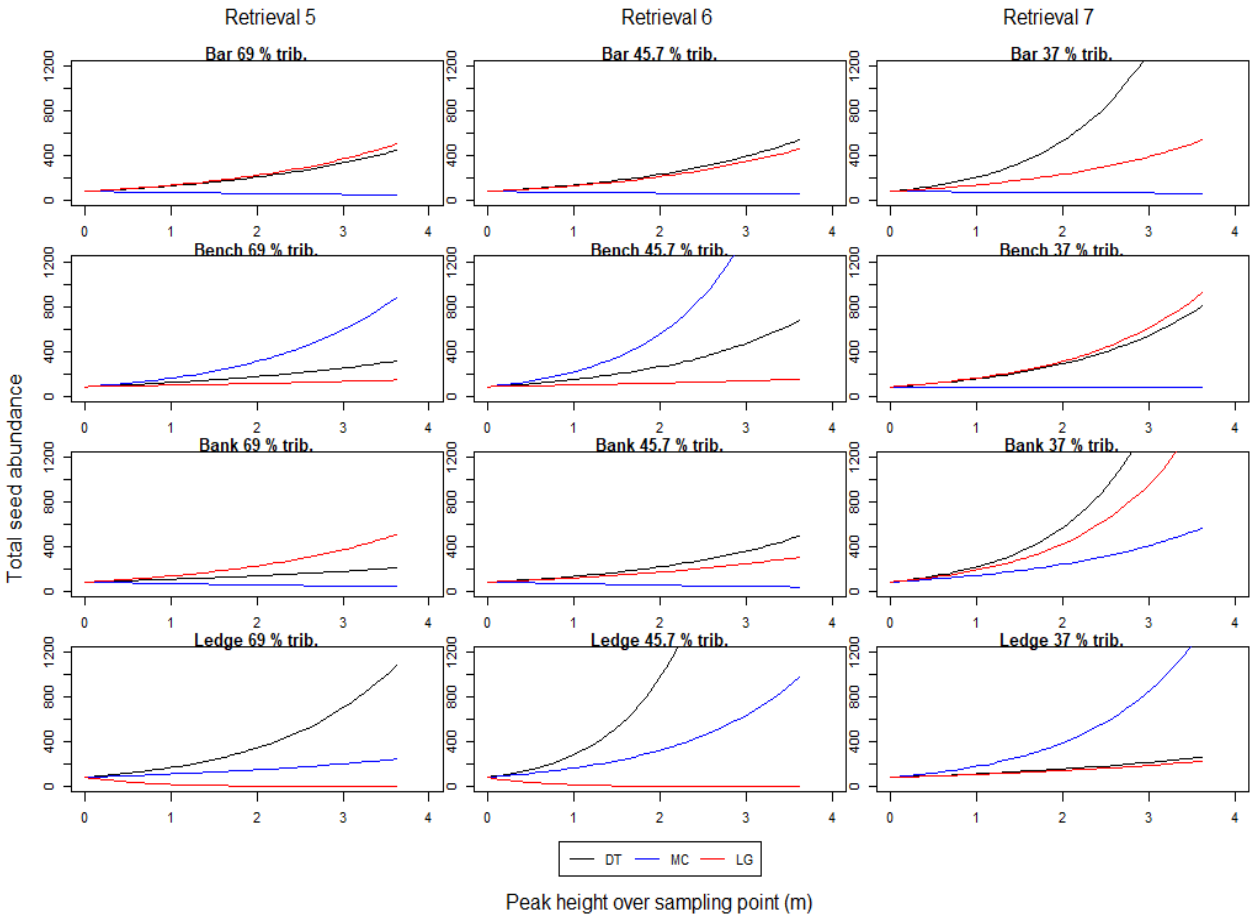


Figure 9-5 Simulated median total seed abundance against peak height over sampling point, by feature (bank, bar, bench and ledge, in rows) and different retrieval events (with different levels of tributary contribution as labelled, in columns).

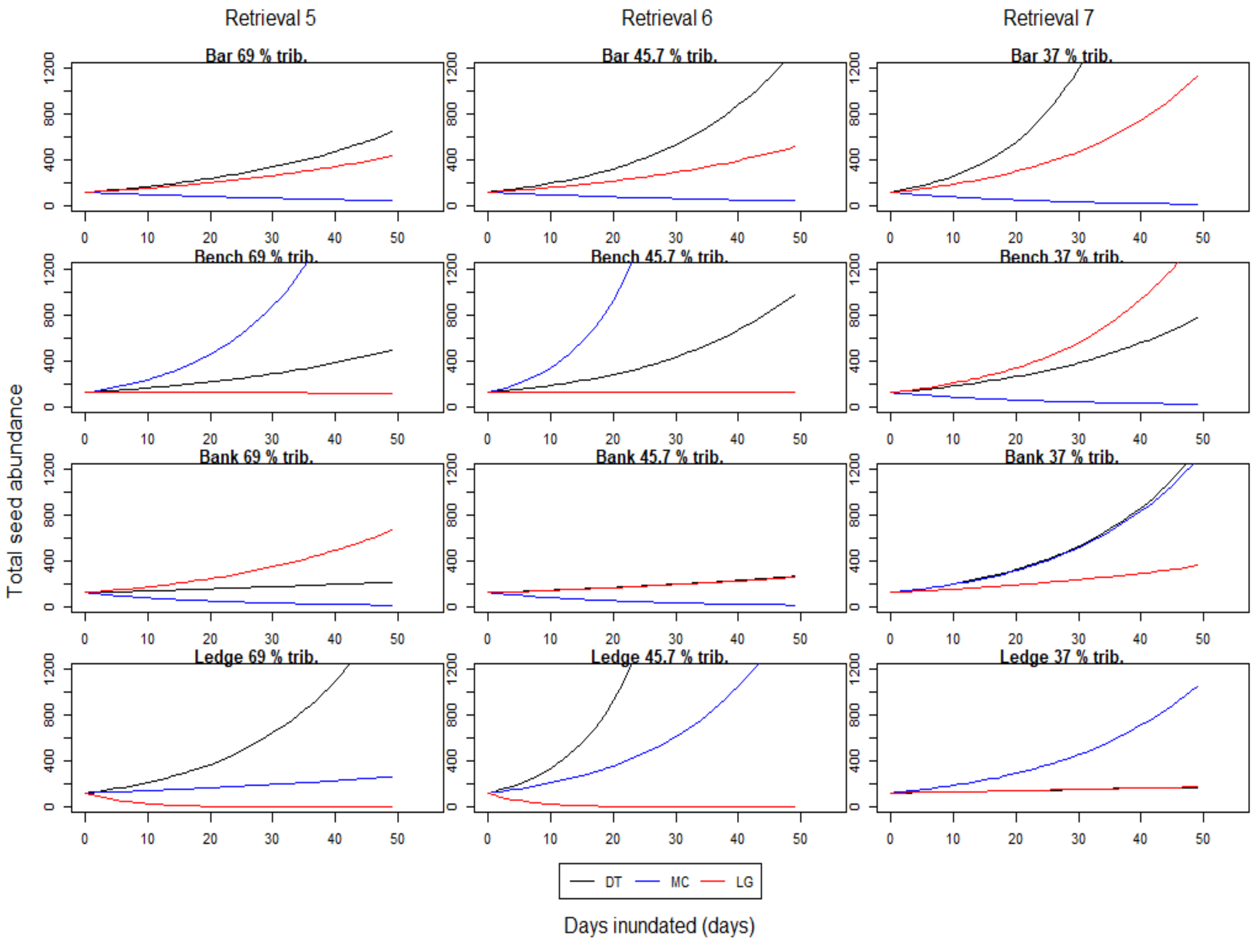


Figure 9-6 Simulated median total seed abundance against number of days inundated, by bank condition (bank, bar, bench and ledge, in rows) and different retrieval events (with different levels of tributary contribution as labelled, in columns).

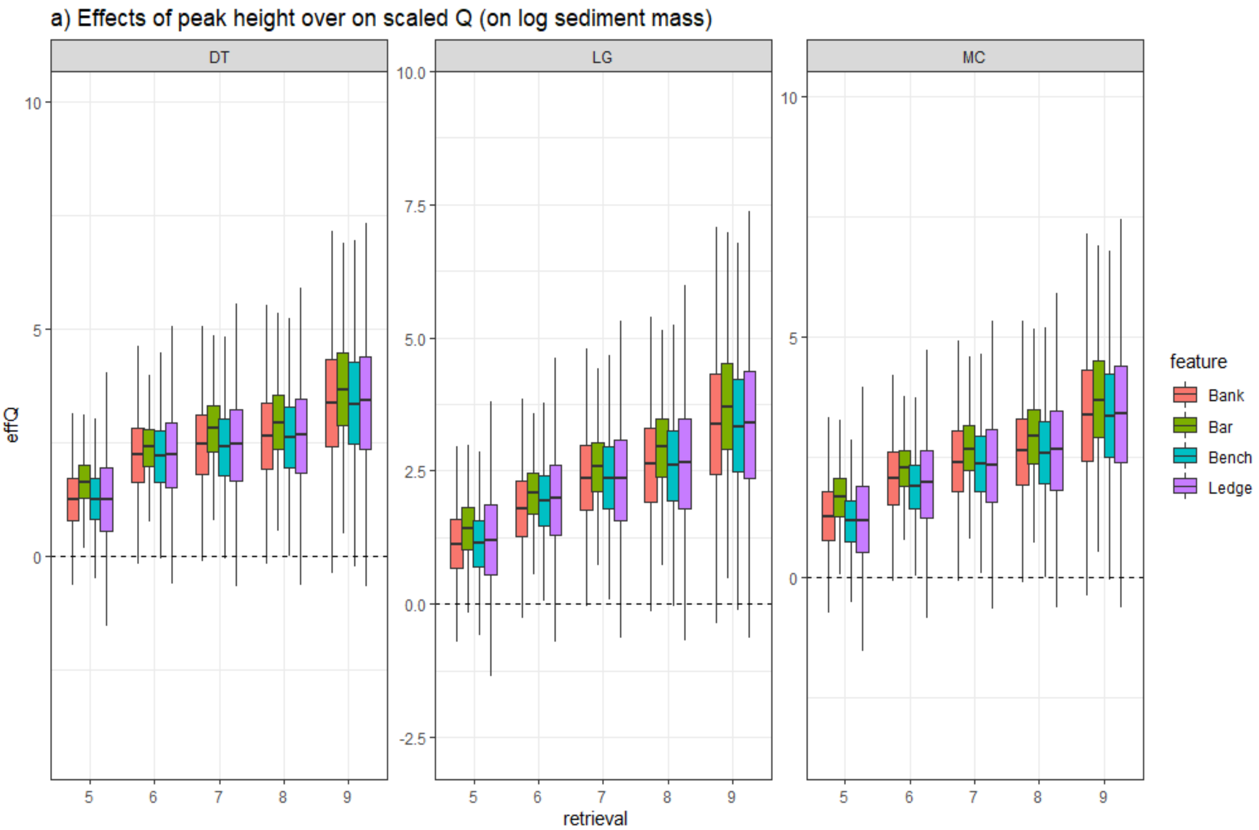


Figure 9-7 Effect of flows on sediment mass in different sites, with peak inundation height as indicator.

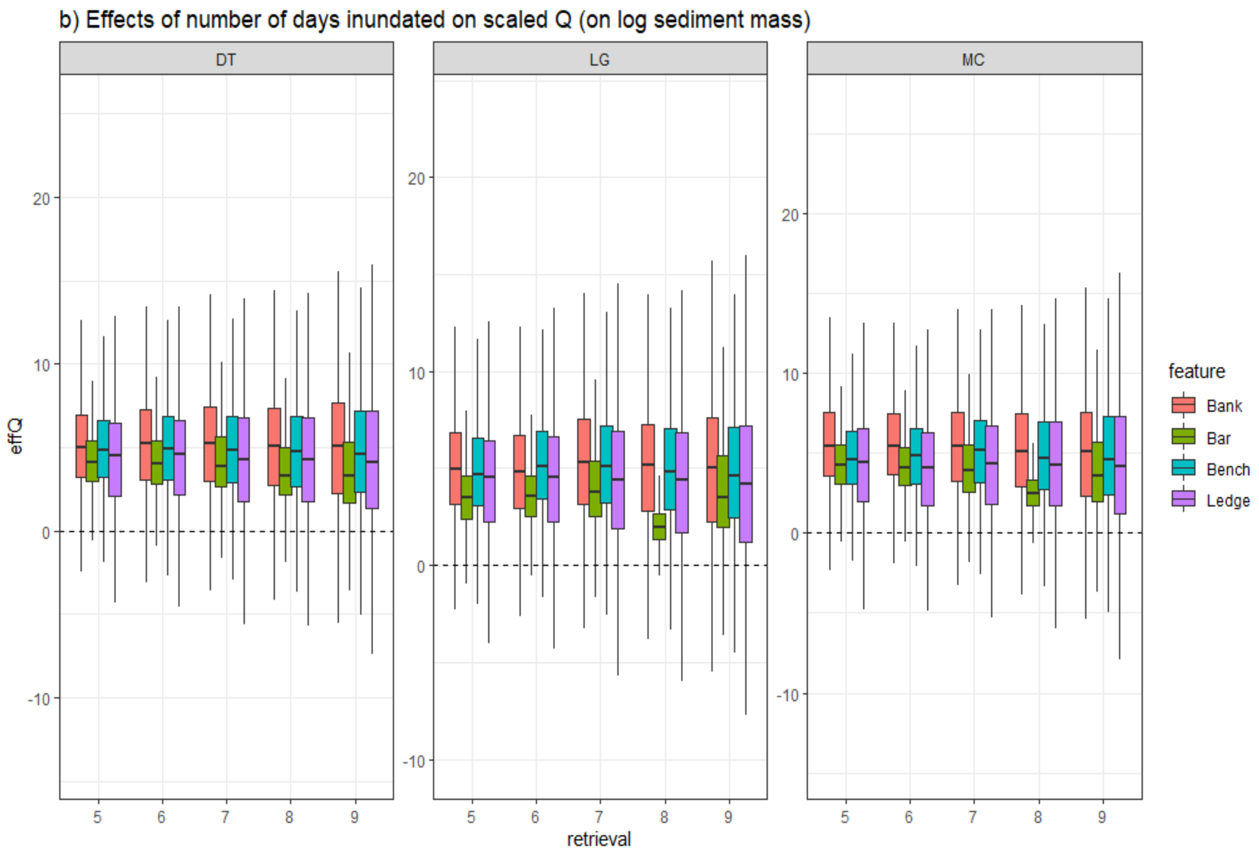


Figure 9-8 Effect of flows on sediment mass in different sites, with number of days inundated as indicator.

9.5.2. Propagule sample composition

A total of 8,266 (2,733/m^2), 10,811 (3,910/m^2) and 4,798 (1,791/m^2) seedlings were counted from the mat samples for retrievals 5, 6 and 7, respectively. More than 80% of all seedlings were accounted for by five monocot species (asterisk indicate exotic species): *Cyperus eragrostis**, *Cyperus exaltatus*, *Eragrostis parviflora**, *Juncus amabilis* and *Juncus usitatus*. River Red Gum (*Eucalyptus camaldulensis*) seedlings were also relatively common in both the winter and spring fresh samples of 2019 (R5 and R6), but not the early spring fresh of 2020 (R7).

While greater abundances of propagules were generally observed for Bar samples at Darcy's Track and McCoy's Bridge, largest abundances of propagules were observed for Bench samples at Loch Garry (Figure 9-9).

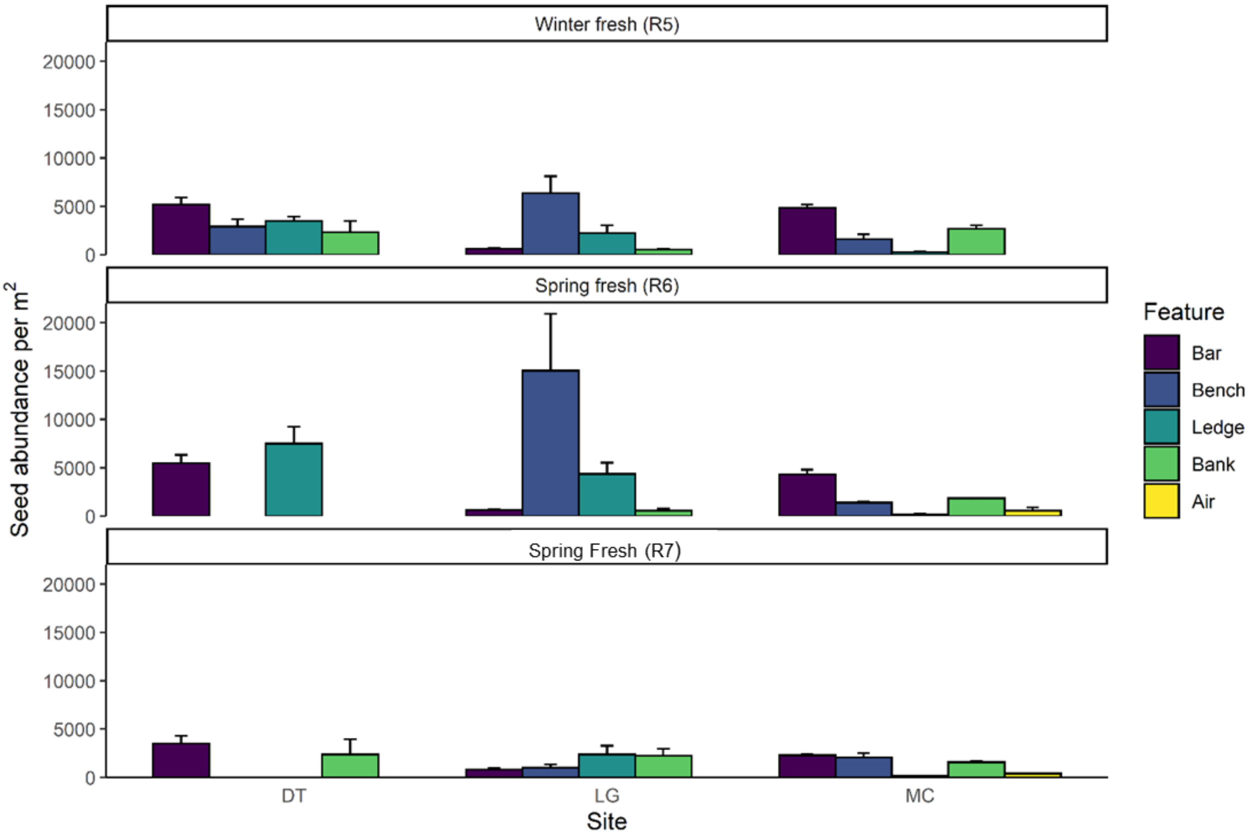


Figure 9-9 Seed abundance of material deposited on turf mats across different geomorphic features (Bar, Bench, Ledge, Bank, Air) at three sites, DT—Darcy's Track, LG—Loch Garry and MC—McCoy's Bridge for retrievals following a winter and spring fresh in 2019 (R5 and R6) and a spring fresh in 2020 (R7). Mats were stolen and thus no samples were collected for some features at Darcy's Track following R6 and R7.

A total of 42, 46 and 51 different plant taxa germinated from the mat samples for retrievals 5, 6 and 7, respectively (species list provided in Appendix J). Bar samples tended to have the greatest taxa richness, except at Loch Garry where similar taxa richness was observed across all features (Figure 9-10). Indicator species analyses (not presented here) showed that while most species were found most commonly in Bar samples, *Juncus amabilis* and *Persicaria hydropiper* were associated with Bench samples, and *Eucalyptus camaldulensis* seeds with Bank samples.

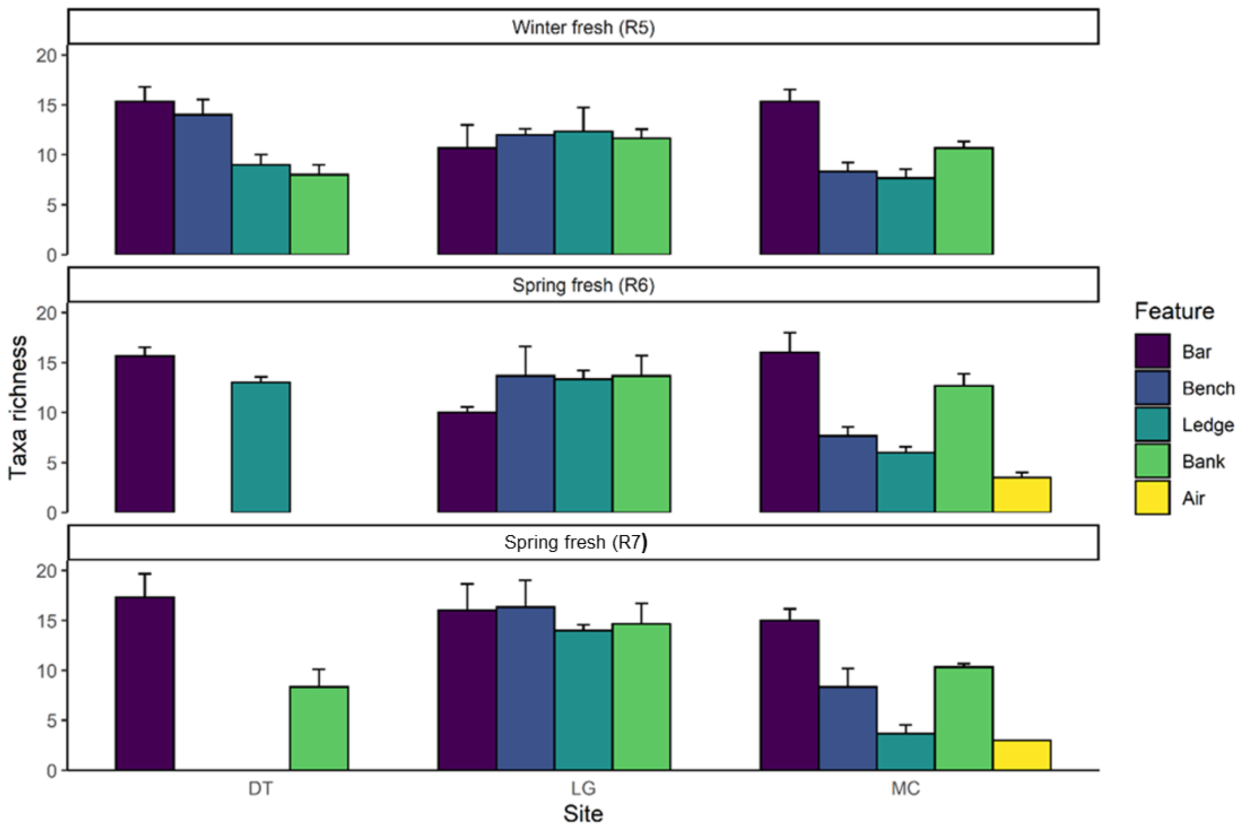


Figure 9-10 Taxa richness of material deposited on turf mats across different geomorphic features (Bar, Bench, Ledge, Bank, Air) at three sites, Darcy's Track, Loch Garry and McCoy's Bridge for retrievals following a winter and spring fresh in 2019 (R5 and R6, respectively) and a spring fresh in 2020 (R7). Mats were stolen and thus no samples were collected for some features at Darcy's Track for R6 and R7.

As indicated by the overall models, there was a positive relationship between inundation duration and abundance of seeds deposited (Figure 9-11). However, this relationship was not a strong one (R^2 = 3%), with some features inundated for long periods (e.g. bars) receiving similar abundances of propagules to those inundated for shorter periods (e.g. banks). Conversely, some features that were inundated for relatively short periods received high abundances of seeds (e.g. Benches at Loch Garry).

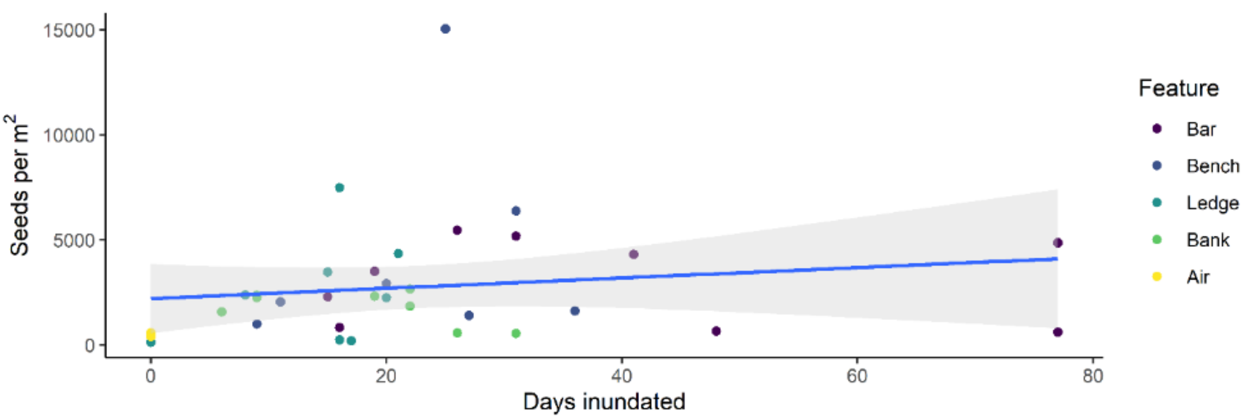


Figure 9-11 Relationship between inundation duration and abundance of seeds deposited on mats across different geomorphic features (Bar, Bench, Ledge, Bank, Air) pooling across all three sites and events.

In contrast, the taxonomic richness of deposited seeds showed a better correlation with inundation duration (Figure 9-12). These divergent relationships are in part a result of the tendency of some of the commonly observed species (e.g. *Cyperus* and *Juncus* spp.) to produce large abundances of light buoyant seeds that are deposited along 'strandlines'. Thus, longer inundation generally increases the diversity of propagules (both floating and non-floating) arriving at a site, but not the abundance of propagules, because large numbers of floating seeds are deposited along 'strandlines' where inundation periods are relatively short.

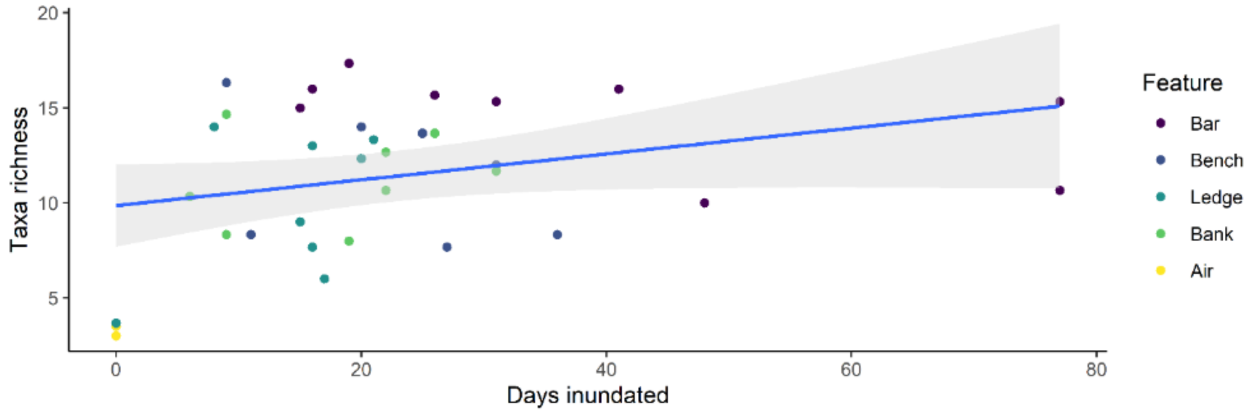


Figure 9-12 Relationship between inundation duration and taxa richness of seeds deposited on mats across different geomorphic features (Bar, Bench, Ledge, Bank, Air) pooling across all three sites and events.

Comparing the daily rates of sediment and seed deposition and numbers of taxa recorded across all sites for the three events reported on here, the spring fresh event in 2020 is notable for the large volumes of sediment and abundances of seeds deposited across all features (Figure 9-13). Indicator species analyses indicate that large numbers of *Juncus usitatus* seeds were associated with this event. Conversely, plant taxonomic richness of deposited material has remained fairly consistent across events.

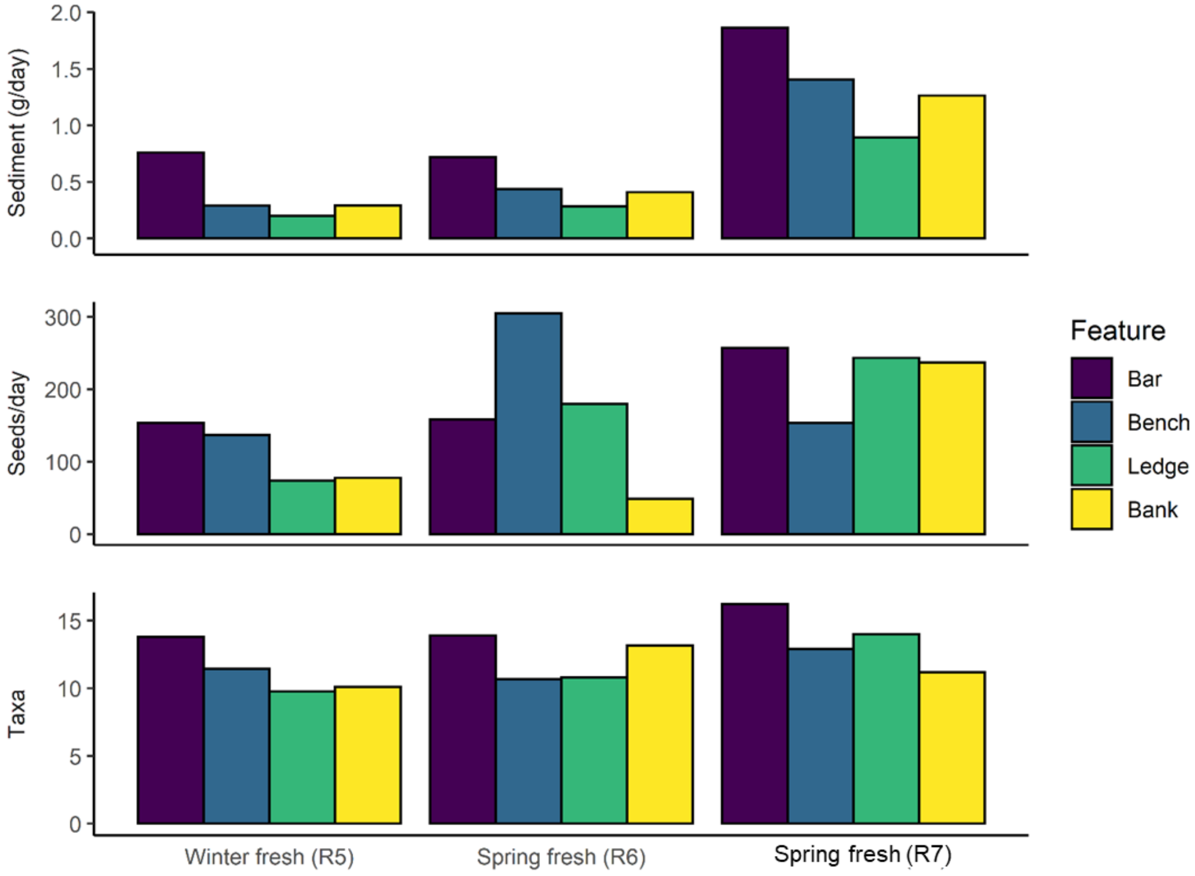


Figure 9-13 Sediment (g/day), seed abundance (seeds/day) and taxa richness of material deposited on turf mats across different geomorphic features (Bar, Bench, Ledge, Bank) across all three sites, for the three events reported on here (R5–7). N.B. R8 and R9 propagules samples have yet to be fully processed.

Across all events, in general, the more sediment that is deposited the more seeds and taxa present within the samples (Figure 9-14). This relationship is clearer for taxa (R^2 = 27%; Figure 9-14) than for seeds (R^2 = 10%; Figure 9-14), again, probably because of the predominance of a few species in the seeds deposited, particularly for events/samples with high seed abundances.

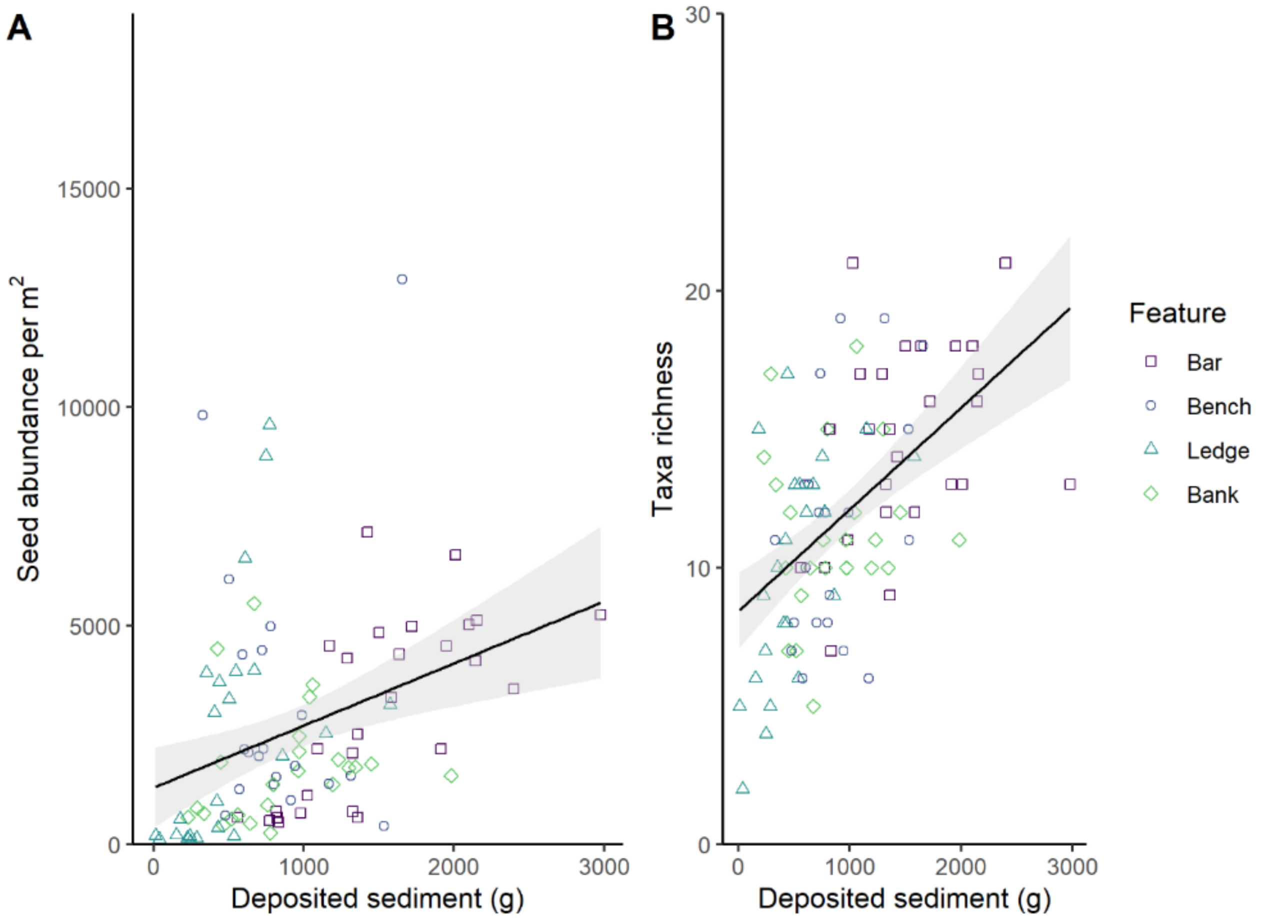


Figure 9-14 Relationship between sediment deposition and, A) seed abundance, or B) taxa richness of material deposited on turf mats across different geomorphic features (Bar, Bench, Ledge, Bank) across all three sites, for the three events reported on here (R5–7).

10. Contingency Monitoring – Pelagic Metabolism

10.1. Introduction

As described above (Section 5), stream metabolism is the production of organic carbon by photosynthesis and the consumption of that carbon through respiration (see Section 5 for more detail). Within any body of water, metabolic processes can take place in two main locations. *Pelagic* metabolism occurs within the water column. Photosynthesis occurs through water-borne phytoplankton; respiration 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 within biofilms, in macroalgae and in plants (macrophytes) on the stream bed. Hard surfaces like large woody debris and rocky substrates are ideal for the formation of biofilms. Respiration will occur within these same organisms and also in benthic bacteria and animals.

The core monitoring program is measuring whole-stream metabolism across these two compartments in the Goulburn River (Section 5), but it is useful to understand the relative contributions of benthic and pelagic environments, particularly with regards to organic carbon produced through photosynthesis. 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 bed 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 local 'scraper' and 'grazer' 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.

Therefore, investigating the relative contributions of benthic and pelagic metabolism provides finer-grade information regarding the metabolic processes of the Goulburn River and importantly a better sense of whether the system might be food-limited. This is an important consideration when assessing the beneficial effects of environmental flows. In this contingency monitoring project, we set out to disentangle the two compartments of stream metabolism – primarily focusing on primary production – in the lower Goulburn River. We used the light-dark bottle method (Grace & Imberger 2006) to measure pelagic production and respiration and then computed benthic metabolism by subtracting this amount from the whole stream metabolism being measured by the core program. This project was undertaken as a final year research project by Master of Engineering students at the university of Melbourne. The final report is included as Appendix K. This chapter will provide a brief overview of methods and results, with some being repeated from the report document. Full details are reported in Appendix K.

10.2. Main findings from monitoring program

The main findings from the pelagic metabolism monitoring are:

- Most primary production in the lower Goulburn River is occurring on benthic surfaces. Across seven field visits, the proportion of whole-stream metabolism taking place in the benthic compartment varied between 75 and 99%.
- Therefore, most of the organic carbon by photosynthesis in the lower Goulburn River produced is available to consumers in the immediate local area.
- There is a strong relationship between pelagic primary production and light availability. The turbid waters of the lower Goulburn River mean that benthic primary production is depth limited.
- We did not detect a strong influence of temperature on the rate of pelagic metabolism, but this may reflect the restricted time period (5 months) and resulting narrow range of water temperatures over which data were collected.
- We did not detect any strong relationship between rates of production and nutrient availability. This result likely reflects the low nutrient status of the Goulburn River, typical of lowland Australian rivers.
- We did not detect any strong relationship between rates of production and pelagic chlorophyll levels. This is surprising, given that chlorophyll is an indicator of the amount of pelagic phytoplankton. This result is likely explained by the strong relationship between production and light availability – the mere presence of phytoplankton does not necessarily imply that it is photosynthesizing if there is light limitation.

Implications of these findings for flow management of the lower Goulburn River

- With most primary production occurring in the warmer months of the year (determined from the whole-stream metabolism monitoring), and with the strong dependence of benthic primary production on light availability, the best way to boost benthic primary production is to maintain low flows during the warmer months. Any periods of high flow should be short.
- Given the primacy of benthic primary production, whole stream primary production may be enhanced by increasing the availability of hard surfaces suitable for biomfilm formation in the lower Goulburn River. This includes the type of habitat augmentation being undertaken in the integrated research project (Section 12).

10.3. Methods

We used the 'light and dark bottle method' (Grace & Imberger 2006) to determine pelagic primary production and respiration. Water samples are collected in transparent (light) and opaque (dark) bottles. The bottles are then suspended at different depths in the water column (Figure 10-1) to assess the effect of light penetration on photosynthesis through measuring the concentration of dissolved oxygen (DO). The water column DO is measured before deployment and the bottle DO is measured after deployment to identify the change in DO at various depths. From the DO change in the dark bottles, we can identify the respiration rate, while the light bottles experience both respiration and photosynthesis.

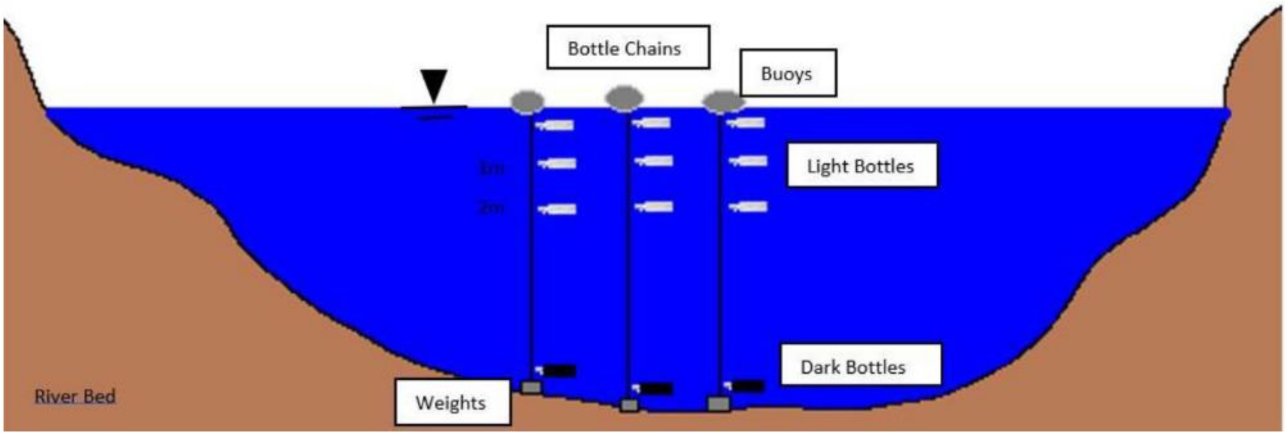


Figure 10-1 Schematic diagram of the light-dark bottle setup in the river.

The light (clear) and dark (opaque) bottles were filled using surface water from the middle of the river. Three identical bottle chains were formed with the light bottles suspended at the surface and depths of 1 m and 2 m, and one dark bottle (the bottle was wrapped with gaffer tape) attached to the chain near the stream bed (Figure 10-1). A buoy was attached to the bottle chains to keep it afloat, and a 2-kg weight was suspended at the bottom to prevent the chains from moving. Three light and temperature loggers (HOBO MX2202 Temp/Light) were attached to one bottle chain at the same depths as the light bottles. The bottle chains were left in the water column for a minimum of an hour and thirty minutes.

From the same section of the river, a YSI multiprobe ProDSS was used to determine the temperature, turbidity, conductivity, pH, and dissolved oxygen levels of the river water.

A sample of water was taken for chlorophyll analysis after rinsing a bucket with the same water. A syringe was used to filter approximately 800 ml (with the exact amount being recorded) of the water sample through a 0.7-micron filter paper. The filter paper with the residue was wrapped in aluminium foil and stored in a cooler to be sent for laboratory analysis of Chlorophyll-a levels.

The bottle chains were retrieved from the river after an hour and thirty minutes and the exact time of removal was recorded for each bottle chain. The dissolved oxygen level in each bottle was measured using the DO YSI Probe and 80 ml of water sampled from five bottles randomly chosen in the bottle chain was filtered through a 0.2-micron filter separately into five 65 ml clear plastic bottles. The bottles were stored in a cooler with ice, to be taken back to the lab for nutrient concentration analysis. Chemical and chlorophyll analyses were undertaken at the NATA-accredited Water Studies Centre laboratory that is also used for other water quality measurements in the lower Goulburn MER Program.

10.4. Sites and sample dates

Monitoring was undertaken at sites: Darcy's Track, Loch Garry and McCoy's Bridge. These sites are fully described in other chapters of this report (see Figure 2-1).

We undertook seven field trips (22 December 2020, 11 January 2021, 27 January 2021, 8 February 2021, 28 February 2021, 14 March 2021, 7 April 2021). Each trip began on the day listed and ran for two days. Generally, we completed monitoring at two sites on the first day and then the third site on the second day.

10.5. Data analysis

Data analyses are described fully in Appendix K. Importantly, it should be noted.

- High variability meant that estimates of production and respiration were averaged at the different depths at each site and for each visit.
- Similarly, nutrient and chlorophyll concentrations were also averaged.
- Even after averaging, oxygen concentrations for the different depths were still very variable, precluding a direct approach to estimating a pelagic metabolism at each site x time combination. Instead, pelagic metabolism was determined using a combination of modelling and extrapolation. First, we plotted measured production against light, pooling all data from all trips, and determining the relationship. Another relationship was then substituted for light based on the light vs. depth relationship for each site visit. This gave a relationship for GPP based on the depth of the water column for that site x time combination. This relationship was then used to model the rate of pelagic metabolism for the entire cross-section of the river at each site where sampling had taken place (cross-section data were provided by Streamology). These cross-sectional values of pelagic GPP formed the basis of analysis against all other measured parameters.
- Additional operations were used to make whole-stream metabolism data comparable to the pelagic metabolism data on the days of pelagic sampling. This involved some smoothing and interpolation around values that did not meet the 'good fit' criterion employed in the whole-stream metabolism program (Appendix K).
- Euphotic depth (depth where light intensity is reduced to 1% of the surface value and the point at which photosynthesis is assumed to cease) were determined using the recorded depth vs light relationship.
- The percentage of riverbed above the euphotic depth was determined using the cross-sectional data provided by Streamology and the river level data, publicly available via the Department of Environment, Land, Water, and Planning (DELWP, https://data.water.vic.gov.au/). The percentage value was calculated as the cross-sectional length of the riverbed above the euphotic depth.

10.6. Results

There was a clear exponential relationship between light intensity and GPP when all of the depth-averaged data were pooled (Figure 10-2). This provided a strong basis for modelling the amount of GPP across all depths with light availability for the different field trips.

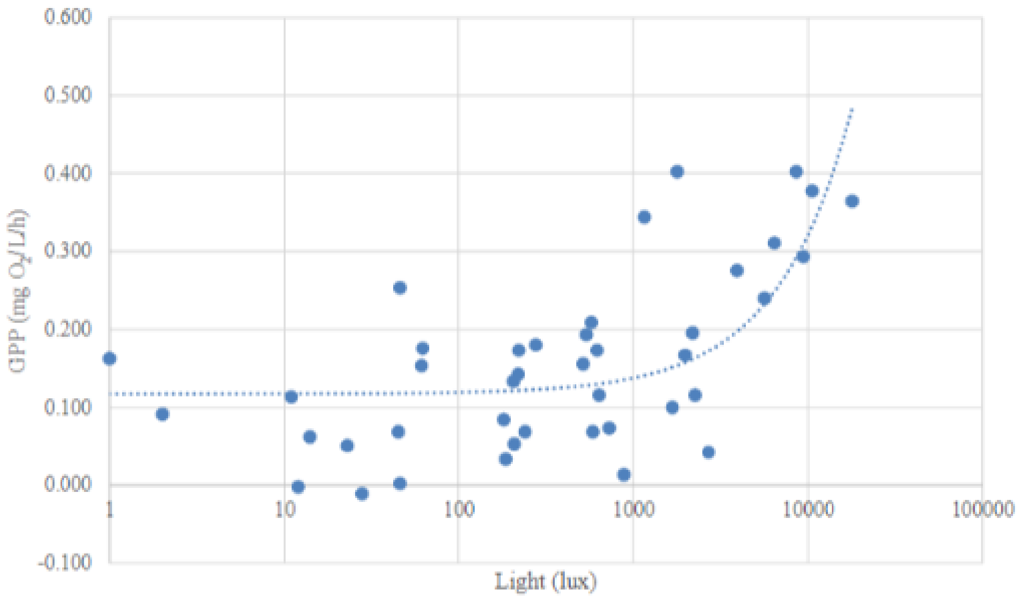


Figure 10-2 Depth-averaged GPP versus light availability with data from all sites and sampling trips pooled together.

Compared to whole-stream GPP monitored at the same time, pelagic GPP ranged from 1-25% of the daily primary productivity at the sites (Table 10-1), 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 10-3).

Table 10-1 Pelagic gross primary productivity versus whole-stream primary production. Pelagic and whole-stream (WS) GPP figures are in mg O_2 / L / hr. All results reported to three significant figures.

	Darcy's Track			Loch Garry			McCoy's Bridge		
Field Trip	Pelagic	WS	%	Pelagic	WS	%	Pelagic	WS	%
22-Dec	0.129	1.95	6.61	0.142	2.69	5.27	0.149	2.31	6.45
11-Jan	0.133	6.17	2.16	0.142	6.57	2.16	0.154	2.73	5.64
27-Jan	0.139	4.25	3.27	0.131	0.680	19.2	0.156	9.24	1.68
9-Feb	0.145	1.10	13.1	0.100	3.71	2.69	0.0993	0.650	15.3
1-Mar	0.132	1.83	7.21	0.156	1.38	11.3	0.177	3.94	4.49
15-Mar	0.162	1.39	11.7	0.210	0.820	25.6	0.222	1.42	15.6
8-Apr	0.164	1.72	9.56	0.139	0.850	16.3	0.237	1.77	13.4

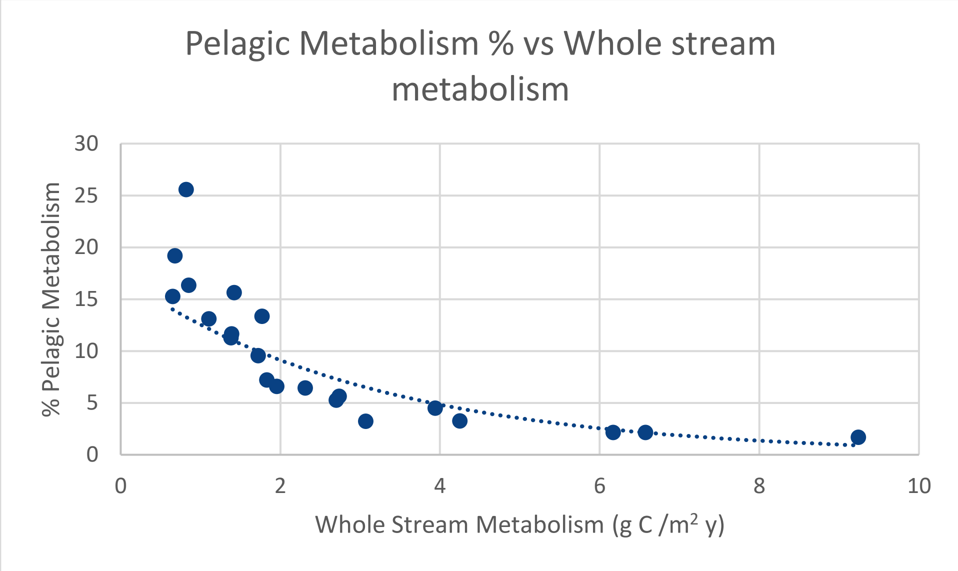


Figure 10-3 Whole-stream primary production versus % pelagic primary production.

We found no evidence of any relationship between GPP (either pelagic or whole stream) and any of the other measured physico-chemical variables (DOC, TP, TN, NH3, FRP, NOx, Chlorophyll-a, temperature; Table 8 in Appendix JK). We believe this further demonstrates the importance of light limitation for both pelagic and benthic metabolism in the lower Goulburn River.

10.7. Discussion

The results show that benthic areas of the lower Goulburn River are the primary contributors to primary production. Benthic metabolism is beneficial to river health as it provides food to organisms in the local area, providing benefit and growth to larger locally based organisms and wildlife in the river.

Generally, a decrease in temperature results in a decrease in both primary production and ecosystem respiration, thereby resulting in a decrease in stream metabolism (Roberts & Mulholland 2007). However, we did not find such a relationship over the study period. Possible reasons for this could be that sunlight and nutrients are limiting and hence water temperature does not have a great effect. Alternatively, the relationship given by our results may not be indicative of actual trends. When analysing the effect of temperature, units used should be in degrees Kelvin rather than Celsius. This means that the observed difference in temperature across the period of this study equates to only a 2.7% difference across the project period. To be able to draw stronger conclusions about the effects of temperature on metabolism, more data would be needed over a greater range in temperature.

We found no correlation of primary production with nutrient concentration. Since the Goulburn River is characterized by high turbidity and low nutrient concentration (Pollino et al. 2004), primary productivity is low. The low nutrient values may maximize the impact of measurement errors that obscure relationships between the indicators. The nutrients TP, TN, NH_3, FRP, and NOx are all forms of nitrogen or phosphorous and can be highly correlated if they come from the decomposition of plant and animal detritus. The low pelagic metabolism rates at Loch Garry and McCoy's Bridge on the 8th of February occurred after a significant storm/rainfall event. While water turbidity levels showed no substantial differences to previous field trips, visual observations on-site showed more material (leaves, branches) flowing down the river. This observation was reflected by the euphotic depth on this day being much shallower than any other day during the study period. The decrease in pelagic metabolism rates is thus implied to be caused by the reduction in euphotic depth. The storm also caused higher flow rates which can cause scouring of biofilms, suppressing primary production.

Our data results lead to the primary conclusion that both benthic and whole-stream metabolism in the lower Goulburn River is primarily limited by light. Therefore, 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.

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 12) 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.

11. Contingency Monitoring – Murray Fish Larvae

11.1. Introduction

Young-of-year golden perch are rarely collected in the annual population surveys in the Goulburn River. This is likely because early life stages (eggs, larvae) drift downstream and into the Murray River. Indeed, recent analysis of otolith strontium shows that golden perch spawned in the Goulburn River act as a source of fish to the Murray River. However, information on the contribution of golden perch (and silver perch) spawning in the Goulburn to the Murray River is limited. The aim of this project is to compare catches of golden perch and silver perch eggs/larvae between the lower Goulburn and Murray rivers. In particular, we aim to assess whether catches of eggs in the Murray River increase following spawning events in the Goulburn River.

11.2. Main findings from monitoring program

- There was no noticeable increase in the catches of golden perch eggs in the Murray River following spawning in the Goulburn River.
- Catches of silver perch eggs in the Murray River downstream of the junction increased slightly in late November, coinciding with spawning being detected in the lower Goulburn River.
- Spawning of golden perch and silver perch in the Murray River occurs over a broader time frame compared to the Goulburn River.

11.3. Methods

Fish eggs and larvae were sampled using drift nets at three sites around the Goulburn-Murray junction: the Murray River immediately upstream and downstream of the Goulburn River junction, and in the Goulburn River immediately upstream of the Murray River confluence. This sampling was conducted on five occasions at weekly intervals from around late October to late November 2020. Drift nets were of 500-µm mesh, 150 cm long with a 50 cm mouth diameter, and had flow meters (General Oceanics, Florida, USA) fitted to the mouth of the net to measure the volume of water filtered. Nets were set in late afternoon (1500–1900 hours) and retrieved the following morning (0800–1200 hours). Drift samples were inspected briefly in the field to obtain fertilised eggs so that these could be taken to the laboratory for hatching to assist identification. The remainder of the samples were preserved in 90% ethanol and taken to the laboratory for processing and identification. These methods are the same as those used for the core larval monitoring program.

11.4. Results and discussion

Over 3200 individuals (eggs and larvae) representing five native and one exotic species were collected from the drift sampling around the junction of the Goulburn and Murray rivers (Table 11-1). 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 was detected in the lower Goulburn River in late November coinciding with a within-channel environmental flow pulse. Spawning of golden perch was detected in the Murray River both upstream and downstream of the junction over a longer time frame encompassing late October to late November. However, there was no noticeable increase in the catches of golden perch eggs in the Murray River following spawning in the Goulburn River.

Spawning of silver perch was detected in the lower Goulburn River in late November coinciding with a within-channel environmental flow pulse. Spawning of silver perch was detected in the Murray River upstream of the junction in early November, and downstream of the junction over a longer time frame encompassing early to late November. 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.

Spawning of golden perch and silver perch in the Murray River occurs over a broader time frame compared to the Goulburn River. This finding may reflect differences in flow conditions between the rivers. For instance, in the Murray River there is often a sustained high discharge throughout the late spring-summer spawning period due to irrigation demand, whereas in the lower Goulburn River discharge is often relatively low throughout the spawning period with the exception of short duration targeted environmental flow pulses. Further research is needed to comprehensibly assess the extent to which golden perch and silver perch spawned in the Goulburn River act as a source of fish to the Murray River.

Table 11-1 Numbers of eggs (E) and larvae (L) of fish species collected in drift net surveys from the Murray/Goulburn junction sampling in 2020. Species with asterisk are exotic species.

Site	Golden perch	Silver perch	Murray cod	Australian smelt	Cod sp.	Common carp*	Flathead gudgeon
Goulburn upstream junction	110E, 33L	529E	144L	4E	1L		3L
Murray upstream junction	546E, 4L	72E	43L	12E	4L	4L	
Murray downstream junction	1472E, 8L	173E	242L	40E		1L	
Total	**2173**	**774**	**242**	**56**	**5**	**5**	**3**

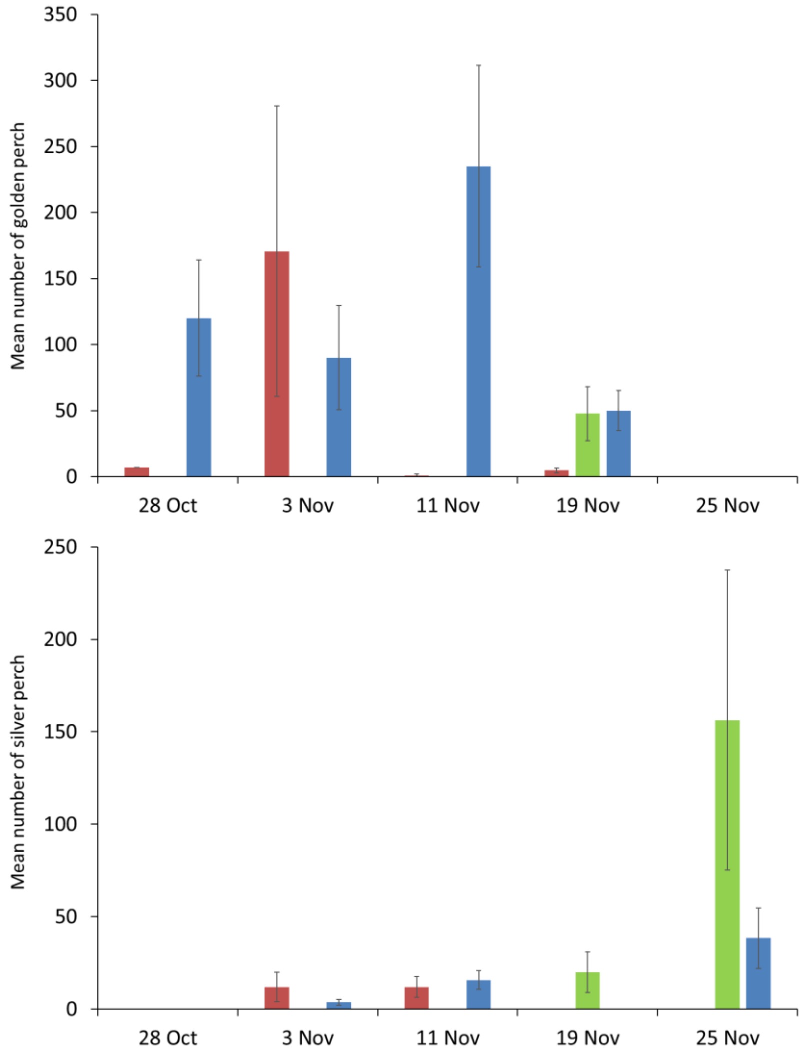


Figure 11-1 Mean (±se) number of golden perch (top panel) and silver perch (lower panel) eggs/larvae collected in the lower Goulburn (green), and Murray upstream (red) and downstream (blue) of junction.

12. Research Activities - Collaborative research project

12.1. Introduction

Through the development of the Goulburn MER plan 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. slack waters, 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, where human activities have simplified the channel and caused potential losses of habitat.

A collaborative research project was established to address these questions and a literature review and project team workshop identified 'slackwaters' as a habitat type of particular interest in the lower Goulburn River. Slackwaters are areas of shallow, slow flowing or still water that may support various ecological processes (e.g. as sites of sediment and seed deposition; areas for organic carbon retention and processing) and may be required habitat for some organisms or life history stages (e.g. low-flow refuges for larval and juvenile fish). Off-channel slackwaters such as anabranches and floodplain wetlands were identified by the EWKR program as important sources of carbon and zooplankton for fish food, and generated more food than main channel habitats (Thurgate et al. 2020), but these types of overbank slackwaters are not readily engaged in the Goulburn River. We are interested, therefore, in the extent to which similar habitats may be present within the main channel.

The proposed research program aims to identify whether slackwater habitats occurring within the channel of the lower Goulburn River play an important role in river's ecological function, and whether these habitats can be optimised through flow manipulation, or other measures, to achieve benefits for biota and ecosystem processes.

12.2. Project overview

The research program seeks first to identify types of slackwaters and habitat characteristics of slackwaters that are important for biota and ecological processes occurring in the lower Goulburn River. Second, it seeks to identify the distribution of important habitat types and management actions (e.g. required flows) to optimise these habitat types. The research program seeks to identify:

- The sizes and distribution of slackwaters at sites on the lower Goulburn River.
- The types and characteristics of slackwaters that provide the best habitat for biota and ecological processes occurring in the lower Goulburn River.
- Management actions (e.g. required flows) to optimise the amount and quality of slackwater habitat in the lower Goulburn River.

Research activities are grouped into five main components:

1. **Question refinement / development of hypotheses:** Convene a workshop to elicit the hydraulic conditions / physical characteristics that are expected to be important for plants, fish, macroinvertebrates, ecosystem processes etc. Refine research questions and develop hypotheses for testing. This component was largely completed in 2019-2020 and it was decided to study slackwaters, areas of shallow (≤ 0.5 m) still or slow-flowing water (≤ 0.05 m/s) at four selected sites on the Lower Goulburn River.
2. **Map habitats**: At selected reaches, use existing hydraulic models to identify potential slackwater areas for field investigations.
3. **Field Surveys:** Conduct field surveys of water depth and velocity to verify size and location of slackwaters identified from modelled data. Conduct surveys and collect samples of biota to describe the habitat characteristics and resident taxa of slackwater habitats in the lower Goulburn River. Examine changes in habitat quality and habitat use by various taxa across a range of relevant discharges to inform flow management to optimise these habitats and promote species abundance and diversity.

4. **Field experiment:** "Reinforce" slackwaters with woody structure to promote retention of carbon resources required by invertebrates, with an aim to boost abundance and diversity of biological communities.
5. **Analysis and reporting**: Assess against hypotheses, validate relationships, update conceptual model, identify flow bands for optimising habitats / hydraulic conditions, incorporate outcomes into refinement of water delivery (both for environmental flows and water supply delivery) and other potential management actions.

12.3. Research activities: 2020-2021

The bulk of Research Component 1, was completed in 2019-2020 and details reported in the Goulburn MER Scientific Report 2019-2020 are not repeated here. Research activity in 2020-2021 focused on components 2, 3 and 4, mapping slackwater habitats, conducting field surveys, and establishing the field experiment. Activities completed during the 2020-2021 reporting period are summarised in Table 12-1. Data analysis for several activities is underway but it is premature to report outcomes here. Instead a brief overview of selected activities is presented in the sections below.

Table 12-1 List of activities completed for each research component during the 2020-2021 reporting period.

Component	Date	Description
1. **Refine questions & hypotheses**	May 2020	Workshop to refine research questions and develop hypotheses for testing.
2. **Map habitats**	March 2021	Produce 2D modelling outputs (maps) predicting the size and location of slackwaters across a range of relevant flows (summer flows from 1000 – 3000 ML/day).
3. **Field surveys**	Dec 2020	**Site scoping:** Familiarisation with sites, site access and habitat types present in the Lower Goulburn River. No data collected
	Feb 2021	**Survey 1:** Scoping survey to identify and compare key habitat types in the Lower Goulburn River at IVT flow levels.
	April 2021	**Model verification surveys:** Measure water depth and velocity to verify the sizes and positions of slackwaters identified from model outputs.
	April 2021	**Survey 2:** Targeted survey to compare habitat characteristics between Wide vs Narrow slackwater types at baseflow levels. that were identified and mapped during mapping and model verification surveys
	April 2021	Concurrent with **Survey 2**, collection of invertebrate samples to compare diversity and abundance of organisms using Wide vs Narrow slackwater types at baseflow levels.
4. **Field experiment**	June 2021	A manipulative field experiment was established in 24 slackwaters to increase amounts of woody structure and promote retention of carbon resources required by invertebrates, with an aim to boost abundance and diversity of biological communities.
5. **Analysis & reporting**	July 2020	Data entry, sample processing, statistical analyses underway
	August 2020	Goulburn MER Annual Scientific Report - 2019-20
	Feb 2021	Goulburn MER Forum 2021 – Project X update presentation
	August 2021	Goulburn MER Annual Scientific Report - 2020-21

12.4. Sites

The project studies four sites, located along the full length of the Lower Goulburn selected area, between the townships of Nagambie and Echuca Figure 2-1. All research activities described below have been conducted at these sites:

- Moss Road, Goulburn Weir
- Darcy's Track, Tatura East
- Loch Garry, Loch Garry Wildlife Reserve
- McCoy's Bridge, Kotupna

Each site is confined within a 'mapped area', for which water depth and velocity have been previously modelled during the LTIM program (Webb et al. 2016). We have confined our research within these modelled areas because we can model the predicted sizes and locations of slackwater areas.

12.5. Mapping habitats

Mapping of slackwater habitats was a two-step process. First, water depth and velocity data were modelled to produce maps showing the predicted sizes and locations of prospective slackwaters. Second, these maps were used to guide field-truthing surveys (described in Section 12.7 Field Surveys) to measure water depth and velocity to confirm the locations and spatial dimensions of slackwaters at each site.

In this study, slackwaters are defined as areas ≤ 0.5 m deep, with water flows not exceeding 0.05 m/s. Both thresholds are within the range of values used in other studies of slackwaters (Vietz et al. 2013). The depth threshold of 0.5 m is the maximum safe working depth for field surveys which require wading, sometimes in very deep silt.

Modelling was conducted by research partners Streamology, as per the methods described in (Webb et al. 2016) to produce overlays of predicted slackwater area at 12 discharges ranging from 300 – 12,000 ML / day (Figure 12-1). Model outputs for three relevant discharges were overlaid to produce maps showing prospective changes in the size (m^2) and location of slackwater areas throughout a typical summer (Figure 12-2). These maps were used to identify the number of slackwaters per site and changes in the size and location of individual slackwaters with increasing levels of discharge.

From these maps we identified two types of slackwater areas that may provide different types of habitat and accommodate different organisms. 'Wide' slackwaters, often associated with benches or shallow-sloping banks, are characterised as places where bands of modelled slackwater do not overlap at different discharges (Figure 12-2), suggesting that slackwaters migrate in space (up the bank) with increasing discharge. 'Narrow' slackwaters are associated with steeper banks and are almost ubiquitous along the channel margins in models outputs for all sites and all summer discharges. Narrow slackwaters are places where areas of modelled slackwater overlap at different discharges, indicating that slackwaters move little in space with increasing discharge (Figure 12-2).

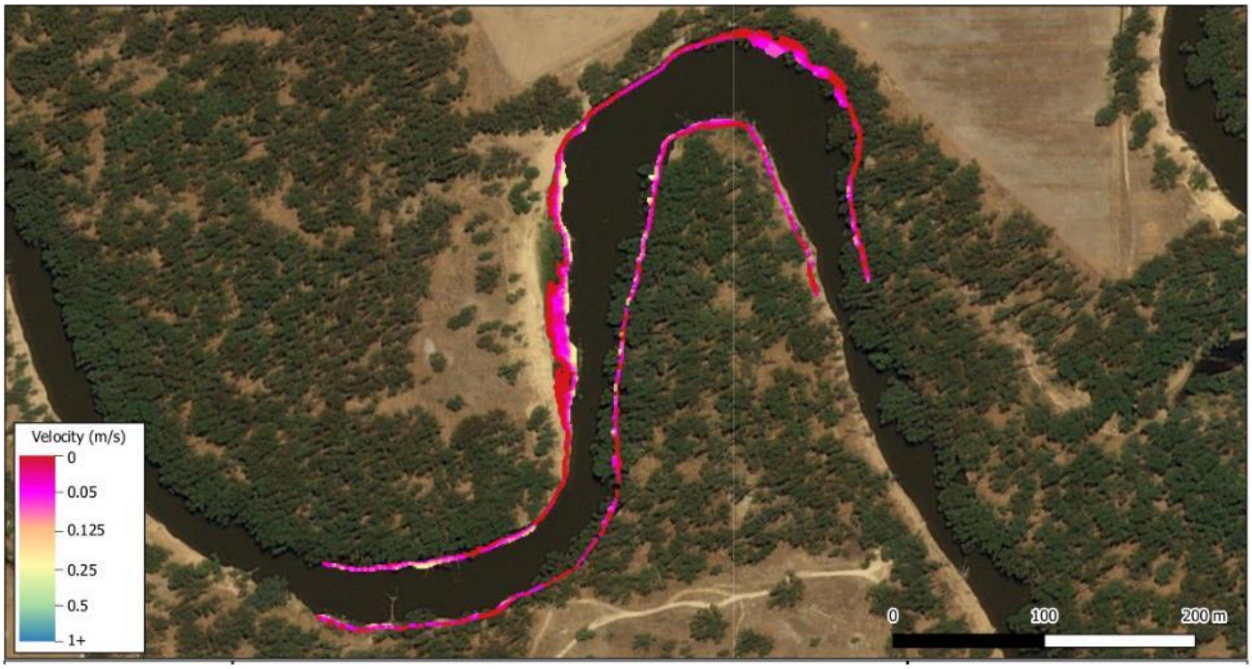


Figure 12-1 Example of 2D modelling output for site McCoy's Bridge, showing slackwater areas (pink and red shading, ≤ 0.05 m/s) at a discharge of 2000 ML / day. Water velocity (m/s) is modelled for areas that are ≤ 0.5 m deep.

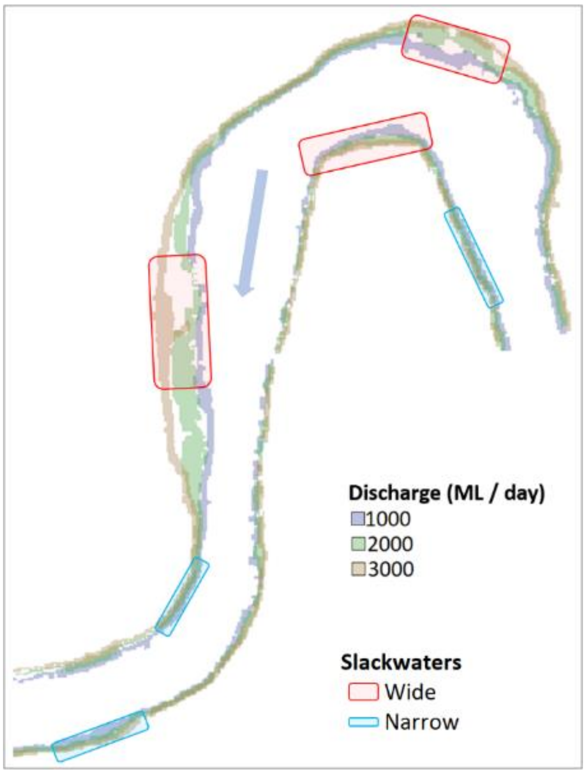


Figure 12-2 Example of 2D modelling output showing predicted slackwater areas (water depth ≤ 0.5 m; water velocity ≤ 0.05 m/s) at relevant summer discharges of 1,000 (baseflow), 2,000 and 3,000 ML/day. Site: McCoy's Bridge, Kotupna.

12.6. Wide vs Narrow slackwaters

We believe that decades of regulation have reduced the availability of Wide slackwaters, replacing them with Narrow slackwaters as the channel becomes simpler and simpler. Any loss of Wide slackwaters may have ecological costs, because we predict that Wide slackwaters provide a better type of habitat that should be preserved to maintain species abundance and diversity in the Lower Goulburn River.

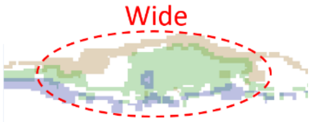
Organisms, and particularly small, poorly mobile organisms may encounter different challenges and benefits in Wide versus Narrow slackwaters that might affect their fitness in either environment (Table 12-2). On average, Wide slackwaters may cover larger areas than Narrow slackwaters, providing space for larger accumulations of woody habitat and energetic resources (e.g. carbon in the form of plant detritus), but exact slackwater dimensions are likely to vary with discharge. In the lower Goulburn River, we observed Wide slackwaters (mean width (±SD) = 3.11 ± 1.61 m) were approximately twice the width of Narrow slackwaters (1.70 ± 0.84 m) at a discharge of ~1,500 ML/day (for methods, see Model verification below). Large areas of slackwater may also offer a more hydraulically stable environment for small, flow-sensitive organisms that are vulnerable to flushing (i.e. being washed downstream by high flows). In Narrow slackwaters organisms may be more likely to stray into seams of faster flowing water and be flushed downstream. Further, Narrow slackwaters are often associated with adjacent deep water that may provide safe access for large fish predators to feed in these areas more readily than in Wide, shallow slackwaters.

On the other hand, Narrow slackwaters are more stable spatially, because the slackwater horizontal location moves little with changes in discharge. Inhabitants of Wide slackwaters must undertake lateral migration with changes in water level, which may be impossible for some organisms with low or no mobility (e.g. plants).

On the balance of potential pros and cons of each slackwater type (Table 12-2), we predict that Wide slackwaters provide better habitat and pose the hypothesis that:

> ***H_1:*** *Wide slackwaters support more species and greater densities of individuals than Narrow slackwaters.*

Table 12-2 Positive (✓) and negative (×) attributes of each slackwater type.

Slackwater type	Relative area (m²)	Hydraulic stability	Spatial stability	Refuge
	**Large** ✓ Space for abundant resources & inhabitants	**High** ✓ Flow-sensitive organisms less vulnerable to flushing	**Low** × Position changes with discharge, inhabitants must follow	**High** ✓ No deep-water access for fish predators
	**Small** × Little space for resources & inhabitants	**Low** × Flow-sensitive organisms vulnerable to flushing	**High** ✓ Position changes less with discharge	**Low** × Deep-water access for fish predators

12.7. Field surveys

12.7.1. Model verification

In April 2021, we conducted a survey campaign to collect measurements of water depth and velocity with two aims: (1) to test the accuracy of the modelled data regarding the sizes and locations of slackwater patches; (2) to identify suitable areas of slackwater for subsequent research. Wide slackwaters were identified from maps of model outputs and ranged in length from 20 – 50m. Because Narrow slackwater was almost ubiquitous along the wetted channel margins, we selected 30 m sections of Narrow slackwater at random.

Surveys mapped the boundaries of slackwater areas by measuring water depth and velocity at 5 m intervals along the length of each slackwater. At each interval we started from the wetted margin and moved out into the channel, measuring depth and velocity until we identified the thresholds of 0.5 m deep and 0.05 m/s velocity. Distances from the wetted margin to the depth and velocity thresholds were recorded and plotted to delineate the boundaries of each slackwater, as defined by our depth and velocity criteria (e.g. Figure 12-3). Initially these data were used to confirm suitable slackwater areas for ongoing study. However, we note that some slackwaters were bounded by depth criteria, and others by velocity seams (Figure 12-3) and this distinction might have implications for organisms inhabiting these slackwaters. For example, where depth determines the slackwater boundary, inhabitants may be somewhat buffered from flushing because they are less likely to stray across velocity boundaries. The majority of slackwaters surveyed (73 % of Narrow slackwaters; 60 % of Wide slackwaters) were bounded by the depth threshold.

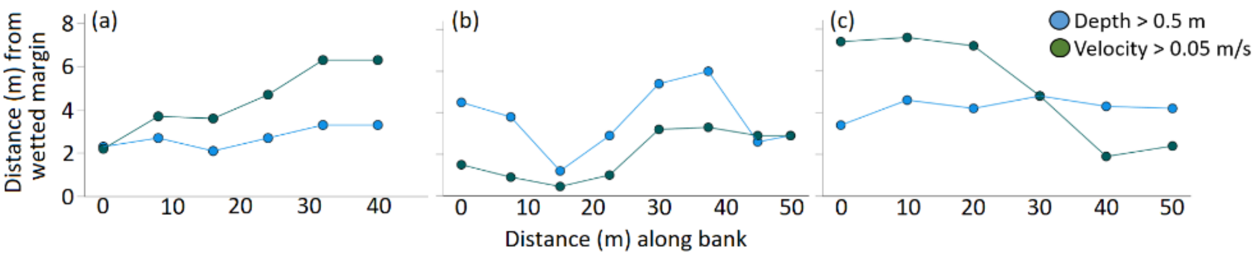


Figure 12-3 Line graphs showing measured depth and velocity boundaries for three slackwaters. Note that slackwaters may be bounded by depth (a), velocity (b), or a combination of both (c).

12.7.2. Survey 2 – Physical & biological attributes of slackwaters

Survey 2 was conducted to examine and compare three main attributes of slackwater habitats.

1. **Amounts of wood and vegetation**, which provide:
   a. **Habitat complexity** - cover, shade, substrata etc.
   b. **Structural retentiveness** – physical structures within the channel that may trap and retain resources of plant detritus, making them available to invertebrates.

2. **Amounts of coarse plant detritus** – organic particles (⌀ ≤ 20 mm) which are a vital source of food and habitat for aquatic invertebrates and other small-bodied organisms.
3. **Abundance and diversity of aquatic invertebrates** – Shrimp and aquatic insects, which may depend on complex habitats and/or resources of detritus

Surveys were conducted and samples collected concurrently from six slackwaters (3 Wide, 3 Narrow) at each of the four sites. Within each slackwater, densities of wood, vegetation and plant detritus were surveyed along transects. Samples of invertebrates (shrimp and aquatic insects) were collected with a standard sweep-net technique. Data collected during Survey 2 will be used to test four main hypotheses:

H_1: *Wide slackwaters support more species and more individuals than Narrow slackwaters.*

H_2: *Slackwaters with more structural retentiveness (i.e. more wood and vegetation) will retain more resources of plant detritus.*

H_3: *Slackwaters with more plant detritus will harbour higher abundance and diversity of invertebrates that require detritus resources.*

H_4: *Slackwaters with more wood and vegetation will harbour higher abundance and diversity of invertebrates that require complex habitats.*

Transect surveys

Amounts of wood (living trees and Large Woody Debris ⌀ > 50 mm, Fine Woody Debris ⌀ < 50 mm), vegetation, and coarse plant detritus (particles ≤ 20 mm ⌀) were surveyed along transects using the method of Bovill et al. (2020). Transects were oriented perpendicular to flow and were randomly located (one transect per 5 m of slackwater length). Each transect was divided into wet and dry zones (Figure 12-4), with the wet zone extending from the water edge to the slackwater boundary (velocity exceeding 0.05 m/s or depth exceeding 0.5 m) and the dry zone extending up the bank from the water edge to approximately the 3000 ML / day water level (~50 cm above the water level at time of sampling). Surveys of the wet zone describe instantaneous amounts of vegetation and woody structure (habitat complexity) and detritus (resources/carbon) available to biota at the time that invertebrate samples were collected (see Sweep Samples below). Surveys of the dry zone describe the prospective densities of wood, vegetation and detritus that may become periodically available as water levels fluctuate.

Along each transect, the total amount (m) of wood, vegetation and detritus was measured and these raw amounts may be converted to linear densities (e.g. m of wood / m of transect) for comparisons between slackwaters. Analysis of these data is underway but it is premature to present any results in this report.

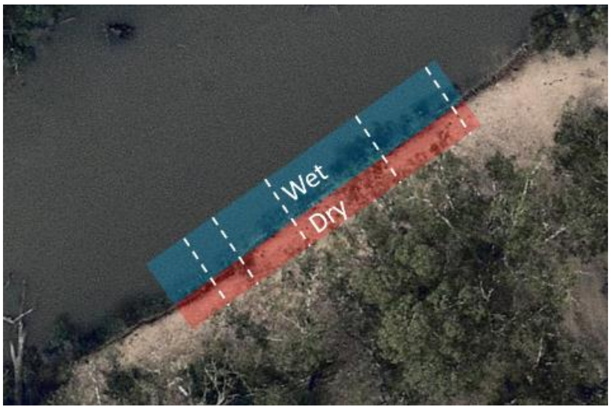


Figure 12-4 Example of cross sectional transects (dotted lines) encompassing parts of the dry and wet channel.

Sweep samples

Each slackwater was sampled for invertebrates with three replicate sweep samples. Replicate sampling areas were randomly located, and each covered an area bounded by the waterline and the slackwater boundary and extending for 10 %

of total slackwater length. A standard dipnet (frame: 300 mm × 300 mm; mesh: 500 µm) was swept vigorously through each replicate area for approximately 30s until all parts of the area had been sampled. Samples were pooled to produce one sample of invertebrates per slackwater, collected from approximately 30 % of the slackwater area. Samples were preserved in 70 % Ethanol and will be processed later in 2021.

12.8. Field experiment

Plant detritus (leaves, bark, wood) is an important base resource that provides food and habitat for a variety of small organisms such as shrimp, aquatic insects and potentially, larval fishes. In rivers, plant detritus accumulates by deposition in hydraulic dead-zones (hydraulic retention) and on hard structures such as wood and vegetation that trap and hold onto drifting detritus in flowing water (structural retention).

Slackwaters may accumulate detritus by hydraulic retention, but many of the slackwaters studied in Survey 2 lack significant structural features (wood, vegetation). We predict that stocks of detritus may be washed away from these slackwaters during periods of elevated discharge and that, without a stable supply of detrital resources, these slackwaters may not be able to support large abundances and diversity of organisms.

To test for and mitigate these hypothesised effects we designed an experiment to increase densities of plant detritus and dependent organisms in slackwaters, by augmenting amounts of hard retentive structure. Other studies have used hardwood garden stakes, driven into the riverbed, to successfully boost structural retentiveness and increase densities of detritus and invertebrates in streams in central Victoria (Lancaster & Downes 2017, Lancaster & Downes 2021). We applied similar methods to establish a manipulative field experiment in the same 24 slackwaters studied in Survey 2 (4 sites; 3 Wide, 3 Narrow slackwaters per site). The experiment will test 3 simple hypotheses that, compared to controls, areas with added retentive structure will have:

> ***H_5:** More resources of plant detritus.*
>
> ***H_6:** Higher densities of aquatic invertebrates and larval and small-bodied fishes*
>
> ***H_7:** Higher diversity of aquatic invertebrates and larval and small-bodied fishes*

Experimental design

To allow direct comparisons between Wide and Narrow slackwaters, slackwater area was standardised to areas 30 m long and 1.5 m wide. This matches the average dimensions of Narrow slackwaters in Survey 2. For Wide slackwaters, which were typically larger, we selected a random 30 m length of slackwater for the experiment. Within each experimental area we established four replicate experimental units, two units with stakes and two control units without stakes (Figure 12-5). Replicate units were a constant size (4 m X 2.5 m = 10 m^2) and were divided into two zones centered around the 1000 ML/day water level. Discharge in the Lower Goulburn River rarely falls below 1000 ML/day, so we established a 6 m^2 'permanently wet' zone below the 1000 ML/day water level and 4 m^2 'lower bank' zone above the 1000 ML/day water level. Samples and surveys from the permanently wet zone will test the main hypotheses (H_{5-7}). The lower bank zone was established to test whether added structural retentiveness on the lower bank can increase stability in this zone by increasing deposition and reducing export of sediments and plant seeds. We will test the hypothesis that:

> ***H_8:** recruitment of littoral vegetation is higher in staked vs control areas*

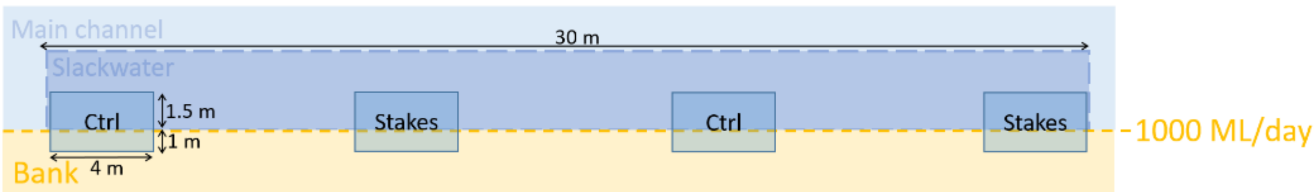


Figure 12-5 Layout of experimental units within each slackwater. Experimental units were evenly spaced to maximise independence. Treatment (Stakes, Control) was allocated at random to the first experimental unit and alternated thereafter. Each unit was established around with 1,000 ML/day water level, with an area 1 m × 4 m located above the 1,000 ML/day waterline and with an area 1.5 m × 4 m located below the 1,000 ML/day waterline.

Stake densities were determined from a range of potential configurations, simulated with a mock-up experimental area during covid lockdown (Figure 12-6). We selected a density of 30 stakes per experimental unit, arranged as 15 pairs of stakes spaced 30cm apart. This was the highest density logistically feasible, equivalent to 7.5 times the density of stakes used in previous research (Lancaster & Downes 2017) and is expected to provide the best chance of accumulating high densities of detritus in treatment areas.

Data collection

Before inserting stakes, we surveyed each Staked and Control area to establish the background densities of wood, vegetation and detritus. Each was surveyed with three randomly located transects, using methods described above (Survey 2). Analysis of these survey data is underway.

The experiment was established in June and will remain in place for at least 12 months. Multiple surveys (wood, vegetation, detritus) and samples of aquatic organisms will be collected during this period to compare densities of resources and biota between staked and control areas. Since establishing the experiment, a large winter fresh (environmental water followed by sustained natural flows) has drowned the experimental units with flows up to 9,400 ML/day. Due to covid lockdown it is not currently possible to assess the effects that these elevated flows have had on experimental units, but stakes were driven ~0.5 m into the riverbed and are expected to be robust to the physical forces of elevated flows. The main predicted effect of the sustained winter fresh is that these flows may mobilise detritus from the riverbank and deliver it to staked areas, but this remains to be determined.

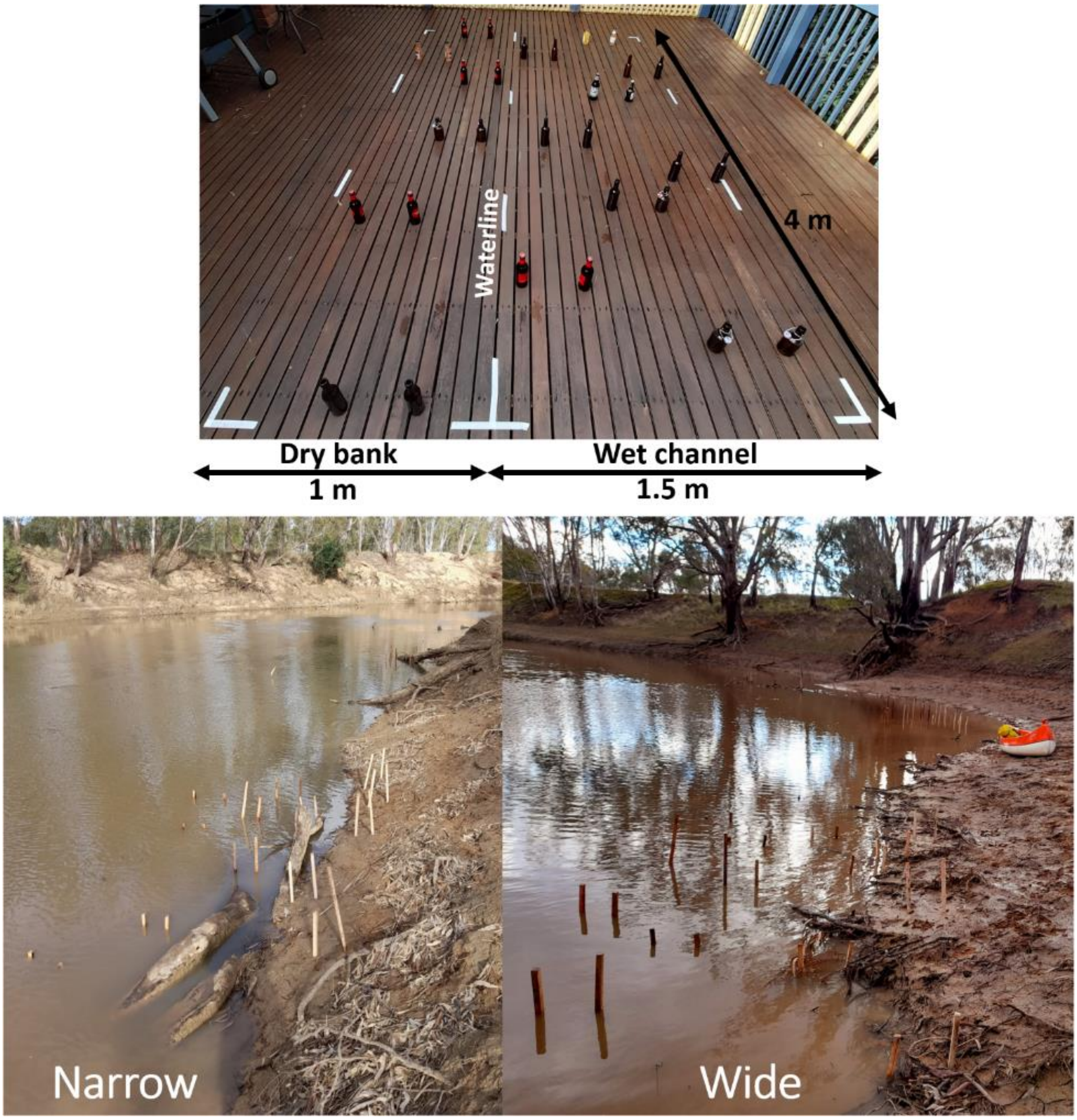


Figure 12-6 Top: Backyard mock-up of an experimental unit during Covid lockdown. Beer bottles were arranged in different densities and configurations to determine the optimal number and arrangement of stakes. Bottom: examples of experimental units established in Narrow and Wide slackwaters at the McCoy's Bridge site. A second experimental unit is visible in the background of each photograph. Note the steep slope of the Narrow slackwater, where some stakes are fully submerged.

13. Engagement and Communication

13.1. Engagement

The health and management of the Goulburn River continued to be a focus of the local and regional community as the Victorian Government reviewed the rules governing the trade and delivery of water from the Goulburn River to the Murray River. The review set out preferred changes to the rules to avoid sustained high flows during summer and autumn, because these have caused environmental damage. Anglers, local government, businesses and the broader community sought information from the GB CMA, collected as part of current and past monitoring programs, to provide feedback on the proposed rule changes. In June 2021, the Victorian Government announced that it would introduce an interim trade rule for 2021-22 and extend interim operating arrangements for another 12 months. In addition, the Victorian Government committed $2.7 million for monitoring over the next three year to help inform long-term improvements to the rules. Collaborating with and empowering the community to bring about these change is a perfect example of best-practice community engagement (IAP2 public participation spectrum - https://www.iap2.org.au/resources/spectrum/).

The Victorian Government's communication protocols during the coronavirus pandemic created challenges, but the GB CMA was 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 VEWH.

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 (Horne et al. 2020).

13.2. Communication

The following communication and engagement actives were undertaken during 2020-21 to inform stakeholders and the broader community about the aims and results of the Goulburn River Flow-MER Project and the role of the Commonwealth Environmental Water Office in environmental water management. Selected examples of communications are included in Appendix L.

13.2.1. Media releases and other articles

Between July 2020 and June 2021, a number of media releases were prepared, and 20 columns/advertisements were run in the *Shepparton Advisor* (free – circulation 60,000) and the *Country News* (paid - circulation 35,000). These promoted the project, Commonwealth environmental water use in the Goulburn River and ecological responses (native fish movement and breeding, changes to macroinvertebrate biomass, bank vegetation growth and bank erosion) to environmental flows. There were corresponding articles published in local newspapers including the *Shepparton Advisor, Alexandra Standard, Riverine Herald* and the *Country News*. ABC Goulburn Murray and local TV stations (WIN and Nine) also interviewed staff and/or ran the media releases in their news bulletins. A number of the articles focused on the impact of the high IVT flows on lower Goulburn River ecological values and how monitoring is informing mitigation measures. Articles were also included in the GB CMA electronic newsletter *Connecting Community and Catchment*, which has over 1100 subscribers. Streamology also promotes the Goulburn River Flow-MER Project research it undertakes on its website and through their electronic newsletter.

Anglers continue to be passionate advocates for river health activities and we continue to engage with them via a number of platforms, including fishing shows and expos.

13.2.2. Technical publications

Technical communication and engagement activities were limited compared to prior years due to COVID-19 restrictions impacting the latter half of the year. However, several publications have appeared in or been submitted to the peer-reviewed scientific literature that incorporate aspects of the Goulburn River LTIM and MER projects. These including two papers that appeared in a special issue of the journal *River Research and Applications* to honour the life and memory of Professor Wayne Erskine:

1. Watts et al. (2020), which examined how adaptive management is being applied across the LTIM/MER selected areas and how learnings from one Selected Area may be better captured to inform future management at other areas. (Watts RJ, Dyer F, Frazier P, Gawne B, Marsh P, Ryder DS, Southwell M, Wassens S, Webb JA, Ye Q (2020)

Learning from concurrent adaptive management in multiple catchments within a large environmental flows program in Australia. *Riv. Res. Appl.* **36**, 668-680.)

2. Gawne et al. (2020), which provides an overview of the LTIM/MER approach to large-scale monitoring and evaluation of environmental flows, given that these programs have no parallel anywhere in the world (Gawne B, Hale J, Stewardson MJ, Webb JA, Ryder DS, Brooks SS, Campbell CJ, Capon SJ, Everingham P, Grace MR, Guarino F, Stoffels RJ (2020) Monitoring of environmental flow outcomes in a large river basin: The Commonwealth Environmental Water Holder's long-term intervention in the Murray–Darling Basin, Australia. *Riv. Res. Appl.* **36**, 630-644.)

3. Geoff Vietz, Neil Sutton, Jess Houghton, Thom Gower, and Christine Lauchlan Arrowsmith, 2021. Assessing waterways from the sky: A new era in monitoring using drones. Proceedings of the 10th Australian Stream Management Conference 2020, Kingscliff, NSW.

Goulburn MER research was also used to contribute to the following external programs:

1) GBCMA Environmental Water Program funding proposal for EC5 (Environmental Contributions Levy)
2) Goulburn to Murray Trade Review Regulatory Impact Statement
3) Operating Plan for the delivery of water from the Goulburn IVT Account

13.2.3. Social Media

Numerous Facebook and Instagram posts and tweets promoted the project and the benefits of environmental water. These were viewed thousands of times and are usually amongst GB CMA's most popular and engaging posts. Currently, the GB CMA has over 4,700 social media followers.

1) https://www.facebook.com/gbcma
2) https://twitter.com/gbcma
3) https://www.instagram.com/goulburnbrokencma/

To acknowledging the Traditional Owners (Yorta Yorta Nation Aboriginal Corporation), they are usually tagged in social media and they along with MLDRIN, frequently share information about the monitoring program and outcomes among their networks.

Innovative approaches, such as Streamology using drones to monitor bank condition, continue to attract community and media attention, with posts on this topic among the most popular and engaging.

13.2.4. Websites

The Water for the Environment section of the GB CMA's website was updated and given greater prominence in-line with an overall update and revamp of site. The development of the FLOW-MER website and the ability to link to it helps provide better context for how the Goulburn project aligns with the broader Basin monitoring activities as well as providing access to regularly updated science and information via newsletters and other material generated by CEWO. The bank condition monitoring program was described in the Flow-MER story below

https://flow-mer.org.au/assessing-soil-from-the-sky-drone-monitoring-in-the-murray-darling-basin/

13.2.5. Presentations

GB CMA staff and research leads presented/provided updates to a number of government, community and agency groups throughout the year on environmental water management and the Goulburn FLOW-MER project. These groups included:

- Yorta Yorta Nation Aboriginal Corporation;
- Taungurung Land and Waters Council;
- Parks Victoria;
- DELWP;
- Goulburn-Murray Water;

- Schools;
- Recreational fishing groups and fish management agencies;
- GB CMA partnership group; and
- Environmental Water Advisory Groups.

Of note, La Trobe 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 project. The workshops were attended by the GB CMA's environmental water delivery partners (GMW, PV, Greater Shepparton City Council, DELWP 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.

The drone-based program was featured as part of the basin-scale team's 'Flow-MER Fridays' series of presentations.

https://flow-mer.org.au/series-2-webisode-4-assessing-soil-and-plants-from-the-sky-a-new-era-in-waterway-monitoring-using-drones/

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Appendix A: Detailed summary of watering actions and volumes delivered

The following table provides a breakdown of all water delivered to the lower Goulburn River in 2020-21. All releases are from Goulburn Weir (Murchison) and volumes are provided for Murchison (M) and McCoy's (Mc). Travel time to McCoy's Bridge is 4 days and differences in volumes between Murchison and McCoy's Bridge are due to lag times and tributary inflows between the two locations (Source 2020-21 Goulburn Water Use Acquittal Report – CEWO unpublished, 2021).

Table A-1 Environmental water delivered to the lower Goulburn River in 2020-21.

Date (start/end of action)	Flow component type and planned magnitude, duration, timing	CEW volume used (ML)	Other environmental water (ML) VEWH, TLM, WQR	Non-environmental water IVT Other (min, passing, trib and natural flows)	Total river flow (ML)
01 July to 04 July 2020 Mc	At least one winter/spring fresh (July-Oct) >6 600 ML/day for 14 days	0	0	22,337 Mc	22,337 Mc
01 July to 07 Sept 2020 M (69 days) 05 July to 11 Sept 2020 (69 days) Mc	At least one winter/spring fresh (July-Oct) >6 600 ML/day for 14 days Deliver using tributary flows where possible, rather than releases from Eildon. If there is no natural event then deliver as a managed event in Sept/Oct 2020	CEW 0 M 0 Mc	VEWH 0 M 0 Mc TLM 0 M 0 Mc	IVT 0 M 0 Mc Other 284,306 M 333,782 Mc	Total 284,306 M 333,782 Mc
08 Sept to 24 Sept 2020 M (17 days) 12 Sept to 28 Sept 2020 M (17 days)	Following natural flows (all year) Provide water for a slower recession or add pulses following natural cues/unregulated flows.	CEW 27,714 M 28,554 Mc	VEWH 0 M 0 Mc TLM 5,637 M 5,712 Mc	IVT 0 M 0 Mc Other 6,658 M 9,863Mc	Total 40,009 M 44,129 Mc
25 Sept to 30 Oct 2020 M (36 days) 29 Sept to 03 Nov 2020 Mc (36 days)	At least one winter/spring fresh (July-Oct) >6 600 ML/day for 14 days Deliver using tributary flows where possible, rather than releases from Eildon. If there is no natural event then deliver as a managed event in Sept/Oct 2020.	CEW 75,473 M 76,306 Mc	VEWH 6,991 M 9,518 Mc TLM 12,205 M 13,300 Mc	IVT 0 M 0 Mc Other 33,500 M 63,711 Mc	Total 128,169 M 162,835 Mc

Date (start/end of action)	Flow component type and planned magnitude, duration, timing	CEW volume used (ML)	Other environmental water (ML) VEWH, TLM, WQR	Non-environmental water IVT Other (min, passing, trib and natural flows)	Total river flow (ML)
31 Oct 2020 to 11 Nov 2020 M (12 days) 04 Nov to 15 Nov 2020 Mc (12 days)	Spring/summer low flow (after a spring fresh) <1 000 ML/day for 5–6 weeks.	CEW 6,428 M 6,495 Mc	VEWH 0 M 0 Mc TLM 714 M 722 Mc	IVT 0 M 0 Mc Other 3,433 M 7,482 Mc	Total 10,575 M 14,699 Mc
12 Nov to 28 Nov 2020 M (17 days) 16 Nov to 02 Dec 2021 Mc (17 days)	Spring/summer fresh (Nov/Dec) When possible, >6 600 for 1 day This will not be delivered if the spring/summer 5-6 weeks low flow for vegetation has not been achieved.	CEW 6,904 M 7,556 Mc	VEWH 11,690 M 12,925 Mc TLM 767 M 840 Mc	IVT 25,626 M 25,952 Mc Other 12,276 M 6,222 Mc	Total 57,263 M 53,495 Mc
29 Nov 2020 to 25 March 2021 M (117 days) 03 Dec 2020 to29 March 2021 Mc (117 days)	Summer/autumn low flows between pulses. Flows are not to exceed 1 000 ML/day for more than 20 consecutive days, with a minimum of 7 days between pulses.	CEW 0 M 0 Mc	VEWH 0 M 0 Mc TLM 0 M 0 Mc	IVT 110,703 M 110,703 Mc Other 42,315 M 42,630 Mc	Total 153,018 M 153,333 Mc
26 March to 09 May 2021 M (45 days) 30 March to13 May 2021 Mc (45 days)	Autumn fresh (March/April) When possible >5 600 ML/day for 2 days Note that delivery of the summer/autumn low flows between pulses is a trigger for this action.	CEW 9,481 M 10,830 Mc	VEWH 0 M 0 Mc TLM 5,815 M 7,583 Mc	IVT 71,874 M 72,721 Mc Other 24,921 M 15,605 Mc	Total 112,091 M 106,739 Mc
10 May to 30 June 2021 M (52 days) 14 May to 30 June 2021 Mc (48 days)	Low flow (all year) 500-940 ML/day	CEW 17,746 M 18,261 Mc	VEWH 0 M 0 Mc TLM 10,027 M 8,142 Mc	IVT 6,494 M 6,494 Mc Other 14,367 M 21,658 Mc	Total 48,634 M 54,555 Mc
Not delivered	Winter fresh (June/July 2021) Up to 15 000 ML/day[3] with more than 14 days above 6 600 ML/day.				

[3] Note the peak flow achievable with environmental water under current operating rules is approximately 9 500 ML/d in the lower Goulburn. The full target flow of 15 000 ML/d can however be met with unregulated tributary inflows.

Appendix B: Bank condition Digital Elevation Models of Difference (DEMODs)

This appendix presents detailed evaluation of DEMODs for each flow event at each monitoring location. A summary of different locations that were captured in the monitoring is provided in Table B-1.

Table B-1 Summary of banks where change was successfully captured for each flow period.

Site and Bank	Spring Fresh	IVT	Autumn Fresh
Darcy's Track Bank B			✔
Darcy's Track Bank D	✔	✔	✔
Loch Garry Bank C	✔	✔	✔
McCoy's Bridge Bank C		✔	✔
McCoy's Bridge Bank D		✔	✔
McCoy's Bridge Bank E	✔	✔	✔

B1 - Spring fresh event

The following banks were monitored before and after the Spring Fresh to capture changes to bank condition during this period:

- *Darcy's Track - Bank D*
- *Loch Garry – Bank C*
- *McCoy's Bridge - Bank E*

Darcy's Track – Bank D

Figure B-1 shows the DEMOD for the Spring Fresh period at Darcy's Track bank D. Observations:

- Erosion is the dominant pattern of change with 5-10 cm occurring along the length of the lower bank (below 1,500 ML/d). Distinct line at a uniform elevation indicates the formation of notching.
- There was minimal deposition except for small, localised areas on the mid-upper upper bank (approximately 2,000 ML/d and above), particularly around obstacles such as trees and woody debris.

This pattern of change partially supports the hypothesis for this flow type.

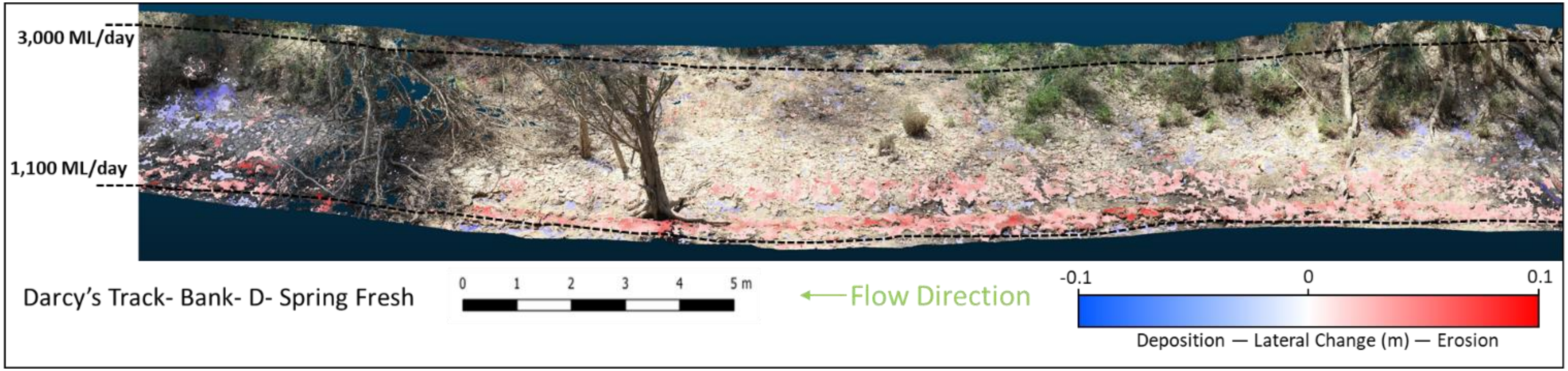


Figure B-1 DEMOD illustrating change in response to Spring Fresh event at Darcy's Track bank D.

Loch Garry – Bank C

Figure B-2 shows the DEMOD for the Spring Fresh period at Loch Garry bank C. Observations:

- The dominant process across the entire bank is deposition, with up to 5 cm occurring on both on the lower bank (below the notch) and upper bank.
- There is sporadic and very minor erosion in place on the lower bank.

This pattern of change partly supports the hypothesis for this flow type.

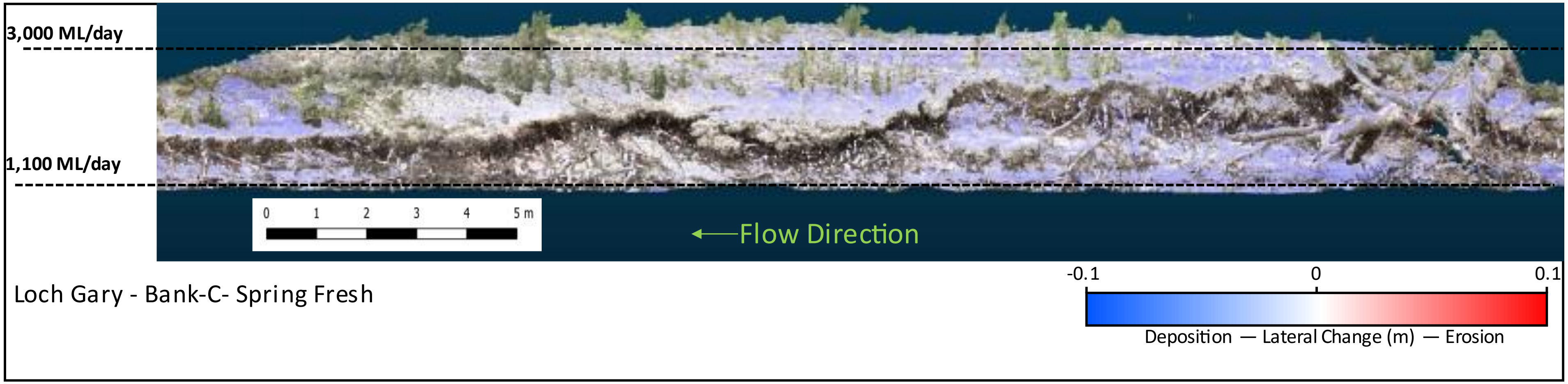


Figure B-2 DEMOD illustrating change in response to Spring Fresh event at Loch Garry bank C.

McCoy's Bridge – Bank E

Figure B-3 shows the DEMOD for the Spring Fresh period for McCoy's Bridge bank E. Observations:

- Deposition (mostly less than 5 cm) is dominant upstream and along the lower bank where it is more severe (below 1,500 ML/d level).
- Erosion of similar magnitudes is dominant on the upper bank at the downstream end.

This pattern of change supports the hypothesis for this flow type.

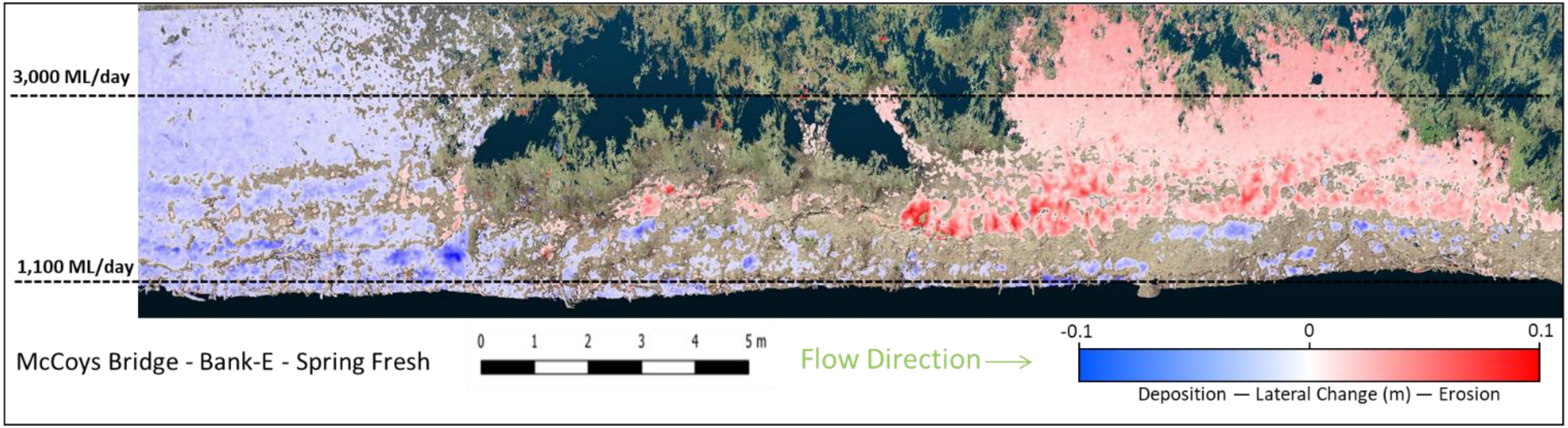


Figure B-3 DEMOD illustrating change in response to Spring Fresh event at McCoy's Bridge bank E.

B2 - IVT period

The following banks were monitored before and after the IVT period to capture changes to bank condition during this period:

- *Darcy's Track - Bank D*
- *Loch Garry - Bank C*
- *McCoy's Bridge - Bank C, Bank D, and Bank E*

Darcy's Track – Bank D

Figure B-4 shows the DEMOD for the IVT period at Darcy's Track bank D. Observations:

- The dominant pattern is one of widespread and deep erosion (10-20 cm) on the lower-mid bank (estimated to be in the 1,300 – 2,000 ML/d range). The severity of erosion is greater than observed as a result of the Spring Fresh.
- There was minor deposition (<3cms) in areas above (>2,000 ML/d) and below (<1,300) areas of major erosion.

This pattern of change strongly supports the hypothesis for this flow type.

Figure B-4 DEMOD illustrating change in response to IVT period at Darcy's Track bank D. Note the wider colour scale (-0.2m to 0.2m) to capture the large magnitude changes.

Loch Garry – Bank C

Figure B-5 shows the DEMOD for the IVT period at Loch Garry bank C. Observations:

- Erosion is the dominant process at this site, with deep erosion (up to 20 cm) primarily expressed on the downstream end of bank and most evident near the toe (estimated at 1,200- 1,500 ML/d level).
- Minor erosion was also observed across the same zone in the upstream section.
- Deposition was minor (<3cm) and spares in areas relating to flows >1,500 ML/d, in particular where there is increased roughness (for example due to vegetation).

This pattern of change supports the hypothesis for this flow type.

Figure B-5 DEMOD illustrating change in response to IVT period at Loch Garry bank C.

McCoy's Bridge – Bank C

Figure B-6 shows the DEMOD for the IVT period at McCoy's Bridge bank C. Observations:

- Defined erosion (4-7 cm) on the lower bank as a defined thin line at the lowest visible area of bank (around 1,100 ML/d flows) and higher (up to 1,700 ML/d) on the downstream bar feature.
- Widespread deposition (3-7 cm) across the middle and upper bank is largely the result of accumulated organic debris (e.g. leaf litter), not sediment deposition from flows.
- Erosion evident on path down the bank arguably from water or campers.

This pattern of change supports the hypothesis for this flow type.

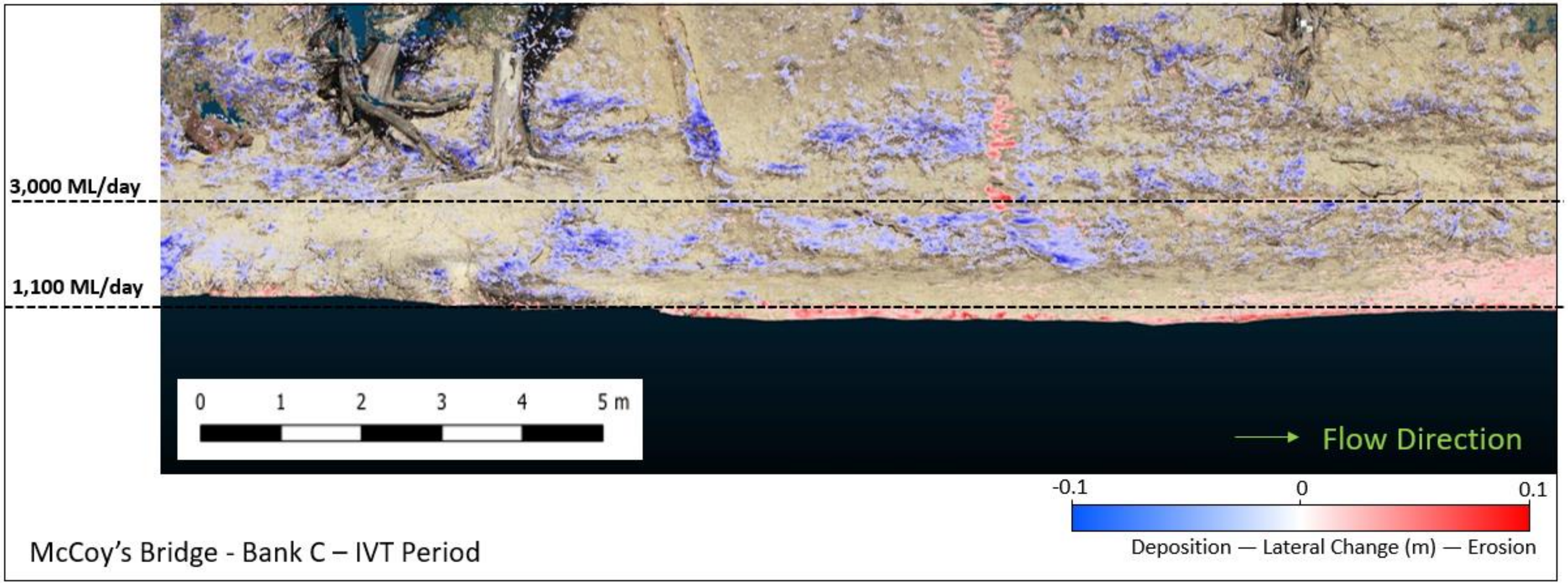


Figure B-6 DEMOD illustrating change in response to IVT period at McCoy's Bridge bank C.

McCoy's Bridge – Bank D

Figure B-7 shows the DEMOD for the IVT period at McCoy's Bridge bank D. Observations:

- Major erosion (up to 7 cm) roughly in the 1,300-2,000 ML/d flow range at the upstream end.
- Moderate scattered erosion in upper areas (>2,000 ML/d) on the downstream end of bank.
- Extensive deposition (3-6 cm) across the lower bank relating to flows of 1,100 – 1,300 ML/d and in areas above (2,000 ML/d) at the upstream end of bank.

This pattern of change does not support the hypothesis for this flow type.

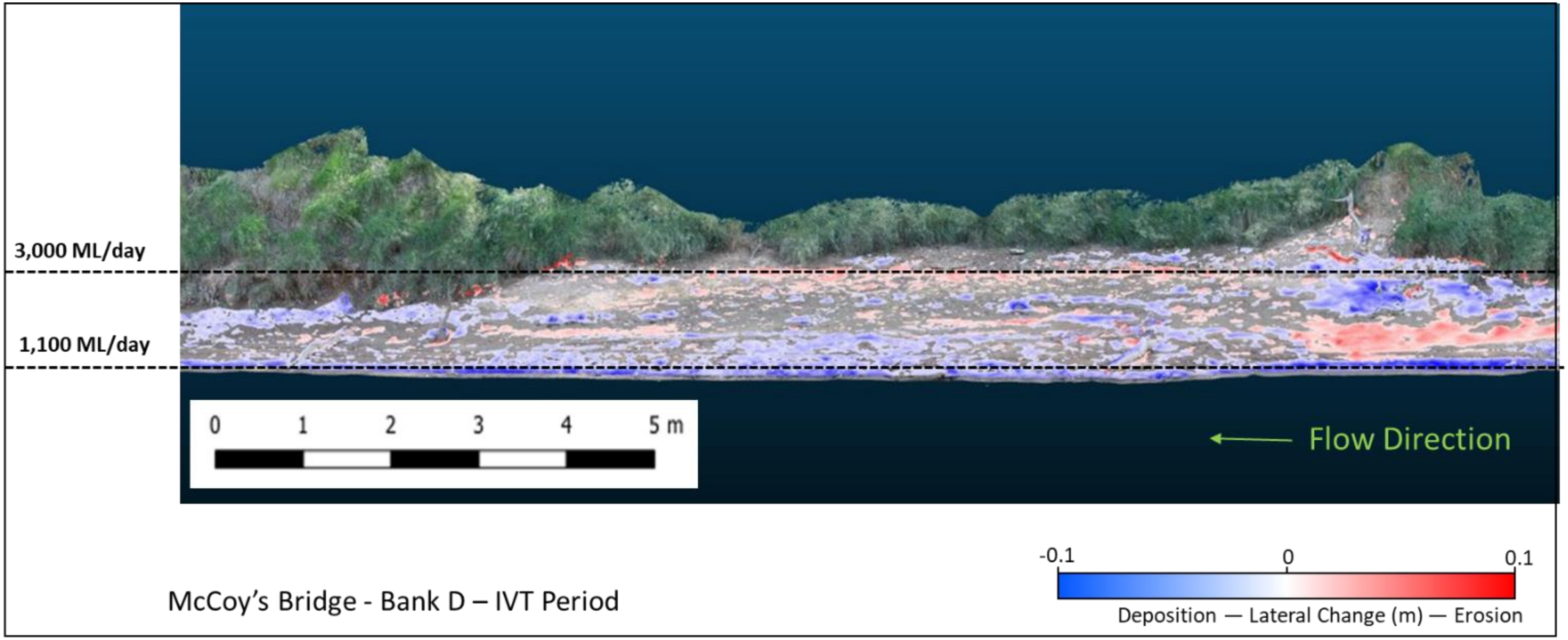


Figure B-7 DEMOD illustrating change in response to IVT period at McCoy's Bridge bank D.

McCoy's Bridge – Bank E

Figure B-8 shows the DEMOD for the IVT period at McCoy's Bridge bank E. Observations:

- Erosion of 2-5 cm in depth across steeper sections of the lower bank (relating to flows around 1,100-1,500 ML/d).
- Deposition of similar magnitude in a defined line along the lower bank (flows around 1,100 ML/d), and on the mid bank (1,500-2,000 ML/d).
- Negligible change on the upper bank (above ~2,000 ML/d).

This pattern of change partially supports the hypothesis for this flow type.

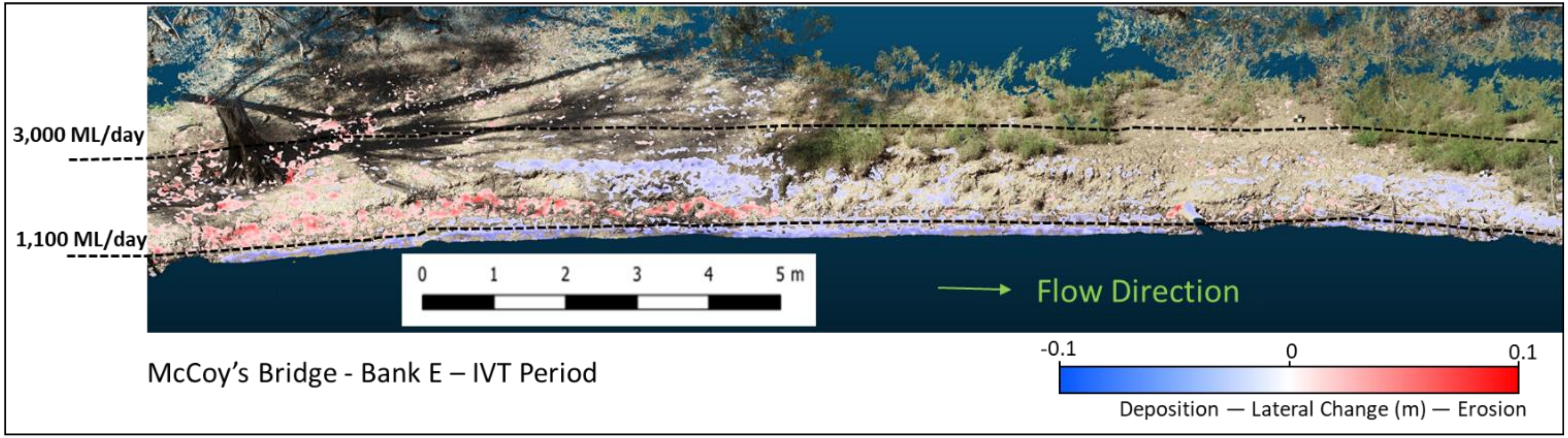


Figure B-8 DEMOD illustrating change in response to IVT period at McCoy's Bridge bank E.

B3 - Autumn fresh event

The following banks were monitored before and after the Autumn Fresh to capture changes to bank condition during this period:

- *Darcy's Track - Bank B and Bank D*
- *Loch Garry - Bank C*

- *McCoy's Bridge - Bank C, Bank D, and Bank E*

Darcy's Track – Bank B

Figure B-9 shows the DEMOD for the Autumn Fresh period at Darcy's Track bank B. Observations:

- Moderate deposition (up to 5 cm) on the lower bank (roughly in 1,000 - 2000 ML/d range) at the downstream end of the site.
- Minor erosion (< 2 cm) also on the lower bank, but largely restricted to the upstream end of the bank.
- Change to the upper bank difficult to assess due to dense vegetation coverage.

This pattern of change partially supports the hypothesis for this flow type.

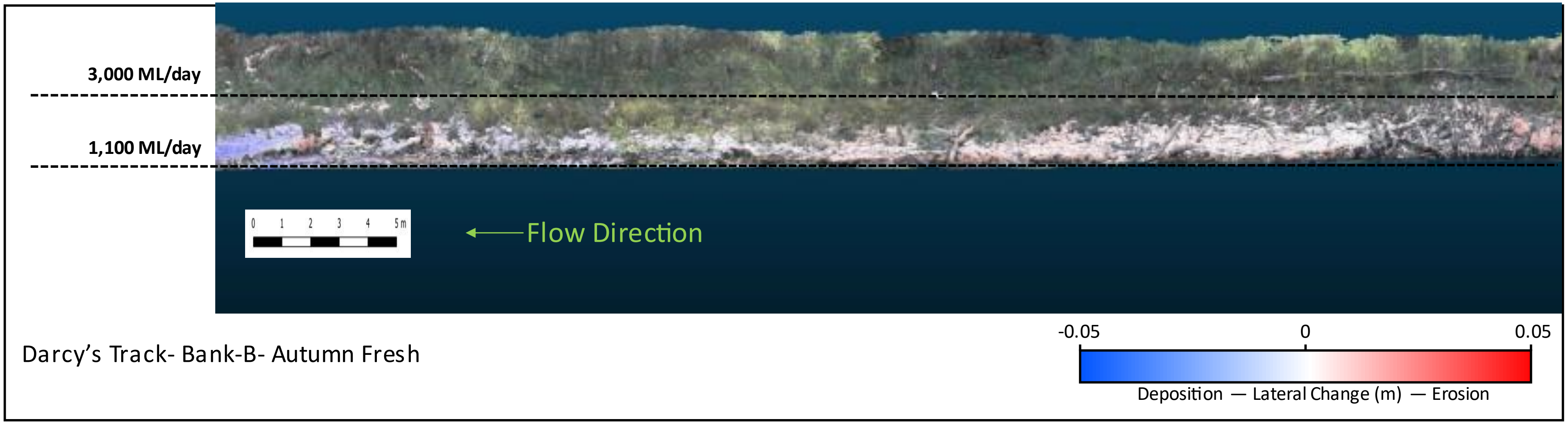


Figure B-9 DEMOD illustrating change in response to Autumn Fresh event at Darcy's Track bank B.

Darcy's Track – Bank D

Figure B-10 shows the DEMOD for the Autumn Fresh period at Darcy's Track bank D. Observations:

- Widespread change (both erosion and deposition) across a large vertical range.
- The most severe erosion is concentrated in patches on the mid bank (~1,500 ML/d level) where existing notches have been enlarged, and also in a thin line along the lowest part of the bank (~1,000 ML/d).
- Deposition is more widespread as erosion, although less severe, and concentrated mostly on the mid-upper bank.

This pattern of change partially supports the hypothesis for this flow type.

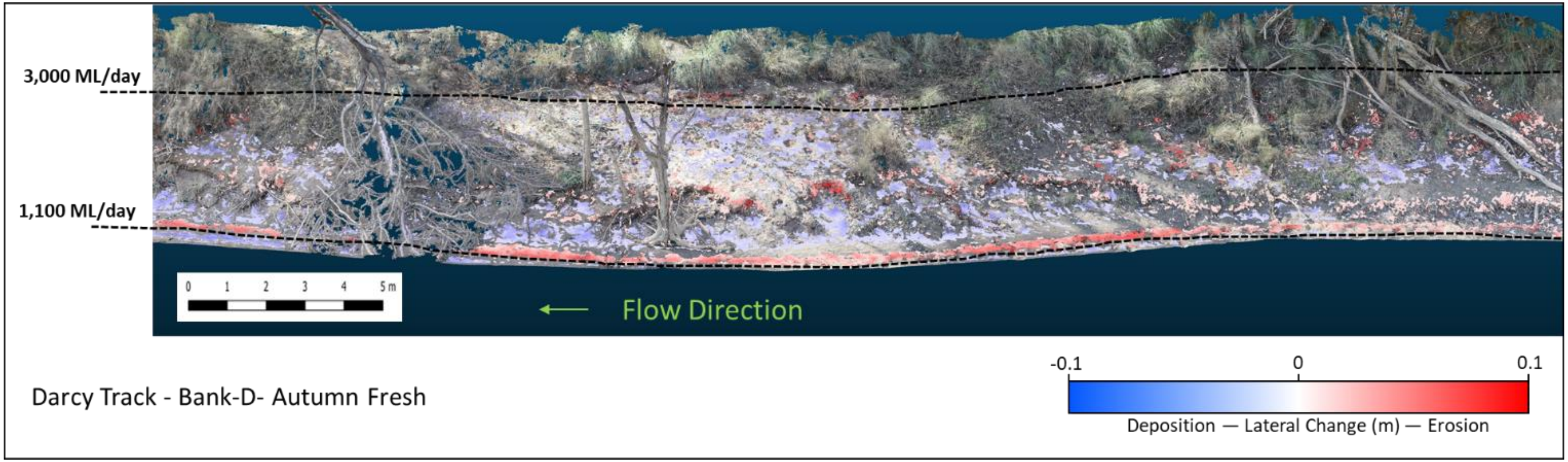


Figure B-10 DEMOD illustrating change in response to Autumn Fresh event at Darcy's Track bank D.

Loch Garry – Bank C

Figure B-11 shows the DEMOD for the Autumn Fresh period at Loch Garry bank C. Observations:

- Change of any sort is minimal at this bank.
- Minor deposition (<5 cm) is widespread across the whole bank, including below the current notch (approximately below 3,000 ML/d flow).
- Erosion is minor (<5cm) and largely in patches on the upper bank at the downstream end (above the existing notch).

This pattern of change supports the hypothesis for this flow type.

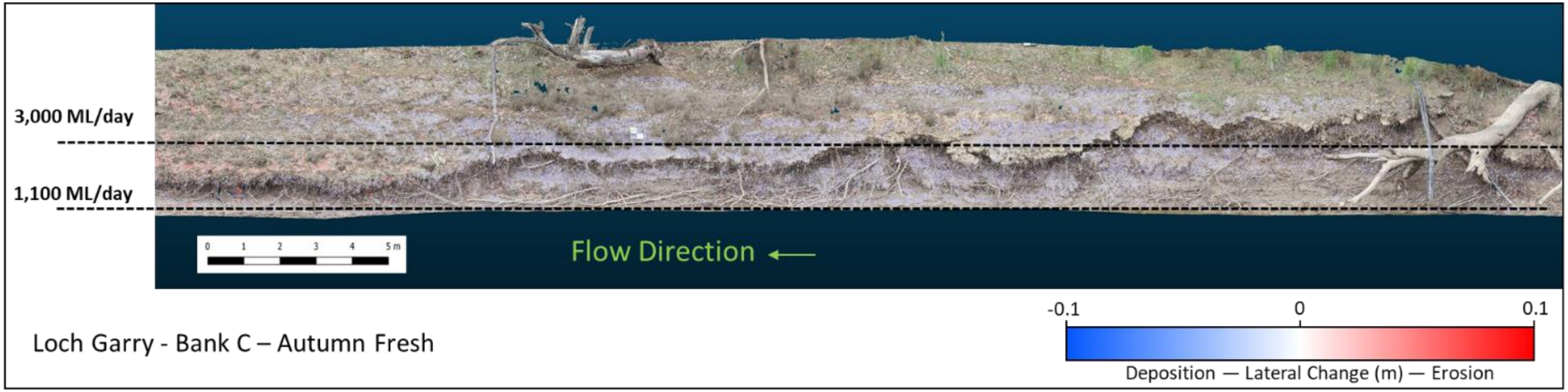


Figure B-11 DEMOD illustrating change in response to Autumn Fresh event at Loch Garry bank C.

McCoy's Bridge – Bank C

Figure B-12 shows the DEMOD for the Autumn Fresh period at McCoy's Bridge bank C. Observations:

- Minimal change of any sort observed at this bank for this flow period.
- Minor and very sporadic erosion and deposition across the whole bank below 3,000 ML/d.

No obvious pattern of change to support or refute the hypothesis.

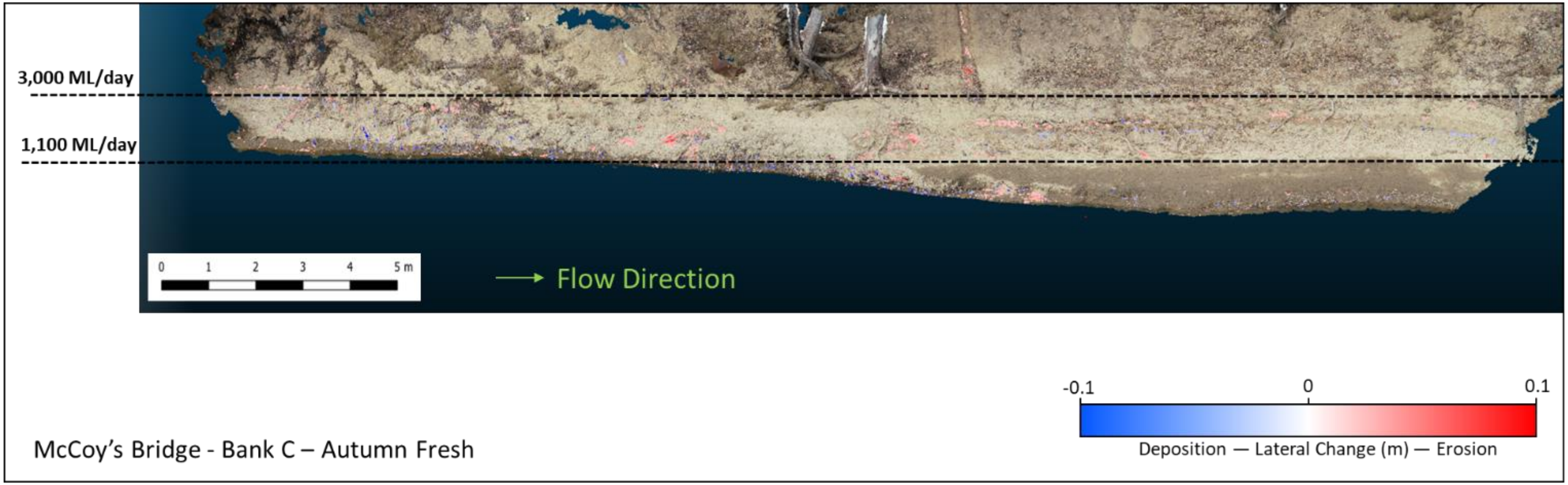


Figure B-12 DEMOD illustrating change in response to Autumn Fresh event at McCoy's Bridge Bank C.

McCoy's Bridge – Bank D

Figure B-13 shows the DEMOD for the Autumn Fresh period at McCoy's Bridge bank D. Observations:

- Widespread deposition (up to 5 cm) across the lower and mid bank (roughly 1,000 – 3,000 ML/d).
- Erosion concentrated mostly on the upper bank (above 3,000 ML/d flow level) with some patches lower.

This pattern of change supports the hypothesis for this flow type.

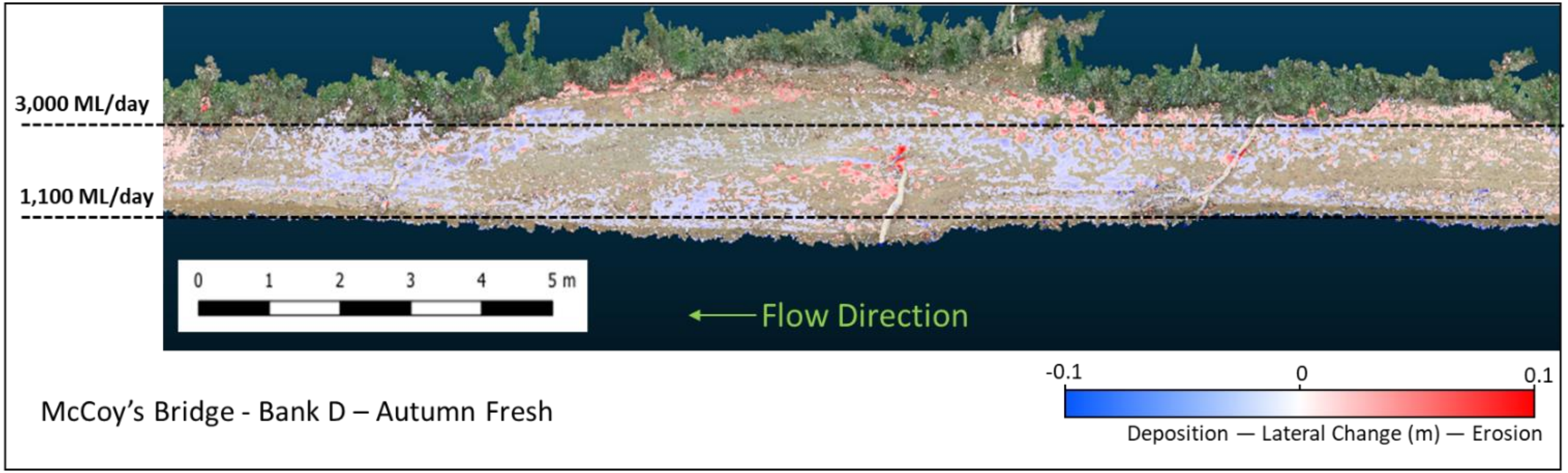


Figure B-13 DEMOD illustrating change in response to Autumn Fresh event at McCoy's Bridge Bank D.

McCoy's Bridge – Bank E

Figure B-14 shows the DEMOD for the Autumn Fresh period at McCoy's Bridge bank E. Observations:

- Minor but consistent erosion along entire length of lower bank (approximately below 1,500 ML/d flow level).
- Deposition generally more prevalent, and prominent on the mid-upper bank, in particular around roughness elements such as debris and vegetation.

This pattern of change partially supports the hypothesis for this flow type.

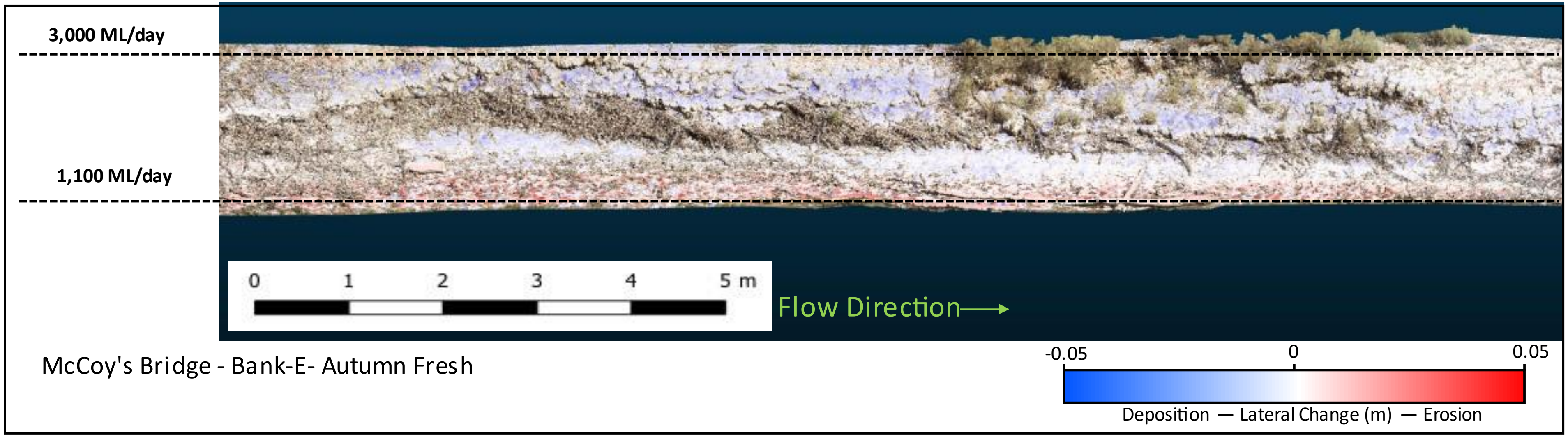


Figure B-14 DEMOD illustrating change in response to Autumn Fresh event at McCoy's Bridge Bank E.

Appendix C: Bank condition modelling – additional context to findings

Environmental Flow Analysis

The 95% credible intervals of regression coefficients (effect of inundation duration) for three erosion levels at three sites are summarized in Table C-1.

Table C-1 95% credible intervals of regression coefficient (eff_inund) for three erosion levels in three sites. The regression coefficients for deposition are inverted, with positive numbers indicating increased disposition with increased inundation. 'Significant' effects (where the 95% credible interval does not cross zero) are printed in bold.

Bank activity	Coefficients	Darcy's Track			Loch Garry			McCoy's Bridge		
		2.50%	50%	97.50%	2.50%	50%	97.50%	2.50%	50%	97.50%
Significant erosion (> 30 mm)	eff_inund	**0.21**	**0.42**	**0.64**	**0.5**	**0.63**	**0.76**	-0.12	0.06	0.24
Erosion (> 5 mm)	eff_inund	-0.09	0.04	0.17	**0.28**	**0.39**	**0.49**	**0.14**	**0.24**	**0.33**
Deposition (> 5 mm)	eff_inund	**0.36**	**0.24**	**0.12**	**0.42**	**0.31**	**0.22**	**0.34**	**0.24**	**0.14**

Predictive curves (Figure C-1) back up the above results, with probability of erosion (both significant minor) and deposition showing increases with increasing simulated inundation periods at all three sites. Consistent with the parameter estimates, the magnitudes of effect on significant erosion at McCoy's Bridge and on minor erosion at Darcy' Track are not as obvious as others.

By running the models with and without the environmental flows delivered from 2019 to 2021, we can see the predicted difference in probability of erosion at different points on the bank (Figure C-2). With a reduction in flows, we expect to see less erosion and deposition (i.e. a positive difference). This can be seen at all three sites, except that there are only minor differences in the probabilities for significant erosion at McCoy's' Bridge and for erosion at Darcy's Track.

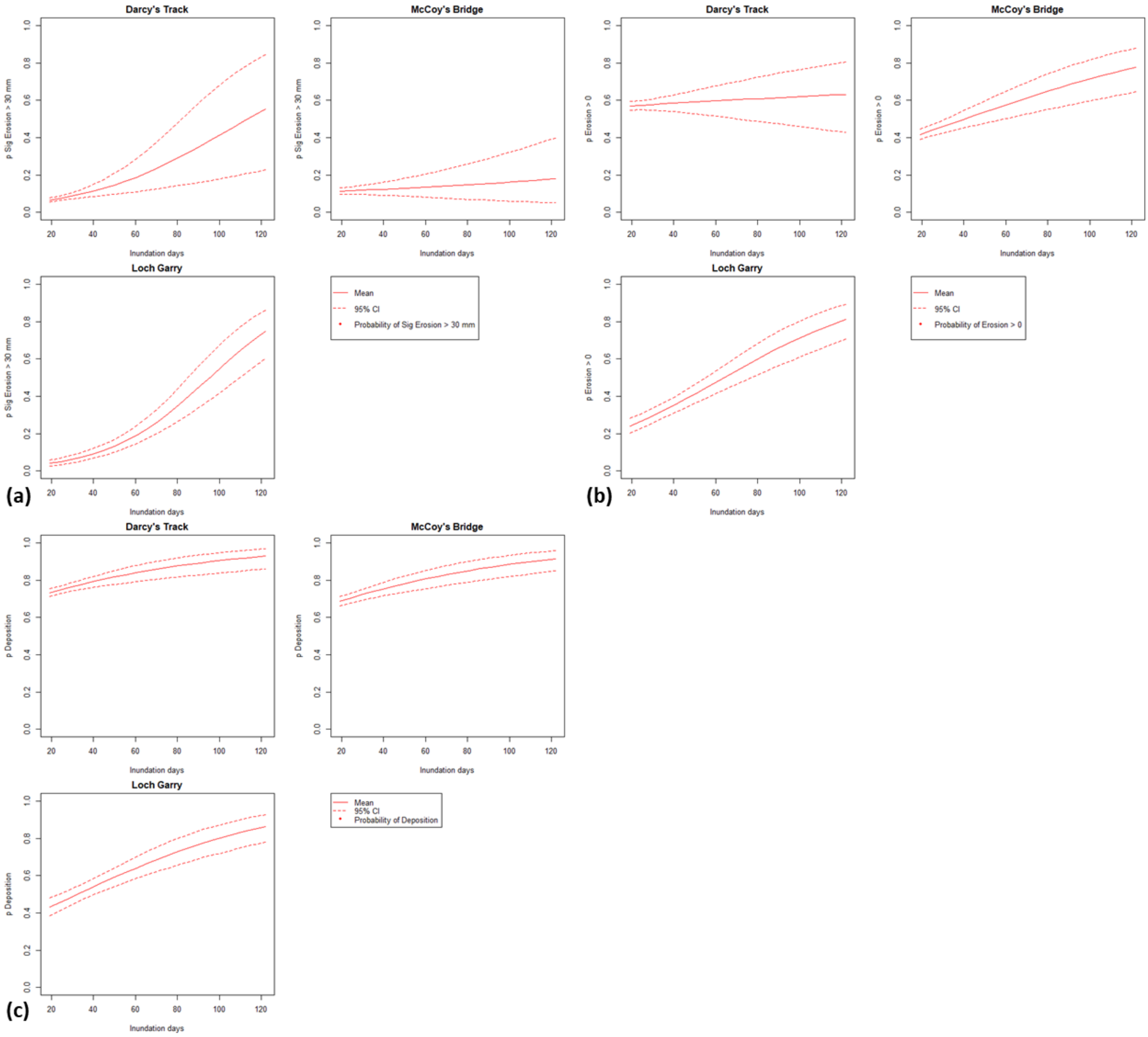


Figure C-1 Relationship between inundation period and simulated probability of erosion. (a) significant erosion: > 30 mm; (b) erosion: > 5 mm; (c) deposition: > 5 mm. For each erosion level, results are shown for three sites (Darcy's Track, Loch Garry, and McCoy's Bridge) in individual panels. The solid line is the median probability of erosion with the dotted lines encompassing the 95% credible interval for the estimate.

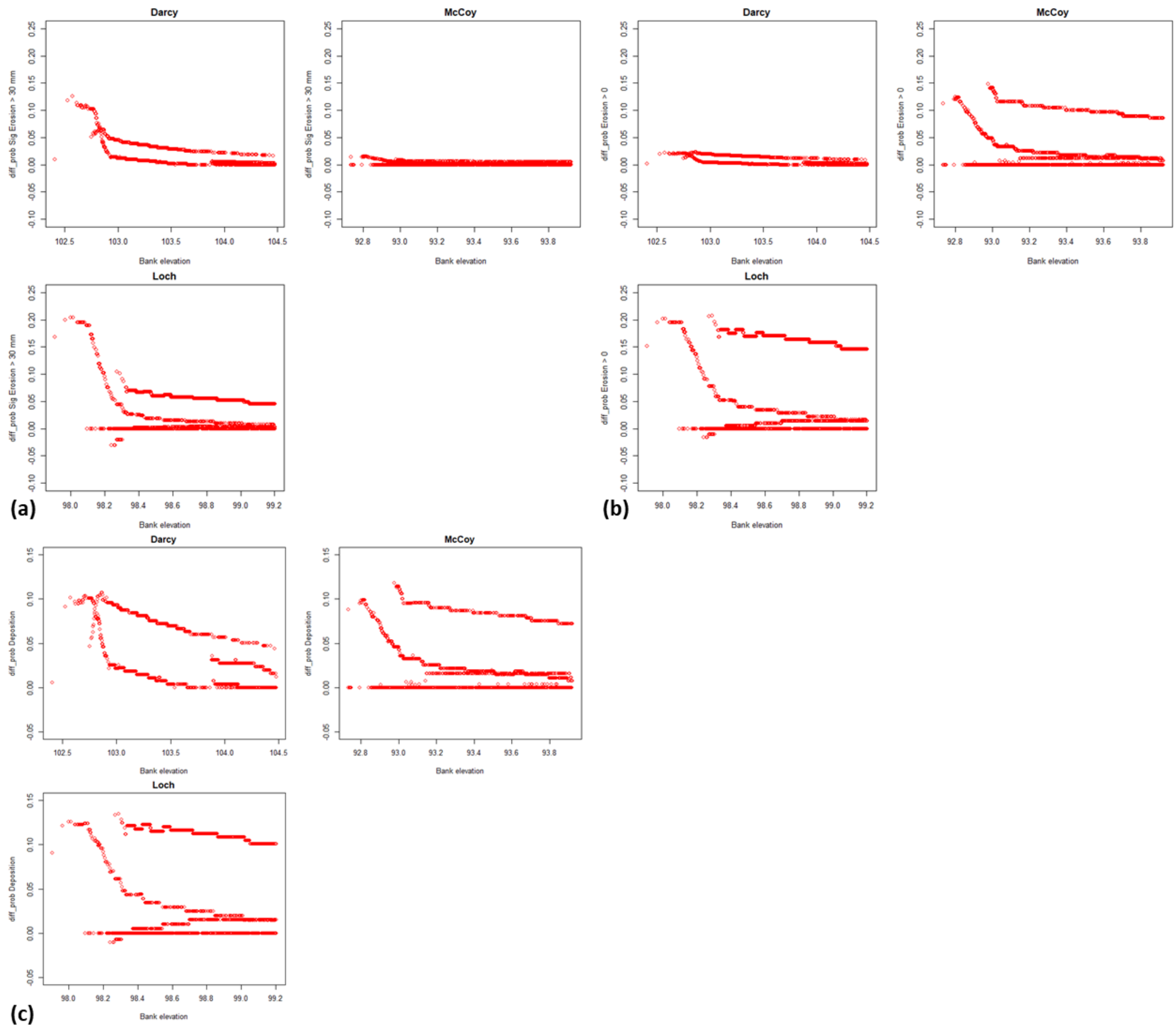


Figure C-2 Effect of the environmental flow component on the probability of erosion, relative to bank elevation (m). (a) significant erosion: > 30 mm; (b) erosion: > 5 mm; (c) deposition: > 5 mm. y axis shows the difference between erosion probabilities WITH and WITHOUT environmental flows. A positive difference implies greater erosion or deposition when environmental flows are being delivered.

Notching Analysis

The 95% credible intervals of regression coefficients (effect of inundation duration and effect of dry period) for three erosion levels at three sites regarding notching analysis are summarized in Table C-2.

Table C-2 95% credible intervals of regression coefficients (eff_inund) for three erosion levels of notching in three sites. As with Table 1, the figures for Deposition are inverted relative to analysis output, and 'significant' parameter values are printed in bold.

Bank activity	Coefficients	Darcy			Loch			McCoy		
		2.50%	50%	97.50%	2.50%	50%	97.50%	2.50%	50%	97.50%
Significant erosion (> 30 mm)	eff_inund	-0.06	0.13	0.31	**0.38**	**0.5**	**0.62**	**-0.41**	**-0.21**	**-0.03**
Erosion (> 5 mm)	eff_inund	**-0.38**	**-0.25**	**-0.13**	**0.51**	**0.61**	**0.72**	-0.06	0.03	0.12
Deposition (> 5 mm)	eff_inund	**-0.13**	**-0.25**	**-0.37**	**0.92**	**0.77**	**0.64**	**0.27**	**0.18**	**0.09**

Similar to the overall erosion/deposition analysis, the predictive curves back up the results regarding the effects of inundation duration for notching analysis (Figure C-3).

The change in the probability of notching-related erosion and deposition with and without environmental flows shows that increases in erosion are confined to the lower levels of the banks, to elevations inundated by baseflows and the higher baseflows of IVT season (Figure C-4). There is less sign of enhanced deposition, with the exception of Loch Garry. The presence of negative changes in probabilities for erosion and deposition reflect the fact that removal of environmental flows will expose some portions of the bank to longer durations of 'near surface' inundation, but probably lower on the bank. It is also worth noting that the removal of environmental flows does not affect the delivery of IVT flows. In future it would be possible to run a counterfactual version of this analysis that removes IVTs from the hydrograph rather than environmental water.

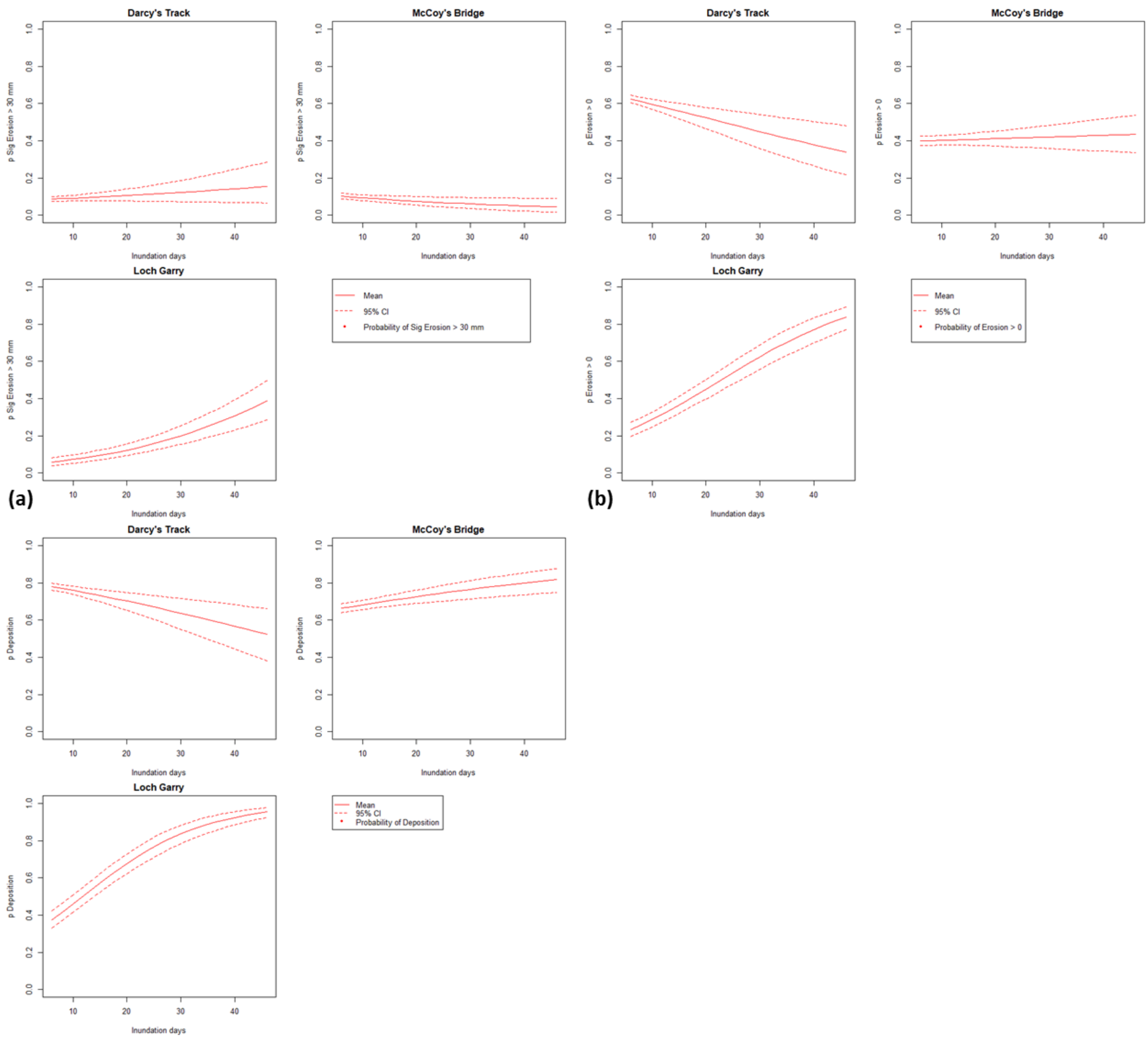


Figure C-3 Relationship between inundation period and simulated probability of notching. (a) significant erosion: > 30 mm; (b) erosion: > 5 mm; (c) deposition: > 5 mm. For each erosion level, results are shown for three sites (Darcy's Track, Loch Garry, and McCoy's Bridge) in individual panels. The solid line is the median probability of notching with the dotted lines encompassing the 95% credible interval for the estimate.

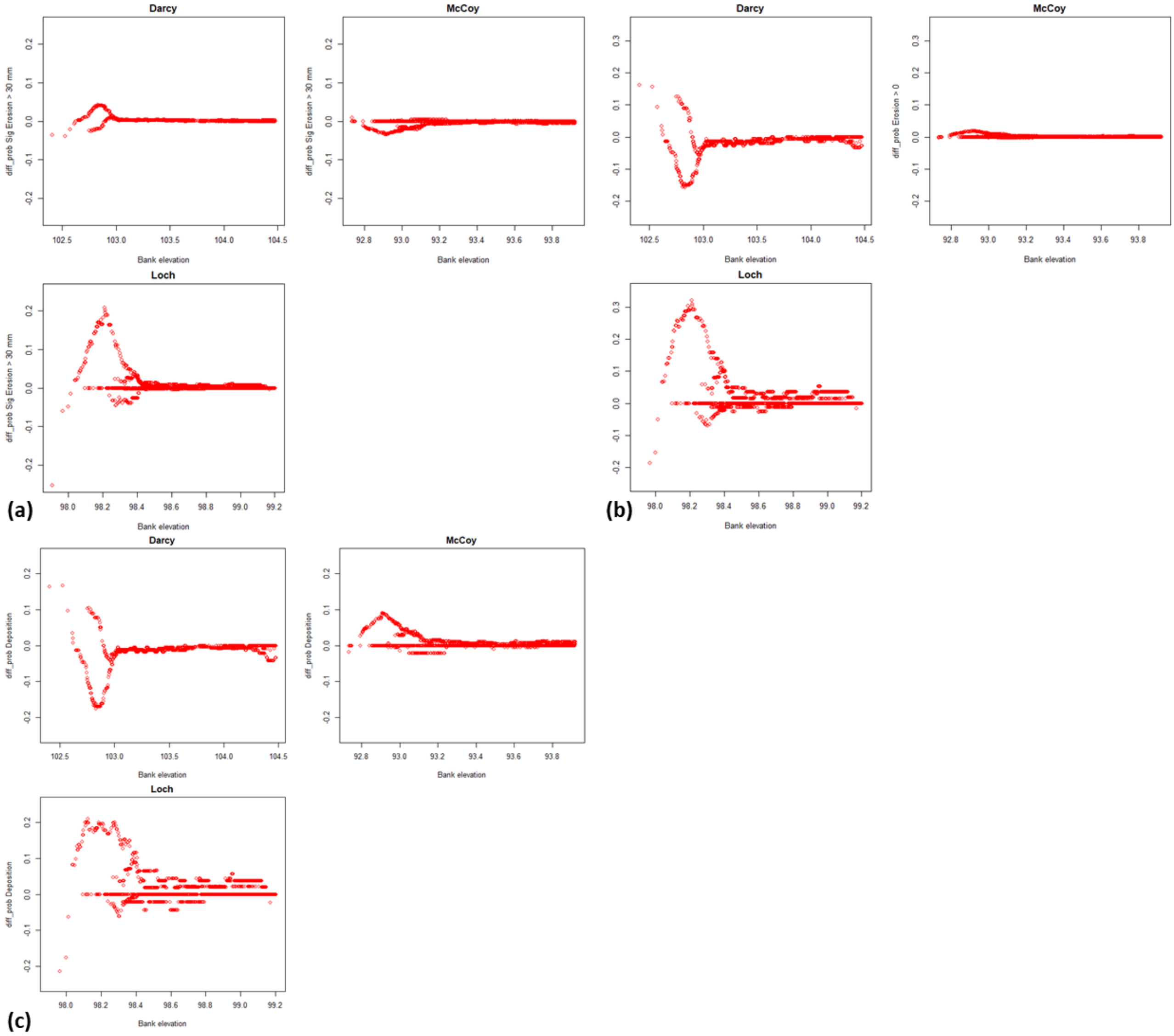


Figure C-4 Effect of the environmental flow component on the probability of notching, relative to bank elevation (m). (a) significant erosion: > 30 mm; (b) erosion: > 5 mm; (c) deposition: > 5 mm. y axis shows the difference between erosion probabilities WITH and WITHOUT environmental flows.

Appendix D: Turbidity and Nutrient (N, P & C) concentrations of water samples collected from the five study sites over the period May 2019 to April 2021.

Site	Date	Turbidity (NTU)	EC (µS/cm)	NOx (mg N/L)	Ammonia (mg N/L)	Total N (mg N/L)	Total P (mg P/L)	FRP (mg P/L)	DOC (mg C/L)	Chlorophyll-a (µg/L)
Arcadia Downs	26/11/2019	12	55	0.025	0.003	0.32	0.031	0.014	2.4	9.3
	19/12/2019	10	51	0.008	0.002	0.28	0.023	0.003	1.8	12.0
	9/01/2020	11	50	0.012	0.004	0.31	0.031	0.003	1.9	12.0
	27/02/2020	11	63	0.003	0.002	0.25	0.022	0.003	1.9	10.0
	17/03/2020	49	102	0.320	0.043	0.82	0.053	0.003	4.4	7.6
	29/04/2020	38	120	0.370	0.023	0.91	0.059	0.003	5.5	4.9
	18/05/2020	30	122	0.340	0.018	0.94	0.048	0.003	7.6	2.2
	18/06/2020	26	122	0.360	0.044	0.92	0.095	0.003	6.1	2.5
	23/07/2020	37	154	0.320	0.027	1.20	0.096	0.004	7.2	1.4
	18/08/2020	21	145	0.230	0.010	0.66	0.047	0.005	4.5	3.8
	17/09/2020	15	93	0.280	0.009	0.56	0.028	0.003	3.0	10.0
	20/10/2020	21	115	0.210	0.035	1.00	0.062	0.007	7.2	4.4
	19/11/2020	13	57	0.080	0.004	0.38	0.046	0.003	2.4	12.0
	16/12/2020	10	67	0.008	0.002	0.29	0.025	0.004	2.8	13.0
	18/01/2021	11	60	0.004	0.002	0.21	0.026	0.003	2.2	10.0
	18/02/2021	15	83	0.110	0.025	0.66	0.026	0.003	4.2	11.0
	16/03/2021	10	54	0.032	0.002	0.22	0.020	0.003	2.0	7.8
	19/04/2021	7	57	0.063	0.002	0.23	0.022	0.003	1.9	6.3
McCoy's Bridge	6/05/2019	18	74	0.003		0.27	0.026	0.003	1.9	
	3/06/2019	14	75	0.047		0.38	0.028	0.003	2.7	
	2/07/2019	18	82	0.220		0.52	0.030	0.004	3.3	
	5/08/2019	25	89	0.390		0.75	0.028	0.007	5.4	
	2/09/2019	21	129	0.350		0.79	0.042	0.003	6.4	
	7/10/2019	19	59	0.100		0.86	0.066	0.003	2.7	
	11/11/2019	19	90	0.003	0.004	0.33	0.050	0.004	3.7	7.0
	2/12/2019	30	62	0.003	0.005	0.30	0.038	0.003	2.7	9.7
	6/01/2020	16	59	0.003	0.002	0.36	0.050	0.003	2.1	14.0
	3/02/2020	19	67	0.003	0.005	0.34	0.039	0.003	2.1	8.7
	2/03/2020	13	64	0.003	0.004	0.30	0.032	0.003	2.2	6.2
	6/04/2020	24	83	0.008	0.006	0.42	0.043	0.003	3.1	27.0
	4/05/2020	181	114	0.930	0.083	2.33	0.280	0.013	9.1	4.9
	1/06/2020	48	183	0.330	0.040	1.53	0.200	0.057	13.0	4.2
	6/07/2020	43	164	0.280	0.021	1.23	0.130	0.020	9.4	2.6
	3/08/2020	31	115	0.310	0.012	0.64	0.059	0.004	4.6	3.7
	7/09/2020	46	131	0.370	0.079	1.05	0.068	0.009	7.6	2.5
	5/10/2020	22	122	0.170	0.008	0.59	0.067	0.005	5.3	11.0
	10/11/2020	27	118	0.003	0.003	0.62	0.071	0.006	6.5	38.0
	7/12/2020	31	75	0.005	0.002	0.38	0.044	0.003	2.7	15.0
	5/01/2021	35	72	0.035	0.002	0.36	0.050	0.003	2.7	13.0
	2/02/2021	26	70	0.004	0.003	0.30	0.037	0.003	2.5	19.0
	2/03/2021	59	91	0.069	0.002	0.44	0.034	0.003	3.9	21.0
	6/04/2021	29	69	0.003	0.003	0.31	0.027	0.003	2.6	12.0
Murchison	20/05/2019	9	66	0.075		0.30	0.014	0.003		
	19/06/2019	10	66	0.200		0.47	0.024	0.003		
	16/07/2019	15	77	0.160		0.46	0.047	0.003		
	22/08/2019	20	137	0.400		0.80	0.043	0.003		
	17/09/2019	13	114	0.290		0.62	0.032	0.003		
	15/10/2019	8	65	0.069		0.22	0.015	0.003		
	19/11/2019	9	77	0.062	0.004	0.28	0.018	0.003	1.8	
	11/12/2019	10	58	0.029	0.009	0.28	0.019	0.003	1.7	
	23/01/2020	11	52	0.018	0.011	0.31	0.028	0.003	2.0	8.5
	20/02/2020	11	60	0.020	0.008	0.30	0.017	0.003	2.1	12.0
	18/03/2020	55	113	0.430	0.080	1.10	0.068	0.004	5.6	7.1
	16/04/2020	76	130	0.490	0.076	1.14	0.068	0.010	6.8	2.4
	13/05/2020	36	114	0.42	0.029	1.320	0.06	0.005	7.800	1.9
	17/06/2020	21	133	0.33	0.028	0.880	0.04	0.005	5.100	2.6
	23/07/2020	26	140	0.36	0.055	1.030	0.06	0.003	5.200	1.6
	19/08/2020	20	141	0.25	0.016	0.720	0.05	0.005	4.900	3.8
	16/09/2020	14	90	0.32	0.007	0.710	0.03	0.003	2.900	7.7
	29/10/2020	14	112	0.19	0.013	1.000	0.05	0.008	5.300	7.3
	17/11/2020	13	63	0.11	0.002	0.450	0.05	0.005	2.600	10.0
	17/12/2020	13	58	0.031	0.039	0.451	0.03	0.003	3.400	7.6
	19/01/2021	11	55	0.005	0.002	0.215	0.02	0.003	2.500	9.4
	17/02/2021	19	67	0.21	0.016	0.610	0.03	0.003	4.400	11.0
	18/03/2021	10	56	0.017	0.004	0.217	0.02	0.003	1.600	6.9
	20/04/2021	11	52	0.058	0.002	0.288	0.02	0.003	2.200	3.8

Site	Date	Turbidity (NTU)	EC (µS/cm)	NOx (mg N/L)	Ammonia (mg N/L)	Total N (mg N/L)	Total P (mg P/L)	FRP (mg P/L)	DOC (mg C/L)	Chlorophyll-a (µg/L)
Loch Garry	26/11/2019	18	68	0.003	0.005	0.31	0.037	0.003	2.0	12.0
	17/12/2019	14	49	0.004	0.004	0.30	0.025	0.003	1.8	13.0
	23/01/2020	16	68	0.006	0.003	0.34	0.039	0.004	2.3	21.0
	25/02/2020	14	59	0.003	0.002	0.34	0.040	0.003	2.0	8.6
	24/03/2020	52	123	0.450	0.060	1.20	0.087	0.003	5.2	12.0
	27/04/2020	60	150	0.470	0.065	1.20	0.094	0.003	6.4	4.4
	26/05/2020	48	156	0.380	0.029	1.30	0.120	0.024	10.0	2.8
	25/06/2020	38	166	0.530	0.031	1.30	0.120	0.083	9.0	2.2
	22/07/2020	39	200	0.320	0.032	1.20	0.140	0.011	9.9	1.6
	26/08/2020	58	125	0.320	0.018	0.92	0.090	0.008	6.2	3.8
	24/09/2020	16	104	0.220	0.007	0.56	0.055	0.009	3.7	9.7
	28/10/2020	24	104	0.180	0.016	0.71	0.078	0.015	5.8	7.3
	24/11/2020	15	57	0.063	0.049	0.38	0.033	0.003	2.4	16.0
	17/12/2020	29	69	0.003	0.021	0.43	0.044	0.003	2.9	14.0
	27/01/2021	19	56	0.005	0.005	0.35	0.033	0.003	3.2	16.0
	24/02/2021	20	77	0.099	0.003	0.66	0.055	0.003	3.7	16.0
	30/03/2021	18	70	0.007	0.003	0.29	0.024	0.005	2.4	18.0
	26/04/2021	12	53	0.110	0.006	0.42	0.044	0.004	2.1	3.0
Shepparton	20/05/2019	14	71	0.050		0.29	0.029	0.010		
	19/06/2019	19	88	0.210		0.53	0.034	0.003		
	16/07/2019	17	73	0.180		0.43	0.034	0.003		
	22/08/2019	22	131	0.310		0.74	0.045	0.003		
	17/09/2019	14	101	0.220		0.54	0.037	0.003		
	15/10/2019	12	64	0.069		0.26	0.021	0.003		
	19/11/2019	12	76	0.003		0.26	0.021	0.003		
	11/12/2019	16	58	0.003		0.27	0.026	0.003		
	23/01/2020	19	104	0.014		0.26	0.024	0.003		
	20/02/2020	13	57	0.003		0.26	0.020	0.003		
	18/03/2020	45	100	0.330		0.83	0.058	0.006		
	16/04/2020	87	143	0.560		1.31	0.078	0.054		
	13/05/2020	52	133	0.470		1.44	0.099	0.008		
	17/06/2020	33	133	0.330		1.05	0.079	0.007		
	23/07/2020	36	152	0.350		1.09	0.084	0.008		
	19/08/2020	45	153	0.240		0.87	0.085	0.008		
	16/09/2020	23	105	0.310		0.69	0.048	0.006		
	29/10/2020	24	115	0.180		1.38	0.073	0.004		
	17/11/2020	19	74	0.099		0.46	0.047	0.003		
	17/12/2020	16	68	0.005		0.29	0.034	0.003		
	19/01/2021	16	62	0.004		0.22	0.028	0.003		
	17/02/2021	21	93	0.170		0.50	0.031	0.003		
	18/03/2021	12	60	0.011		0.27	0.024	0.006		
	20/04/2021	15	57	0.061		0.27	0.027	0.004		

Appendix E: Summary of McCoy's Bridge flow and metabolism data

Table D-1 Summary of McCoy's Bridge flow and metabolism data stratified by season, then divided into 6 equal-sized bins (combined data set from LTIM and MER).

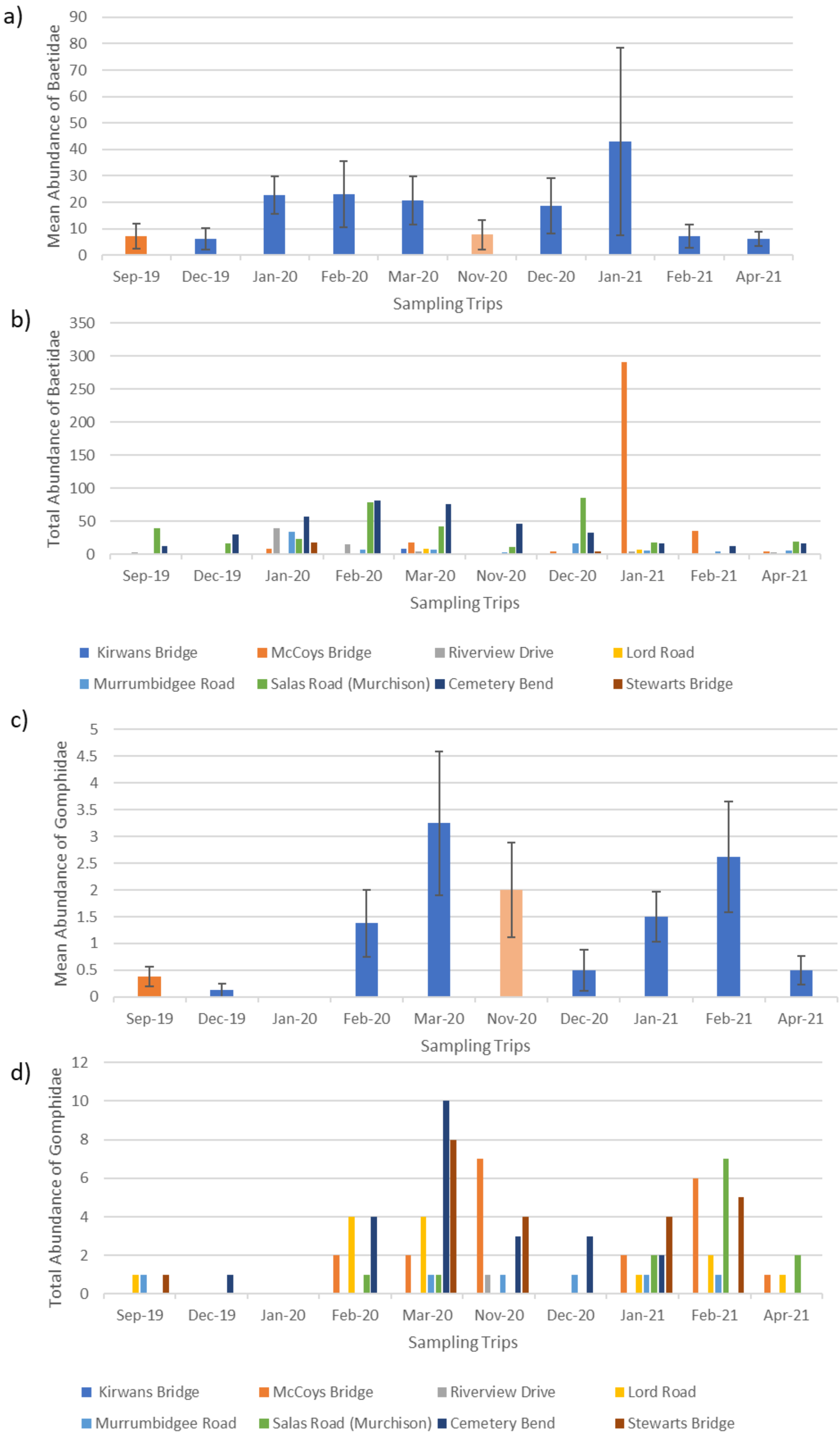
Season	Bin	n	Flow Min (ML/Day)	Flow Max (ML/Day)	Mean GPP (mg O_2/L/Day)	Mean ER (mg O_2/L/Day)	Median GPP (mg O_2/L/Day)	Median ER (mg O_2/L/Day)
Autumn	1	73	684	930	1.27	2.85	1.14	2.61
	2	73	931	1022	1.27	2.89	1.17	2.78
	3	73	1023	1280	1.31	2.99	1.16	2.66
	4	73	1295	1852	1.23	2.60	1.09	2.12
	5	73	1872	2628	1.31	1.81	1.32	1.69
	6	73	2632	5615	1.48	1.46	1.46	1.36
Season	Bin	n	Flow Min (ML/Day)	Flow Max (ML/Day)	Mean GPP (mg O_2/L/Day)	Mean ER (mg O_2/L/Day)	Median GPP (mg O_2/L/Day)	Median ER (mg O_2/L/Day)
Spring	1	59	504	891	1.62	4.85	1.47	4.56
	2	59	891	1076	1.40	2.84	1.34	2.47
	3	59	1077	1426	1.57	2.10	1.45	1.80
	4	59	1438	2325	1.75	2.15	1.53	2.13
	5	59	2337	4518	1.08	1.51	1.05	1.30
	6	58	4564	7673	0.65	1.00	0.63	0.90
Season	Bin	n	Flow Min (ML/Day)	Flow Max (ML/Day)	Mean GPP (mg O_2/L/Day)	Mean ER (mg O_2/L/Day)	Median GPP (mg O_2/L/Day)	Median ER (mg O_2/L/Day)
Summer	1	77	551	991	2.43	6.01	2.01	5.26
	2	77	992	1228	1.94	5.66	1.41	4.65
	3	77	1230	1396	1.62	4.16	1.43	3.71
	4	77	1396	1955	1.28	3.14	1.28	3.02
	5	77	1958	2663	1.34	2.32	1.12	2.16
	6	78	2664	3317	1.90	2.19	2.00	2.27
Season	Bin	n	Flow Min (ML/Day)	Flow Max (ML/Day)	Mean GPP (mg O_2/L/Day)	Mean ER (mg O_2/L/Day)	Median GPP (mg O_2/L/Day)	Median ER (mg O_2/L/Day)
Winter	1	21	632	981	0.78	3.44	0.81	2.00
	2	21	983	1042	0.75	3.49	0.75	1.98
	3	21	1044	1104	0.83	2.90	0.77	2.07
	4	21	1111	1254	0.61	4.09	0.54	3.18
	5	21	1255	1572	0.45	3.51	0.50	2.44
	6	20	1620	8050	0.21	2.74	0.14	1.96

Appendix F: Summary of daily GPP loads

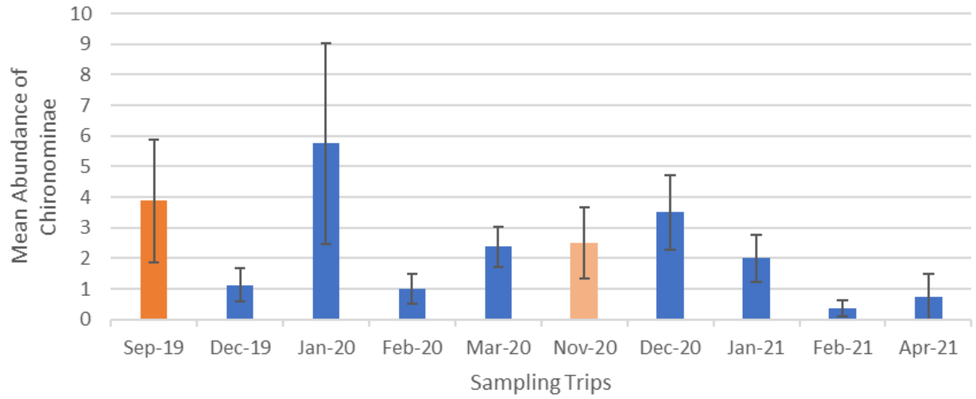
Table E-1 Summary of daily GPP loads (kg Org C/Day) from CEW and non-CEW water (combined data set from LTIM and MER).

Season	Flow Category	n	Mean Daily GPP Load from CEW (kg Org C/Day)	Mean Daily GPP Load from non-CEW (kg Org C/Day)	% Contribution to Total Organic Carbon Load from CEW
Spring	Very Low	177	162	397	29
	Moderately Low	235	296	598	33
	Low Fresh	107	435	482	47
	Medium Fresh	137	829	427	66
Summer	Very Low	134	121	1022	11
	Moderately Low	542	68	991	6
	Low Fresh	346	55	1509	4
	Medium Fresh	30	84	2099	4
Autumn	Very Low	113	109	345	24
	Moderately Low	310	117	468	20
	Low Fresh	159	187	905	17
	Medium Fresh	62	983	523	65
Winter	Very Low	16	126	114	53
	Moderately Low	128	120	134	47
	Low Fresh	27	123	71	63
	Medium Fresh	17	32	193	14

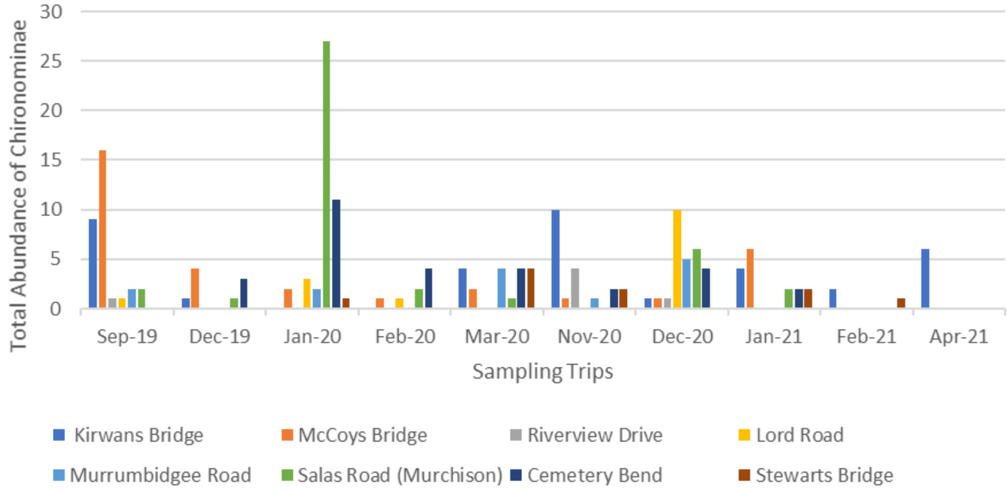
Appendix G: Macroinvertebrate common taxa



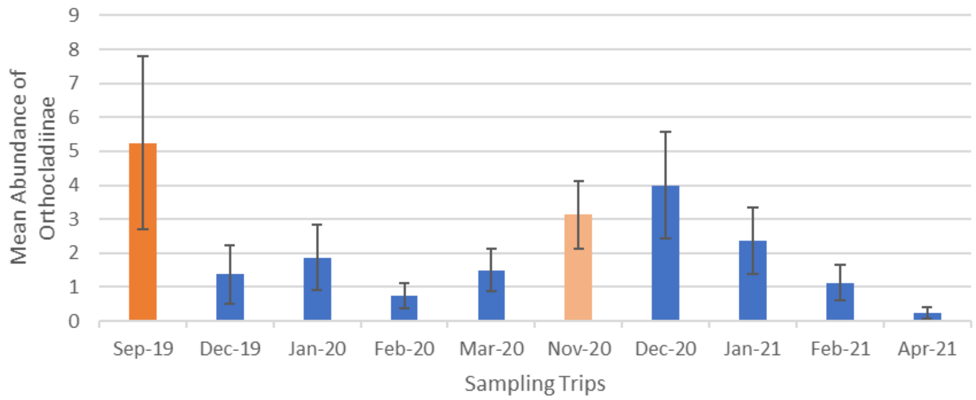
e)


Mean Abundance of Chironominae
10
9
8
7
6
5
4
3
2
1
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips

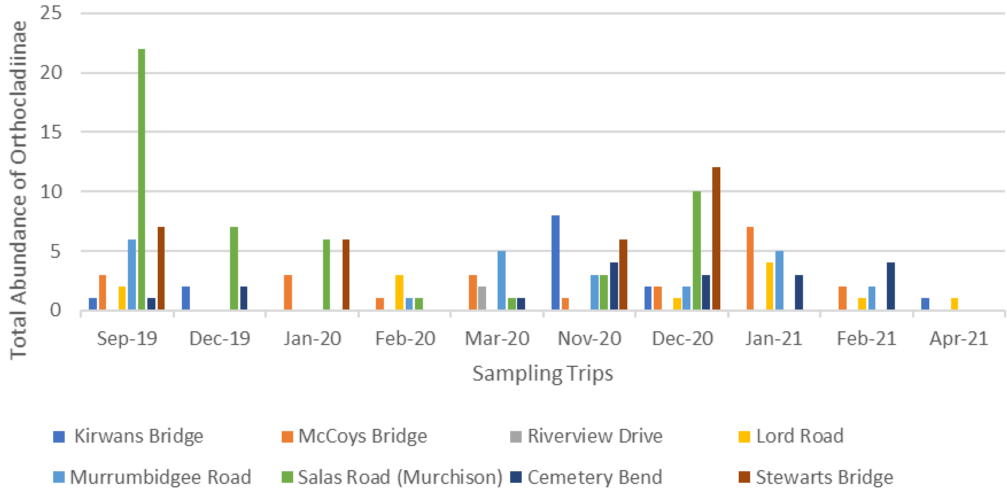
f)


Total Abundance of Chironominae
30
25
20
15
10
5
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips
Kirwans Bridge
McCoys Bridge
Riverview Drive
Lord Road
Murrumbidgee Road
Salas Road (Murchison)
Cemetery Bend
Stewarts Bridge

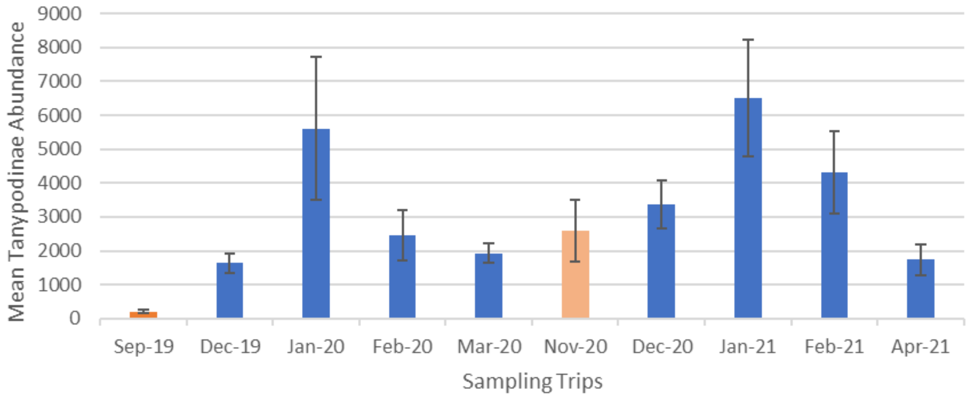
g)


Mean Abundance of Orthocladiinae
9
8
7
6
5
4
3
2
1
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips

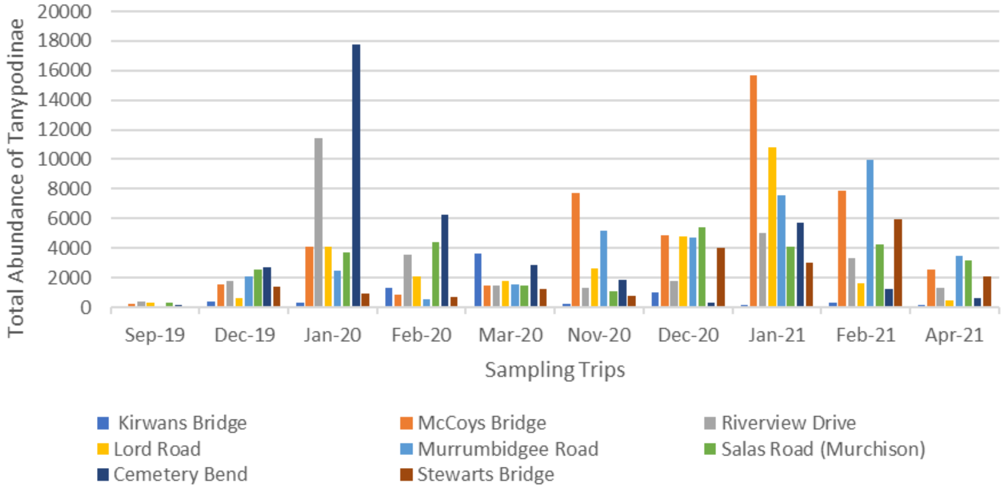
h)


Total Abundance of Orthocladiinae
25
20
15
10
5
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips
Kirwans Bridge
McCoys Bridge
Riverview Drive
Lord Road
Murrumbidgee Road
Salas Road (Murchison)
Cemetery Bend
Stewarts Bridge

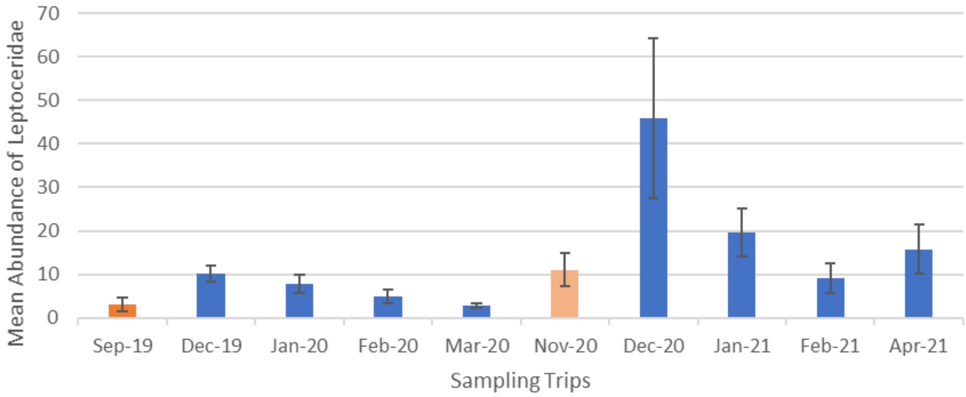
i)


Mean Tanypodinae Abundance
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips

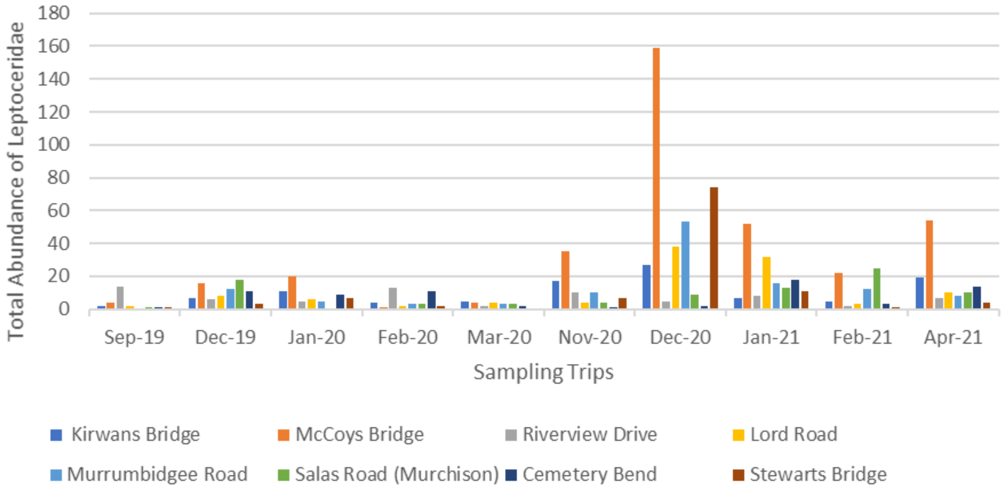
j)


Total Abundance of Tanypodinae
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips
Kirwans Bridge
McCoys Bridge
Riverview Drive
Lord Road
Murrumbidgee Road
Salas Road (Murchison)
Cemetery Bend
Stewarts Bridge

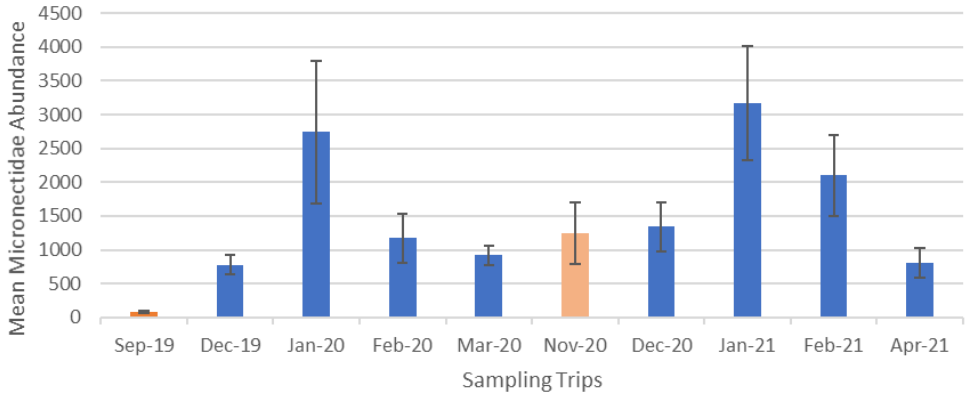
k)


Mean Abundance of Leptoceridae
70
60
50
40
30
20
10
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips

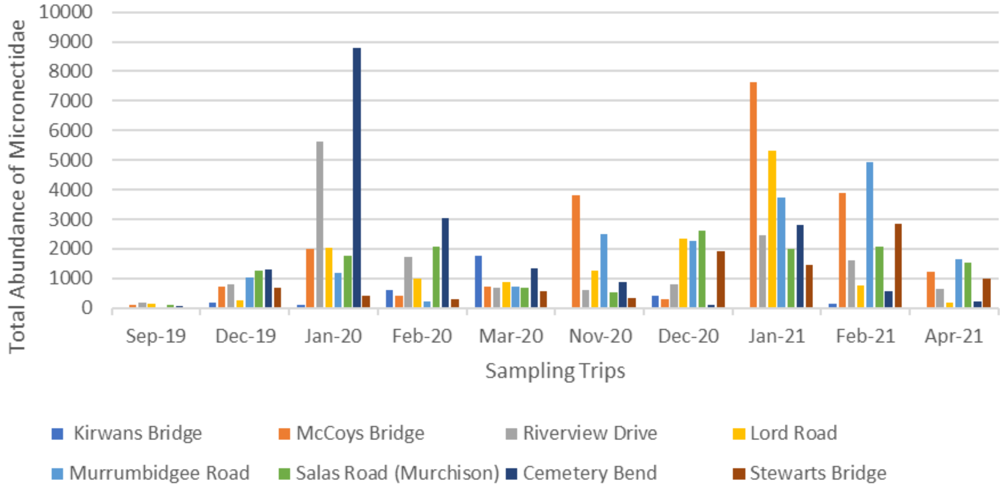
l)


Total Abundance of Leptoceridae
180
160
140
120
100
80
60
40
20
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips
Kirwans Bridge
McCoys Bridge
Riverview Drive
Lord Road
Murrumbidgee Road
Salas Road (Murchison)
Cemetery Bend
Stewarts Bridge

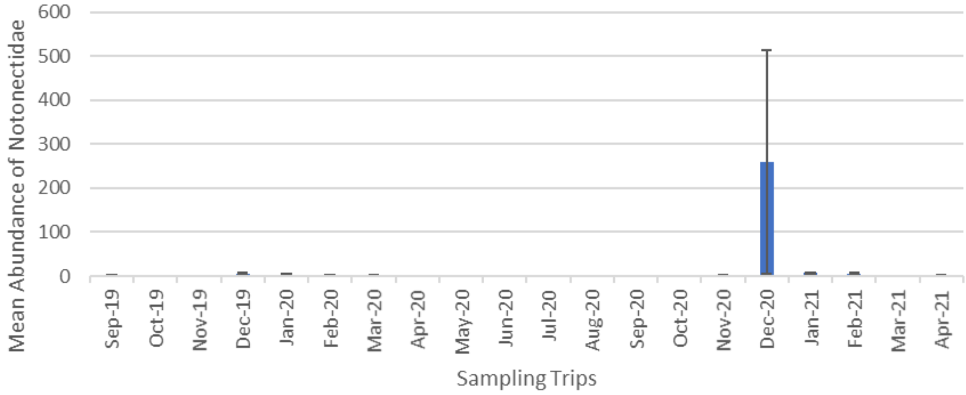
m)


Mean Micronectidae Abundance
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips

n)


Total Abundance of Micronectidae
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips
Kirwans Bridge
McCoys Bridge
Riverview Drive
Lord Road
Murrumbidgee Road
Salas Road (Murchison)
Cemetery Bend
Stewarts Bridge

o)


Mean Abundance of Notonectidae
600
500
400
300
200
100
0
Sep-19
Oct-19
Nov-19
Dec-19
Jan-20
Feb-20
Mar-20
Apr-20
May-20
Jun-20
Jul-20
Aug-20
Sep-20
Oct-20
Nov-20
Dec-20
Jan-21
Feb-21
Mar-21
Apr-21
Sampling Trips

p)

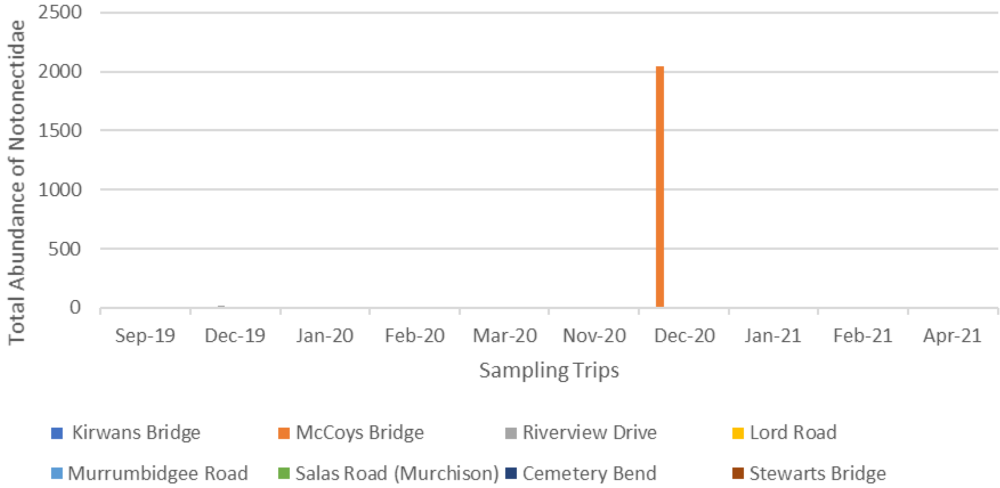

Total Abundance of Notonectidae
2500
2000
1500
1000
500
0
Sep-19
Dec-19
Jan-20
Feb-20
Mar-20
Nov-20
Dec-20
Jan-21
Feb-21
Apr-21
Sampling Trips
Kirwans Bridge
McCoys Bridge
Riverview Drive
Lord Road
Murrumbidgee Road
Salas Road (Murchison)
Cemetery Bend
Stewarts Bridge

Figure F-1 RBA macroinvertebrate sampling a) mean (± standard deviation) abundance Baetidae caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. b) abundance (± standard deviation) of Baetidae for all sites in different months. c) mean (± standard deviation) abundance of Gomphidae caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. d) abundance (± standard deviation) of Gomphidae for all sites in different months. e) mean (± standard deviation) abundance of Chironominae caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. f) abundance (± standard deviation) of Chironominae for all sites in different months. g) mean (± standard deviation) abundance of Orthocladiinae caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. h) abundance (± standard deviation) of Orthocladiinae for all sites in different months. i) mean (± standard deviation) abundance of Tanypodinae caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. j) abundance (± standard deviation) of Tanypodinae for all sites in different months. k) mean (± standard deviation) abundance of Leptoceridae caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. l) abundance (± standard deviation) of Leptoceridae for all sites in different months. m) mean (± standard deviation) abundance of Micronectidae caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. n) abundance (± standard deviation) of Micronectidae for all sites in different months. o) mean (± standard deviation) abundance of Notonectidae caught per sample in different months. Orange colour: before spring fresh 2019; Pale orange: before 2nd small spring fresh 2020; blue colour: after spring fresh. p) abundance (± standard deviation) of Notonectidae for all sites in different months.

Appendix H: Summary of vegetation survey dates, sampling locations and transects.

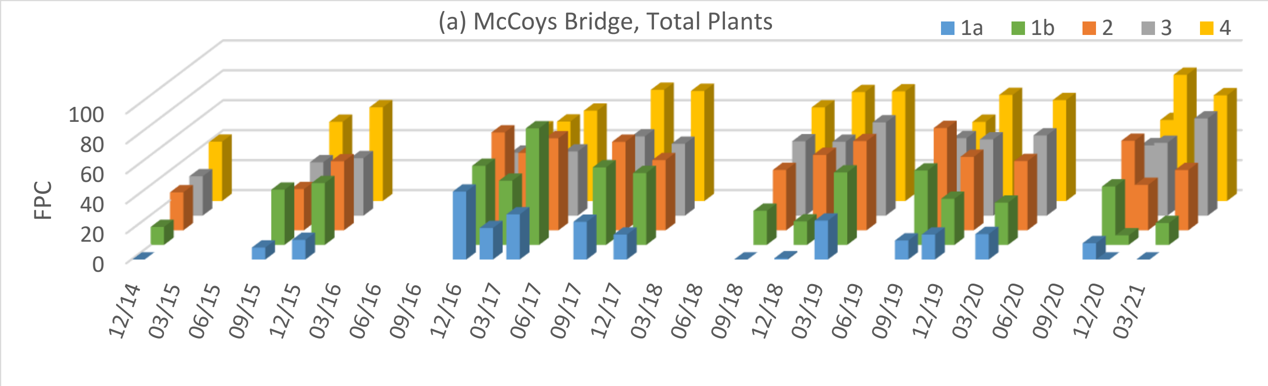
Year	Trip No.	Survey Type	*Date*	Sites sampled	Transects sampled North bank	Transects sampled South bank
2014-15	1	Pre-Spring Fresh	23 Sept & 3 Oct 2014	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13, 15	9, 10, 11, 12, 13
			24 Sept 2014	McCoy's Bridge	1, 2, 3, 6, 8, 10, 12, 13, 15	1, 2, 3, 5, 10, 12, 13, 15
	2	Post Spring Fresh	16 Dec 2014	Loch Garry	1, 3, 5, 8, 9, 12, 13, 15	1,3,5,9,10,12,13,15
			17 Dec 2014	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
2015-16	3	Pre-Spring Fresh	16 Sept 2015	Loch Garry	1, 3, 5, 8, 9,10,12,13	1, 3, 5, 8, 9, 12, 13, 15
			15 Sept 2015	McCoy's Bridge	1, 2, 6, 10, 12, 13,15	2, 3, 6, 10, 12, 13, 15
	4	Post-fresh	16 Dec 2015	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13, 15
			17 Dec 2015	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
2016-17	5	Post natural flood	12 Dec 2016	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13, 15
			13 Dec 2016	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
	6	Pre autumn fresh	21 Feb 2017	Loch Garry	1, 3, 5, 8, 9,10,12,13	1, 3, 5, 8, 9, 12, 13, 15
			22 Feb 2017	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
	7	Post autumn fresh	11 April 2017	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 9, 12, 13, 15
			10 April 2017	McCoy's Bridge	1, 2, 3, 6,10,12,13,15	1, 2, 3, 6, 10, 12, 13, 15
2017-18	8	Pre-Spring Fresh	7 Sept 2017	Loch Garry	1, 3, 5, 8, 10,12,13	1, 3, 5, 8, 9, 12, 13, 15
			8 Sept 2017	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13,15	1, 2, 3, 6, 10, 12, 13, 15
	9	Post Spring Fresh	14 Dec 2017	Loch Garry	8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13, 15
			15 Dec 2017	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
2018-19	10	Pre-Spring Fresh	11 Sept 2018	Loch Garry	1, 3, 5, 8, 10, 12, 13	1, 3, 5, 8, 9,12,13,15
			12 Sept 2018	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
	11	Post Spring Fresh Pre IVT	10 & 11 Dec 2018	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13, 15
			11 & 12 Dec 2018	McCoy's Bridge	1, 2, 3, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
	12	Post IVT	4-5 Mar 2019	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
2019-20	13	Pre-Spring Fresh	17 Sept 2019	Loch Garry	1, 3, 5, 8, 10, 12, 13	1, 3, 5, 8, 9, 12, 13, 15
			16 Sept 2019	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
	14	Post Spring Fresh Pre IVT	28 Nov2018	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13 ,15
			27 Nov 2019	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
	15	Post IVT	2 Mar 2020	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13, 15
			3 Mar 2020	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
2020-21	16	Post natural fresh	4 Nov 2020	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13, 15
			5 Nov 2020	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
	17	Post Fish Fresh Pre IVT	9 Dec 2020	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13 ,15
			10 Dec 2020	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15
	18	Post IVT	10 Mar 2021	Loch Garry	1, 3, 5, 8, 9, 10, 12, 13	1, 3, 5, 8, 9, 12, 13, 15
			11 Mar 2021	McCoy's Bridge	1, 2, 3, 6, 10, 12, 13, 15	1, 2, 3, 6, 10, 12, 13, 15

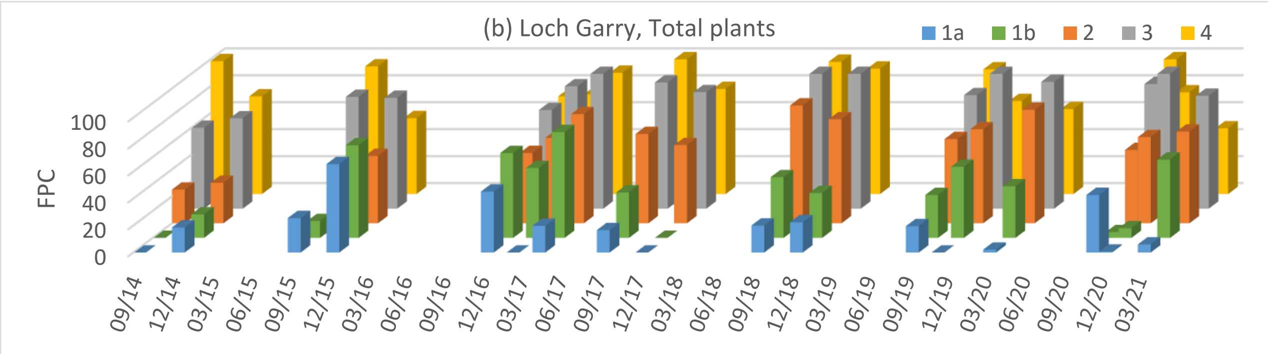
Appendix I: Bank vegetation responses

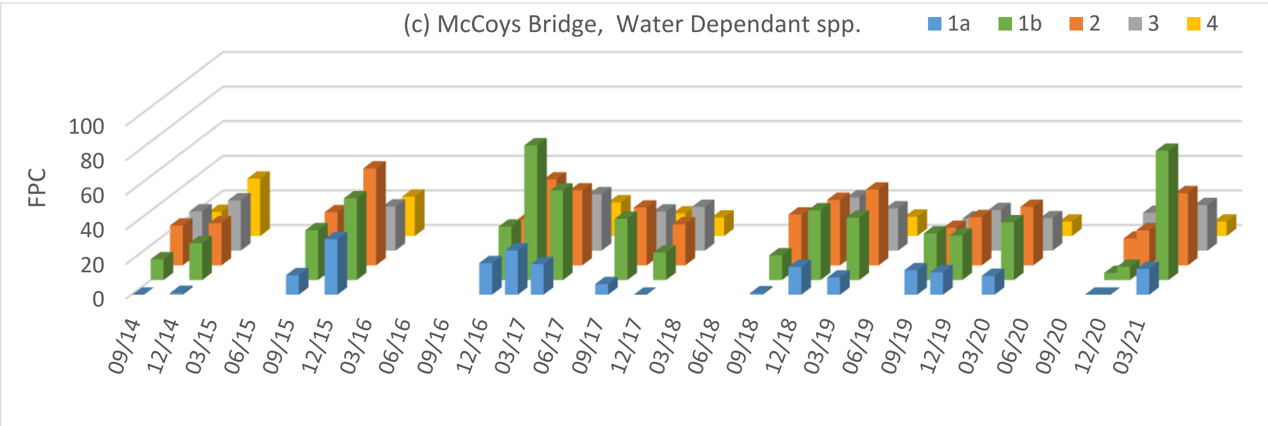
The responses of different vegetation groups and taxa over time in each bank zone are summarised below with relevant graphical responses is provided in Table G-1.

Table G-1 Bank zone elevations and inundation of zone by Spring freshes and Inter Valley Transfers at McCoy's Bridge and Loch Garry.

Site	Zone	Elevation AHD m	Spring fresh	IVT
McCoy's Bridge	Zone 1a	>93.00-93.25	√	√
	Zone 1b	93.25-93.5	√	√
	Zone 2	93.5-94.0	√	√
	Zone 3	94.0-95.5	√	x
	Zone 4	>95.5	x	x
Loch Garry	Zone 1a	<98.3-98.6	√	√
	Zone 1b	98.6-99.05	√	√
	Zone 2	99.05-99.8	√	√
	Zone 3	99.8-101.6	√	x
	Zone 4	>101.6	x	x







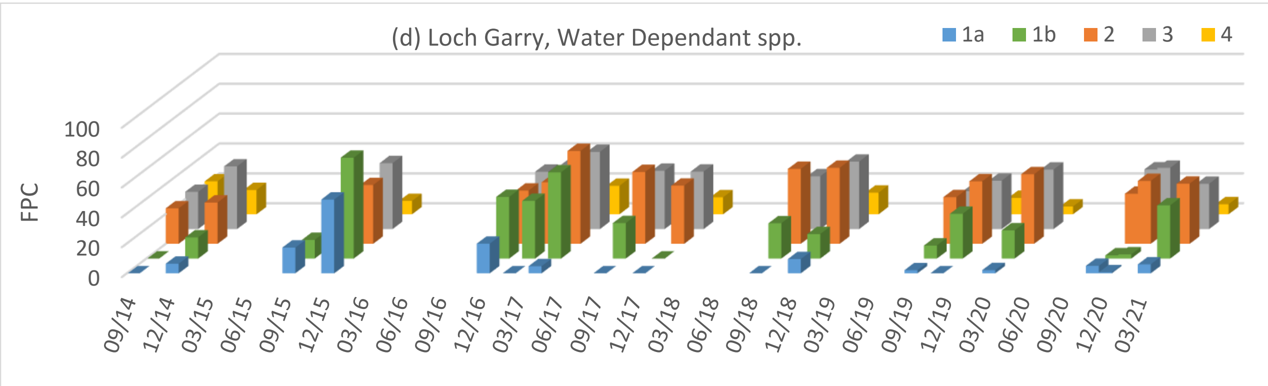
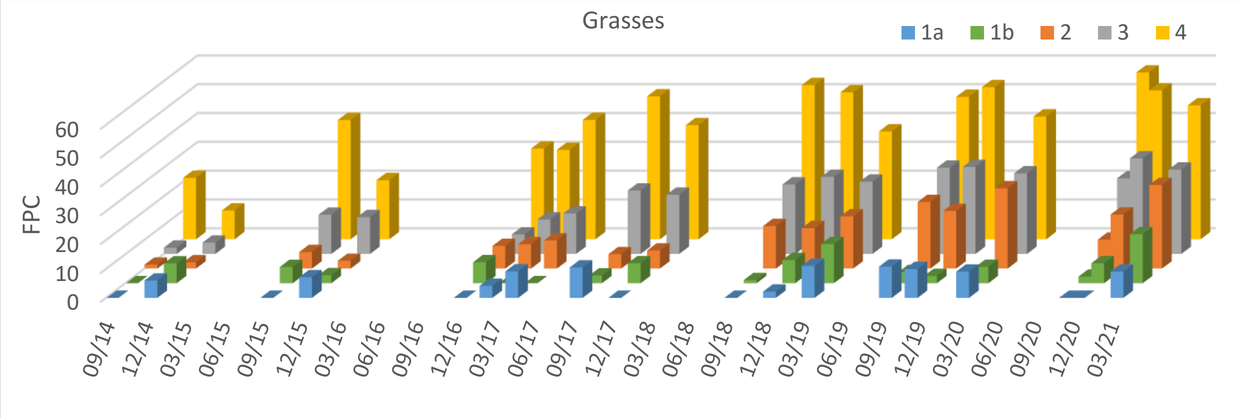
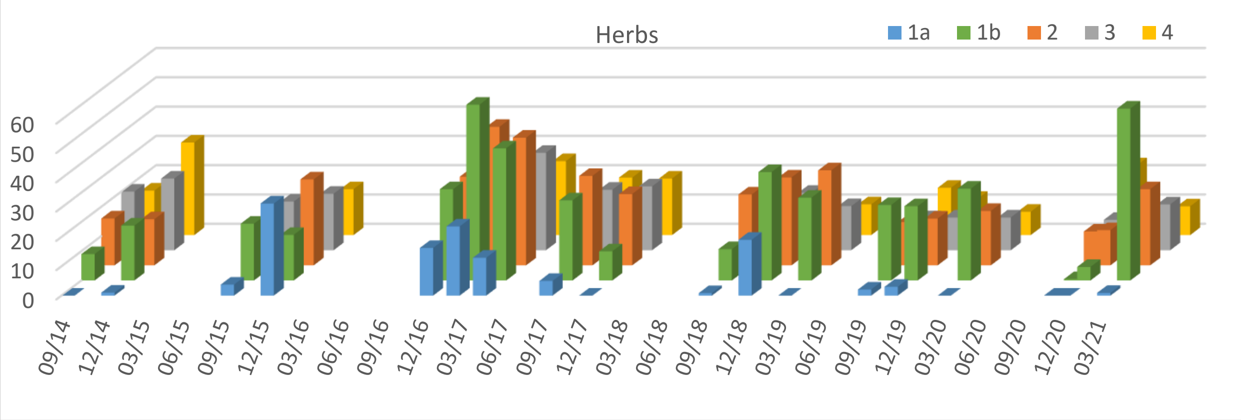
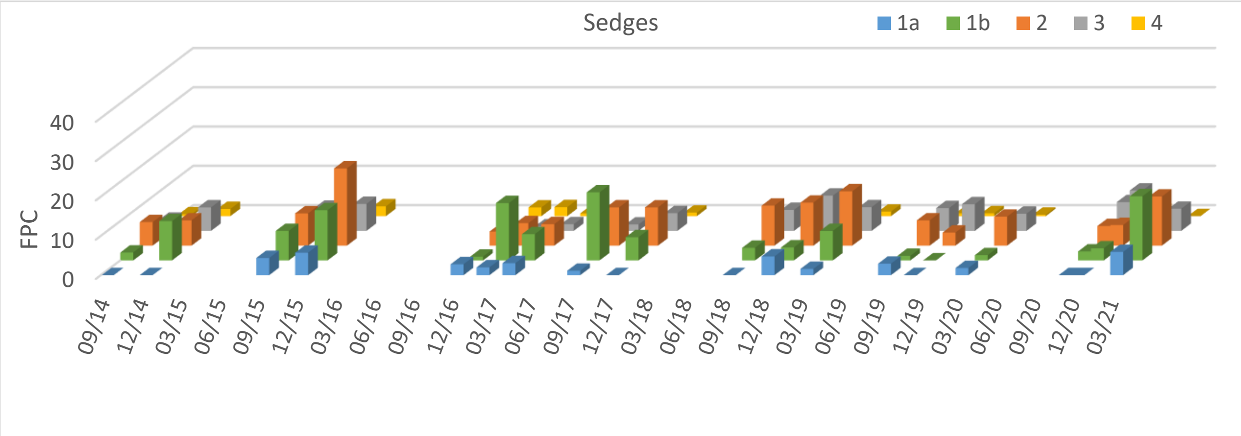


Figure G-1 Average foliage projected cover index of summed cover of ground layer vegetation in each bank zone across surveys for all plants (a,b) and water dependant species (c,d) at McCoy's Bridge (a,c) and Loch Garry (b,d).







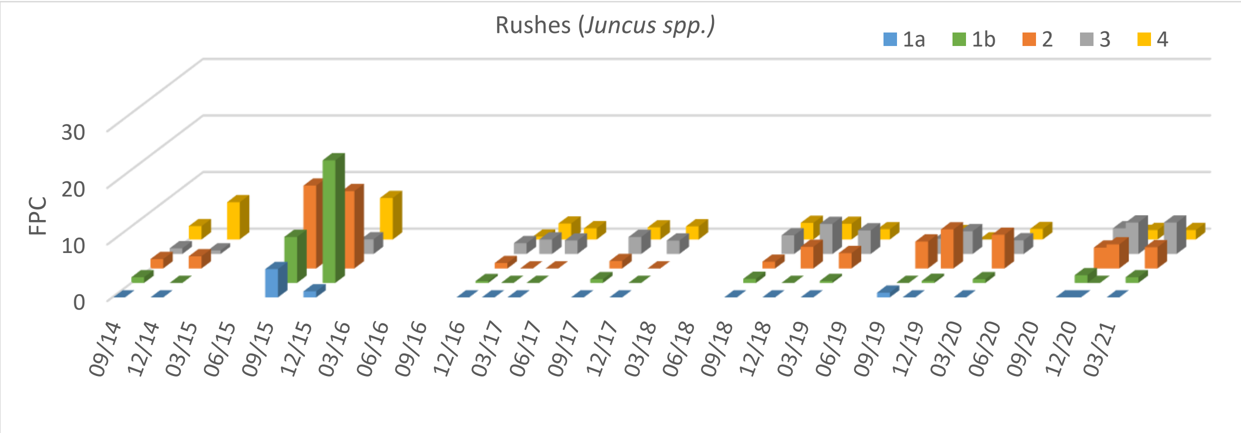
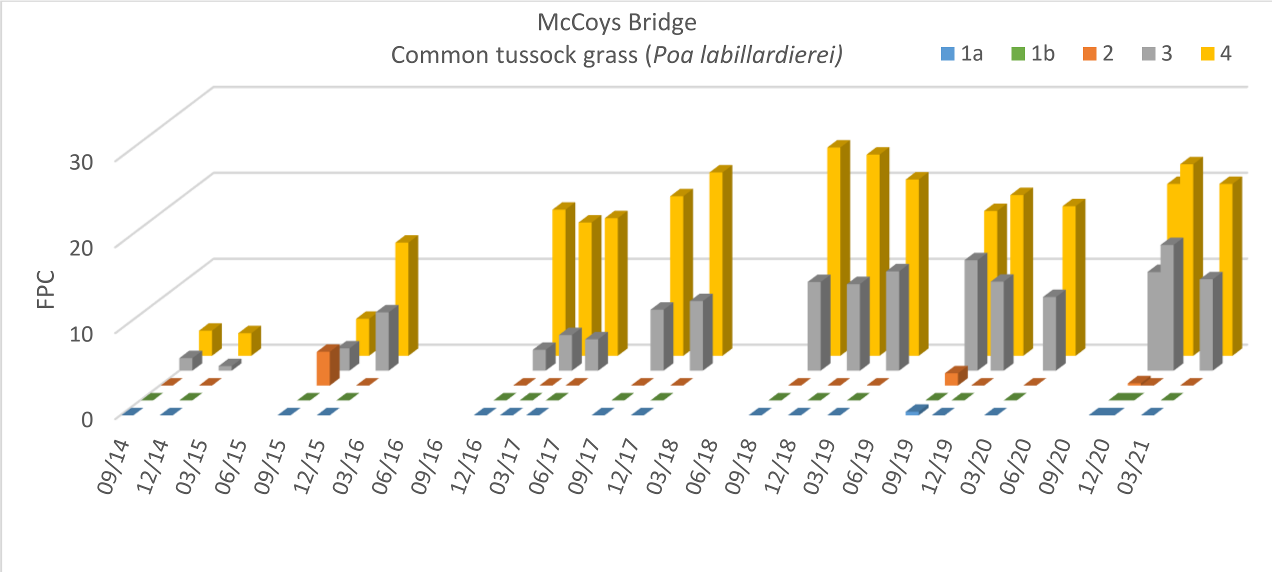


Figure G-2 Average foliage projected cover index of summed cover of ground layer vegetation in each bank zone at McCoy's Bridge across surveys for (a) grasses and (b) herbs and (c) sedges (d) rushes.



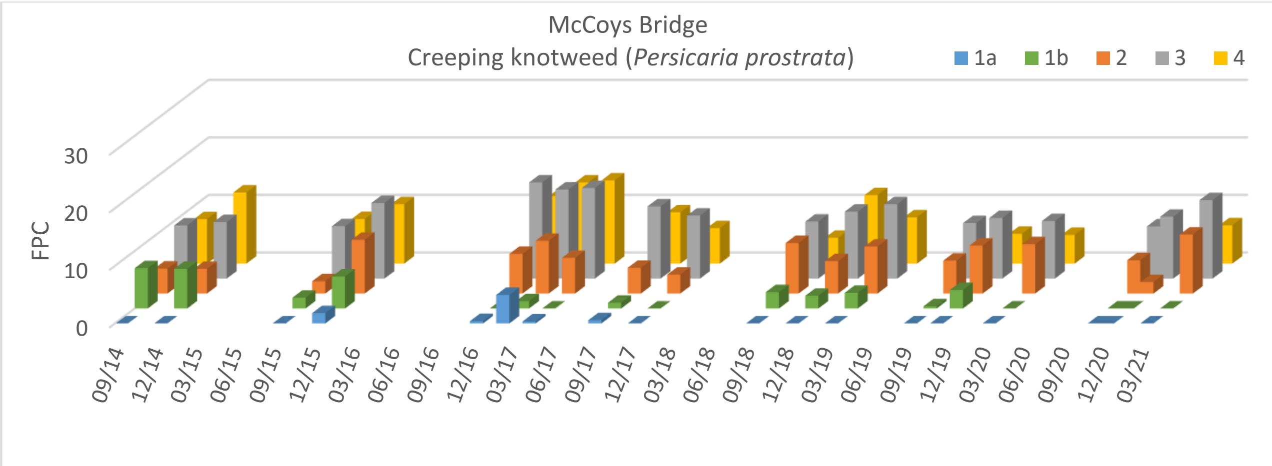


Figure G-3 Average foliage projected cover index (a) Common tussock grass (*Poa labillardierei*) and creeping knotweed (Persicaria prostrata) in each bank zone across surveys at McCoys Bridge.

Appendix J: Taxa recorded deposited on turf mats

Table H-1 All taxa recorded from material deposited on turf mats across different geomorphic features (Bar, Bench, Ledge, Bank, Air) at three sites, Darcy's Track, Loch Garry and McCoy's Bridge for retrievals R5–7. Numbers indicates the abundance of seeds of a particular taxon at a particular site and geomorphic feature for a given retrieval.

Species	DT				LG				MC					Total
	Bank	Bar	Bench	Ledge	Bank	Bar	Bench	Ledge	Air	Bank	Bar	Bench	Ledge	
R5														
Alternanthera denticulata	15	60	26	11	8	19	18	15		76	111	21	11	391
Bromus diandrus				8										8
Callitriche sonderi							2							2
Centipeda cunninghamii	2	9	1			5	21	6		7	22		8	81
Centipeda minima	2	151	7	4	2	3	25	19		8	16	3	3	243
Cyperus difformis		2												2
Cyperus eragrostis	45	314	69	455	30	37	272	111		99	282	46	11	1771
Cyperus exaltatus	371	377	528		38	30	2	22		199	451	187	7	2212
Dysphania ambrosioides		1	1		1						3			6
Dysphania glomulifera					1	6								7
Dysphania pumilo		2									21			23
Elatine gratioloides		1				1				2		1		5
Eragrostis parviflora		1	3		14	9	335	286		9	7	3	1	668
Eucalyptus camaldulensis	42		10	12	8	2	2	1		4	4			85
Fimbristylis spp.			1											1
Gnaphalium polycaulon	21	1			9	13	2	3		10	69	1		129
Juncus amabilis	3	96	12	18	7	6	877	52		235	169	83	1	1559
Juncus articulatus			2											2
Juncus prismatocarpus		3	3			1								7
Juncus usitatus	15	33	42	22	10	21	79	36		38	73	21	8	398
Lachnagrostis filiformis		1						1						2
Laphangium luteoalbum		1	2								1			4
Lipocarpha microcephala												1		1
Lolium sp.1				38										38
Lolium spp.		1												1
Ludwigia palustris	1	77	10		1									89
Lythrum hyssopifolia													1	1
Lythrum salicaria		8				1		2						11
Mollugo verticillata		4	1		2	1				2	5	1		16
Oxalis perennans					5	1		6						12
Panicum coloratum					2	1	7	11			5	3		29
Paspalidium jubiflorum	45			2									6	53
Persicaria decipiens			1											1
Persicaria hydropiper	37		32									49	1	119
Persicaria lapathifolia		185												185
Persicaria prostrata			1	25	3		8	1			12			50
Poa labillardierei											1			1
Polygonum aviculare				1									4	5

Rorippa gigantea							1							1
Rorippa palustris	2	2	1		1	1	1	4			1			13
Symphyotrichum subulatum		12	1	4						1	3			21
Wahlenbergia spp.			1				3	5			4			13
R6														
Acacia dealbata					1									1
Alternanthera denticulata		35		26	14	11	9	18		82	96	12	6	309
Bromus diandrus				2										2
Callistemon spp.								1						1
Centipeda cunninghamii		11		1			87	21		8	2			130
Centipeda minima		163		4	2	10	94	28		5	30	4	1	341
Cyperus difformis		16						1			3	1		21
Cyperus eragrostis		293		1692	21	20	306	181	2	48	107	59	2	2731
Cyperus exaltatus		446			25	25		6	2	151	428	120	1	1204
Dysphania ambrosioides											1			1
Dysphania glomulifera		3		1	6	6	2							18
Dysphania pumilo								2		3	29			34
Ehrharta longiflora									88					88
Elatine gratioloides		1									3			4
Epilobium spp.							2							2
Eragrostis parviflora		17		7	6	4	2278	708		5	10	6		3041
Eucalyptus camaldulensis				4				2	4	32	30		8	80
Euchiton japonicus							3	1			1			5
Gnaphalium polycaulon					5	25	15	4		6	57	1		113
Hypochaeris radicata				1										1
Juncus amabilis		155		54	25	23	790	103		41	113	36	14	1354
Juncus articulatus		5			3									8
Juncus prismatocarpus		22												22
Juncus usitatus		137		61	18	42	85	24	2	88	188	122	14	781
Lachnagrostis filiformis					1		4	1			1			7
Laphangium luteoalbum		1		1	1	2	31			1	3		1	41
Lipocarpha microcephala						1	1							2
Lotus uliginosus				1										1
Ludwigia palustris		88		1							1			90
Lythrum hyssopifolia							5							5
Lythrum salicaria		3			1	1	1							6
Modiola caroliniana		1								2				3
Mollugo verticillata		1			1		2				4	1		9
Oxalis perennans		1			4		1	1						7
Panicum coloratum					2		9	7						18
Paspalidium jubiflorum				27										27
Persicaria prostrata				12	2		3			2	6			25
Poa labillardierei					8			1						9
Polygonum aviculare				1									1	2
Ranunculus sceleratus							1				1			2
Rorippa palustris		1		1				1						3
Rumex brownii					1									1
Solanum nigrum					2									2

Symphyotrichum subulatum		16	41						1	1			59
Typha spp.			1							1		1	3
Verbena officinalis										1			1
Wahlenbergia spp.			2			172	17		4	1			196
R7													
Acacia dealbata				7	2	3	9						21
Alternanthera denticulata	5	23			39	7	2		29	41	6		152
Callitriche sonderi		1								1			2
Centipeda cunninghamii		16		16	1	2	3		1	6	1		46
Centipeda minima		55		13	9	13	18		3	6	5		122
Cyperus difformis		5					1			1			7
Cyperus eragrostis	88	361		143	20	52	239	2	40	151	85	3	1184
Cyperus exaltatus	5	154			38	36	2		113	153	72	1	574
Dysphania ambrosioides							2						2
Dysphania glomulifera					2								2
Dysphania pumilo	1	1			1	4	2			6			15
Elatine gratioloides		1								2			3
Epilobium spp.	1			1		7	1			1	1		12
Eragrostis parviflora		17		126	2	2	215		3	13			378
Erigeron bonariensis				1									1
Eucalyptus camaldulensis		1				1				1			3
Euchiton japonicus					1	1							2
Gamochaeta purpurea				6									6
Glossostigma cleistanthum											1		1
Gnaphalium polycaulon		3		2	22	30	4		18	18	2		99
Hypochaeris radicata				4									4
Isolepis inundata				1	1								2
Juncus amabilis	72	50		74	19	29	40		46	51	103		484
Juncus articulatus	1						1		1				3
Juncus prismatocarpus	1	1											2
Juncus usitatus	423	140		111	26	30	23	1	145	126	245	17	1287
Lachnagrostis filiformis	1	3		1	2		2					2	11
Laphangium luteoalbum		4		5	9	10	2						30
Lipocarpha microcephala						1							1
Lolium spp.	1											10	11
Ludwigia palustris	1	27		1	1								30
Lythrum hyssopifolia				1									1
Lythrum salicaria		5			2	1							8
Mollugo verticillata					3	2							5
Oxalis perennans	1				5	10	5						21
Panicum coloratum				2		2	6			1			11
Paspalidium jubiflorum		1						32					33
Persicaria hydropiper	1	14								2	4		21
Persicaria lapathifolia		3											3
Persicaria prostrata				8	4	2	1		2	2		1	20
Poa labillardierei				1	1	8							10
Ranunculus sceleratus										1			1
Rorippa palustris	1	3		1	1				2	8			16

Rumex brownii							2							2
Solanum nigrum	11													11
Sonchus oleraceus					1			1						2
Symphyotrichum subulatum		18								1	3	3		25
Trifolium spp.					1									1
Typha spp.		1												1
Wahlenbergia spp.					54	4	5	37		4	2	3		109

Appendix K: Pelagic metabolism final report from UoM masters students

Eat in or take away? Separating benthic and water column primary production in the Goulburn River

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Executive Summary: *The Monitoring Evaluation and Research (MER) Program is a 3-year monitoring project being undertaken by the Commonwealth Environmental Water Office to assess ecological responses to environmental water being delivered under the Murray-Darling Basin Plan. Excessive use of the waterways for agricultural purposes and natural droughts over the years have resulted in ecological degradation, hence the Murray-Darling Basin Plan was introduced to bring the river to a healthier level. Ecosystem metabolism, the combination of primary production and ecosystem respiration, is a key process being monitored in the MER program. The focus of this project, as a part of the MER program, is to separate pelagic (in the water column) and benthic (on the riverbed) metabolism in the Goulburn River, the largest Victorian tributary of the Murray-Darling Basin. Local organisms primarily consume organic matter produced benthically, and as a result, benthic metabolism is responsible for higher-order consumers, including fish in the river. Across seven field trips between the summer-autumn season in Australia, sites McCoy's Bridge, Loch Garry, and Darcy's Track were monitored for ecosystem metabolism. The light and dark bottle method was used to determine pelagic Gross Primary Production (GPP) and Ecosystem Respiration (ER). The difference between pelagic and benthic metabolism was determined by comparing pelagic metabolism to whole-stream metabolism being monitored in the MER Program. As the Goulburn is characterized by high turbidity and low nutrient content, analysis shows that pelagic metabolism is driven primarily by sunlight rather than temperature and nutrient levels. Our results conclude that the majority of metabolism is occurring benthically, indicating that any increase to whole stream metabolism should see benefits for local organisms. Increasing benthic hard surfaces and keeping a lower flow in summer are the suggested management actions that could result in the increase of benthic metabolism if implemented.*

1. Introduction

1.1 Background

The Murray-Darling Basin (Figure 1) is one of the most productive agricultural regions in Australia encompassing the drainage basin of the tributaries of the Murray and Darling rivers. The Murray-Darling River system is the largest and the most complex river system of Australia but, natural droughts over the years along with over-extraction of water by upstream users has resulted in severe ecological degradation (Hart, 2016; MDBA, 2021). According to the MDBA (2009), the inflows into the Murray River in the ten years to 2009 were reduced to almost half the recorded historic average. In order to bring the basin back to a healthier level and save the water for future generations, the Murray–Darling Basin Authority (MDBA) plan was introduced in November 2012 (Australian Government, 2012). The Basin Plan included water management strategies to improve the sustainability of the basin, by setting limits on using surface water and groundwater along with a monitoring and evaluation program (MDBA, 2021).

Figure 1 Map of the Murray-Darling Basin (MDBA, 2007)

The Goulburn River is the largest Victorian tributary of the Murray-Darling Basin and is located in central/ northern Victoria. Therefore, it is a focus of environmental flow efforts within the MDBA Plan.

The Monitoring Evaluation and Research (MER) Program is a 3-year monitoring project, which is undertaken by the Commonwealth Environmental Water Office (CEWO), to support the effective and efficient use of Commonwealth environmental water (Webb et al., 2019). Ecosystem metabolism is a key process being monitored in the MER Program and quantifies the total energy processed by all the individual organisms in an ecosystem. The increase (photosynthesis) or decrease (respiration) of the concentration of dissolved oxygen over a specific time is called "Stream Metabolism" and is often expressed as the change in the dissolved oxygen concentration in mg per Litre per day (mg O_2/L/Day). While most measurements fall within 0.5 and 10 mg O_2/L/Day, this number can change between 0.2 to 20 mg O_2/L/Day (Webb et al., 2019). A more in-depth description of stream metabolism can be found in section 2.1.

A healthy aquatic ecosystem needs both photosynthesis and respiration to generate new biomass and break down dead organisms and animal wastes to release nutrients back into the environment (Webb et al., 2019). Too low or too high amounts of metabolic process rates are both a concern and might cause a reduction in the population of organisms, including fish. Sustainable rates of production and respiration primarily depend on the characteristics of the aquatic ecosystem, which vary on a seasonal basis and increase with warmer temperatures (Roberts & Mulholland, 2007; Webb et al., 2019).

Our group aims to estimate the gross primary productivity (GPP) available to organisms in the Goulburn River, by determining the benthic metabolism that occurs in the river. This is described in more detail in section 2.1.

1.2 Monitoring sites

This study was conducted at three sites, Darcy's Track, Loch Garry, and McCoy's Bridge, in order from upstream to downstream Figure 2 and Table 1. show the location of three sites on large scale and the exact location of each site, respectively.

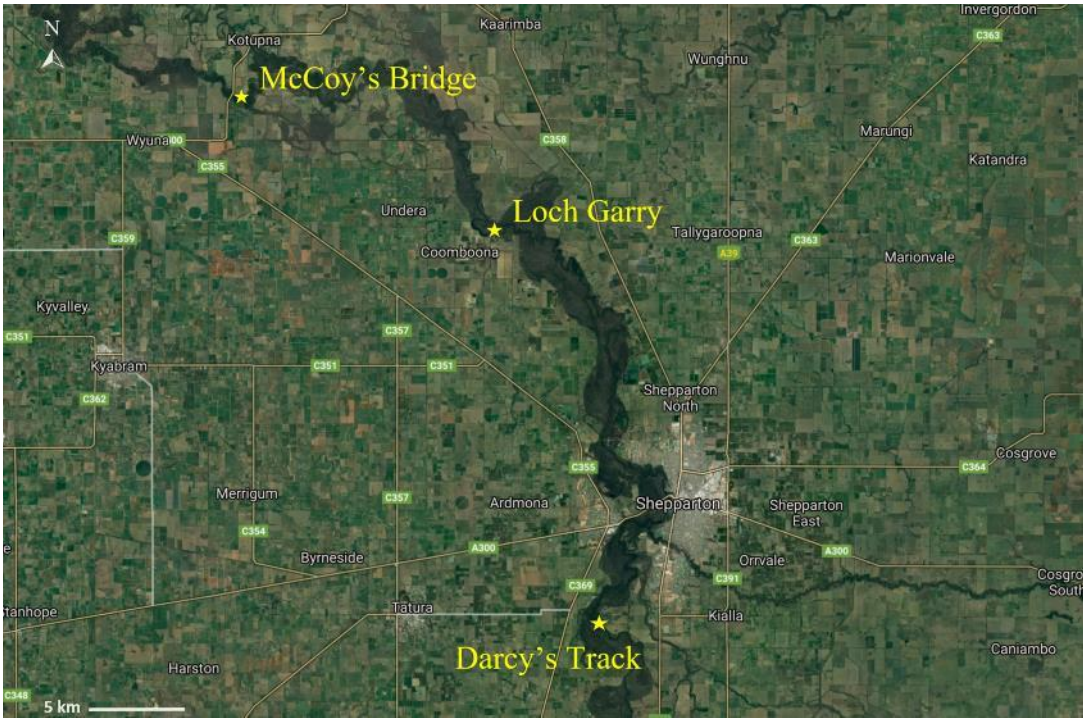
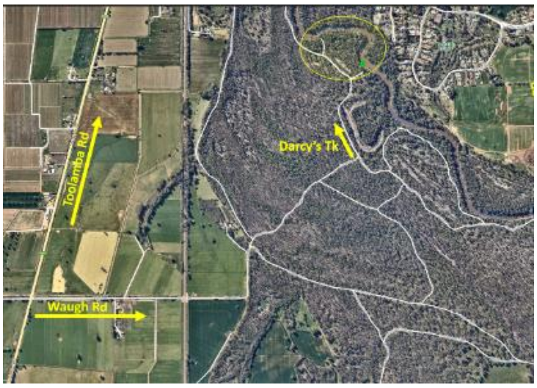


Figure 2 Map showing the location of three monitoring sites. Adapted from (Google Maps, 2021)

Table 1 Exact location of monitoring sites

<table>
<tr><th>Site</th><th>Coordinates</th><th>Location. Adapted from (Google Maps, 2021)</th><th>Photo</th></tr>
<tr><td>Darcy's Track</td><td>-36.4441207, 145.3499070</td><td>
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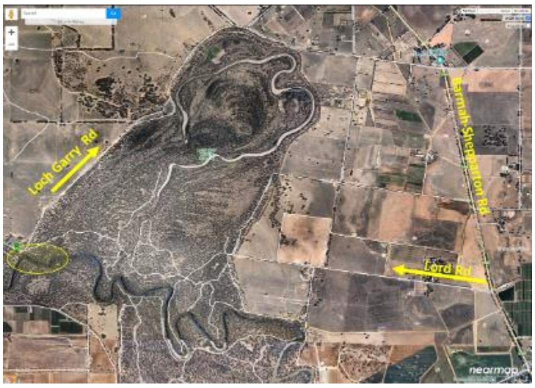
<tr><td>Loch Garry</td><td>-36.2418869, 145.28610</td><td>
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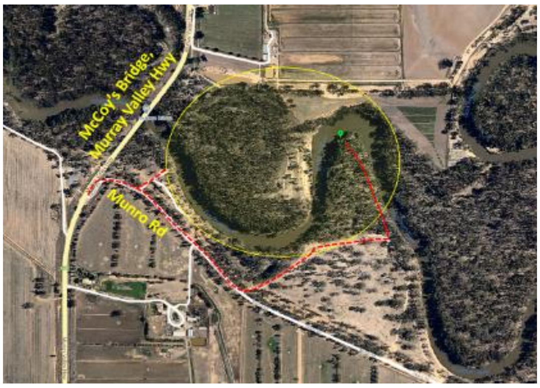
<tr><td>McCoy's Bridge</td><td>-36.1771302, 145.123695</td><td>
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2. Literature Review

2.1 Ecosystem metabolism

A major objective of river management is to maintain and rehabilitate healthy rivers (Gore, 1985). 'River health' does not have a clear definition, but it is interpreted as being comparable to human health by a reasonable person. The absence of disturbance as determined by measurement indicators is one approach to differentiating 'healthy' and 'sick' ecosystems (Rapport, 1989). The Goulburn River is characterized by high turbidity and low nutrient levels that reduce water quality in the river (Pollino, Feehan, Grace, & Hart, 2004), and in turn, limits primary productivity. The integration of a river's physical, chemical, and biological characteristics are important for identifying indicators of river health measurement, and ecosystem metabolism has been identified as a key indicator of ecological distress (Mulholland, Houser, & Maloney, 2005).

Ecosystem metabolism or whole stream metabolism is the combination of the production of organic matter by photosynthesis and the oxidation of organic matter to produce energy, known as primary production and respiration, respectively (Grace & Imberger, 2006). As a result, oxygen is released into the water (primary production) and oxygen is absorbed from the water (ecosystem respiration) (Odum, 1956). The two fundamental rates of metabolism are those of

Gross Primary Production (GPP) and Ecosystem Respiration (ER), and the balance between these two rates is defined as Net Primary Production (NPP) (Bernhardt et al., 2018). Another important process is re-aeration, which is the diffusion of oxygen across the air-water interface to restore 100% DO saturation. The process of re-aeration is abiotic and fundamentally important, but it is not relevant for the light/dark bottle method of measurement used in this project, as the bottles are sealed (Grace & Imberger, 2006). Primary production (photosynthesis) increases the amount of oxygen, while respiration decreases the oxygen content in the river (Webb et al., 2019). The equations governing photosynthesis and respiration are shown in equations 1 and 2, respectively (Zhang, Huang, Yan, & Zhang, 2009).

$$6CO_2 + 6H_2O + Energy \xrightarrow{light} C_6H_{12}O_6 + 6O_2 \qquad \textbf{Equation 1}$$

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Energy \qquad \textbf{Equation 2}$$

Metabolism rates vary on a seasonal basis and are affected by temperature, amount of organic carbon content, nutrient concentration, stream substrate, and hours of direct sunlight (Grace & Imberger, 2006). During the day, oxygen is greater in all rivers and lakes due to the production of photosynthetic oxygen, whereas oxygen is lower at night (Odum, 1956). Warmer temperatures and longer hours of sunlight increase the rates of primary production, while higher organic carbon loads and warmer temperatures can enhance rates of respiration (Roberts & Mulholland, 2007). Overall, GPP and NPP are significantly higher under warmer and wetter conditions (Bernhardt et al., 2018). Rivers in forested and shady areas have lower rates of primary production compared to rivers exposed to direct sunlight because of low nutrient concentration and decreased amount of sunlight from shading. Enhanced rates of both primary production and ecosystem respiration can be harmful as it can result in algal blooms and anoxia (complete depletion of oxygen in the river), respectively. Both photosynthesis and respiration are important processes, and the biomass (food) produced by photosynthesis is consumed by invertebrates, which are then consumed by fish, and so on to maintain the food web (Figure 3). Therefore, stream metabolism is an important phenomenon to be monitored and understood as it is the backbone that maintains the functioning of the aquatic food web (Webb et al., 2019).

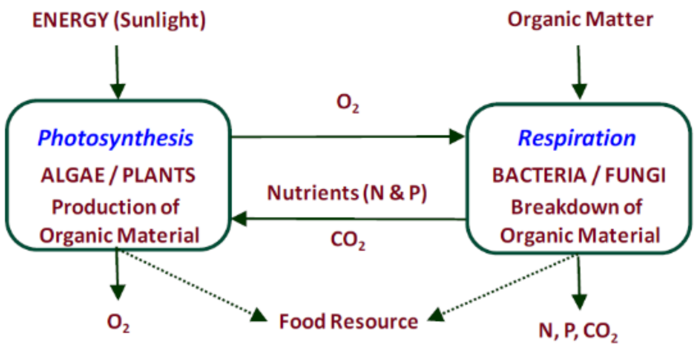

Figure 3 Relationship between photosynthesis and respiration to maintain the food web (Webb et al., 2019)

Total metabolism in the system is a combination of pelagic and benthic metabolism. Benthic metabolism occurs on hard surfaces in the river such as riverbed and bedrock, while pelagic metabolism occurs in the water column. Local organisms can primarily consume only the organic matter produced on the hard surfaces as the food produced in the water column is exported from the river system. Therefore, benthic metabolism is responsible for fish (and other vertebrate) production in the river (Vadeboncoeur, Lodge, & Carpenter, 2001). Understanding the separate contributions of both pelagic and benthic metabolisms is important when studying food production for organisms in the river (Vadeboncoeur et al., 2003). This is done by measuring the whole stream and one component of metabolism, and deducing the other component by the difference between the obtained measurements (Carpenter et al., 2005).

2.2 Conceptual model

The flow chart in Figure 4 is the conceptual model framework governing the project. Stream metabolism is a combination of GPP, and ER as explained in section 2.1. Both these rates of metabolism are affected by dissolved oxygen (DO) and balanced by NPP. Light (Photosynthetic Active Radiation - PAR), DO, and temperature were measured in-situ, while nutrients and Chlorophyll a were measured in the laboratory. Rates of stream metabolism are also affected by confounding variables such as pH and turbidity.

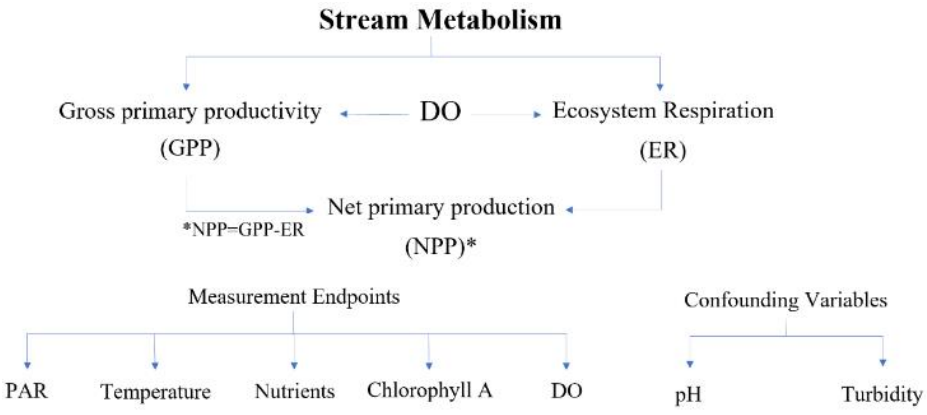

Figure 4 Conceptual model

2.3 Relationship between indicators

Respiration and primary production are relatively independent from a modelling perspective. Ecosystem respiration is unaffected by light, and therefore light and dark respiration are assumed to be identical for monitoring and analysis (Grace & Imberger, 2006). Australian rivers are known for their turbidity due to the arid climate and sporadic vegetative cover which contribute to soil erosion. Light intensity in rivers is measured as a vertical gradient varying with depth, and the depth of water in which photosynthesis can occur is known as the euphotic depth (Khanna, Bhutiani, & Chandra, 2009). As suspensoids, the small colloidal size soil particles which remain suspended due to Brownian motion and responsible for turbidity, absorb and scatter solar radiation, light intensity decreases with depth (Kirk, 1985). Therefore, the euphotic depth is reduced by turbidity, which in turn decreases primary production in rivers (Desortová, 1981; Kirk, 1985). Algal growth can be linked to water quality parameters that drive primary production such as pH, total nitrogen (TN), total phosphorous (TP), temperature, and light intensity, and also DO which is an outcome of primary production (Scholz, 2015). However, Chlorophyll a is a measure of how much algae is present (Jayaweera & Asaeda, 1995; Zhou, Yuan, Huo, & Yin, 2004). High Chlorophyll a levels in the stream correlate to a high algal level and are an indication that a high amount of production is occurring within the water column itself (Grace & Imberger, 2006). The availability of TN and TP limits the growth of algae, as nutrients are incorporated into new algal biomass (Grace & Imberger, 2006; Hecky & Kilham, 1988). In reference to Equation 1 and Equation 2, CO_2 is absorbed during photosynthesis and released during respiration. This results in an increase in pH when CO_2 decreases during primary production, and vice versa during respiration. Algal decomposition release CO_2, which can also reduce the pH (Zang et al., 2011). pH and DO are influenced by photosynthesis and respiration (Scholz, 2015), and a link between the production and consumption of CO_2 and oxygen has been observed (Zang et al., 2011). Figure 5 is a graphical interpretation of the interaction between the various indicators with (1) Light reaction with nutrients; (2) Relationship between Chlorophyll-a, and algal growth; and (3) Euphotic depth affected by light.

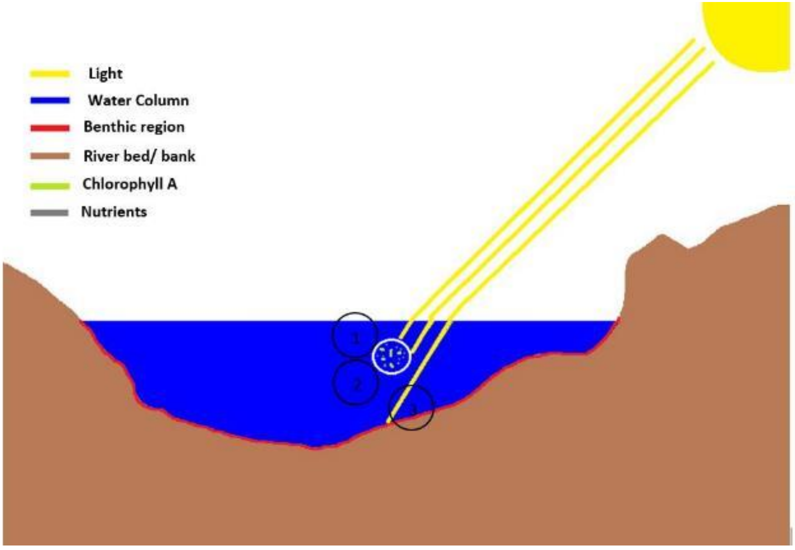

Figure 5 Interaction diagram indicating (1) Light reaction with nutrients; (2) Relationship between Chlorophyll a, and algal growth; (3) Euphotic depth affected by light.

3. Methods and Resources

3.1 Methodology and methods

We reviewed the literature on stream metabolism and the ongoing MER Program on the Goulburn River to determine methods for this project. Before the field trips, the YSI multiprobe PRODSS was calibrated for DO, conductivity, pH, and turbidity for onsite measurements. A total of seven field trips were conducted across the Australian summer-autumn period, at a frequency of approximately two weeks depending on coronavirus restrictions. The field trips dates were December 22 & 23 2020, January 11 & 12, January 27 &28, February 8 & 9, February 28 & March 1, March 14 & 15, and April 7 & 8 2021. The water samples were sent to the NATA-accredited Water Studies Centre laboratory at Monash University for analysis of nutrient and chlorophyll levels.

The chosen method for determining GPP and ER is the light and dark bottle method (Grace & Imberger, 2006). In this simple and cheap in-situ method, water samples are collected in transparent (light) and opaque (dark) bottles. The bottles are then suspended at different depths in the water column (Figure 6) to understand the effect of light penetration on photosynthesis through measuring the concentration of dissolved oxygen. The water column DO is measured before deployment and the bottle DO is measured after deployment to identify the change in DO at various depths. From the DO change in the dark bottles, we can identify the respiration rate, while the light bottles show both respiration and photosynthesis (Grace & Imberger, 2006).

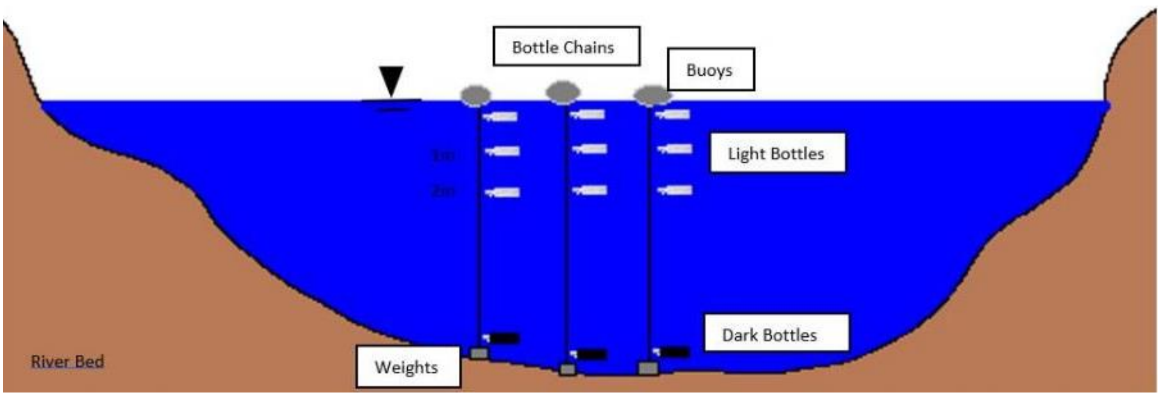

Figure 6 Diagram of the bottle chains setup in the river

3.2 Sampling protocol

Using a plastic bottomed kayak, light (clear) and dark (opaque) bottles were filled using surface water from the middle of the river. Three identical bottle chains were formed with the light bottles suspended at the surface and depths of 1m and

2m, and one dark bottle (the bottle was wrapped with gaffer tape) attached to the chain at the bottom (Figure 6). A buoy was attached to the bottle chains to keep it afloat, and a 2-kg weight was suspended at the bottom to prevent the chains from moving. Three light and temperature loggers (HOBO MX2202 Temp/Light) were attached to one bottle chain at the same depths as the light bottles. The loggers were connected via Bluetooth to a smartphone application called HOBOconnect (Figure 7). These bottle chains along with the loggers were then lowered into the water (Figure 8) with the exact time noted, ensuring that the bottle chains were not close enough that they block light from one another. The bottle chains were left in the water column for a minimum of an hour and thirty minutes (Figure 9).

From the same section of the river, a YSI multiprobe ProDSS was used to determine the temperature, turbidity, conductivity, pH, and dissolved oxygen levels.

A sample of water was taken for chlorophyll analysis after rinsing a bucket with the same water. While waiting for the bottle chains to complete their incubation period, a syringe was used to filter approximately 800 ml (a minimum of 600ml can be used but the exact amount must be recorded) of the water sample through a 0.7-micron filter paper (Figure 10). The filter paper with the residue was wrapped in Aluminum foil and stored in a cooler to be sent for lab analysis of Chlorophyll a level.

The bottle chains were retrieved from the river after an hour and thirty minutes and the exact time of removal was recorded for each bottle chain. The dissolved oxygen level in each bottle was measured using the thin DO YSI Probe (Figure 11) and 80ml of water sample from five bottles in the bottle chain was filtered through a 0.2-micron filter paper into five 65 ml clear plastic bottles (Figure 12) separately. The bottles were stored in the cooler with ice, to be taken back to the lab for nutrient level analysis.

The same process was repeated at every location and for every field trip.

Figure 7 Connecting HOBO loggers via Bluetooth to a smartphone to take light and temperature measurements.

Figure 8 Deploying the bottle chains in the river.

Figure 9 Deployed bottle chains in the river.

Figure 10 Filtering the water sample to be sent to the lab for Chlorophyll-A measurement.

Figure 11 Taking DO measurements from bottles.

Figure 12 Filtering through water samples through a 0.2-micron filter paper into five 65 ml clear plastic bottles be sent to the lab for Nutrient analysis.

3.3 Statistical analysis

In order to analyse the collected data from onsite, the GPP, ER, and NPP values calculated as per Equation 3, Equation 4, and Equation 5. (Lieth, 1975), per bottle chain were averaged to gain singular values for each depth and location per site trip (i.e., the three concentrations for the 'surface' bottle were averaged at each site x time combination, etc.). Results regarding nutrient and chlorophyll levels, performed at the Monash Water Studies Centre, were again averaged to give one value per site per visit.

$$\boldsymbol{Respiration\ rate\ (ER)\ =\ (dark\ DO - initial\ DO)\ /\ time} \quad \textbf{Equation 3}$$

$$Gross\ productivity\ (GPP)\ =\ (DO\ of\ bottle - dark\ DO)\ /\ time \quad \textbf{Equation 4}$$

$$Net\ Productivity\ (NPP)\ =\ (DO\ of\ bottle - initial\ DO)\ /\ time \quad \textbf{Equation 5}$$

Even after averaging, oxygen concentrations for the different depths were still very variable, precluding a direct approach to estimating a pelagic metabolism at each site x time combination. Instead, pelagic metabolism was determined using a combination of modelling and extrapolation. First, we plotted measured GPP against light, pooling all data from all trips, and determining the relationship. Another relationship was then substituted for light based on the light vs depth relationship for each site visit. This gave a relationship for GPP based on the depth of the water column. This relationship was then used to model the rate of pelagic metabolism for the entire cross-section of the river at each site where sampling had taken place (cross-section data were provided by another MER Program partner, Streamology). These cross-sectional values of pelagic GPP formed the basis of analysis against all other measured parameters.

Whole stream metabolism is measured as the change of dissolved oxygen induced by biological processes and reaeration in a litre of river water summed over a 24-hour period. That litre of water is influenced by both pelagic and benthic processes as well as the reaeration. It is assumed that the river is well mixed both laterally and vertically giving units of mg O_2/L/day. As part of the ongoing MER Program (section 1.1), there are permanent data loggers distributed along the Goulburn River and one located in close proximity to each of the sites where data were collected. Whole stream metabolism data were retrieved from these permanent loggers on each site. Where the whole stream metabolism data showed poor fits based on the MER program conditions (see Webb et al. 2019 for the definition of a poor fit), the data were smoothed taking into account the trends of 'good fit' data taken either side of the required day while also ensuring that the recorded reaeration ('exchange of gases between atmosphere and water, maintaining oxygen near saturation (George, 1978)) values were realistic and did not differ dramatically. Pelagic metabolism calculations were calculated in terms of mg O_2/L/hour and as a result whole stream metabolism data was converted into the same rate. This was done using light values from nearby light loggers (Shepperton Drain 12 Tahbilk, and Goulburn Weir). The whole stream metabolism values were converted by calculating the percentage of light over the study period, this percentage was then used to find the rate for each study period in mg O_2/L/hour.

The light data from these sites were also used to fill missing surface light data from the site visits. This was completed by comparing the relationship between the nearby light values and actual light data recorded on-site across other visits. The light data from the nearby loggers was then used to determine the assumed light value data on-site.

Corresponding euphotic depths, where euphotic depth is the depth where light intensity is reduced to 1% of the surface value and the point to which photosynthesis is assumed to occur, for these occurrences were determined using the recorded euphotic depth vs light relationship.

The percentage of riverbed above the euphotic depth was determined using the cross-sectional data provided by Streamology and the river level data, publicly available via the Department of Environment, Land, Water, and Planning (DELWP, https://data.water.vic.gov.au/). The percentage value was calculated as the cross-sectional length of the riverbed above the euphotic depth.

Charts were completed using the basic plot function in Microsoft Excel, while the correlation coefficients were determined using the correlation function in Microsoft Excel's data analysis add-in.

4. Results

The results in this report are all from onsite water quality monitoring in the lower Goulburn River between the 22^{nd} of December 2020 and the 8^{th} of April 2021. Summarized data for each site is presented in tables while key figures are also presented with appropriate trend lines, if necessary. All other figures can be found in the appendix.

4.1 Process

Figure 13 shows there was a clear exponential relationship between measured metabolism and light intensity within the water column.

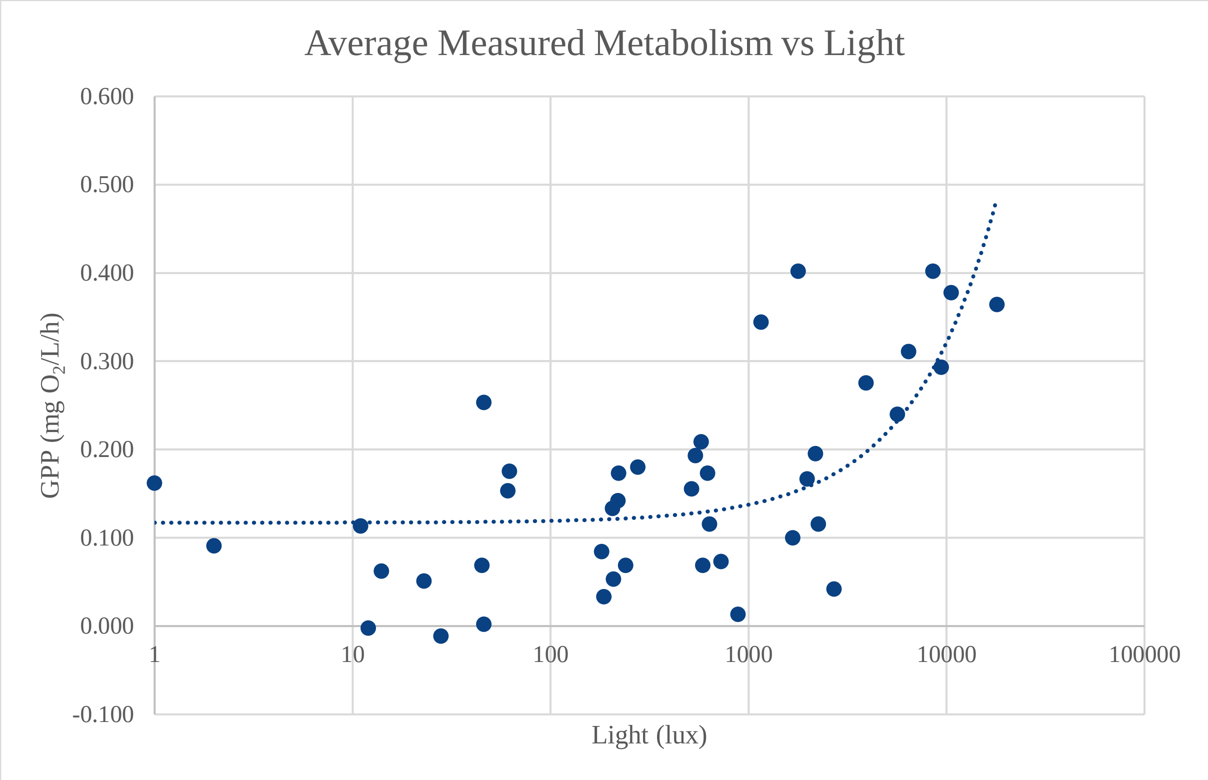

Figure 13: Average GPP vs Light Intensity

The results comparing pelagic metabolism to whole stream metabolism across all three sites shows much greater variability in whole stream results when compared to pelagic metabolism. Including outliers with extreme percentages of pelagic metabolism, the average percentage is 46%, and excluding values where the percentage is above 100%, the average is reduced to 40%. This infers that the majority of metabolism occurring throughout the river can be attributed to benthic metabolism (Table 2, Table 4, and Table 6).

4.2 Darcy's Track

Table 2: Darcy's Track results

Date	*Pelagic GPP (mg O_2/L/h)*	*Whole stream GPP (mg O_2/L/h)*	*Pelagic %*	*Temp (°C)*	*DOC (mg/L)*	*TP (mg/L)*	*TN (mg/L)*	*NH3 (mg/L)*
22-Dec	0.129	0.530	24.34	21.3	2.81	0.018	0.323	0.033
11-Jan	0.133	1.294	10.29	25.0	2.02	0.01	0.268	0.010
27-Jan	0.138	0.991	14.01	23.3	2.62	0.01	0.308	0.012
9-Feb	0.144	0.230	63.07	20.6	3.08	0.01	0.340	0.014
1-Mar	0.131	0.323	40.88	20.0	3.08	0.01	0.248	0.006
15-Mar	0.162	0.257	63.06	18.2	2.32	0.01	0.296	0.009
8-Apr	0.164	0.330	49.80	18.6	2.66	0.01	0.354	0.016

Table 3: Darcy's Track results

Date	*FRP (mg/L)*	*NOx (mg/L)*	*Chlorophyll-a (mg/L)*	*Light PAR (lux)*	*Euphotic depth (m)*	*Riverbed % > euphotic depth*	*River level (m)*	*Respiration (mg O_2/L/h)*
22-Dec	0.007	0.013	2.000	4771	2.104	95	2.173	-0.027
11-Jan	0.003	0.011	1.300	4324	2.127	100	2.011	0.069
27-Jan	0.005	0.014	1.700	5893	2.048	100	1.924	0.031

9-Feb	0.005	0.081	0.700	2254	2.640	100	2.291	0.082
1-Mar	0.003	0.029	2.700	1674	2.179	100	2.087	-0.116
15-Mar	0.002	0.025	2.300	637	8.290	100	2.437	-0.078
8-Apr	0.003	0.025	0.300	728	3.330	100	1.672	0.150

4.3 Loch Garry

Table 4: Loch Garry results

Date	*Pelagic GPP (mg O_2/L/h)*	*Whole stream GPP (mg O_2/L/h)*	*Pelagic %*	*Temp (°C)*	*DOC (mg/L)*	*TP (mg/L)*	*TN (mg/L)*	*NH3 (mg/L)*
23-Dec	0.142	0.418	34.02	21.9	2.975	0.013	0.275	0.020
11-Jan	0.142	0.765	18.60	26.3	2.64	0.010	0.284	0.014
27-Jan	0.130	0.136[4]	96.00	25.7	2.6	1.321	0.973	0.733
8-Feb	0.099	0.743	13.43	22.8	3.48	1.747	1.299	0.978
28-Feb	0.155	0.276	56.46	21.7	4.18	2.096	1.549	1.166
14-Mar	0.209	0.164	127.85	19.9	2.68	0.010	0.322	0.011
7-Apr	0.138	0.170	81.68	19.8	2.86	0.012	0.390	0.016

[4] Data for this point was subject to large inconsistency and so should be taken with much larger error margin

Table 5: Loch Garry results

Date	FRP (mg/L)	NOx (mg/L)	Chlorophyll-a (mg/L)	Light PAR (lux)	Euphotic depth (m)	Riverbed % > euphotic depth	River level (m)	Respiration (mg O_2/L/h)
23-Dec	0.006	0.005	3.100	5250	2.081	90	2.461	0.231
11-Jan	0.002	0.001	3.700	2349	2.226	94	2.459	0.433
27-Jan	0.587	0.565	0.300	1979	1.843	86	2.462	-0.016
8-Feb	0.784	0.657	0.300	3931	1.157	49	2.462	0.000
28-Feb	0.934	0.788	0.300	17977	1.290	61	2.462	-0.076
14-Mar	0.002	0.004	3.300	6433	2.450	99	2.462	-0.178
7-Apr	1.002	0.006	0.300	2704	2.385	98	2.462	0.120

4.4 McCoy's Bridge

The following table show all the results from data collection and analysis for McCoy's bridge site.

Table 6: McCoy's Bridge results

Date	Pelagic GPP (mg O_2/L/h)	Whole stream GPP (mg O_2/L/h)	Pelagic %	Temp (°C)	DOC (mg/L)	TP (mg/L)	TN (mg/L)	NH3 (mg/L)
23-Dec	0.149194639	0.336	44.42	23	3.3	0.010	0.315	0.008
12-Jan	0.154327578	0.593	26.05	25.7	2.82	0.010	0.260	0.008
28-Jan	0.155678173	3.201	4.86	24.43	2.54	0.010	0.228	0.006
8-Feb	0.099307094	0.163	61.01	22.2	4.56	0.022	0.654	0.018
28-Feb	0.177099083	0.865	20.47	21.3	4.86	0.012	0.580	0.017
14-Mar	0.222040436	0.328	67.78	19.8	3.02	0.010	0.456	0.016
7-Apr	0.236597214	0.495	47.81	19.5	3.02	0.010	0.488	0.020

Table 7: McCoy's Bridge results

Date	FRP (mg/L)	NOx (mg/L)	Chlorophyll-a (mg/L)	Light PAR (lux)	Euphotic depth (m)	Riverbed % > euphotic depth	River level (m)	Respiration (mg O_2/L/h)
23-Dec	0.004	0.001	1.700	4925	2.097	100	1.722	0.713
12-Jan	0.003	0.001	1.700	5480	2.069	100	1.608	-0.022
28-Jan	0.005	0.000	5.000	1781	1.998	100	1.556	0.018
8-Feb	0.006	0.083	0.700	5655	1.026	44	1.825	-0.007
28-Feb	0.004	0.086	0.300	8563	1.824	100	1.725	-0.147
14-Mar	0.003	0.005	0.300	10565	2.450	100	1.976	-0.167
7-Apr	0.002	0.009	0.300	9408	2.480	100	1.457	0.127

The nutrient analysis found no strong correlations between any of the nutrients measured and pelagic metabolism. TP, TN, NH_3, and NO_x all have extremely high correlations. In fact, from Table 8 pelagic metabolism is not highly correlated to any other parameter measured. There is also a high correlation between chlorophyll-a levels and Whole stream GPP as opposed to pelagic metabolism which has almost zero correlation to chlorophyll-a levels.

Table 8: Pearson correlation table

	Pelagic GPP	*Wholestream GPP*	*Pelagic %*	*Temp*	*DOC*	*TP*	*TN*	*NH3*	*FRP*	*NOx*
Pelagic GPP	1.000									
Wholestream GPP	-0.110	1.000								
Pelagic %	0.380	-0.744	1.000							
Temp	-0.428	0.577	-0.452	1.000						
DOC	-0.096	-0.253	0.043	-0.128	1.000					
TP	-0.272	-0.170	0.071	0.193	0.285	1.000				
TN	-0.201	-0.268	0.154	0.076	0.513	0.952	1.000			
NH3	-0.270	-0.173	0.070	0.188	0.288	1.000	0.953	1.000		
FRP	-0.286	-0.260	0.213	0.029	0.194	0.768	0.745	0.768	1.000	
NOx	-0.297	-0.206	0.101	0.182	0.342	0.992	0.962	0.992	0.751	1.000
Chlorophyll-a	-0.032	0.585	-0.297	0.269	-0.410	-0.368	-0.528	-0.373	-0.435	-0.415
Light	0.395	-0.183	0.145	-0.082	0.533	0.411	0.539	0.415	0.250	0.391
River level	-0.305	-0.282	0.286	-0.034	-0.132	0.433	0.331	0.435	0.513	0.426
Euphotic depth	0.237	-0.143	0.128	-0.467	-0.419	-0.285	-0.335	-0.287	-0.236	-0.287
Bed %>euphotic	0.520	0.208	-0.063	-0.139	-0.565	-0.664	-0.761	-0.665	-0.490	-0.681
Respiration	-0.168	0.208	-0.327	0.294	-0.142	-0.177	-0.231	-0.178	-0.099	-0.208

Pearson correlation table continued

Chlorophyll-a	*Light*	*River level*	*Euphotic depth*	*Bed %>euphotic*	*Respiration*
1.000					
-0.349	1.000				
0.044	-0.057	1.000			
0.145	-0.358	0.144	1.000		
0.303	-0.290	-0.266	0.389	1.000	
0.155	-0.231	-0.102	-0.078	0.121	1.000

4.5 Key figures

Figure 14 shows the whole stream metabolism figures against the percentage of pelagic metabolism occurring within the whole stream cross-section. The figure shows a clear trend, that as whole stream metabolism decreases, the percentage of pelagic metabolism does not decrease at the same rate. Hence, the figure shows larger percentages of pelagic metabolism at lower whole stream metabolism rates. This also indicates a major finding that the majority of metabolism in the river is occurring in benthic regions and that benthic metabolism is more variable with light.

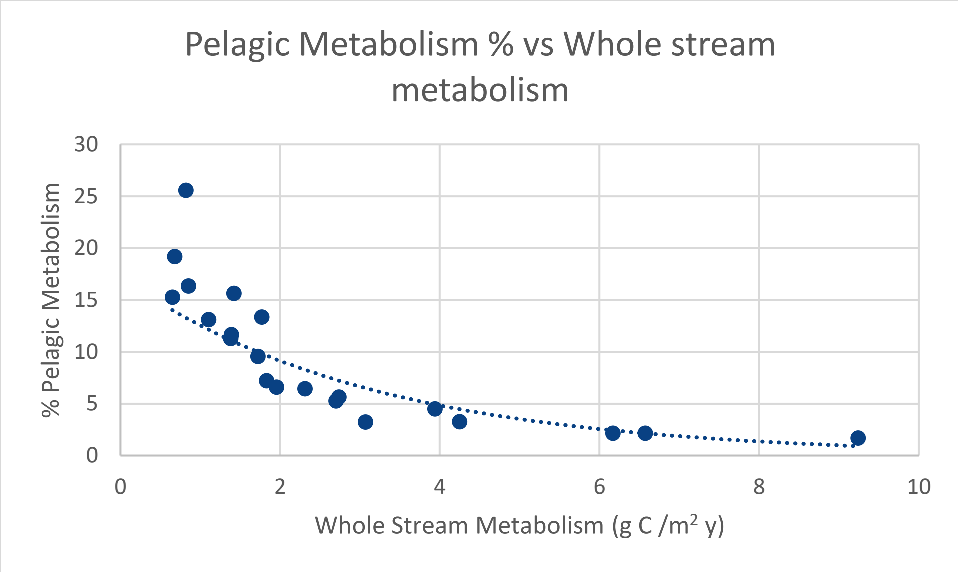

Figure 14: Pelagic % vs Whole Stream Metabolism

Figure 15 shows the relationship between euphotic depth and pelagic metabolism rates. From this figure, a trend can be gauged that shows that as euphotic depth increases so does the rate of pelagic metabolism, albeit with one extreme outlier.

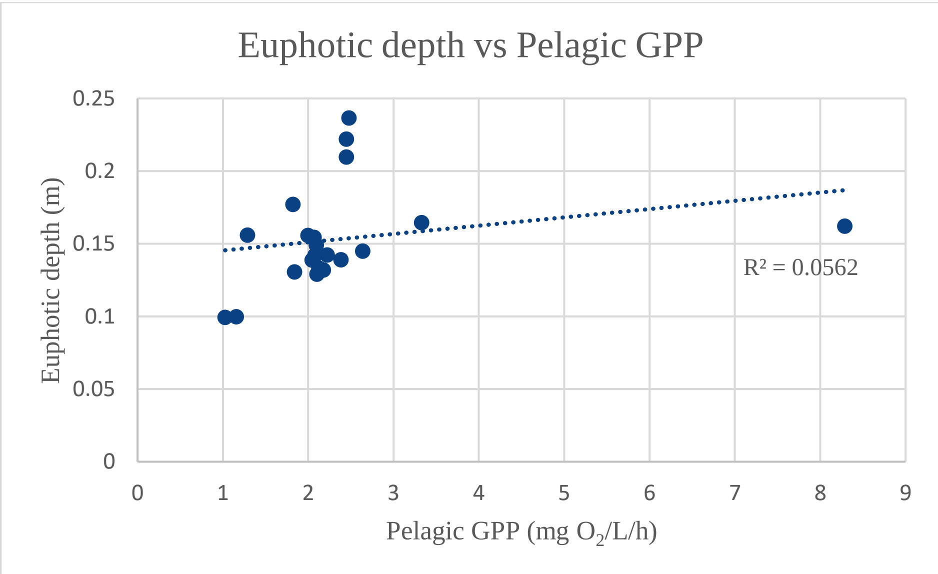

Figure 15: Euphotic depth vs Pelagic Metabolism

With an increase in temperature, we observe weak relationships that decrease with pelagic metabolism and increase with whole stream metabolism, respectively. This suggests that metabolism in the lower Goulburn water column is driven more by the availability of sunlight and nutrients rather than the temperature of the water body (Figure 16 and Figure 17).

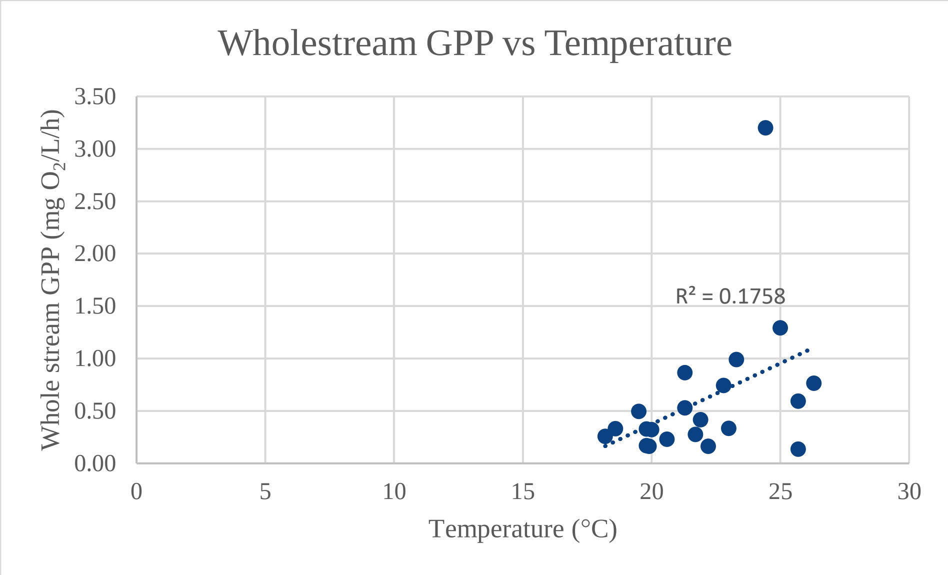

Figure 16: Whole stream metabolism vs Temperature

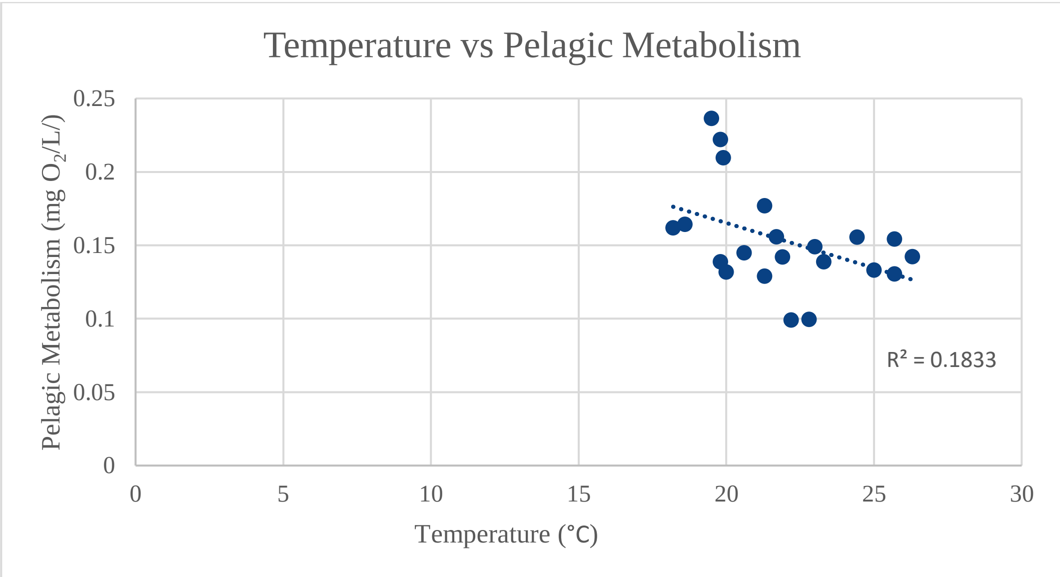

Figure 17: Temperature vs Pelagic Metabolism

5. Discussion

5.1 Main finding

Pelagic metabolism provides an average of 40% of whole stream metabolism meaning benthic areas of the Goulburn River are the primary contributors to river production. Benthic metabolism is beneficial to river health as it provides food to organisms in the local area, providing benefit and growth to larger locally based organisms and wildlife in the river. This finding shows that if we wanted local wildlife populations to increase, increasing the overall metabolism rate in the river should help, assuming that food availability is the limiting factor of growth rather than suitable habitat, or other breeding factors. This could potentially help to ensure that native fish such as the Murray cod and Golden perch have stable populations for the years to come.

5.2 General findings

Generally, a decrease in temperature results in a decrease in both primary production and ecosystem respiration, thereby resulting in a decrease in stream metabolism (Roberts & Mulholland, 2007). The results from this analysis showed that temperature does not have a significant effect on metabolism rates in the lower Goulburn. Possible reasons for this could be that sunlight and nutrients are limited and hence water temperature does not have a great effect. Alternatively, the relationship given by our results may not be indicative of actual trends. When analysing the effect of temperature, units used should be in degrees Kelvin, not Celsius which is shown in the figures. This results in what originally appears to be a 30% change in temperature to a change of only 2.7% across the project lifetime. This means that the changes in Pelagic metabolism are most likely driven by fluctuations in light intensity rather than temperature change. To be able to effectively conclude that the effects of temperature on metabolism were not behaving as hypothesized, then a larger range of data would be needed over greater changes in temperature.

Since Goulburn is characterized by high turbidity and low nutrient concentration (Pollino et al., 2004), primary productivity is low. The low nutrient values may maximize the impact of measurement errors that obscure relationships between the indicators. The nutrients TP, TN, NH_3, FRP, and NOx are all forms of nitrogen or phosphorous and can be highly correlated if they come from the decomposition of the same plant and animal detritus (including algal detritus).

The low pelagic metabolism rates on the 8th of February occurred after a significant storm/rainfall event. While water turbidity levels showed no significant change, visual observations on-site showed more material (leaves, branches) flowing down the river. This observation was reflected by the euphotic depth on this day being significantly smaller than any other day monitored over the time period. The decrease in pelagic metabolism rates is then implied to be caused by the reduction in euphotic depth. This observation is logical as a reduction in euphotic depth results in less pelagic metabolism occurring in the deeper areas of the water column resulting in a lower overall cross-sectional rate. The storm also caused higher flow rates which lead to enhanced scouring of biofilms, which as a result suppresses benthic production, interestingly this result was seen only at McCoy's bridge and not Loch Garry. However, due to the greater depth and width of the river at Loch Garry, increases in water level were insignificant compared to changes at McCoy's bridge, possibly accounting for this.

Chlorophyll-a measured in the field is representative of the algae content in the water column, high algae contents are often correlated with production within the water column. Hence, we expect to see correlations between pelagic and chlorophyll-a, suggesting production happening in the water column. On the contrary, there is a correlation between whole stream metabolism and chlorophyll-a. Since chlorophyll-a is measured from the water surface we cannot conclude that algae is present in the benthic areas, however, if these regions are being scoured after production occurs this could lead to the results seen.

Respiration was calculated from each bottle chain at every site however, there were large inconsistencies between bottle chains from the same sites at the same time. We have no explanation as to why dissolved oxygen rates were higher in the black bottles and as such this was a source of significant error. Metabolism rates were able to be smoothed out through the use of light intensity (Figure 13), however, for respiration calculations, this could not be achieved and as a result, we see a highly sporadic chart with largely varying respiration rates (Figure 20).

5.3 Method discussion

This section focuses on various aspects of the project that could be improved for better research and analysis in the future. We conducted seven field trips from December 2020 to April 2021. Our results showed consistent pelagic metabolism rates throughout the study period. With a longer period of monitoring, we could see if this is the case across the whole year. We used three bottle chains, which were suspended a small distance from each other. There were differences in DO levels at each bottle chain, therefore, and a better representation of the actual values could have been achieved if we had had a greater number of bottle chains with more bottles per chain. The bottle chains were suspended in the river for approximately an hour and a half, where significant DO changes could be observed. However, greater changes in DO levels could be observed if the incubating period of the bottles were increased. Though a 2-kg weight was attached to the bottle chain to keep it from moving, the bottles moved occasionally due to the velocity of the river and wind. While depth remains constant, movement of the bottle chains or simply changes in times of day could result in significant changes to the data. The major change occurring affecting results would be change in light intensity over time. The statistical analysis used the average light intensity however changes in shadow or cloud movement result in different light intensity. While these effects cannot be avoided in the field, the effects on the light intensity average would be minimised by longer incubation periods as it negates the effect of random changes such as debris or boats passing over the bottle chains.

5.4 Data collection discussion

The data collection was not fool proof and had its own set of uncertainties. After the incubation period, the water samples in the bottles were measured for DO concentrations. The DO concentrations are expected to decrease with depth because the intensity of light decreases with depth, and light is essential for primary productivity. However, that was not the case in all locations in many field trips. This could be due to the time interval between taking the bottles out from the river and measurement. Also, there is a possibility of oxygen entering the bottle when measured for DO. Two different YSI ProDSS were used: one with all the probes (turbidity, conductivity, pH, and DO), and the other with only the DO probe. The reason for this is because the light/dark bottles have a small opening and the YSI ProDSS with all the probes cannot be used to measure the bottle DO. By using two different probes for measuring DO, we increase the probability of systematic differences in readings because of different calibrations between the two instruments. Using a single DO probe to measure both before and after deployment DO concentrations could reduce the differences in errors. The DO readings must be taken as soon as possible after removing the bottle chains from the river to ensure the concentrations remain constant. Longer bottle chain deployment durations, more bottles per bottle chain, more bottle chains, more field trips, and a longer monitoring duration could help develop more accurate models with clear trends representative of reality.

5.5 Statistical analysis discussion

During the statistical analysis of the nutrient levels, it could be seen that results for TP, FRP, and NOx either barely or did not meet the detection limits of the tests conducted by the Water Studies Centre, this meant that these results carried a significant error factor of as high as 50%. Other nutrient levels in the Goulburn are also quite low and this can lead to high degrees of error. Above, we noted that nutrient levels are highly correlated to each other but not to pelagic metabolism levels; a possible reason for this could be that the low nutrient values received hold a high degree of error, as such changes of 0.001 can cause a 33% change to the result. Hence this could affect pelagic metabolism correlation with nutrient levels.

The calculations for pelagic metabolism could also be improved with the use of more light data points on the deployed bottle chains or more accurately recorded metabolism rates. Light data would yield higher accuracy light vs depth equations while improved metabolism rates would create an initial model with higher accuracy. Currently, this data feeds into Figure 13, where errors in this trend will compound throughout other measurements. Hence, this report is limited by initial inaccuracy which is used to determine pelagic metabolism rates. While adding additional data points in continuation of lower Goulburn monitoring would be beneficial, it is recognized that similar projects would likely not collect more data and hence a stronger focus should be on reducing sources of error as discussed in section 5.4.

5.6 Implications for management

We understand that increasing the whole stream GPP could be beneficial to the local organisms as most of the metabolism is occurring benthically on the riverbed. One management action designed to increase whole stream GPP can be increasing the benthic hard surfaces on the river to ensure more metabolism happens in the riverbed. We also concluded that sunlight is a prime driver of metabolism. Therefore, ensuring a lower flow in summer can increase light penetration to the bed, thereby promoting metabolism. An inflow of water brings in a large amount of nutrients promoting primary production, but the inflow must be managed in a way that metabolism occurs in the riverbed. Reducing human interference in the river can improve benthic metabolism during low flows due to reduced turbidity and better light penetration to the riverbed. A large amount of data was collected for this project however, improvements can be made on reducing the sources of error within our existing program.

6. Conclusion

The project was undertaken to assess the proportion of whole stream metabolism that is benthic and therefore is available to organisms in the Goulburn River. Darcy's Track, Loch Garry, and McCoy's Bridge were the sites used for the monitoring project. Ecosystem metabolism being a key parameter monitored as part of the MER Program, the rates of metabolism, GPP, and ER were determined by the light and dark bottle method. Using the whole stream metabolism data from the permanent loggers at the monitoring sites, pelagic and benthic metabolism were separately identified.

The key findings after the statistical analysis are as follows:

- Metabolism in the lower Goulburn River is driven by the availability of sunlight rather than the temperature of the water body.
- Most of the GPP occurs at the riverbed in the benthic region, suggesting that an increase in the overall metabolism rate will result in an increased population of fish and other higher organisms.
- There is a strong correlation between euphotic depth and pelagic metabolism.

Therefore, to increase benthic metabolism rates in the lower Goulburn River it is suggested that hard surfaces be added to the river as well as the river being kept at low flows to promote light interaction with the benthic areas of the river.

7. Acknowledgments

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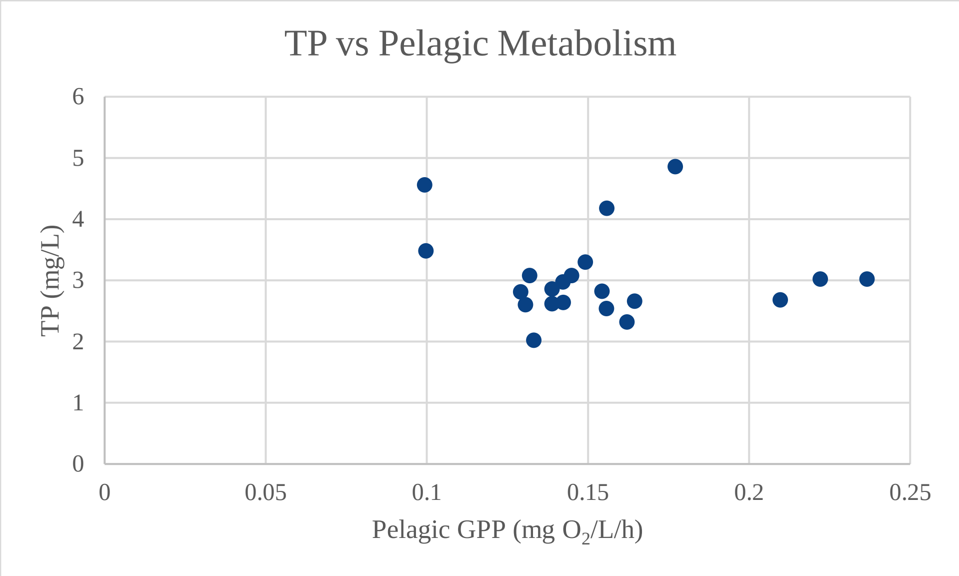

Figure 18 Total Phosphorus vs Pelagic Metabolism

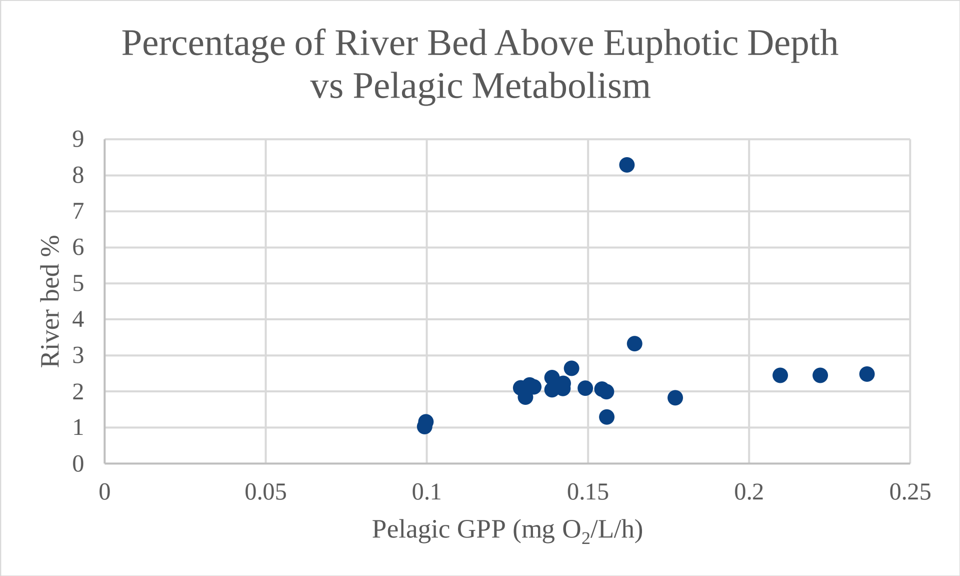

Figure 19 Percentage of riverbed above euphotic depth vs Pelagic Metabolism

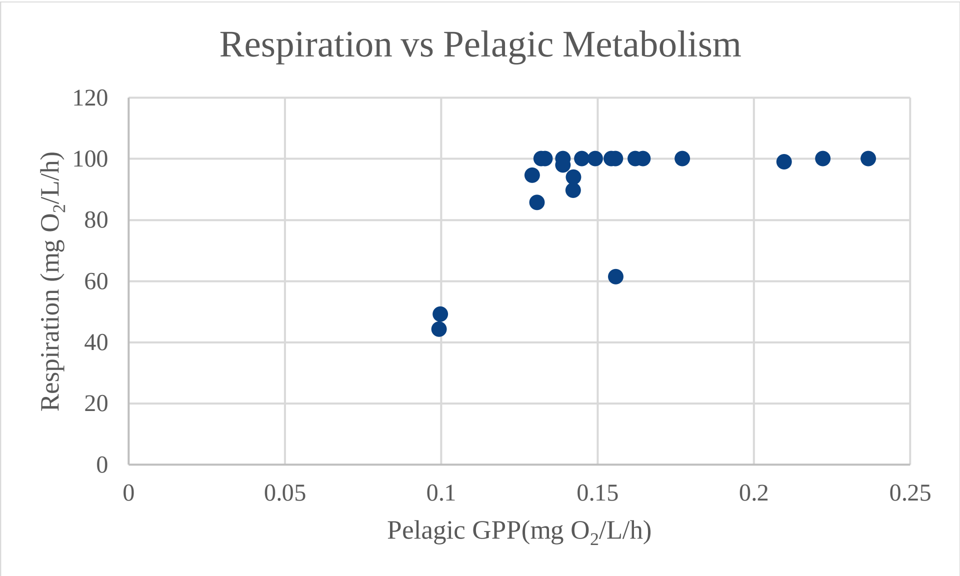

Figure 20 Respiration vs Pelagic Metabolism

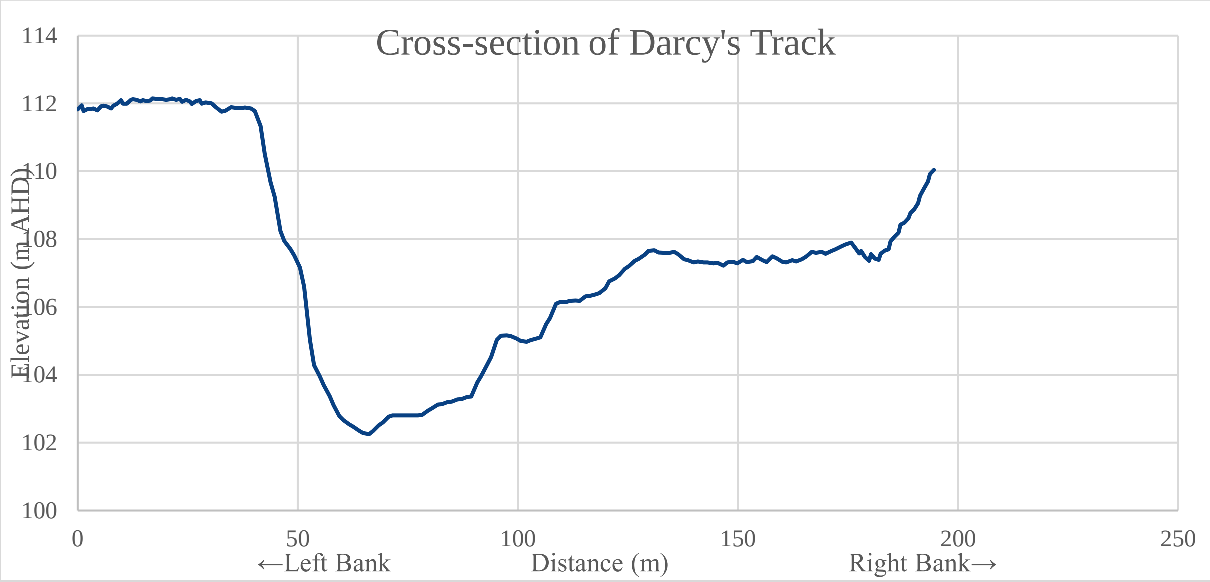

Figure 21 Cross-section of Darcy's Track

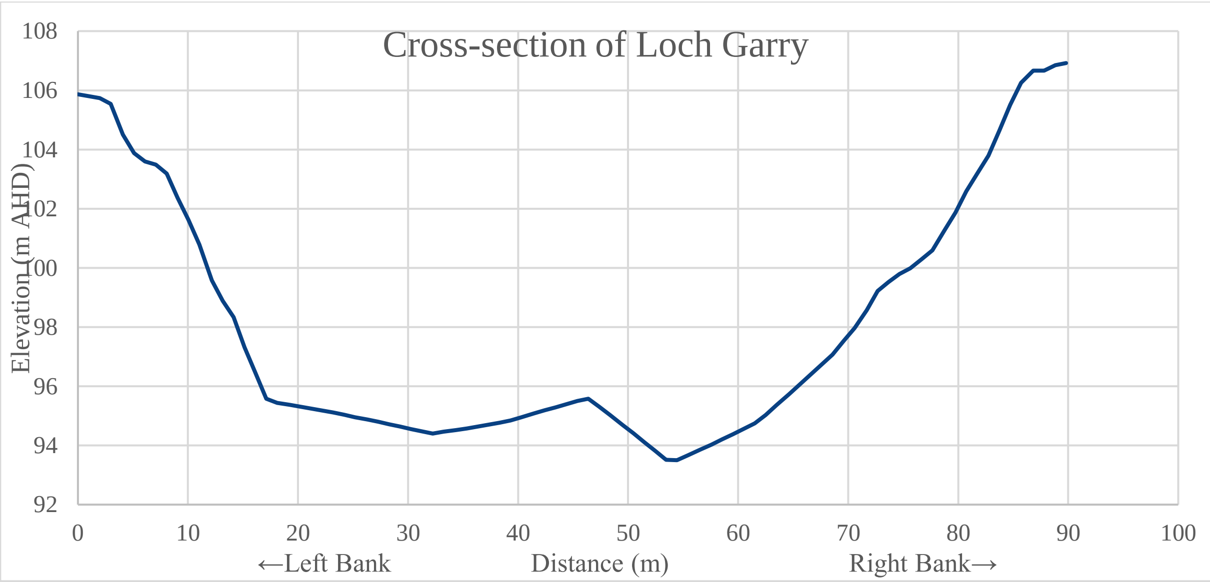

Figure 22 Cross-section of Loch Garry

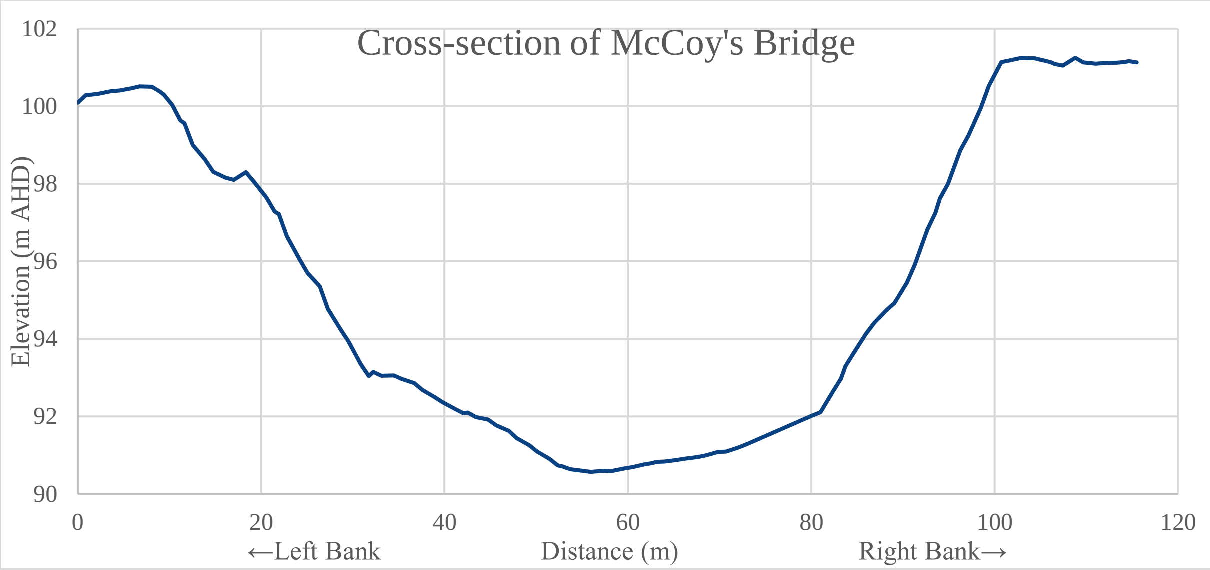

Figure 23 Cross-section of McCoy's Bridge

Appendix L: Examples of media communications

19 May 2021 Shepparton News

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

Victorian Landcare Grants

Applications are now open for the 2021 Victorian Landcare Grants.

The Victorian Government is providing $2.55 million funding to support Landcare and environmental volunteering groups and networks for on-ground works, education, and capacity building projects that protect, enhance, and restore our land and natural environment.

Up to $30,000 is available for project grants and up to $500 for support grants.

Grants are open to all Victorian Landcare and environmental volunteering groups and networks that have a focus on on ground land and natural environment improvement work.

Applications close 5pm Wednesday June 16. For more information go to www.gbcma.vic.gov.au

Upcoming workshops

- **May 22 – Warrenbayne –** Gecko Clan invites you to join Ag Vic Senior Researcher Dr Meredith Mitchell to learn about native grass identification and management of native pasture grazing systems. Registration is essential. Contact Kim Magnay on 0419 482 409 or geckoadmin@inet.net.au for more information.
- **May 28 – Hilldene –** Ag Vic's Brad Costin will discuss erosion management principles. A paddock walk is also part of the event. Registration is essential. Contact Kerstie Lee on 0437 310 840 or kerstiel@gbcma.vic.gov.au
- **May 29 – Broadford –** Join South West Goulburn Landcare and Ron Litjens for an informative discussion about "paddock trees as prime real estate". Registration is essential. Contact Sonia Sharkey on 0409 515 630 or swg_landcare@mitchellshire.vic.gov.au for more information.

These workshops are supported by the Goulburn Broken CMA through funding from the Australian Government's National Landcare Program.

Goulburn River flows

Recovering riverbank vegetation received a welcome drink with water for the environment delivered along the lower Goulburn River in recent weeks. The environmental flow also benefited water bugs and instream productivity to support native fish.

The response of vegetation to the water delivery, as well as bank condition and fish and bug numbers, will be measured as part of the Commonwealth Environmental Water Office's Monitoring Evaluation and Research (Flow-MER) project.

To check flows in the Lower Goulburn, view the hydrograph on Goulburn Broken CMA's website: http://fcnmccoys.hydronet.com/ (updated weekly).

www.gbcma.vic.gov.au


Goulburn Broken CMA
25 May ·
Super fun & informative afternoon with younger members of the Burnanga Indigenous Fishing Club & RMIT University ecologists learning about macroinvertebrates (aka #fishfood or #water bugs) as indicators of water quality and how they respond to changes in flows in the Goulburn River! Read more about Flow-MER monitoring here: https://bit.ly/3wWENMi #waterfortheenvironment #welovescience #yortayorta
+3


Goulburn Broken CMA
13 April ·
Great morning out at Loch Garry with Gina & Michael from RMIT University monitoring #waterbugs and water quality as part of the #Goulburn The Flow-MER Program. More: https://bit.ly/3wWENMi
#autumn
#fishfood
+2

Goulburn Broken CMA @GBCMA · May 26

Super fun day with members of the Burnanga Indigenous 🎣 Club & @RMIT_aquest learning about macroinvertebrates (aka#fishfood) as indicators of H2O quality in the Goulburn River! More on monitoring here: bit.ly/3wWENMi

#waterfortheenvironment #welovescience #yortayorta

The Flow-MER Program and 2 others

Goulburn Broken CMA @GBCMA · Apr 22

Mid-bank veg on the Goulburn River (and a dog) is getting a drink before winter. #waterfortheenvironment helps bank-stabilising plants grow &spread and provides habitat for water bugs, fish & other aquatic wildlife. bit.ly/3mELhKS

Environmental Water and 4 others

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