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Long Term Intervention Monitoring Project

Goulburn River Selected Area evaluation report 2016–17

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Executive Summary

The Lower Goulburn River Long-Term Intervention Monitoring (LTIM) Project is a joint venture between the University of Melbourne, Jacobs, Arthur Rylah Institute for Environmental Research, Monash University, Streamology, Goulburn Valley Water, and the Goulburn-Broken Catchment Management Authority. It is funded by the Commonwealth Environmental Water Office, with additional contributions from the Victorian Environmental Water Holder and Department of Environment Land Water and Planning, Victoria.

The Lower Goulburn River LTIM Project takes a science-practice partnership approach, where a highly effective and collaborative relationship has been established between government agencies, local water managers and the scientific community. This means that researchers have better access to ongoing and up-to-date information on flows from the water and catchment management authorities, and practitioners see field verification of management intentions and/or adaptive updating of management decisions.

This report is structured as follows. This executive summary focuses on making a brief statement on the major ecological responses observed to Commonwealth environmental water. The main body report that follows focuses on the evaluation of each response, and also includes context, synthesis and adaptive management implications of the results. The executive summary and main body are designed to be able to be read as stand-alone documents if desired. The technical appendices are designed to be read in conjunction with the main body, rather than as stand-alone sections. They provide a much greater level of detail on methods used for monitoring and evaluation, the results, and discussion similar to that seen in scientific papers, but do not repeat the evaluations provided in the main body.

Flows and Monitoring in 2016–17

River flows in the Lower Goulburn in 2016–17 were much higher than in previous years, especially the extremely dry year of 2015–16. These flows were considerably larger than what can be delivered as an environmental flow, and introduced organic matter into the river channel and reconnected riparian wetlands, both of which are expected to be beneficial for river ecology. In contrast, in late December 2016, heavy rainfall in the Seven Creeks catchment caused a blackwater event in the Goulburn River that contributed to fish kills. Blackwater events typically occur when excess organic material is deposited in the water column and is rapidly decomposed leading to a rapid decline in dissolved oxygen. The rate of decomposition and hence dissolved oxygen decline increases with increasing temperature, so high flows in summer present a particular risk.

Because of naturally high flows between August and November 2016, the delivery of the planned spring fresh was cancelled. Subsequently, Commonwealth environmental water was used to deliver a summer/autumn and winter fresh, and to maintain baseflows from late spring to winter.

The high spring flows led to the delay and cancellation of some planned monitoring activities. For cancelled activities, alternative, additional monitoring was undertaken. This monitoring was primarily aimed at detecting beneficial effects of the spring floods (macroinvertebrates) and the recovery from flooding of vegetation.

Monitoring in the Goulburn River LTIM Project focuses on the stretch of river between the confluence of the Broken River near Shepparton, down to the Murray River confluence near Echuca (known as Zone 2). There is also a smaller amount of monitoring being done between Goulburn Weir and the Broken River confluence (Zone 1). Environmental Matters being investigated include the hydraulic, geomorphological, fish, vegetation, macroinvertebrate and stream metabolism responses to environmental flows. A summary of ecological outcomes for these matters is provided in the table below.

Matter	Major Ecological Outcomes in 2016–17
Physical habitat - hydraulic habitat	• Pool area, slackwater area, and wetted area increase with flow – up to 2,000 ML/d (for slackwater area and wetted area) or 5,000 ML/d (for pool area). Beyond these flows diminishing returns are seen for increases in flow rate. • Adding a fresh of 5,000 ML/d to baseflow can triple substrate turnover, reduce sediment smothering and increase bed sediment diversity. • High flow freshes may transport the seeds and provide favourable conditions (wetting, low velocity) to encourage vegetation germination and growth on benches and banks. High velocities may also be an important factor in the creation of niches for seed deposition and the removal of unwanted vegetation at higher discharges.

Matter	Major Ecological Outcomes in 2016–17
Physical habitat – bank condition	• Current environmental flows do not contribute to greater erosion than would occur under regulated flows • The longer a bank is underwater the greater likelihood of both erosion and deposition. For example, doubling the duration of bank inundation from 10 to 20 days leads to a 50% increase in the probability of minor erosion. • Bank erosion and deposition are highly variable spatially, both along the bank and with elevation, and over time, with a single point on the bank often changing from erosion to deposition with subsequent flow events. • Peak discharge or volume of water is not related to bank erosion. • Mud drapes that encourage vegetation establishment most commonly develop during slower rates of flow recession (how fast the flow recedes). • A faster drawdown rate can increase minor erosion and decrease deposition. However, there is no influence of the rate of drawdown on significant erosion events (i.e. erosion > 30 mm).
Stream metabolism: production and respiration	• Daily total amounts of oxygen produced and consumed, and amounts of organic carbon created and consumed per kilometre increased with flow rate but plateaued at 4000 ML/d. • Even including the major flood, no relationship was found between flow and direct rates of Gross Primary Production – dissolved oxygen produced by photosynthesis (GPP) and Ecosystem Respiration – dissolved oxygen consumed by respiration of plants, bacteria, fungi and animals (ER). • Metabolic rates are consistent at the same time period across years, e.g. GPP (and ER) rates were consistently highest during December-January. • There were no long lasting effects of the major flood on rates of GPP and ER over ensuing weeks and months. • Small watering actions that remain within-channel have a beneficial effect on the total food resources produced for fish and other components of the biota. • Stream metabolism appears to be constrained by low bioavailable nutrient concentrations, particularly phosphate. For the third year in a row, phosphate concentrations are lower than the median values over the last decade. • Reaeration rate and GPP were insufficient (singly and in combination) to quickly overcome very low DO levels that resulted from blackwater entering the Goulburn from tributaries after heavy rainfall in late December 2016.
Macro-invertebrate biomass and diversity	• After the winter/spring floods, macroinvertebrate richness, abundance and large crustacean biomass increased in both Goulburn and Broken rivers. Increased macroinvertebrate diversity, abundance and biomass in edge habitats was observed following the natural spring flood. This response was larger than the effect observed for smaller managed spring flow events in previous years. • After the high natural flows, there was an increased abundance of adult insects in the river riparian zone that have aquatic larval stages. • Decreased macroinvertebrate productivity occurred in January in both rivers. • The January blackwater event adversely affected water quality, increasing stress, mortality, and causing macroinvertebrates to drift.
Bankside vegetation abundance and diversity	• Prolonged natural flooding in spring 2016 caused significant declines in cover and occurrence of establishing sedges. • Fewer taxa were identified following the natural floods than for corresponding surveys in 2015 following a managed spring fresh. However, taxa numbers increased over the remainder of the survey period, suggesting a delay to seasonal growth patterns from the floods. • The March 2017 summer/autumn fresh appeared to provide some positive effects for mature native grasses. • Natural flooding and spring freshes both produce a similar suppression of exotic pasture grass cover • The increase in cover and distribution of lesser joyweed (*A.denticulata*) and common sneezeweed (*C.cuninghamii*) in 2016-17 shows that some taxa can respond rapidly to wet conditions when high flows recede. • The high spring flows and summer/autumn fresh both influenced soil moisture. At greater elevations on the bank, the effect on soil moisture was reduced, both in terms of the depth of soil affected and the duration of increased moisture between inundation events. • Not delivering the spring fresh following the natural flood was beneficial for new vegetation.
Native fish movement	• Long-distance movements of golden perch (mostly downstream) coincided with elevated flows. Twenty-eight of 81 tagged fish moved 20 km or more. • Movements corresponded to the timing of spawning, suggesting reproduction is a driver of fish movement.

Matter	Major Ecological Outcomes in 2016–17
	• Attraction flows (the extended autumn fresh in March) saw the movement of some tagged sub-adult silver perch into the lower Goulburn River. These results are not evaluated directly in this report as monitoring was not undertaken as part the LTIM Project.
Native fish spawning	• Golden and silver perch eggs were collected during the natural flow event in mid-November, with silver perch eggs collected slightly later and at higher water temperatures (20.7°C vs. 18.5°C). • Golden perch egg occurrence in the lower reach corresponded with the movements of tagged fish. • The majority of golden perch eggs (and carp larvae) coincided with the falling limb of the hydrograph.
Fish assemblage	• Higher numbers of silver perch were found in 2017, and this is likely due to immigration from the Murray River. • The elevated spring flows that improved the recruitment of semi-aquatic bank vegetation may explain the higher abundance of Murray River rainbow fish (listed as threatened in Victoria) as well as carp spawning and recruitment. • Higher abundance of bony herring may represent transient fish that enter the Goulburn River when conditions are stable. • Absence or reduction of trout cod and Murray cod possibly due to the blackwater event. • No young of year golden or silver perch were found, implying early life history stages may be taking place outside the Goulburn River. • Fish death in January due to the blackwater event appear to have impacted fish diversity and abundance, and may reflect the absence or reduction of some species such as trout cod and Murray cod.

Synthesis

Year 3 (2016–17) monitoring therefore continued to build upon the results from the first two years of the Lower Goulburn River LTIM Project to improve our knowledge of environmental responses to flow variation and environmental flows in the lower Goulburn River. The spring floods required a responsive approach to monitoring, and we were able to take advantage of funds freed up by the cancellation of some activities to more closely target additional monitoring to measure the response to this flooding. The late December blackwater event had noticeable impacts on all monitoring matters except physical habitat. It will be interesting to see how the system recovers from this major disturbance over the next two years of monitoring. The innovation in environmental flows that occurred in 2016–17 was the provision of 'attraction' flows for sub-adult golden and silver perch, made possible by aligning the timing and duration of the summer/autumn fresh with lower flows in the Murray River. Additional monitoring around this event, funded by the MDBA and DELWP revealed positive effects for silver perch recruitment.

Monitoring in 2016–17 has further elucidated linkages among the environmental matters being investigated. Links are now evident between the hydrology and (i) ecosystem metabolism, (ii) physical habitat (hydraulic habitat) and (iii) physical habitat (bank condition). There is also some tentative support for links between ecosystem metabolism and macroinvertebrates, and between the hydraulic habitat, fish and vegetation. Uncertainty remains, particularly for links between environmental flows and slower-responding variables (e.g. adult fish populations and bank vegetation). Chapter 8 discusses these linkages and future years of LTIM will attempt to better elucidate these relationships.

The Lower Goulburn LTIM Project is also continuing to demonstrate its value for adaptive management. Examples of monitoring results that have affected decision-making for environmental water delivery can be identified for all monitoring matters, with these being discussed in the main body of the report. The probable single largest benefit for adaptive management of environmental water in the Goulburn River is the rapid two-way transfer of information between the Monitoring Provider and the environmental water managers. This allows decisions to benefit from knowledge gained from monitoring in near real-time for within-season decision making. At the annual scale, monitoring results are being used to inform development of seasonal watering proposals, with direct involvement of the Monitoring Provider through an annual workshop. Both of these activities, made possible through the successful science-management partnership of the Lower Goulburn LTIM Project, greatly foreshorten the response time for management to incorporate monitoring results into their decision-making processes. Chapter 9 provides example changes already made to environmental watering actions in response to monitoring results, and implications for future monitoring and management. We also expect that the body of knowledge generated over the five years of the LTIM Project will be a substantial feed-in to future revisions of environmental flow recommendations for the Goulburn River.

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1. Introduction

The Commonwealth Environmental Water Office (CEWO) is funding a Long-Term Intervention Monitoring (LTIM) Project in seven Selected Areas to evaluate the ecological outcome of Commonwealth environmental water use throughout the Murray-Darling Basin. The LTIM Project is being implemented over five years from 2014–15 to 2018–19 to deliver five high level outcomes. These are:

1. Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authorities (MDBA) Environmental Watering Plan;

2. Evaluate the ecological outcomes of Commonwealth environmental watering in each of the seven Selected Areas;

3. Infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin not monitored;

4. Support the adaptive management of Commonwealth environmental water; and

5. Monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

This report describes the monitoring activities undertaken in the lower Goulburn River Selected Area in 2016–17 and summarises the results and analysis outcomes of that monitoring. Where appropriate, it compares results to those obtained in the first two years of the program 2014–15 and 2015–16. Detailed descriptions of results and analyses for each monitoring discipline are provided in the appendices. The report has been prepared by all discipline leaders of the Lower Goulburn River Monitoring and Evaluation Provider and is also used for the Basin-scale evaluation of the LTIM Project.

1.1 Lower Goulburn River selected area

The Goulburn River extends from the northern slopes of the Great Dividing Range north to the Murray River near Echuca (Figure 1-1). Mean annual flow for the catchment is approximately 3,200 GL (CSIRO 2008), and approximately 50% of that is on average diverted to meet agricultural, stock and domestic demand.

The Goulburn River Selected Area includes the main river channel between Goulburn Weir and the Murray River (235 km), along with any low-lying riparian or wetland/floodplain assets that are connected to the river by in-channel flows up to bankfull. The Selected Area corresponds to Reach 4 (Goulburn Weir to confluence with Broken River at Shepparton) and Reach 5 (confluence of Broken River to Murray River) described in environmental flow studies and environmental watering plans (Cottingham et al. 2003, Cottingham et al. 2007, Cottingham and SKM 2011). Environmental flows in the lower Goulburn River are not used to deliver overbank flows or to water the floodplain. Therefore, for the purposes of the LTIM Project, the Lower Goulburn River Selected Area is considered a Riverine System under the Australian National Aquatic Ecosystem (ANAE) classification (Brooks et al. 2013).

Previous environmental flow monitoring programs in the lower Goulburn River, for example, the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) (Miller et al. 2015), and the Commonwealth short-term environmental water monitoring programs (Stewardson et al. 2014, Webb et al. 2015), based their sampling design around the existing environmental flow reaches. In order to complement this historical monitoring, promote consistency in the data sets, and to allow incorporation of historical data into analyses, the Goulburn River LTIM Project does the same.

The Goulburn LTIM Project divides its monitoring locations by ‘zones’. These are:

- 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 (i.e. Environmental Flow Reach 4).

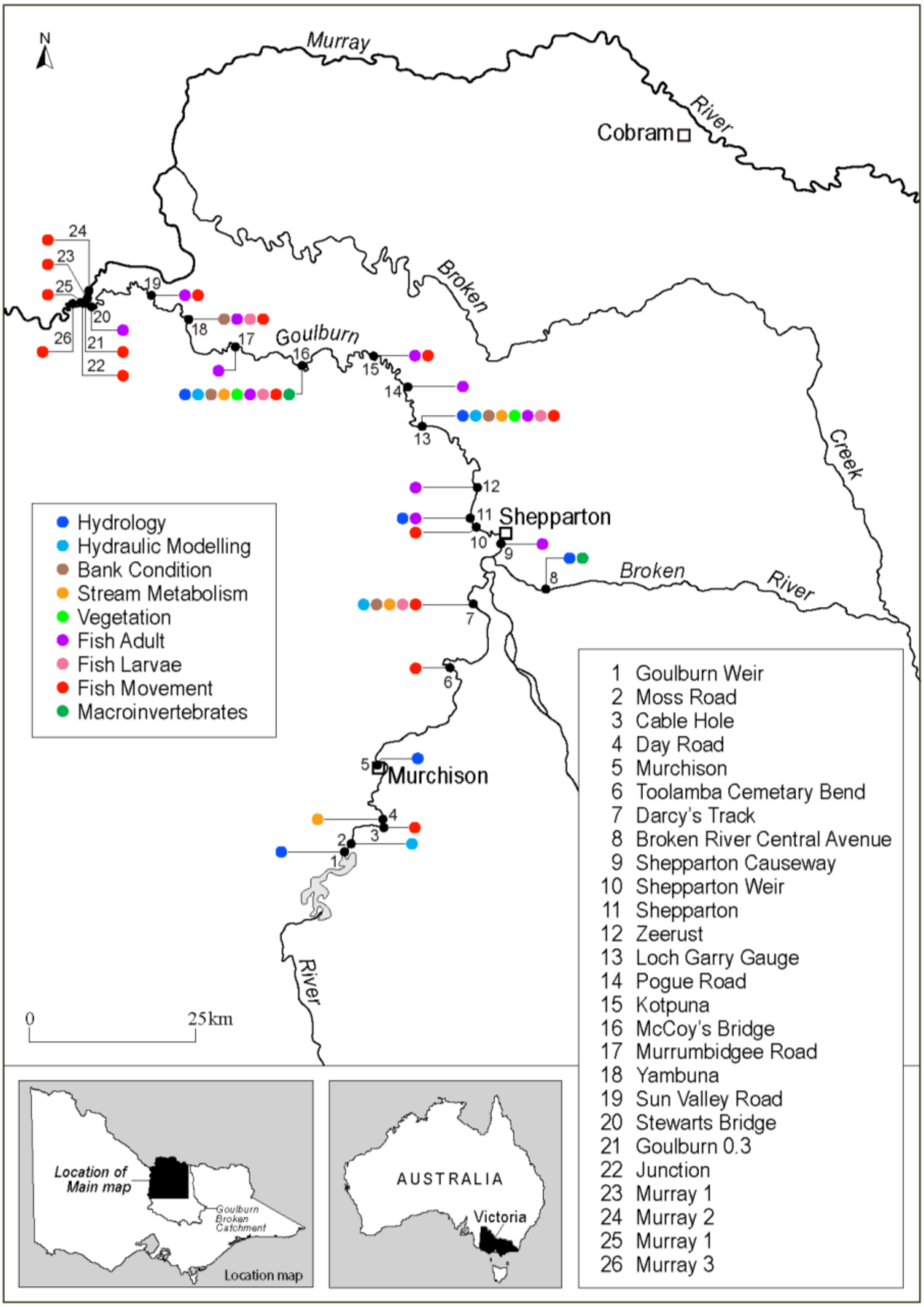


Figure 1-1. Map of the lower Goulburn River, with all monitoring sites marked, along with flow gauges used to generate flow data used in this report. Some sites extend into the Murray and Broken rivers. Colours denote different monitoring activities, with some sites being used for multiple activities. 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.

- 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 are several sites outside these zones: the control site for macroinvertebrate monitoring in the lower Broken River, and several acoustic monitoring stations in the Murray River near the Goulburn confluence.

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. The Monitoring Providers for the Lower Goulburn River Selected Area decided to invest effort in many monitoring activities in a single zone, rather than a small number of monitoring activities in both zones, and are focussing on responses to environmental flows in Zone 2. This is where most of the previous fish surveys in the Goulburn River have been conducted and where high rates of golden perch spawning have previously been recorded. Improving native fish populations is one of the highest priority environmental flow objectives for the lower Goulburn River. Zone 2, is also close to other LTIM Project Selected Areas including the Edward Wakool system, the Murrumbidgee System and the Lower Murray system.

Ecological Matters to be investigated are the hydraulic, geomorphological, fish, vegetation, macroinvertebrate and stream metabolism responses to environmental flows in Zone 2. Some responses to environmental flows in Zone 1 are also included, as is the control site for macroinvertebrate monitoring (Broken River) and several fish movement acoustic monitoring stations (Murray River). Specific monitoring sites within each zone and the monitoring activities undertaken at each site are detailed in Table 1-1.

Table 1-1. LTIM monitoring sites in each zone and the monitoring activities undertaken at each site.

Site No.	Site Name	Adult Fish	Larval fish	Fish move-ment	2D Model	Bank Cond-ition	Veg-etation diversity	Stream metab-olism	Macro-inverte-brates
Zone 1 – Goulburn Weir to Broken River									
1	Moss Road			■	■				
2	Day Road							■	
3	Toolamba/Cemetery Bend		■	■					
4	Darcy's Track			■	■	■		■	
Zone 2 – Broken River to Murray River									
1	Shepparton Causeway	■							
2	Shepparton	■		■					
2	Shepparton Weir			■					
3	Zeerust	■							
4	Loch Garry Gauge	■	■	■	■	■	■	■	
5	Pogue Road	■							
6	Kotpuna	■		■					
7	McCoy's Bridge	■	■	■	■	■	■	■	■
8	Murrumbidgee Road	■							
9	Yambuna	■	■	■		■			
10	Sun Valley Road	■		■					
11	Murray Junction			■					
Outside of zones 1 & 2									
1	Central Avenue, Broken River								■
2	Murray 2			■					
3	Murray 1			■					
4	Murray -1			■					
5	Murray -3			■					

1.2 Environmental values and flow regulation of the lower Goulburn River

The Goulburn Broken Regional River Health Strategy (GBCMA 2005) identifies the Goulburn River as a high priority waterway due to its significant environmental values. The river and its associated floodplain and wetland habitats support intact River Red Gum forest, and numerous threatened species such as Murray cod, trout cod, squirrel glider, and eastern great egret. The river and its associated floodplain and wetland habitats also contain many important cultural heritage sites, provide water for agriculture and urban centres, and support a variety of recreational activities such as fishing and boating. Further description of the lower Goulburn River is included in Gawne et al. (2013).

The two major water regulation structures on the Goulburn River are Lake Eildon and Goulburn Weir. Lake Eildon has a capacity of approximately 3,334 GL and provides water to the majority of the Shepparton, Central Goulburn, Rochester and Pyramid/Boort irrigation areas. Water may be diverted at Goulburn Weir into the East Goulburn Main Channel and harvested into Waranga Basin (capacity 432 GL).

Flow in the middle Goulburn River (i.e. Between Lake Eildon and Goulburn Weir) is higher than it would naturally be in summer and early autumn to supply irrigation needs, but is lower than natural at other times of the year. The diversion of irrigation water at Goulburn Weir and inflows from tributaries such as the Broken River and Seven Creeks have helped to retain the natural seasonal flow patterns (i.e. high winter flows and low summer flows) in the lower Goulburn River. Significant Inter-Valley Transfer (IVT) flows may also be released into the lower Goulburn River from Goulburn Weir during summer and early autumn to supply water entitlements traded from the Goulburn River system to the Murray River system. The regulation described above has reduced the average annual flow in the lower Goulburn River downstream of Goulburn Weir to 1,340 GL, which is less than half of the estimated pre-regulated flow of 3233 GL.

The sections of the Goulburn River between Lake Eildon and Shepparton (including Zone 1 of the Lower Goulburn River Selected Area) have a naturally confined floodplain (up to 4 km wide). Constructed levees confine the floodplain along the Goulburn River downstream of Shepparton (i.e. Zone 2 of the Lower Goulburn River Selected Area). Flood water leaving the Goulburn River downstream of Shepparton either returns to the channel (where blocked by levees), or flows north via the Deep Creek system that discharges to the Murray River downstream of Barmah (but upstream of the confluence of the Goulburn and Murray Rivers). The Broken River is a major tributary of the Goulburn River, discharging at Shepparton. Other tributaries (all between Goulburn Weir and Shepparton) are; Seven Creeks, Castle Creek and Creightons/Pranjip Creek.

As well as the impact of long term flow reduction, the lower Goulburn River was heavily affected by the Millennium Drought when amphibious and flood tolerant bank vegetation dried-out and was replaced by terrestrial vegetation. The extended floods in 2010-11 and 2012 killed-off all the terrestrial vegetation leaving bare river banks susceptible to erosion. Vegetation has begun to re-establish over recent years. Golden perch, a flow-cued spawner, did not spawn during the drought (Koster et al. 2012), making spawning a priority to rebuild populations and age classes.

1.3 Overview of Commonwealth environmental watering

As of 31 August 2017, the Commonwealth held 278.4 GL of high security and 29.4 GL of low security environmental water entitlements in the Goulburn River (Table 1-2). The Goulburn River receives other environmental flows including from the Victorian Environmental Water Holder and The Living Murray program. Inter-Valley Transfers are also used to meet environmental flow targets when possible (see Gawne et al. 2013 for further details). In 2016–17 the Commonwealth environmental water entitlement provided most of the environmental water used to meet specific environmental flow objectives in the lower Goulburn River channel.

1.3.1 What type of watering was planned?

High priority watering actions for 2016–17 in Reaches 4 and 5 included continuous baseflows throughout the year for habitat, and winter/spring and autumn freshes for bank vegetation. Watering actions dependent upon seasonal water allocations included a spring/summer fresh to stimulate golden perch spawning, a summer/autumn fresh to attract young of year fish migrating up the Murray River into the Goulburn, recession flows to augment unregulated flow events, and an autumn/winter fresh to benefit vegetation, water quality and macroinvertebrate habitat (GBCMA 2016). Watering actions that can occur depend on climatic conditions and water availability and the viability of each option is discussed between all water holders and the river operators throughout the year.

Table 1-2. Commonwealth environmental water entitlements as at 31 August 2017 (http://www.environment.gov.au/water/cewo/about/water-holdings).

Entitlement type	Entitlement held (GL)	Entitlement held - Long term average annual yield (GL)
Goulburn (high reliability)	278.4	263.8
Goulburn (low reliability)	29.4	12.9

When environmental flows are to be above 3,000 ML/day at Goulburn Weir landowners are advised ahead of time to allow for pumps at risk of being inundated to be moved. Unless otherwise agreed, Commonwealth environmental water will only contribute to flows up to 15,000 ML/day at McCoys Bridge. Fresh actions are unlikely to exceed 9,500 ML/day at McCoy's Bridge, but in the event of high natural flows, watering may commence at 15,000 ML/day at McCoy's Bridge to slow-down flow recession rates.

To maximise the efficient and effective use of Commonwealth environmental water, where possible, return flows from the Goulburn River are traded for use downstream, providing significant environmental benefits at multiple sites including Gunbower Forest, Hattah Lakes, the lower River Murray channel and floodplain wetlands, Lower Lakes, Coorong and Murray Mouth (CEWO 2014).

1.3.2 What were the expected watering outcomes?

Environmental flows in the lower Goulburn River were intended to achieve the following ecological outcomes (GBCMA 2016):

- Year-round minimum and high baseflows - to maintain water quality and provide suitable habitat and food resources to support small-bodied native fish and macroinvertebrates condition and survival.
- Winter fresh (Jun-Aug) - to support condition and survival of native vegetation and scour fine sediments from riffle surfaces to maintain habitat for macroinvertebrates and macrophytes.
- Spring fresh (Sep-Nov) - long duration - targeting in-channel native vegetation condition and reproduction; macroinvertebrate diversity and abundance; movement and condition of native fish; biotic dispersal; and the transport of nutrients, carbon and sediment.
- Spring/summer fresh (Oct-Dec) - short duration - to promote movement and breeding of native fish (flow cued spawners).
- Summer/autumn fresh (Feb-Apr) - low magnitude, long duration - to support the survival and condition of in-channel native vegetation and contribute to the movement of young-of-year native fish into the Goulburn River.

These are the priorities for the lower Goulburn River Selected Area monitoring (Table 1-3).

1.3.3 Practicalities of watering

Commonwealth environmental water is sourced using managed releases from Lake Eildon and/or Goulburn Weir. Throughout the year river flows from natural catchment runoff, normal minimum flows or irrigation releases (e.g. Inter-Valley Transfers) are assessed to see how well they are meeting identified flow targets in the lower Goulburn River. If available, environmental water can be released to increase the flow rate and duration to meet these targets.

Monitoring the physical and ecological effects of environmental flows is particularly sensitive to the timing of fresh actions, as well as catchment runoff and irrigation releases, because high flows and localised heavy rainfall can restrict access to the river or monitoring sites and reduce sampling efficiency. These constraints can, in some cases, affect the capacity to reliably evaluate the effect of particular flow events, although it is not expected to be a major issue for managed environmental flow releases.

1.4 Environmental water delivered in 2016–17 and context

In 2016–17 a total of 230 GL of environmental water was delivered, with the major environmental water holders providing 182 GL (Commonwealth Environmental Water Holder), 28 GL (Victorian Environmental Water Holder), and 20 GL (The Living Murray). High priority base flows were delivered and the autumn and winter freshes were delivered. IVTs delivered 88 GL, contributing to base flows (Table 1-3).

Table 1-3. Summary of planned and actual environmental flow for the Lower Goulburn River 2016–17. Information on planned delivery and expected outcomes from (CoA 2016). Information on actual delivery provided by CEWO (unpubl. data).

Flow component type and target/planned magnitude, duration, timing	Expected outcomes	Actual delivery details and any operational issues that may have affected expected outcomes
Baseflow **(Year round)** **540-940 ML/day at McCoys Bridge** **For 2016–17 a higher baseflow of 1186/1505 was also used when required.**	1a. Contribute to minimum baseflows year-round to maintain water quality and provide suitable habitat and food resources to support native fish and macroinvertebrate condition and survival. 1b. Contribute to higher baseflows year-round, but especially in winter/spring to provide additional habitat and food resources to support native fish and macroinvertebrate condition and survival.	Commonwealth environmental water (CEW) was used to help meet baseflow targets from 1 Jul–1 Aug, 29 Oct–5 Jan, 31 Mar–21 Jun. At other times, the target base flows were met through unregulated inflows and/or inter-valley transfers.
Winter fresh **(Jun-Aug)** **Up to 15,000 ML/day at Murchison & McCoys Bridge with 14 days above 6,600 ML/day**	1c. Contribute to winter freshes to support the condition and survival of native vegetation as part of the ongoing system recovery following prolonged drought and subsequent flooding; provide channel maintenance and promote the transport of nutrients, carbon, sediment and biota.	CEW was used to deliver a winter fresh beginning 22 June, 2017. Flows reached 8,895 ML/day by 30 June.
Spring fresh **(Sep-Nov)** **Up to 15,000 ML/day at Murchison & McCoys Bridge with 14 days above 5,600 ML/day**	1d. Contribute to long-duration freshes in spring targeting in-channel native vegetation condition and reproduction; macroinvertebrate diversity and abundance; movement and condition of native fish; biotic dispersal and the transport of nutrients, carbon and sediment.	With the exceedingly high natural spring flows (Figure 1-2c), the spring fresh was not delivered.
Spring/summer fresh **(Oct-Dec)** **7,000 to 15,000 ML/day at Murchison & McCoys Bridge for 2 days**	1e. Contribute to short-duration freshes between October and December to promote movement and breeding of native fish (flow cued spawners).	This fresh was cancelled because of potential adverse impacts on vegetation and the river banks following the previous high unregulated flows in Aug–Sep.
Summer/autumn fresh **(Feb-Apr)** **Up to 5,600 ML/day at Murchison & McCoys Bridge for 2-4 days**	1f. Contribute to low magnitude, long-duration freshes between February and April to support the survival and condition of in-channel native vegetation and promote the transport of nutrients, carbon, sediment and biota. This fresh may also contribute to fish migration.	CEW was used to deliver a summer fresh from 25 Feb–30 Mar, 2017. Flows reached 4,626 ML/day on 4 Mar and were above 4,000 ML/day for 11 days. This fresh was slightly re-purposed to test hypotheses regarding sub-adult fish migration into the Goulburn River, with positive results. We did not expect positive outcomes for vegetation.

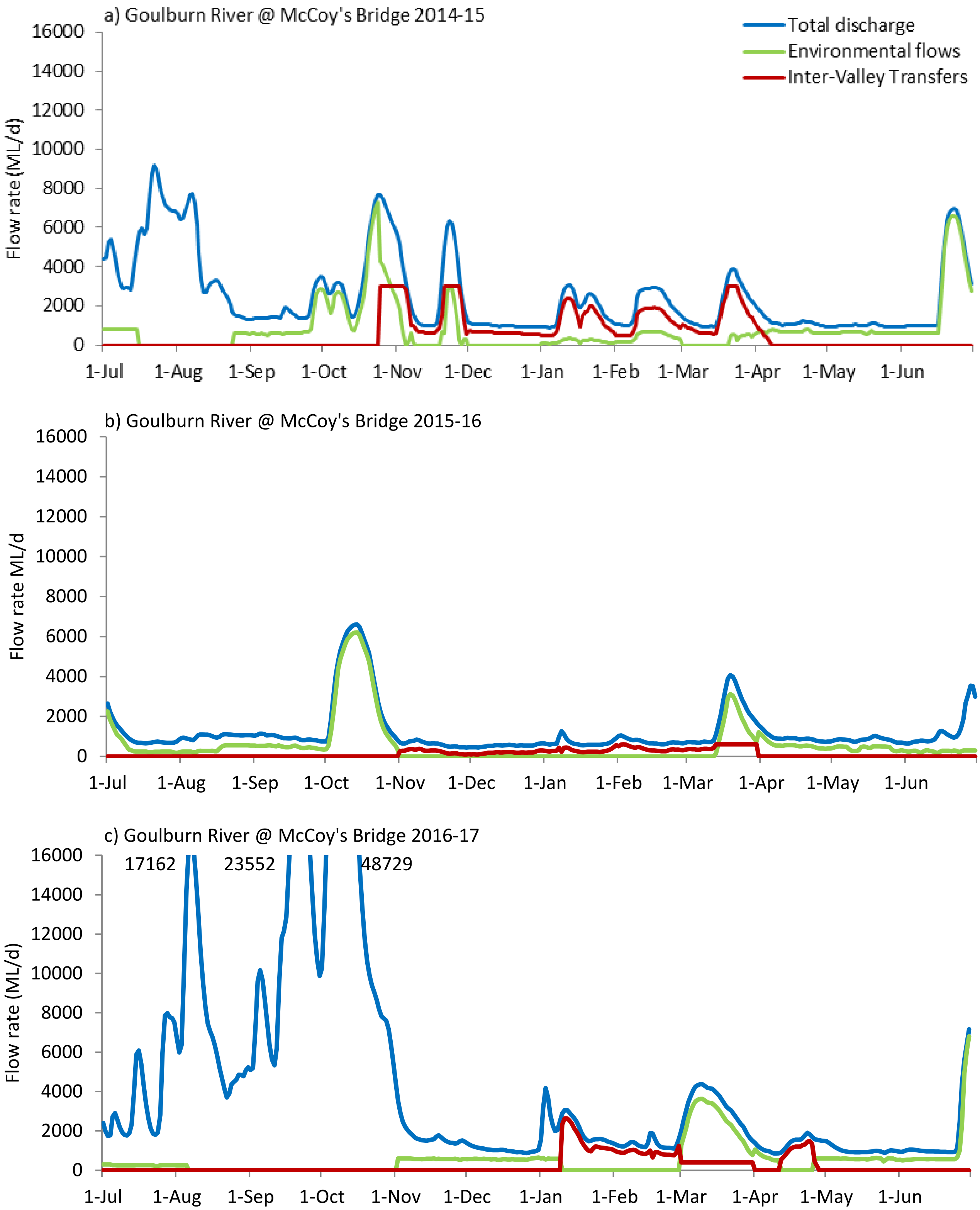


Figure 1-2. Summary of environmental flows delivery in the lower Goulburn River 2014–15 (a), 2015–16 (b), and 2016–17 (c). Chart shows total flow rate (ML/d) at the McCoy's Bridge gauging station near the bottom of the system, along with managed environmental flows delivered at that point, and inter-valley transfer flows, which were also managed to deliver parts of environmental flow components (see Appendix A for explanation of the hydrological data used in this report). Each panel has the same maximum y-axis value to facilitate comparison among years. For panel (c) peak flow rates are shown for the three events that extend beyond the top of the y-axis. Evaluation in this report covers the period from the start of the monitoring program (~September 2014) to the collection of adult fish monitoring data in May 2017.

Planned environmental water actions were disrupted by extremely high flows in spring. These reached almost 50,000 ML/day at McCoy's Bridge in early October, and there were two other flow peaks of over 15,000 ML/day during spring (Figure 1-2). The unregulated flows caused minor flooding in reaches 4 and 5 and impacted upon the deployment of monitoring equipment. Against this backdrop, the planned spring fresh was not delivered, and this left sufficient water to deliver all other priority flow components.

Flows in the Goulburn River in 2016–17 were much higher than in 2014–16 particularly August – October when the large flood events occurred (Figure 1-2). The major use of environmental water in 2016–17 was to deliver increased baseflows from late spring through to winter, and for the autumn and winter freshes delivered in March and June (Figure 1-2c).

2. Overview of monitoring undertaken in 2016–17

High flows and flooding in spring meant that not all of the planned monitoring activities outlined in the Monitoring and Evaluation Plan (MEP; Webb et al. 2014) were implemented during 2016–17. The majority of activities were implemented, although not necessarily exactly on the original schedule (see Table 2-1). Deployment of the oxygen loggers for Stream Metabolism, and planned visits for Bank Condition, were delayed by the high flow conditions. The early spring 'before-fresh' samples for Vegetation Diversity and Macroinvertebrates had to be cancelled altogether. Funds for the cancelled activities for Vegetation Diversity and Macroinvertebrates were directed towards additional activities. For Vegetation Diversity, two extra field trips were undertaken later in Summer and in Autumn to assess vegetation recovery from the spring floods and to assess longer-term response to the autumn fresh (See Section 6). The third survey was funded by an extra co-contribution from the Department of Environment, Land, Water and Planning. For Macroinvertebrates, funds were used to conduct bait-trap based surveys of large-bodied macroinvertebrates to assess whether there was a biomass response to the spring floods (See Section 5).

The periods of monitoring for each activity are based upon the expected responses to flow variation, optimised for budgetary and logistic considerations. These reasons are given more fully in the MEP (Webb et al. 2014). Updated Standard Operating Procedure (SOP) appendices are also included in that document to describe the additional monitoring described above. More detailed discussions of monitoring activities, how they differed from planned activities, and preliminary results are presented separately for each discipline in the following chapters, and more particularly in the technical appendices.

Table 2-1. Schedule of planned and actual monitoring activities by month for 2016–17. D indicates planned/actual timing for downloading data from fish movement loggers; I indicates planned/actual deployment of artificial substrates and yellow sticky traps for macroinvertebrate sampling, O indicates planned/actual retrieval of artificial substrates and yellow sticky traps for macroinvertebrate sampling. C indicates additional sampling for biomass of crustaceans undertaken in 2016–17.

Monitoring activity	No of sites per Zone		Planned / Actual	Schedule of planned and actual activities in 2016-17											
	Zone 1	Zone 2		J	A	S	O	N	D	J	F	M	A	M	J
Adult Fish		10	Planned												
			Actual												
Fish Larvae	1	3	Planned												
			Actual												
Fish Movement	3	8	Planned			D			D			D			D
	+ 4 stations in the Murray River		Actual					D		D			D		
Vegetation Diversity		2	Planned												
			Actual												
Macroinvertebrates		1	Planned				I	O		I	O				
	+ 1 control site in the Broken River		Actual					I	O	OC	C	C			
Stream Metabolism	2	2	Planned												
			Actual												
Bank Condition	2	2	Planned												
			Actual												
2D Hydraulic Model	2	2	Planned												
			Actual												

3. Physical habitat and bank condition

Physical habitat monitoring aims to understand the relationship between discharge, the distribution of hydraulic habitats (e.g. areas of slow and fast velocity, shallow and deep habitats, etc.) and river bank condition (patterns of sediment erosion and deposition), and the influences these characteristics have on biota and overall ecosystem health. Activities include hydraulic modelling and bank condition monitoring. Hydraulic modelling has been completed for four sites and a range of relationships between discharge and distributions of hydraulic habitats have now been developed. The details of hydraulic model development are described in the 2014-15 annual report (Webb et al. 2016), a selection of these relationships, developed in conjunction with the ecological team, are summarised here, and detail on model verification is provided in Appendix B of this report. River bank condition monitoring (erosion and deposition) was continued with environmental flows delivered in 2016-17. The period of monitoring to date has provided a range of hydrologic characteristics conducive to fieldwork and the assessment of physical habitat.

The results presented for bank condition monitoring in this report include data up to mid-February 2017. Statistical results are presented from the entire period 2015–2017. Observations, however, are made just for the 2016-17 monitoring period.

The adaptive management approach to bank condition on the Goulburn River has involved staff from the VEWH, CEWO and GBCMA and resulted in ongoing adjustments to flow management and improved opportunities for monitoring.

The derivation of results and more detailed analyses are described in more detail in Appendix B.

3.1 Evaluation

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. This information also forms the basis of Basin-scale evaluation – where area-level results are scaled up to the Basin level.

3.1.1 Area specific evaluation questions

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did CEW contribute to the provision of productive habitat (e.g. slackwaters) for the recruitment, growth and survival of larval and juvenile fish?	The provision of baseflows and freshes in the 2016-17 season contributed to variation in the type and distribution of hydraulic habitat known to be of value to fish.	Both baseflows and freshes increase wetted perimeter, pool area and mean depth. The area and number of Slackwater (slow and shallow) habitats increase with increasing baseflows up to ~ 2,000 ML/d. For higher discharges (~2,000-4,000 ML/d) slackwaters are reduced in area and patch size, but there is an increase in the number of slackwater patches as benches are inundated. High velocities are considered to be important triggers for fish recruitment and migration. Mean velocity tends to increases with increasing discharge. However, high (99th percentile) and maximum velocity tends to be highest at flows <2,000 ML/d. This is because flow is confined to the lower channel at low discharge, so the confined channel generates areas of faster flow and an overall more varied velocity distribution (i.e. large areas of slackwater and areas of faster flow). Rates of change in velocity as discharge changes are also highest at flows <2,000 ML/d –	Habitat relationships developed from hydraulic habitat models for four sites. These relationships will be used to undertake further hydrologic understanding of the influence of environmental flows.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
		rates of change in velocity may provide important cues for fish movement and spawning.	
What did CEW contribute to the provision of diverse and productive macroinvertebrate habitats?	Baseflows and freshes, such as provided in the 2016-17 season, are known to provide habitat for macroinvertebrates.	Baseflows increase the wetted area of the channel bed, and freshes increase wetting on higher, often more productive features such as bars and benches. Freshes greatly increase the turnover of bed sediments; the area of sandy bed sediments mobilised is tripled when a fresh of 5,000 ML/d is provided, compared to a baseflow of 1,000 ML/d. This is important for flushing and renewal of bed sediments and habitats for macroinvertebrates.	
What did CEW contribute to inundating specific riparian vegetation zones and creating hydraulic habitats that favour the dispersal and deposition of plant seeds and propagules?	Freshes and variable flow levels, such as those achieved through flow management during the 2016-17 season, are known to increase opportunities for the dispersal and deposition of plant seeds and propagules.	Variable discharges and flow levels provide greater opportunities for the recruitment, transport and dispersal of seeds and propagules. High flow freshes, in particular, may transport the seeds and provide favourable conditions (wetting, low velocity) to encourage vegetation germination and growth on benches and banks. High velocities may also be an important factor in the creation of niches for seed deposition and the removal of unwanted vegetation at higher discharges. Results showed that velocity increases with increasing discharge, but that velocity along the banks was generally lower than in the middle of the channel. These outcomes require confirmation by coordinating hydraulic results with vegetation analyses.	Hydraulic models have demonstrated changes in velocities at banks where vegetation is sampled. Mud drapes observed (and measured) following higher discharges have been observed to be zones of vegetation growth. Further coordination of hydraulic results and vegetation will confirm relationships.
How does CEW affect bank erosion and deposition?	Magnitude, frequency and duration of flows were all appropriate to prevent excessive rates of riverbank erosion and to also allow for deposition.	Environmental flows have little influence on bank erosion. The levels of erosion were higher than the levels of aggradation/deposition but this may also be an artefact of sensitive banks being targeted for this study. No mass failure (bank slumping) was observed at any of the four reaches. Episodic changes observed are not expected to be outside natural levels of variation, and where erosion does occur this was observed to provide niches for vegetation establishment.	Bank condition is based on quantitative measurements of bank erosion using erosion pins. At each site erosion pins, located at varying levels and locations, are remeasured pre/post events to assess bank change (levels of erosion or deposition). Statistical models compared predicted erosion/deposition under actual flow regime and one from which environmental flows had been removed.
How does the amount of river bank erosion affect vegetation responses to environmental water delivery?	Inundation frequency was appropriate to encourage lower bank vegetation, velocities at banks were not excessive, and mud drapes resulted following drawdown.	Whilst vegetation response has not been formally incorporated into the bank condition assessment at this stage, the flows delivered maintained appropriate rates of erosion and deposition and were found, in some cases, to encourage vegetation establishment. Low rates of recession commonly left 'mud drapes' on banks that provides suitable substrate for the germination of a range of plants.	Assessment of hydrologic conditions, qualitative assessments of erosion mechanisms, and observations (including repeat photographs) have enabled an assessment of bank condition and the potential for vegetation establishment and this will be quantified by coordinating the bank monitoring and vegetation results.

3.2 Other main findings from the physical habitat program 2016–17

Other main findings from 2016–17 monitoring include:

Hydraulic habitat:

- Bed mobilisation, developed in 2016–17, demonstrates that increases in discharge significantly increase the potential for bed substrate turnover, this 'disturbance' is important for refreshing sediment, promoting the processing of organic material and nutrients and providing a mosaic of benthic habitats for a range of biota, including macroinvertebrates, algae and macrophytes.

- Slow and shallow 'slackwater' area (where depth is less than 0.5 m and velocity is less than 0.05 m/s) is increased from zero flow as the bed is inundated. The relationship between discharge and slackwater area and distribution varies across sites, but area tends to be maximised at flows in the range of 2,000-6,000 ML/d (depending on individual sites). As flows increase further the total area of slackwater decreases and mean patch size decreases, however, the number of individual patches increases (i.e. higher discharges result in more but smaller slackwater patches). The optimal slackwater patch size is not known and could be a source of further investigation.

- The relationship between velocity and flow rate depends greatly on the metric selected, thus the metrics must be specifically defined relative to the hydraulic habitat of interest. For example, mean velocity increases with flow rate (for all sites). Maximum velocity, however, decreases for increasing flow rate until approximately 2,000 ML/d, then gradually increases for increasing flows. The distribution of velocities across the channel also vary with discharge, for example, velocity on the banks tends to be lower than in the channel. Velocities greater than 0.3 m/s may have the capability to influence vegetation and may assist with explaining changes to bank vegetation. The rate of change in velocity with flow rate is of interest to understanding fish spawning and migration cues. The modelling suggests that rates of change in velocity are greatest for lower flows, less than ~2,000 ML/d.

Riverbank condition:

- Bank erosion and deposition is highly variable with time, with a single point on the bank changing from erosion to deposition with subsequent flow events. Erosion also varies spatially, both along the riverbank and with elevation, often over small spatial scales of centimetres to metres.

- As with previous years, the 2016-17 monitoring shows there is marginally more erosion than deposition, but this may also be an artefact of targeting sensitive banks to better understand relationships between flow and bank condition. However, significant erosion (>30 mm) was not common, No mass failure events occurred at the erosion pin sites, or were observed at the sites more generally. The large majority of erosion pins displayed no erosion or deposition between surveys.

- The likelihood of erosion is most strongly linked to the duration of inundation. The longer the duration of bank inundation, the higher the likelihood of some minor erosion (< 30 mm) occurring (an increase in inundation duration from 10 to 20 days leads to a 50% increase in the probability of minor erosion). High rates of drawdown and freshes/high flows following dry periods in summer (the hot season) also marginally increase the probability of minor erosion occurring, but the increases are not statistically significant.

- Freshes that inundate sediment after a dry period in summer were hypothesised to result in higher likelihood of erosion (compared to freshes in spring), but the results are not significant and suggest that even though clay sediments are visibly dry and cracked, they are not significantly more susceptible to erosion when re-wetted in autumn than in spring.

- There appears to be no influence of peak discharge or flow volume on bank erosion.

- There is a slightly higher probability of minor bank erosion at lower bank elevations with increased inundation due to environmental flows (~10% increase). This is not surprising considering increased frequency of inundation of the lower banks and the relationship to inundation (as described above). The trend is less pronounced for significant erosion. However, deposition is also increased due to inundation of the lower banks by environmental flows (i.e. erosion occurs during the rising flow and deposition occurs on the descending flow, so the net impact is small and variable).

3.3 Discussion, implications and recommendations for Commonwealth Environmental Water

3.3.1 Discussion and Implications

Hydraulic conditions (such as velocity, depths and bed substrate turnover) for specific biota can be manipulated through flow management. For example, adding a fresh of 5,000 ML/d to baseflow can triple substrate turnover, reducing sediment smothering and increasing bed sediment diversity. The key element to the strategic use of hydraulic conditions as a tool for flow management is in understanding the preferred conditions for biota and the timing of these requirements. The quantification of habitat relative to discharge is providing opportunities for the water managers to understand the potential implications of particular discharge and tailor flow events accordingly. The mechanistic links between hydraulic habitat and biota will be further developed as the program proceeds.

Riverbanks respond to flow, so both erosion and deposition can be assessed as a response to characteristics of the flow regime. In particular, the longer the duration a bank is underwater, the greater the likelihood the bank will undergo erosion, but also deposition. Importantly, bank erosion is not related to peak discharge or the volume of water over the bank, and as such these are not necessary considerations. Results suggest that mud drapes (material deposited on the flow recession and see Figure 3-1), are most common during slower rates of recession of flow events. These mud drapes are important for encouraging vegetation establishment. It is hypothesised that mud drapes are greatest when flows coincide with high, rainfall-generated, tributary inflows (e.g. the Broken River), providing the necessary sediments, organic material (and seeds).

Figure 3-1. Sediment drapes (deposition) were more common during slow rates of recession and can encourage vegetation establishment.

Bank erosion monitoring evidence suggests that strategic environmental water management, including water provided as freshes, has not caused significantly greater erosion beyond what would have occurred under the regulated flow regime. Since the additional water had little impact on the probability of erosion, and since this study deliberately targeted locations suspected to be most susceptible to erosion, it is considered that environmental flow actions are not significantly contributing to increased erosion in the lower Goulburn River. The results for bank condition monitoring demonstrate that environmental flow delivery can proceed with confidence that it is not having major adverse effects on the banks of the Goulburn River.

The perception of risk, and the perception of erosion occurring in the Goulburn River, appears to be greater than the actual erosion measured. Indeed, many banks that appeared to be eroding experienced deposition. The perception of erosion may arise because the deposited sediment can appear to look like erosion has occurred. These facts relative to visual observations may demonstrate the importance of ongoing community education on the dynamics of rivers and how appearance may differ from actual impacts.

3.3.2 Interim recommendations

- Continue to use the outcomes from hydraulic habitat relationship modelling to refine flow planning and adjust flow conditions to suit targeted outcomes and minimise potential risks;
- Current flow management approaches in the Goulburn River are not leading to excessive riverbank erosion and current considerations for event management should be continued (these are elaborated on in the following points):
    - Manage maximum rates of flow recession within current levels to avoid bank surcharging and erosion, and allow mud drapes to develop (mud drapes on banks have been associated with vegetation growth on banks, and the potential for increasing mud drapes requires further investigation);
    - Maintain variability in flows and water levels to maintain bank wetting at varying levels on the bank; and thus avoid bank ‘notching’ (these are hypotheses still to be tested);
    - Maintain ‘piggy backing’ on tributary inflows to ensure sediment from tributaries is transported and deposited at higher levels in the channel (bars, benches, upper banks) during high flow freshes; and
    - Continue the modification of flow management as a collaborative effort between the researchers and water managers.

4. Stream metabolism

Whole stream metabolism measures the production (or Gross Primary Production – GPP) and consumption (or Ecosystem Respiration - ER) of dissolved oxygen gas (DO) by the key ecological processes of photosynthesis (by algae and submerged plants) and community respiration (of plants, bacteria, fungi and animals) (Odum 1956). Healthy aquatic ecosystems need both processes to generate new biomass (e.g. plant material, 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. Metabolism is expressed as the increase (photosynthesis) or decrease (respiration) of DO concentration over a given time frame.

Stream metabolism was monitored at four sites (Figure 1-1) over the period November 2016–April 2017. During this period there was substantial flooding during spring 2016 (Figure 1-2), and as shown in Table 1-3, delivery of base flows, and a late summer-autumn fresh. A winter fresh, beginning in late June 2017, was outside the scope of the stream metabolism monitoring for Year 3. However, it may be picked up in the Year 4 report for the one site with continuous, year-round monitoring (McCoy's Bridge). The flooding in August-October 2016 prevented deployment of DO loggers at 3 sites until early November rather than the planned time of late August. Logger inaccessibility at McCoy's Bridge meant that data were lost during October 2016 due to an inability to replace batteries.

There were no immediate changes observed to rates of stream metabolism as a result of these flows, apart from initial declines due simply to dilution by the added water, but there were demonstrable effects upon the total amount of metabolism. For the first time, results show that even small flows/watering actions could have beneficial ecological outcomes despite water remaining within channel. Importantly, the results also showed the impact of a high intensity rainfall event in the Seven Creeks catchment in late December 2016 that caused a blackwater event in early January 2017, and a significant DO slump in the lower Goulburn River.

The derivation of results, issues encountered, and more detailed analyses are included in Appendix C.

4.1 Evaluation

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. This information also forms the basis of Basin-scale evaluation – where area-level results are scaled up to the Basin level.

4.1.1 Basin-scale evaluation questions

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did CEW contribute to patterns and rates of decomposition?	Yes	The initial effect of CEW was to reduce rates of Ecosystem Respiration (ER) simply by dilution effects. However, by examining the amount of oxygen consumed (load) per day and even more importantly, the amount of organic matter consumed each day in a nominal 1 km stream reach, it is clear that even small, within-channel watering actions will have beneficial ecological outcomes on nutrient recycling.	Bayesian modelling of the effects of environmental flows (natural, inter-valley transfer or CEW) showed a slight suppression of ER, although this was not statistically significant. However, calculating O_2 consumption on a daily mass basis and the mass of organic carbon consumed per stream kilometre showed increases with increasing water level.
What did CEW contribute to patterns and rates of primary productivity?	Yes	Similar to ER rates, the initial effect of CEW was to reduce rates of Gross Primary Production (GPP) due to dilution. There were no consistent patterns in flow versus GPP relationships. However, increased discharges resulted in increased amounts of oxygen produced on a	Bayesian modelling of the effects of environmental flows (natural, inter-valley transfer or CEW) showed a very slight suppression of GPP, although as with ER this was not statistically significant. However, O_2 production on

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
		mass basis per day and even more importantly, an increase in the amount of organic matter produced each day in a nominal 1 km stream reach. As above, it is clear that even small, within-channel watering actions will have beneficial ecological outcomes. It is expected that if environmental watering actions introduce more nutrients, algal growth will take days to a few weeks to respond.	a daily mass basis and the mass of organic carbon produced per stream kilometre showed increases with increasing water level. It is likely, as in past years, that very low bioavailable nutrient concentrations are constraining GPP.

4.1.2 Area specific evaluation questions

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
How does the timing and magnitude of CEW delivery affect rates of Gross Primary Productivity and Ecosystem Respiration in the lower Goulburn River?	Yes	As noted above, apart from the initial dilution effect, there was no consistent effect of flow increases (including those from CEW delivery) across the 4 sites on rates of either GPP or ER over the period of record and in past years. However, there was a positive effect of flow increases, even those constrained within channel, on total amounts of GPP and ER expressed as either mass (load) of oxygen per day or as the amount of organic carbon per km stream reach (per day). This increase with flow plateaued at around 4000 ML/Day. These positive ecological outcomes were found even when the increased discharge was constrained within the river channel.	Based on regression of daily discharge versus rates of GPP and ER, and on calculated loads of O_2 and organic carbon per stream kilometre. There was sufficient variability of flow levels to detect significant positive regressions. Bayesian models relating daily estimates of GPP and ER to water velocity were used to determine optimal lag periods for both GPP and ER.
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	As found in previous years, stream metabolism rates were slightly lower in the Goulburn River compared to the Edward-Wakool. The actual CEW and natural flows in the Edward-Wakool prevented determination of flow-metabolism relationships. Both systems had very low bioavailable nutrient concentrations (especially phosphorus) which was a significant constraint on GPP (and affected ER too). Very low bioavailable phosphorus (and nitrogen) is the reason metabolic parameters are at the lower end of international values.	Based on daily estimates of rates of GPP and ER regressed with daily flow rate, photosynthetically active radiation (PAR) (GPP only), and temperature. Monthly nutrient sampling was assumed to be representative of nutrient concentrations most/all of the time.

4.2 Other main findings from stream metabolism monitoring program 2016–17

Other main findings from 2016–17 monitoring are:

- Rates of Gross Primary Production (GPP) and Ecosystem Respiration (ER) vary with season (higher in spring and summer due to longer daylight hours and warmer temperatures) but still sit within a relatively small range at the lower end of rates observed in river systems around the world, and are similar to rates found in other Selected Areas in the LTIM program. Whether these rates are ‘low’ or are typical of Australian lowland river systems, will become more apparent as the LTIM Project progresses.

- Comparisons across years at the McCoy's Bridge site indicated annual similarities in response of both GPP and ER to seasonal changes enabling future establishment of counterfactual estimations of these parameters in the absence of environmental flow delivery. This preliminary analysis will be strengthened in years 4 and 5. In year 3 it showed that there were no long lasting effects of the major flood on rates of GPP and ER over ensuing weeks and months (with the exception of a likely enhancement of ER closest to Goulburn Weir at Day Road)

- Rates of Gross Primary Production (GPP) and Ecosystem Respiration (ER) showed no consistent relationship with flow rate apart from an initial decline due to dilution effects.

- In contrast, daily total amounts of oxygen produced (GPP) and consumed (ER) and the amount of organic carbon (food resource) created and consumed per stream kilometre both increased with flow rate. This is the first time that ecological benefits from small within-channel increases in discharge have been documented. The finding from earlier reports that within-channel watering actions have no effect on stream metabolism (and hence food resources) is therefore replaced with this new, positive result. Importantly, these effects were observed at relatively low flows (~4,000 ML/d), so there are potential benefits to the ecosystem health even if the fresh target is not reached. This is important for years with low allocations because it means that even low discharge events are still worth considering.

- Stream metabolism, and hence the energy base of the aquatic food webs, was almost certainly constrained by very low bioavailable nutrient concentrations, most notably phosphate which was typically only 0.003 mg P/L. Again as noted in the previous two years, these concentrations are marginally lower than median values measured over the last decade at McCoy's Bridge.

4.3 Discussion, Implications and Recommendations for Commonwealth Environmental Water

4.3.1 Discussion and Implications

Apart from the spring flood, flow rates experienced during the 2016–17 monitoring period meant that water was always retained within the river channel, rather than reconnecting major backwaters or accessing the floodplain. Hence there was no significant introduction of nutrients and organic carbon into the river. Higher flows are required to facilitate reconnection, with approximately 18,000 to 19,000 ML/d required to provide substantial reconnection of flood runners below bankfull level (GBCMA, unpubl.). While such flows are allowed-for in environmental flows planning, they are currently constrained by third party risks and infrastructure limitations.

However, a key finding from the Year 3 study is that even small watering actions that remain within-channel will still have a beneficial effect on the stream ecology and specifically the food resources available for fish and other biota of the food web. This is a major change from years 1 and 2 where no benefit was detected, primarily because the metrics used were just the direct rates of GPP and ER. Extending the analysis to the amount of oxygen and organic carbon produced has enabled this advancement.

In early January 2017, there was a very low DO event that raised concerns about the immediate effects on aquatic biota. Like in 2015-16, this event, arising from black water coming down the Pranjip/Sevens/Broken system after heavy rainfall in late December, was of short duration (typically 3-4 days). Of highest relevance to this project, it is readily apparent that the reaeration rate and gross primary production rate were both insufficient (singly and in combination) to quickly overcome this low DO further downstream resulting in a low DO 'slug' traversing the Goulburn River over a number of days.

4.3.2 Interim recommendations

- The investigation of medium sized events, where backwaters and flood-runners are reconnected is still recommended as there is as yet insufficient information to determine whether this will provide additional food resources (organic carbon) by overcoming very low nutrient concentrations.

- The role / importance of small in-channel events (e.g. ~4,000 ML/d) needs further investigation and outcomes incorporated into flow recommendations.

5. Macroinvertebrates

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 the lower Goulburn River, macroinvertebrate responses have been measured to increase our understanding of how Commonwealth environmental water (CEW) affects these organisms.

Macroinvertebrate monitoring is usually conducted before and after CEW is delivered as spring freshes. In the 2016-17 monitoring period, CEW was not delivered in spring due to above average rainfall in the catchment during winter and spring and consequent flooding. Macroinvertebrate monitoring was hence suspended but resumed on the 24th of November to add valuable data to the long-term dataset at the Goulburn River (McCoys Bridge) and Broken River. Four monitoring methods were used: Replicated Edge Sweep Sampling (RESS) in edge habitats (November), deploying artificial substrates for macroinvertebrate colonisation over six weeks (November to January) and deploying Yellow Sticky Traps (YST) to assess riparian insects for one week (November), and monitoring of crustaceans using overnight bait trapping and monthly RESS samples from December to March. This monitoring was also useful in helping to evaluate impacts associated with a low-oxygen “blackwater” event in the Goulburn River following heavy rainfall in late December.

The derivation of results and more detailed analyses are described in more detail in Appendix D.

5.1 Evaluation

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. This information also forms the basis of Basin-scale evaluation – where area-level results are scaled up to the Basin level.

5.1.1 Area specific evaluation questions

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did CEW contribute to macroinvertebrate diversity in the lower Goulburn River?	Flows provided are consistent with our understanding of macroinvertebrate responses.	Macroinvertebrate diversity was not affected by CEW in the lower Goulburn River, but natural floods did increase diversity in edge habitats.	Qualitative analysis of monitored results across all survey periods.
What did CEW contribute to macroinvertebrate abundance and biomass in the lower Goulburn River?	Yes	Increased flows (natural and CEW freshes) were associated with an increase in the abundance and biomass of some taxa.	Qualitative analysis of abundance data from RESS and yellow sticky traps. Statistical analyses were conducted on abundances from artificial substrates and biomass from RESS and artificial substrates.
What did CEW contribute to macroinvertebrate emergence (and hence recruitment) in the lower Goulburn River?	Flows provided are consistent with our understanding of macroinvertebrate responses..	Increasing flows positively affect the abundances of insects with aquatic life stages in the riparian zone.	Qualitative analysis of post-flow results from each year.

5.2 Other main findings from the macroinvertebrate program

Other main findings from 2016–17 monitoring for each of the monitoring methods are:

Artificial substrates:

- Macroinvertebrate diversity (richness) and the abundances of several common taxa were lower in response to increasing flows in 2016-17 (e.g. *Ecnomus pansus,* a type of caddisfly). Only one genus, *Rheotanytarsus* sp. (a type of non-biting midge or chironomid), increased in abundance in response to increasing flows.

- In 2016-17 the biomass of large macroinvertebrates (crustacea, mayflies, caddisflies, dragon flies and stoneflies) was reduced compared to post-flow sampling in previous years, but there was no clear relationship between biomass and increasing flows.

Replicated edge sweep samples (RESS):

- The overall diversity and abundance of macroinvertebrates in edge habitats was greater in 2016-17 compared to 2015-17 but responses varied between species.

- Abundances of some individual taxa increased in response to the unregulated 2016-17 spring floods compared to post-CEW in the previous year, including shrimps (*Paratya australiensis*), prawns (*Macrobrachium australiense*) and worms (Oligochaeta).

- There was a positive relationship between increasing flows and large macroinvertebrate biomass, driven by the increase in abundance of shrimps and prawns.

- In summary, large natural flows in 2016-17 caused a greater increase in macroinvertebrate diversity, abundance and biomass in edge habitats compared to smaller spring freshes provided by CEW in previous years.

Yellow sticky traps:

- Increasing flows had no obvious effect on total invertebrate abundance in the riparian zone, but there was a positive effect on the abundance of insects with aquatic life stages, which were more abundant at both sites in 2016-17 compared to post-CEW monitoring in previous years.

- Only a few species showed different responses to large, natural flows compared to CEW spring freshes. For example, *Tanytarsus palmatus*, increased in abundance while *Cricotopus parbicinctus* adults were absent from both sites in 2016-17. Both of these species are types of non-biting midges (Chironomids), so any flow effects appear to impact species within the same sub-families differently, or they are responding to other environmental variables (e.g. temperature, light etc) and flow is not necessarily the most critical factor.

Additional crustacean surveys (RESS):

- Immature crustaceans were caught in the RESS samples in all months and were most abundant in January and February.

- Shrimp abundance and biomass was much greater in December 2016 than post-CEW sampling in 2015-16, but this declined in January, most likely a result of the late December blackwater event. Shrimp sizes were variable across sites and months showing different aged individuals were present, while ovigerous (i.e. carrying eggs) shrimp were present from December to February.

- Prawns were more abundant at McCoys Bridge than Loch Garry and in December than in later months, perhaps due to the blackwater event in late December. No ovigerous females were caught in February or March, while variable carapace lengths indicated different aged individuals were present in the populations at both sites.

Additional crustacean surveys (bait traps):

- Prawn abundance and biomass was highest in December and declined in subsequent months at both sites, with no obvious preference for habitat type. No ovigerous females were caught in February or March, while captured individuals tended to be larger, similarly sized animals.

- Shrimps were less common in bait traps, making it difficult to discern patterns in their abundance and biomass across sites and months. At McCoys Bridge, they showed a preference for macrophytes and depositional areas. Animals tended to be larger individuals of a similar size. No ovigerous females were captured in March.

5.3 Discussion, implications and recommendations for Commonwealth Environmental Water

5.3.1 Discussion and Implications

Large, natural flows in 2016-17 provided an opportunity to assess macroinvertebrate responses to flows that were considerably larger than what can be delivered as environmental water. Comparisons of these data to previous years reinforced the notion that macroinvertebrate responses to flows, including environmental water, are complex and species-specific.

Two effects of increased flows were observed:

- *Increased macroinvertebrate productivity*, which was observed in samples taken in November and December after the winter/spring floods. This included increased macroinvertebrate richness, abundance and large macroinvertebrate biomass in edge habitats (RESS) and bait traps in both the Goulburn and Broken Rivers.

- *Decreased macroinvertebrate productivity* was observed in samples collected in January (e.g. artificial substrates, additional edge habitat samples and bait traps) in both rivers.

Both types of macroinvertebrate responses probably stem from the fact that larger natural flows, unlike environmental water, introduce more organic matter into the river channel due to overbank flooding and reconnecting riparian wetlands to river channels. Increasing organic matter would increase food availability for macroinvertebrates such as detritivores (e.g. prawns, shrimp and worms) and the availability of particular habitats, including still littoral habitats and slackwaters that are especially important for prawn and shrimp larvae (Price and Humphries 2010). Increasing organic matter can also adversely affect water quality by causing hypoxia (low dissolved oxygen), as was seen with the blackwater event in January. This would cause stress and mortality in macroinvertebrates, and may induce some species to drift away from impacted areas.

The additional sampling shed light on the biology of key crustacean species in the Goulburn River. Immature crustaceans increased in abundance in January, which is in line with what is known about the breeding seasons of prawns and shrimps (Williams 1977; Lui 1980; Hancock and Bunn 1997; Richardson and Humphries 2010). Their increased abundance in January and February also reflects how they are dispersed in flows (Price and Humphries 2010), so the release of environmental water to alleviate blackwater event conditions probably dispersed larvae into the study area from unimpacted sites upstream. In addition, ovigerous females from both species were most abundant in December but absent in March, confirming breeding patterns described elsewhere (Williams 1977; Lui 1980; Hancock and Bunn 1997; Richardson and Humphries 2010). Similar sizes of prawn caught in bait traps might reflect the complex, agonistic (aggressive) social behaviours displayed by this species (Lee and Fielder 1983; Lammers et al. 2009). In contrast, the preference shrimp showed for bait traps deployed in depositional areas or among macrophytes reflects their habitat use (macrophytes and silt habitats) and their diets as detritivores that also graze on biolfims and algae (Williams 1977, Sheldon and Walker 1998, Burns and Walker 2000).

The two different effects of overbank flows on macroinvertebrates highlight the complexity of predicting and providing suitable flows that benefit macroinvertebrates. The spring floods, which rose slowly and inundated parts of the floodplain for relatively long durations appeared to promote positive responses in some species. This is contrast to the intense rainfall and rapid catchment runoff from Seven Creeks that generated the January blackwater event when conditions were much warmer. Although delivery of environmental water as spring freshes may not induce such strong positive responses in macroinvertebrates as natural flooding in spring, controlled freshes do not carry the same risks for blackwater events as they are not sourced from floodplain runoff. In addition, it is likely that there is not a simple linear relationship between flows and species-specific responses. Rather, macroinvertebrate responses are likely to be non-linear, with some “optimal” flow that increases macroinvertebrate productivity. Other environmental factors are also likely to be as or more important than flow, for example temperature and light. As more data become available, future modelling will be adapted to address the non-linearity of macroinvertebrate responses to flow.

5.3.2 Interim recommendations

- Aim to piggy back CEW freshes on unregulated tributary inflows (e.g. Broken River), or pass flows through wetlands, in order to enhance the organic carbon content of the water and hence help promote a more pronounced macroinvertebrate response.
- Continue monitoring macroinvertebrate (crustacean) responses to spring freshes using bait traps and additional edge habitat (RESS) sampling on a monthly basis;
- Investigate the relationship between macroinvertebrate responses and flows using non-linear modelling as more data become available.

6. Vegetation diversity

Riparian and aquatic vegetation underpins aquatic systems by: (i) supplying energy to support food webs, (ii) providing habitat and dispersal corridors for fauna, (iii) reducing erosion, and (iv) enhancing water quality. In the Goulburn River, drought and floods have reduced the quantity, quality and diversity of riparian and bankside vegetation over the last 10-15 years. Minimum summer and winter low flows and periodic freshes are being used to help rehabilitate and maintain vegetation along the lower Goulburn River. The recommended flow components shape aquatic plant assemblages by influencing (i) inundation patterns in different elevation zones on the bank and hence which plants can survive in each zone; (ii) the abundance and diversity of plant propagules dispersing in water; and (iii) where those propagules are deposited and germinate.

In 2016 the delivery of the spring fresh to meet vegetation objectives was cancelled due the natural high flows that occurred between June and November 2016. These were expected to have met vegetation objectives. It was therefore not possible to evaluate responses of vegetation to delivery of environmental water in spring. Vegetation was sampled in December 2016 and again in February and March 2017 to: evaluate responses to this large natural flood event, and to provide a wider range of inundation histories to inform predictive models of the relationships between vegetation and hydrological variables.

Monitoring was carried out before and after the summer/autumn watering action to (i) understand rates of recovery of vegetation following the natural flood and (ii) to assess response of vegetation to late season watering to inform future flow planning.

The derivation of results and more detailed analyses are included in Appendix E.

6.1 Evaluation

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. This information also forms the basis of Basin-scale evaluation – where area-level results are scaled up to the Basin level.

6.1.1 Basin-scale evaluation questions

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did Commonwealth environmental water contribute to vegetation species diversity?	The spring fresh was cancelled in 2016–17 as natural flooding was deemed to have met vegetation objectives of the spring fresh. March flows were provided to meet fish objectives. It was not expected that these would be appropriate for vegetation.	Although additional data on the response of vegetation to environmental water delivered as spring freshes could not be gathered in 2016–17 qualitative and quantitative analysis of the data collected by the LTIM program so far are consistent with spring freshes contributing to maintaining or increasing the cover of water dependent taxa and reducing the cover of terrestrial grasses, indicating an overall benefit for vegetation diversity. The extent and duration of inundation provided by spring freshes was correlated with the distribution and cover of vegetation along the bank face. A number of plant species associated with wet habitats including lesser joyweed (*A. denticulata*), creeping knotweed (*Persicaria prostrata*) and sedges (mostly *Cyperus eragrostis*) are more prevalent and had higher cover at elevations inundated by spring freshes. In contrast, common tussock grass (*Poa labillardierei*) is restricted in its distribution to elevations at or above the level inundated by spring freshes.	Qualitative examination of species cover plots versus elevation and inundation profiles. Statistical analyses of probability of occurrence and cover with days inundated.
What did Commonwealth environmental water contribute to vegetation community diversity?	The spring fresh was cancelled in 2016–17 as natural flooding was deemed to have met vegetation objectives.		

6.1.2 Area specific evaluation questions

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What has CEW contributed to the recovery (measured through species richness, plant cover and recruitment) of riparian vegetation communities on the banks of the lower Goulburn River that have been impacted by drought and flood and how do those responses vary over time?	The spring fresh was cancelled in 2016–17as natural flooding was deemed to have met vegetation objectives of the spring fresh. The flows experienced are of the type expected to be of benefit to species diversity. Climatic conditions modify these relationships (see Appendix E for further discussion of flow management).	The mean cover for grasses decreased following spring freshes in 2014–15 and 2015–16. In contrast, mean cover for water-dependant taxa examined increased following spring freshes. The extent and duration of inundation provided by spring freshes was correlated with the distribution and cover of vegetation along the bank face. A number of plant species associated with wet habitats including lesser joyweed (*A. denticulata*), creeping knotweed (*Persicaria prostrata*) and sedges (mostly *Cyperus eragrostis*) are more prevalent and had higher cover at elevations inundated by spring freshes. In contrast, the perennial native grass common tussock grass (*Poa labillardierei*) is restricted in its distribution to elevations at or above the level inundated by spring freshes.	Trends in mean cover over time and species cover plots versus elevation and inundation profiles.
How do vegetation responses to CEW delivery vary between sites with different channel features and different bank conditions?		The mean cover of vegetation across all sampled location was lower at McCoys Bridge compared with Loch Garry for all taxa but responses of vegetation to environmental water and unregulated flows were similar between sites. Data analysed in 2014–15 found that the cover of vegetation tended to be lower on outside bends of the river compared with straight sections or inside bends. This pattern is consistent with typical distributions of bank stability in rivers with inner bends generally being most stable and thereby providing suitable conditions for vegetation establishment.	Qualitative examination of species cover plots versus elevation and inundation profiles.
Does the CEW contribution to spring freshes and high flows trigger germination and new growth of native riparian vegetation on the banks of the lower Goulburn River?		In 2015-16 the spring fresh delivered for vegetation increased the occurrence and cover of establishing sedges (mostly *Cyperus eragrostis*) along the river margin at base flow.	Visual observation
How does CEW delivered as low flows and freshes at other times of the year contribute to maintaining new growth and recruitment on the banks of the lower Goulburn River?		Low base flows and/or the longer interval between freshes in 2014-15 may have contributed to increased occurrence of sedges at the river margin at base flows observed in 2015-16. Prolonged inundation associated with natural flooding reduced the occurrence and cover of establishing emergent vegetation near the river margin at base flows. In contrast some species rapidly colonised wet banks upon drawdown of flood waters.	Qualitative examination of species cover plots versus elevation and inundation profiles in different years Statistical analyses of probability of occurrence across the elevation gradient before and after the delivery of March fresh.

6.2 Other main findings from vegetation surveys in 2016–17

Other main findings from vegetation monitoring in 2016–17 are:

- The number of taxa identified in December 2016 following natural spring flooding was lower than the number identified in 2015 following spring freshes that lasted three weeks. However, taxa numbers increased over the remainder of the survey period suggesting that the flood may have delayed seasonal patterns of growth.
- Woody recruits represented by silver wattle (*Acacia dealbata*) and river red gum (*Eucalyptus camaldulensis*) were rare on the banks and restricted to higher elevations that experience shorter and more shallow inundation. This indicates that environmental flows are achieving their objective of limiting the encroachment of terrestrial vegetation down the bank by maintaining sufficient duration of inundation above the threshold for woody plant establishment.
- Prolonged inundation associated with natural flooding reduced the occurrence and cover of establishing emergent vegetation near the river margin at base flows. In contrast lesser joyweed (*Alternanthera denticulata*) and to a lesser extent, common sneezeweed (*Centipeda cunninghamii*), rapidly colonised wet banks upon drawdown of flood waters.
- Vegetation sampling before and after the March fresh found an increase in grass cover. This suggests that freshes delivered when grasses are more mature may favour their growth.
- The underlying causes of the differences in mean cover among sites are uncertain but it is possible that subsurface water flows may differ between sites. Data collected from soil moisture probes may help to evaluate if differences in bank soil moisture contribute to differences among sites.
- Models of changes in the occurrence and cover of common taxa with the number of days inundated the year prior reveal different hydrological requirements of the taxa examined. As such, flow objectives should be developed for different taxa. Flows delivered to benefit target taxa will need to do so in a way that does not compromise non-target taxa. It is expected that further development of these models will support the evaluation of environmental watering scenarios and provide a valuable planning tool.
- The unregulated elevated flow event in January, and the autumn fresh in March 2017, both influenced soil moisture to the maximum measured depth of 85 cm at both sampled elevations. At the lower elevation, increased soil moisture was evident throughout the soil profile. Increased soil moisture was maintained between the two flow events (~ 40 days) at depths greater than 45 cm. The effects of inundation extended to the high elevation but only in deeper soil layer (> 25 cm) and the effects were smaller in magnitude and shorter in duration, persisting for ~ 10 days.

6.3 Discussion, implications and recommendations for Commonwealth Environmental Water

6.3.1 Discussion and implications

Monitoring and evaluation so far has highlighted that flow planning and management objectives for vegetation will need to consider the influence that unregulated flows and climatic conditions exert on vegetation. Evaluation also needs to acknowledge that different species are distributed unevenly up and down the bank face, with this distribution reflecting their different flow requirements, plus the different inundation histories experienced at different elevations on the bank face.

In 2016, flows were adjusted based on the expected influence of unregulated high flows that occurred from June to November 2016. This resulted in the cancellation of the spring fresh based on the following rationale.

- The natural high flows were likely to have increased soil moisture to the banks and benches and provided a good growing environment for vegetation.

- The lower bank vegetation had been inundated for a long duration at levels that would submerge young emergent plants, preventing photosynthesis and plant growth.
- Young establishing aquatic vegetation are less resilient to prolonged submergence, as they lack the large carbohydrate reserves held in more mature rhizome/tubers that can sustain some aquatic plants during unfavourable conditions. Young plants also may not have developed soil seed banks from which plants can re-establish if lost.
- The natural high flows in spring 2016 are likely to have transported propagules (i.e. seeds and vegetative fragments) from tributaries into the lower Goulburn River, thereby enhancing regeneration potential. These natural flood events are likely to contribute to propagule dispersal to a greater extent than an environmental water release, because dams filter propagules out of the water. The decision to not provide a managed spring fresh after the floods was likely beneficial for new vegetation, as a spring fresh may have removed the deposited propagules and sediment provided by natural flooding.
- Therefore, the vegetation flow objectives of “sustain growth and increased vigour, flowering and seed development” were better achieved in this case by not delivering a spring fresh following the natural flood.

6.3.2 Interim recommendations

Interim environmental flow and monitoring recommendations for the Goulburn River are based on current ecological understanding and findings thus far from the LTIM program. These recommendations will require continued revision as new monitoring data are collected, and understanding is validated by further qualitative and quantitative analyses.

Environmental flows

- Continue to deliver spring freshes to improve bank wetting, and vegetation abundance and diversity going into summer.
- Adjust flow planning in light of antecedent conditions. Where natural high flows have occurred and fulfilled the expected objectives of planned freshes (such as in 2016–17), the delivery of environmental water may not be warranted, and could in fact be detrimental.
- Where possible, couple environmental flows with inputs from tributaries (e.g. Broken River) to promote the transport of propagules carried in tributary flows.
- When possible, maintain a flow regime to support young plants at low elevations to reach more mature and robust life stages and/or develop soil seed banks that will promote recovery from periods of unfavourable conditions. This may include (i) reducing prolonged periods of continuous high flows and (ii) increasing the time between high flows delivered over the growing season so that new germinants can properly establish. In particular, this would mean maintaining variability of flows during inter-valley transfers of irrigation water during summer. This needs to be done within the tolerance range of vegetation at higher elevations on the bank, where the depth, duration and frequency of inundation is lowest.
- Consider using short-duration, mid-range magnitude flow actions (i.e. peaking at ~4000 ML/d) during summer to improve soil moisture and therefore growing conditions for bankside vegetation. This could be done in conjunction with inter-valley transfers.
- In the longer term, consider the need to tailor flow recommendations to specific species based on outcomes of species-specific analysis.

Monitoring

- Continue to monitor bank soil moisture using soil moisture probes installed in December 2016 to assess the role of freshes in replenishing bank soil moisture stores, and to determine if low soil moisture contributes to low cover of vegetation at McCoys Bridge.

- Monitoring before and after flows delivered for fish spawning would help assess if these flows impact on young establishing vegetation at the river margin at base flow. This would require additional funding.

7. Fish

Supporting native fish populations is a key element of the Basin Plan's goal to protect biodiversity. Species of conservation significance in the Goulburn River include trout cod, Murray cod, golden and silver perch, and Murray River rainbow fish. Three fish monitoring methods are employed in the Goulburn River LTIM Project: native fish movement, larval surveys, and annual adult fish surveys.

Native fish movement within and between ecosystems (i.e. connectivity) can be crucial for sustaining populations by enabling fish to recolonise or avoid unfavourable conditions. For some fish species, movement also occurs for the purposes of reproduction and populations may be naturally connected over large scales. The LTIM Project targets golden perch, building on the existing six-year set of acoustic telemetry monitoring data in the Goulburn River and Murray River, and employing an extensive array of acoustic listening stations.

Larval surveys collect larvae of all fish species, but are designed to detect golden perch spawning in particular. Golden perch is one of only two fish species (along with silver perch) in the Murray Darling Basin for which there is strong evidence of the need for increased flow rates to initiate spawning. One of the key flow objectives in the Goulburn River is to deliver freshes to promote golden perch spawning. Larval surveys are carried out in late spring at four sites in the lower Goulburn River

Annual fish surveys track changes in adult populations of all species. Flow-related improvements in populations may be caused by improved movement and spawning for flow-cued species (as above), but may also reflect improved conditions for adults and juveniles over the full year (e.g. provision of more pool habitat from improved baseflows. Annual surveys are done at 10 sites in the lower Goulburn River using electrofishing and fyke nets.

Environmental water was not delivered to the Goulburn River specifically for golden perch or silver perch spawning in spring 2016. A larger natural flow event occurred in the spawning season of 2016 (late October – early November).

The derivation of results and more detailed analyses are included in Appendix F.

7.1 Evaluation

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. This information also forms the basis of Basin-scale evaluation – where area-level results are scaled up to the Basin level.

7.1.1 Basin-scale evaluation questions

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
Long-term evaluation questions			
What did CEW contribute to native fish populations?	Recommended baseflows provided for adults. No provision of fresh flows for reproduction, as flow requirements were met naturally.	It is not possible to associate fish population makeup or diversity to the provision of baseflows at this stage. Over five years, improvements may become apparent (see recommendations).	Population and diversity responses integrate long-term effects of long-term flow regimes. Short-term assessment is not possible.
What did CEW contribute to fish species diversity?			
Short-term evaluation questions			
What did CEW contribute to fish community resilience?	Unknown at this stage		Recovery of fish populations following the January blackwater event may inform this question in 2017–18

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did CEW contribute to native fish survival?	Unknown at this stage		
What did CEW contribute to native fish reproduction?	Environmental water was not delivered specifically for spawning of golden or silver perch in 2016. A large natural flow event occurred in the spawning season in 2016.	Golden perch eggs were collected in late October and early November 2016 during a natural flow event. Silver perch eggs were also collected during the natural flow event in mid-November 2016.	Qualitative observations based on drift netting data. These results were added to statistical models of spawning that use the three years of data collected thus far.
What did CEW contribute to native fish dispersal?	Environmental water was not delivered specifically for movement of golden perch in the lower Goulburn River in 2016. A large natural flow event occurred in the spawning season in 2016. CEW was used to provide 'attraction flows' in March 2017 to see if sub-adult golden and silver perch would be attracted into the lower Goulburn River.	Long-distance movements of golden perch (mostly downstream) coincided with elevated flows. Movements corresponded to the timing of spawning, suggesting reproduction is a driver of fish movement. Attraction flows saw the movement of some tagged sub-adult silver perch into the lower Goulburn River. These results are not evaluated directly in this report as monitoring of this movement was not undertaken as part the LTIM Project.	Qualitative observations and statistical analysis of telemetry data. This evaluation of the effect of attraction flows is based on informal conversations with researchers involved in the attraction flows monitoring.

7.1.2 Area specific evaluation questions

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
Long-term evaluation questions			
What did CEW contribute to the recruitment of golden perch in the adult population in the lower Goulburn River?	The attraction flows project described above provided an autumn fresh designed to facilitate recruitment of golden and silver perch sub-adults into the Goulburn River.	Golden perch spawned during a within-channel flow pulse in 2014, and following a bankfull flow in 2016, but no 0+ (i.e. young-of-year) were collected in surveys in the following autumns (i.e. 2015 and 2017). Silver perch also spawned in 2014 and 2016. This result suggests that spawning may not necessarily translate into immediate recruitment of juveniles into the local population. The results of the attraction flows project described above suggest the importance of autumn flow events for recruitment into the Goulburn River.	Qualitative observations based on comparisons between electrofishing and drift netting data, and in consideration of the attractions flows trial results.
Short-term evaluation questions			
What did CEW contribute to golden perch spawning and in particular what magnitude, timing and duration of flow is required to trigger spawning?	Environmental water was not delivered specifically for spawning of golden perch in 2016. A large natural flow event occurred in the spawning season in 2016.	NA. Golden perch eggs were collected in late October and early November 2016 during a natural flow event. These data have been used to update the predictive statistical model developed. Silver perch eggs were also collected during the natural flow event in mid-November 2016.	Qualitative observations based on drift netting data and updated statistical analysis.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
What did CEW contribute to the survival of golden perch larvae in the lower Goulburn River?	Unknown	Golden perch spawned in 2016 during a natural flow event, but did not show evidence of immediate local recruitment (i.e. there were no 0+ (i.e. young-of-year) fish in 2017 electrofishing surveys).	Qualitative observations based on electrofishing and netting data
What did CEW contribute to the movement of golden perch in the lower Goulburn River and where did those fish move to?	A large natural flow event occurred in the spawning season in 2016. Environmental water was not delivered specifically for movement of golden perch in 2016.	NA. Long-distance movements of golden perch (mostly downstream) coincided with elevated flows associated with a natural flow event. Movements corresponded to the timing of spawning, suggesting reproduction is a driver of fish movement. A small number of sub-adult golden perch were tagged as part of the attraction flows study described above, but none moved into the Goulburn River.	Qualitative observations based on telemetry data. Statistical models predicting the likelihood of movement, and incorporating data from three years of monitoring have also been developed.

7.2 Other main findings from fish monitoring program

7.2.1 Findings from 2016–17

The main findings from 2016–17 monitoring can be summarised as:

Annual surveys

- The nationally endangered silver perch was collected in higher numbers (n = 15) compared to the first two years of the LTIM Project (2015, n = 2; 2016, n = 5).
- The Murray River rainbowfish, listed as threatened in Victoria, was also more abundant (n = 366) compared to previous years (2015, n = 186; 2016, n = 208).
- Bony herring was collected in higher numbers (n = 12) compared to previous years (2015, n = 0; 2016, n = 3).
- Another species of conservation significance, trout cod, collected in the first 2 years (2015 and 2016) between Zeerust and Loch Garry, was not collected in the current surveys.
- Murray cod were collected in lower numbers (n = 53) compared to the last two years (2015, n = 79; 2016, n = 83), particularly at Zeerust (2015, n =14; 2016, n = 14, 2017, n = 3).
- Two pest species, carp and eastern gambusia, were collected in much higher numbers compared to the last two years.

Surveys of eggs and larvae

- Golden perch eggs were collected in late October and early November 2016 during a natural flow event. The majority (99%) of eggs were collected in early November coinciding with the falling limb of the hydrograph. Water temperature at this time was 18.5 °C.
- Silver perch eggs were also collected during the natural flow event in mid-November 2016. Water temperature at this time was 20.7 °C.
- Carp larvae were collected between late October and early November 2016 also during the natural flow event. The majority (96%) of larvae were collected in early November, coinciding with the falling limb of

the hydrograph, and indicating spawning on the falling limb. Water temperature at this time was 18.5 °C.

Golden perch movement

- About one third (28 out of 81) of the golden perch detected undertook long-distance movements (i.e. > 20 km) in 2016. These long-distance movements were most common during August–December and coincided with increases in flow.
- In the 2016 spawning season, the occurrence of golden perch eggs in the lower reach corresponded with the movements of tagged fish into the lower reaches of the river.

7.2.2 How these build on findings from years 1 and 2

These findings build on findings from 2014–15 and 2015–16 by demonstrating:

- Improvements in the population of silver perch in the Goulburn River are likely due to immigration from the Murray River into the Goulburn River.
- Higher numbers of Murray River rainbowfish may be caused by improved littoral habitat and spawning opportunities caused by recent recruitment of semi-aquatic vegetation on the banks of the Goulburn River.
- A blackwater event in January 2017 in the Goulburn River resulted in fish deaths between Shepparton and Loch Garry. An absence or reduction in numbers of some species (i.e. trout cod, Murray cod) may have been caused by this event.
- Spawning data for golden and silver perch in 2017 have highlighted the importance of water temperature as a necessary condition for spawning, and the structure of statistical models of spawning were revised accordingly.
- Golden perch movement in the Goulburn River was strongly seasonal, being most prevalent during the spawning season. Golden perch regularly move between the Goulburn and Murray Rivers, suggesting a high level of connectivity between these habitats.
- Carp spawning and recruitment of juveniles may have benefited from elevated spring flows coupled with improved littoral habitat caused by the desired recruitment of semi-aquatic vegetation on the banks of the river.
- For the first time, fish monitoring was conducted around an autumn flow event, although not funded by the LTIM Project. These results indicated the potential importance of autumn flows for recruitment of sub-adult silver perch into the Goulburn River, an area that has been a substantial knowledge gap until now.

7.3 Discussion, Implications and Recommendations for Commonwealth Environmental Water

7.3.1 Discussion and Implications

The increased abundances of the nationally endangered silver perch may have been driven by recent immigration of silver perch from the Murray River. The attraction flows study mentioned above, and funded by the MDBA and DELWP revealed silver perch tagged in the Murray River moved into the Goulburn River in March-April 2017 coinciding with a within-channel environmental flow fresh in the Goulburn River (Koster unpublished data). The role of within-channel freshes to facilitate movement of fish such as silver perch and golden perch from the Murray River into the Goulburn River and other tributaries to contribute to recruitment and re-colonisation requires further investigation.

The Murray River rainbowfish, listed as threatened in Victoria, was also more abundant in 2017, and this may have been partly driven by the recent recruitment of semi-aquatic vegetation along the banks of the Goulburn River. The species has been documented to use aquatic vegetation for spawning (Milton and Arthington 1984). Furthermore, Murray River rainbowfish were also observed in high abundance in areas with aquatic vegetation during the electrofishing surveys (ARI unpublished data). Thus, an increase in this habitat may have enhanced feeding opportunities, survival as well as breeding of the species. Bony herring was also more abundant in 2017 compared to the last two years. Bony herring have rarely been collected in surveys in the Goulburn River conducted since 2003 (Koster et al. 2012; Koster unpublished data), and the Goulburn appears to be at the south-eastern extreme of the species' natural distribution. The fish collected are most likely to be transient fish that occasionally enter the Goulburn River from other areas when conditions are good.

Spawning of golden perch occurred in the Goulburn River in two out of the last three years, coinciding with bankfull flows (2016) and within-channel flow pulses (2014) in October-November, including targeted managed environmental flows (i.e. spring 'freshes'). These results confirm the importance of a rise in river flow for golden perch spawning (Koster et al. 2014, King et al. 2015) and show that environmental flows can promote golden perch spawning. The observation of spawning well after the peak of flows in 2016 also highlight the importance of water temperature for spawning, with the greatest spawning outcomes at water temperatures ≥18° C. This finding is an important consideration for environmental water management, as it suggests that spawning outcomes will be enhanced when water is delivered at preferred temperatures.

Silver perch spawning also occurred in two out of the last three years (2014 and 2016), with eggs collected during a within-channel fresh in late November 2014, and in early November 2016 following a bankfull flow, at water temperatures of around 20–24 ° C. Similar to golden perch, this result demonstrates that environmental flows can promote silver perch spawning in regulated rivers, and again that temperature is an important consideration.

While golden perch and silver perch have spawned in the Goulburn River in recent years, no young-of-year fish have been collected in surveys in each of the following autumns. The reasons for the absence of young-of-year golden perch and silver perch in the Goulburn River are unclear. One possible explanation is that eggs or larvae drift downstream into the Murray River, and any recruitment into the Goulburn River occurs at a later stage by older fish re-entering the system, and also potentially by fish spawned in other river systems. Indeed, the preliminary results of the acoustic telemetry study of silver perch mentioned above (ARI unpublished data) indicate that migration of silver perch from the Murray River into tributaries could be a substantial driver of tributary populations. Information obtained from otolith microchemistry further shows that native fish species like silver perch and golden perch may be operating at an inter-river scale (e.g. 100s-1000s of km) over extended time periods (Tonkin et al. 2017). Determining whether fish in the Goulburn River were spawned locally, or have migrated into the system from elsewhere, and relating this to patterns of flow, will be investigated as part of the LTIM project using otoliths of fish collected for the annual ageing component of this project (UoM 2013).

The results for golden perch movement demonstrate the importance of a rise in streamflow for golden perch movement. These results are in agreement with previous studies on the movement of this species (Reynolds 1983, O'Connor et al. 2005, Koehn and Nicol 2016, Marshall et al. 2016), and demonstrate that environmental flows, especially in spring, can promote movement of this species. The coincident timing of spawning and movement support the hypothesis that long-distance movements by golden perch during the spawning season are related to reproduction (Reynolds 1983, O'Connor et al. 2005). The relatively common occurrence of movement between the Goulburn and Murray rivers highlights the fact that fish populations do not necessarily conform to artificially constrained management units, and demonstrates the need to consider connectivity among fish populations in river networks (Fausch et al. 2002).

The January 2017 blackwater event may have impacted on fish diversity and abundance. A number of other fish kills in recent years (e.g. 2004, 2010) in the Goulburn River have also had this effect (Koster et al. 2012). There is a need to improve understanding of the responses of native fish to blackwater events and reductions in water quality (e.g. dissolved oxygen depletion), as well as measures (e.g. environmental flows) that can be used to mitigate the risks of reduced water quality for native fish.

It is possible that increased carp spawning and recruitment of juveniles observed over the last two years may have occurred because of elevated spring flows coupled with improved littoral habitat caused by the desired recruitment of semi-aquatic vegetation on the banks of the river (Koehn et al. 2016). The longer-term contribution of these events to the carp population is unknown, although recent modelling indicates that within-channel flows have relatively little effect on carp population dynamics compared to large widespread flood events (Koehn et al. 2017).

7.3.2 Interim recommendations

- The role of within-channel freshes to facilitate movement of fish such as silver perch and golden perch from the Murray River into the Goulburn River to contribute to immigration requires further investigation. Given the success of the externally-funded ‘attraction flows’ monitoring, serious consideration should be given to diverting LTIM funds to further monitoring of sub-adult fish movement from the Murray River into the Goulburn River, if not over the last two years of this LTIM Project, then during a second round of monitoring beginning in 2019–20. Processes governing recruitment of these species into the Goulburn has been a substantial knowledge gap.

- Environmental flow freshes to promote movement and spawning of golden perch should be delivered in spring, particularly in October–November, but only at water temperatures of around ≥18° C.

- Similarly, environmental flow freshes to promote spawning of silver perch should be delivered around November, at water temperatures of around 20–24 °C.

- Adult fish monitoring over the last two years of the LTIM project may help to determine the longer term consequences of the 2017 blackwater event on native fish in the Goulburn River, and in particular their resilience to such disturbances. More generally, development work needs to be undertaken to statistically assess changes in population structure from the adult fish surveys for the year 4 report, and possibly linking this to environmental flows provision for the final report in year 5.

- As part of this project, future monitoring should explore whether golden perch and silver perch were spawned locally or have migrated into the system from elsewhere and relate this to patterns of flow. This is most readily achievable using otolith microchemical analysis.

- The possibility that high numbers of Murray cod larvae collected in 2016–17 were related to the spring floods should be investigated by comparing Goulburn results to other LTIM selected areas that experienced very high spring flows.

- Further work to identify the origins of carp in the Goulburn River and the influence of hydrology on spawning and recruitment would be valuable for the management of this pest species.

8. Integration of monitoring results

Before European settlement and without any water resource development, the Goulburn River had a mean annual discharge of 3,233 GL/year (during historical climate scenarios 1985-2006). Under current climate conditions (1997-2006) the current discharge has been significantly reduced to 1,340 GL/year. Whilst it is not possible to return the river to a natural state, the delivery of environment water can be used as a restoration tool and incorporated into flow planning. As temperature thresholds change, additional water may be required to maintain species persistence.

The monitoring and evaluation plan (MEP) for the Lower Goulburn LTIM Project hypothesised linkages between the different components of the monitoring program, highlighting the importance of multiple lines of evidence (monitoring matters) to more fully understand the effects of environmental flows within the system. In the 2015–16 selected area report (Webb et al. 2017) evidence was assessed to determine support for the original conceptual model, what linkages remained to be supported or disproved, and what new evidence had emerged to update our understanding of linkages. After a further year of monitoring, the level to which the conceptual model is supported can be assessed and updated (Figure 8-1 and described below).

8.1 Direct responses of flow enhancement via hydraulic responses

There are clear areas of integration between the effects of environmental flows in creating suitable hydraulic habitat conditions for some components of the biota. This year, the rate of flow increase showed some relationship with daily total amounts of stream metabolism per stream kilometre. However, as the direct measures of the base of the food web still showed no consistent relationship with flow, even under flood conditions, there is still only weak evidence linking these changes to components higher in the food web. Very low bioavailable phosphate may be constraining these relationships, and substantial overbank flows would be needed to naturally reintroduce this from the floodplain. Future monitoring would ideally extend the measurement of stream metabolism to longer periods of the year. Measuring other base food web components such as phytoplankton may also show reveal better links to stream hydrology.

Stronger evidence was found between hydraulic habitat and vegetation responses. Some taxa were able to respond rapidly to the wet conditions, whilst flows supressed other groups. High flow freshes above 5,000-6,000 ML/d are able to inundate benches, transport seeds and provide favourable conditions for germination and growth. These high velocities create niches for deposition on mud drapes further up the bank and the reduction of terrestrial vegetation encroachment. Future evaluation should formally incorporate vegetation response to bank condition measurements; this would include monitoring drapes to check if they are carrying seeds and how the position on the bank correlates to vegetation success. Concentrating on these more detailed measures of ground cover data instead of less responsive vegetation higher up the bank, plus measuring the biomass of biofilms (e.g. as chlorophyll or organic carbon content) on submerged surfaces (sediment and wood) may help to further strengthen these linkages.

Larger natural flows from flooding also saw both increase and decreases in macroinvertebrate responses; the slow-rising, long-duration natural flood event elicited a generally positive response, the rapid and intense rainfall runoff event in December elicited a negative response, possibly due to consequent low DO conditions. This provided a tentative link for the benefit of the introduction of organic matter from overbank flows increasing food and habitat availability. Some of the responses of larger crustacean species may be behavioural or reflect their habitat use. The strengthening of these relationships may be achieved by quantifying food resources of biofilm and algae within macrophyte beds and depositional areas and through monitoring of particulate and dissolved organic carbon in the water column, especially during and following high flow events to test whether these events do entrain organic material. With more data, non-linear responses to flow by macroinvertebrates can be addressed.

Strong evidence exists for the link between environmental flow freshes and the spawning of golden perch, with greatest levels occurring at water temperatures ≥18°C in October-November, and silver perch around November when water is 20-24°C. High velocities are considered important triggers for fish recruitment and migration, and discharges up to ~2,000 ML/d rapidly increase high (99^{th}%ile) velocities. Monitoring of the effects of longer-term flow regimes (over five years) is required to better assess whether changes in flow have caused change in adult fish population, and whether this reflects improved conditions for movement and habitat. However, during the natural high flows, golden perch movement corresponded with spawning timing, suggesting this behaviour is driven by reproduction. Future analysis of fish otolith data will help determine whether fish were spawned locally or migrated into the Goulburn system; young-of-year golden and silver perch continue to remain absent in surveys, which suggests migration in to the Goulburn River (from the Murray River) is the primary source of recruits.

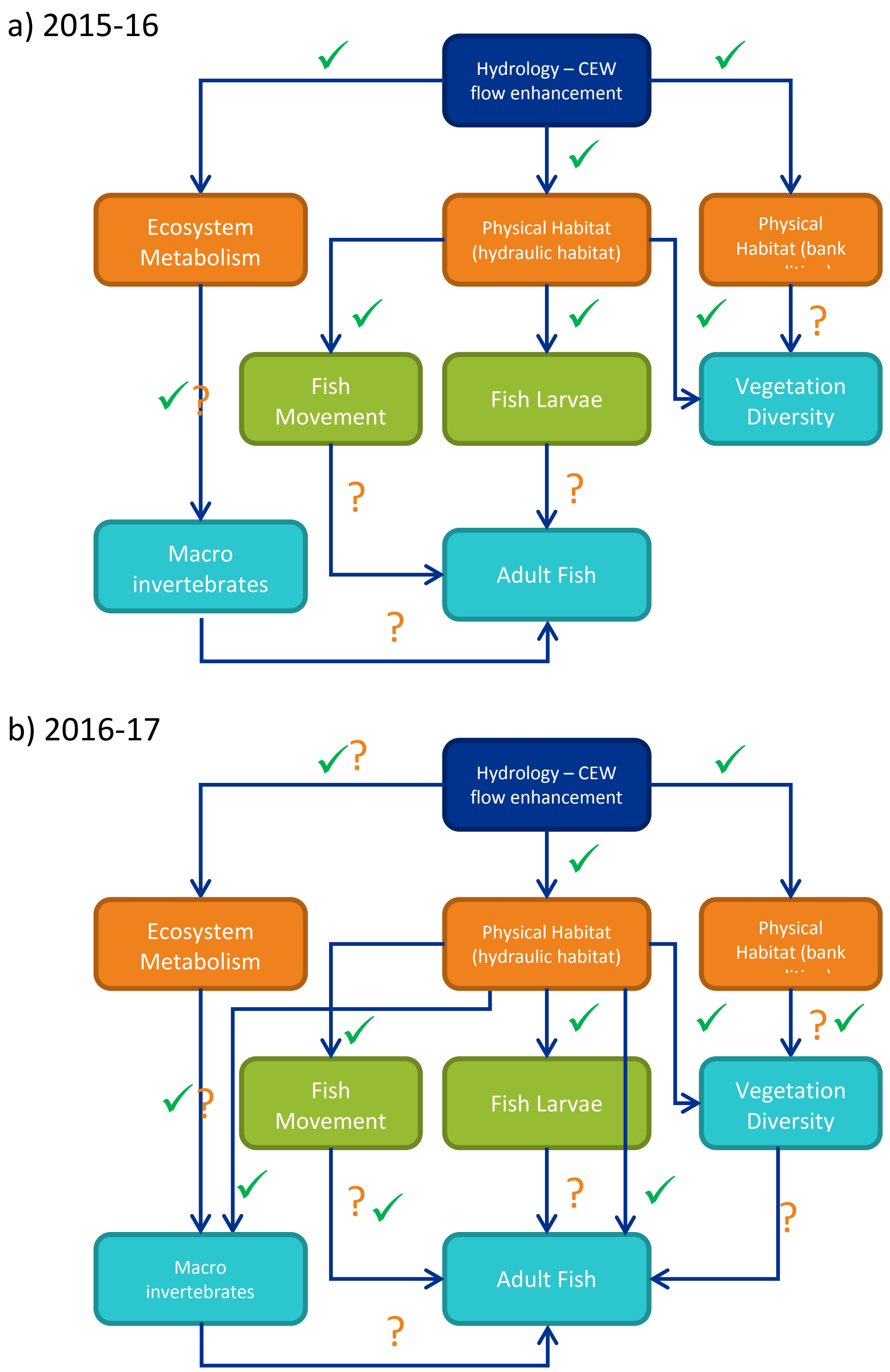


Figure 8-1. Conceptual model of the linkages among monitoring matters in the Goulburn LTIM Project (modified from Webb et al. 2014) between years 2015–16 (a) and 2016–17 (b). Ticks represent linkages supported by data to date, with question marks yet to be confirmed or disproved.

8.2 Linkages among biological monitoring results

Relationships between the biotic elements of the conceptual model are more difficult to establish owing to the longer time scales involved in interspecific interactions. This year, the threatened Murray River rainbow fish was observed in high abundance in the recently recruited semi-aquatic bank vegetation, suggesting synergistic linkages among the two monitoring matters. However, this increase in littoral habitat from high flows may have also benefitted carp spawning (there were high numbers of young-of-year carp following high flows). Managers and local stakeholders need to consider these types of trade-offs if consistent patterns are confirmed.

Ecosystem metabolism results in 2016–17 demonstrate that the total amount of gross primary productivity, and hence carbon production, increases with environmental flow actions, but not the specific volumetric rate of production. In general, rates of ecosystem metabolism will be more important to local aquatic biota, which respond to the local concentration of food, while total amounts of primary productivity will help biota in downstream environments. Higher overall loads may still provide some benefit to local biota, especially if there are a mix of substrates in the littoral zones (i.e. edges of the channel) where biofilms and algae can grow and ultimately fuel localised secondary production.

The macroinvertebrate results are consistent with this hypothesis. We saw an increase in biomass, particularly of large crustaceans, following the spring floods, although this was followed by a sharp drop in biomass accompanying the January blackwater event. A student may be recruited to investigate whether production of biofilms in edge habitats is improved by environmental flows, which would provide greater support for this interpretation of the data. For this research, the 2-dimensional hydraulic models would be used to identify slow-flowing, shallow ‘slackwater zones’ that would be expected to benefit from increased primary production loads.

Further research to establish linkages between the monitoring would involve using stable isotope analysis of all elements in the food web. This would determine which basal resource is driving food web dynamics and where this resource originates by either allochthonous (out of channel) terrestrial leaf litter or autochthonous (produced in channel) aquatic algae. By identifying the sources of carbon and relative importance of each, environmental flows could be better targeted to achieve broader longer term restoration goals, rather than targeting flows for specific biotic life-events. Further effort in 2017–18 will be used to scope the feasibility of collecting and processing data from selected trophic levels.

Non-LTIM monitoring carried out in April 2017 demonstrated the importance of autumn high flow events for attracting sub-adult silver perch into the Goulburn River. These results, while not yet formally released, fill in gaps in our conceptual understanding of these species life history strategies. The general lack of young-of-year of these flow-cued spawning species is well explained if larvae are being exported from the Goulburn River by the high flows that cause spawning, and then recruit to sub-adult stage in the Murray River before migrating into the Goulburn on high flow events in autumn.

The strongest linkages between components of the monitoring program were unfortunately provided by the January blackwater event. High rates of ecosystem respiration caused low oxygen levels in water for long enough to cause high levels of mortality in macroinvertebrates and fish. These impacts were clearly seen in the biomass monitoring of large crustaceans, and in the reduced catches of multiple species in the annual adult electrofishing surveys. The positive note associated with these ecosystem level impacts is that there is now a ‘baseline’ data against which to track recovery of crustacean and fish populations over the last two years of the LTIM Project. This will provide valuable information about the resilience of the biota to major disturbances.

8.3 Conclusion

Monitoring in 2016–17 has further elucidated linkages proposed in the MEP (Figure 8-1), although some remain tentative. The natural flooding in spring 2016 allowed better understanding of some of the linkages. Some linkages are still tentative and further research may be able to provide more evidence. Some links are evident between the hydrology and (i) ecosystem metabolism, (ii) physical habitat (hydraulic habitat) and (iii) physical habitat (bank condition). There is also some tentative support for links between ecosystem metabolism and macroinvertebrates, and between the hydraulic habitat, fish and vegetation. However, uncertainty remains, particularly for the links between environmental flows and slower responding variables (e.g. adult fish populations and bank vegetation). Future years of LTIM will attempt to better elucidate these linkages.

9. Adaptive management

Ecological monitoring has been ongoing for decades across the Murray-Darling Basin and has strongly influenced environmental water management decisions. However, the findings of such efforts are typically considered retrospectively, and there are commonly delays between the delivery of environmental water and description of the results of those actions. The LTIM Project is uniquely underpinned by a two-way transfer of information between the environmental water delivery planners (particularly the VEWH, CEWO, GBCMA, MDBA and GMW) and the researchers. Proactive engagement with the researchers to inform management decisions has occurred via formal presentations and workshops, telephone and e-mail communications, and informal, ad-hoc conversations conveying monitoring results and recommendations.

Environmental water planners now have access to real-time advice and field observations (ahead of formal reporting) to inform decision making before, during and after managed environmental water delivery actions. This is additional to the annual formal reporting, and allows monitoring results to more rapidly inform flow planning for the following water year (i.e. in this case there can otherwise be up to a 2-year gap between monitoring and finalised written results). This highly effective and collaborative relationship established between government and the scientific community allows for an immediate response by water managers throughout the year to both enhance environmental outcomes, and mitigate unintended adverse impacts.

The science-practice partnership has two particular advantages in the management of environmental flows. First, researchers have better access to ongoing and up-to-date information on forecasted flows from the water and catchment management authorities to target sampling periods. Second, practitioners see field-based verification of management intentions. Specific examples of adaptive management in operation for the individual monitoring matters, and implications for future monitoring and management are listed below (Table 9-1).

Flow conditions in 2016–17 tested the capability of the Goulburn LTIM project team to respond to novel circumstances. High flows and flooding in August and September meant that monitoring at that time would have been unsafe. Accordingly, there was a delay in the installation of oxygen meters for Stream Metabolism (Section 4), and a long gap between field visits for Bank Condition (Section 3). More importantly, 'pre-fresh' sampling trips had to be cancelled for Macroinvertebrates and Vegetation, which meant that the before-after approach to data analysis previously employed for these monitoring matters could not be used in 2016–17. Through a responsive approach to monitoring, we were able to implement alternative monitoring to use the resources previously allocated to those cancelled surveys, and opportunistically test several hypotheses specifically related to the 2016 floods (see below).

In addition to the floods, the blackwater event that occurred on 1 January 2017 opened up serendipitous opportunities to understand the impacts of these unpredictable events better and also track recovery from them. These are also outlined below.

Table 9-1. Specific examples of adaptive management undertaken through the Goulburn River LTIM Project and/or implications of 2016–17 monitoring results for adaptive management of future environmental watering decisions. See main sections and technical appendices for more detail.

Matter	Examples of adaptive management and implications for future monitoring and management
2-dimensional hydraulic models	With the enduring nature of the 2-dimensional models, their implications for adaptive management are unchanged from those reported in 2015–16. Their primary value remains the ability translate discharge data into the hydraulic parameters that are actually experienced by organisms living in the Goulburn River. Those parameters can potentially be transferred to other systems and 'back-transformed' into the type of discharges required to achieve them for those systems. For example, if water velocity is the critical factor that triggers golden perch spawning, then investigations that identify critical velocity thresholds in the Goulburn River can be used to design flow pulses that achieve the same velocity (and presumably spawning) in other systems with different sized channels such as the Edward Wakool.
Bank Condition	Flow management has been modified through collaboration with researchers. This includes altering the duration of flows at specific levels so as to increase variability, and reduce the potential for bank notching, and managing rates of fall to reduce the potential for bank failure. Further monitoring of altered flow events suggested low rates of erosion,

Matter	Examples of adaptive management and implications for future monitoring and management
	providing confidence for continued operations. Although our knowledge has continued to build in 2016–17, the basic implications of the bank condition monitoring program for adaptive management remain unchanged from 2015–16.
	Erosion pin measurements have suggested that mud drapes (that encouraged vegetation establishment) were more common during slow rates of recession. Re-establishing bank vegetation had previously been assumed to be driven by spring freshes; however, these observations suggest winter environmental flow deliveries may be more important for this purpose. With the large floods in spring 2016, we have not yet been able to test this hypothesis.
Stream Metabolism	The strong association between metabolism parameters and temperature implies that any flow events specifically aimed at improving stream primary productivity should take place when water temperatures are warm (i.e. late spring or summer). The floods in early spring in 2016 (August-September), despite assuredly mobilizing carbon from the floodplain, did not result in an observable increase in metabolism rates once waters had warmed. The results highlight the need for appropriately timed larger flow events in the future to mobilise carbon and nutrients from major backwaters and the floodplain.
Macro-invertebrates	Macroinvertebrate monitoring over 2016-17 was an example of 'adaptive monitoring'. Unanticipated large, natural flows disrupted the normal monitoring program such that pre-fresh monitoring was cancelled. A decision was made to continue with post-fresh monitoring, which allows the following of longer-term patterns, with additional surveys conducted to measure what appeared to be an increase in macroinvertebrate productivity following spring floods. Using this adaptive monitoring approach, the resources previously used for pre-fresh monitoring were reallocated to investigate post-flood productivity. Serendipitously, this program also provided valuable data on the effects of a blackwater event on crustaceans, with biomass dropping rapidly. It is our intention to repeat this monitoring in 2017–18 to provide a comparison in a (presumably) non-flood year. This flexible approach to monitoring also continues to improve our knowledge of what does and does not work with regards to monitoring macroinvertebrate responses to flow changes in lowland rivers, an approach that is necessary given the experimental nature of the macroinvertebrate program (Webb et al. 2017). The 2016–17 results suggested that carbon added to the river by the spring floods was beneficial for macroinvertebrate production. In future, piggybacking major watering actions on unregulated tributary inflows would improve the amount of carbon delivered by these events. This would require close coordination between environmental water managers and river operators.
Vegetation	As described above, the 2016–17 vegetation monitoring program was also an example of adaptive monitoring, with changes having to be made in response to the spring flooding events. The final design of sampling allowed us to continue to assess long-term vegetation responses to flows, but also allowed a test of vegetation response to the floods themselves. Additional co-investment from the Victorian Department of Environment, Land, Water and Planning allowed a third sampling event around the autumn fresh, plus the installation of soil moisture probes. The observation that vegetation recovered better from the floods than may have been expected builds our confidence to deliver longer-duration flow events in future; these have previously been constrained by concern for bankside vegetation. As with the macroinvertebrate monitoring, there was some evidence that the high unregulated flows in spring delivered more propagules (seeds and vegetation fragments) than is the case for managed spring freshes. Piggybacking spring freshes on unregulated tributary inputs could also have advantages for vegetation outcomes in the Goulburn River.
Fish	Larval monitoring in 2016–17 continued to improve our understanding of the processes driving this important response, necessitating a major change in the way data were analysed. In 2015–16, we modelled spawning as a function of flow changes on the rising limb of flow events (i.e. in response to a positive change in flow). Observation of spawning on the falling limb of the 2016–17 floods necessitated a re-evaluation of this, leading to greater emphasis on temperatures as a minimum condition for spawning, coupled with sufficient discharge.
	Movement data during the spawning season largely reinforced this reinterpretation of the factors driving spawning. In addition to LTIM-funded movement monitoring, staff from ARI in collaboration with GBCMA, CEWO and the MDBA undertook an adaptive management experiment in in March 2017, manipulating flows in both the Goulburn and Murray rivers to see if migrating sub-adult golden and silver perch could be attracted into the Goulburn River by high flows in autumn. This experiment was a success, and goes some way to explaining why we see adult golden and silver perch in electrofishing surveys in the Goulburn River, but very few young of year. This experiment was an example of adaptive learning and science-management collaboration at its very best.

Matter	Examples of adaptive management and implications for future monitoring and management
	A negative highlight of the annual electrofishing surveys in 2016–17 was the observation of reduced fish numbers, with the blackwater event of 1 January presumed to be to blame for fish deaths. However, this observation opens up a good opportunity to observe fish assemblage recovery in the final two years of LTIM monitoring in the Goulburn River. Quantifying the level of resilience in fish populations will help to inform management decisions for flow- and non-flow-related programs.

A number of key learnings have already come from the science-practice partnership that underpins the Goulburn River LTIM Project. First, is the need to better integrate science and practice, incorporating best available science into practice and driving targeted science through collaborations between researchers and managers. This is being achieved, through strong, transparent, yet often informal lines of communication between scientists and environmental water managers and is supplemented by formal reviews that enable holistic consideration of findings from all the different monitoring matters to be incorporated into the design of the environmental flows into the future.

Second, our knowledge of responses to environmental flows has continued to grow, but complete knowledge and absolute certainty of outcomes is not possible in complex environmental systems. Better environmental outcomes may be achieved through doing (i.e. making management decisions), then knowing (through monitoring and evaluation). This approach enables managers to build on current knowledge and modify flows for maximum environmental benefit. The benefits of this approach are quickly realised as managers are provided with rapid feedback about what works and what does not, which in turn provides greater certainty about environmental outcomes in future years.

Third, knowledge developed in one system can often be transferred to other systems. For example, results from the bank condition monitoring are being used by the CEWO to inform flow management in the nearby Loddon River to reduce risks of bank notching associated with freshes. The full value of the LTIM Project will be realised once the results from the seven key locations are combined to develop generalised relationships and understanding.

Related to this last point, adaptive management within the LTIM Project has received far greater attention in 2017 than was previously the case. In April 2017, monitoring providers, monitoring advisers, representatives from CEWO, and selected area stakeholders met in Canberra to discuss and compare the different types of adaptive management being undertaken across the LTIM Project. The Goulburn River LTIM Project is one of the more successful examples of adaptive management within the larger program, although all selected area projects reported at least some success. Success for the Goulburn comes through the now-annual February workshop where monitoring results from the previous year are reported and used as an input to the upcoming year's seasonal watering planning process. Beyond this though the informal lines of communication reported above are still seen as a major strength of the project, a strength also reported by most other LTIM selected areas. This workshop highlighted the fact that the LTIM Project can be considered as something of a large-scale experiment in adaptive management practice. Across the seven selected areas, different approaches are being used and different constraints are encountered, but all with the aim of improving environmental water management decisions. The selected area leads are currently in the process of scoping out a manuscript as a collaborative activity to bring together the collective learning on the process of adaptive management that is being gained through the LTIM project.

10. Stakeholder communications

The following planned communication and engagement actives were undertaken over the 2016-17 period to inform stakeholders and the broader community about the aims and results of the Goulburn River LTIM Project and the role of the Commonwealth Environmental Water Office in environmental water management. Selected examples of communications are included in Appendix G.

10.1 Media Releases and Articles

Between June 2016 and July 2017, 12 media releases were prepared and monthly columns/ads were run in the *Shepparton Advisor* and the *Country News*. These promoted the project, Commonwealth environmental water use in the Goulburn River and ecological responses (native fish movement and breeding, bank vegetation growth and bank erosion) to environmental flows. These resulted in 10 corresponding articles published in local newspapers including the *Country News* and *Shepparton News*. Articles were also included in the GB CMA electronic newsletter 'Connecting Community and Catchment', which has over 900 subscribers.

In addition, Dr Angus Webb was interviewed by Michael Foley from Fairfax Media on August 23, 2017, speaking about the Goulburn River LTIM project. The interview covered all aspects of the monitoring program including adaptive management and stakeholder engagement. However, at the time of writing of this report, the story was yet to appear in print.

10.2 Technical publications

The paper by Geoff Vietz, Angus Webb, Anna Lintern and David Straccione, "River bank erosion and the influence of environmental flow management" was accepted into the special issue of the international journal *Environmental Management*. Delays with the special issue mean that it does not have a publication year or volume/page numbers. However, it is available online and citable through its digital object identifier (doi).

- https://doi.org/10.1007/s00267-017-0857-9

Dr Angus Webb co-authored a paper, with authors from the University of Melbourne and Massey University, New Zealand, "An economic framework for sharing water within a river catchment" (Water Economics and Policy, 3(3), Paper 1650039 that used Goulburn LTIM data on golden perch spawning and physical habitat as part of an optimization model that illustrated trade-offs between consumptive and environmental water uses.

- https://doi.org/10.1142/S2382624X16500399

The Goulburn LTIM project, along with the greater LTIM project were mentioned in several chapters of the recently released book, "*Water for the Environment: from Policy and Science to Implementation and Management*" (Horne et al. 2017), of which Angus Webb was one of the editors

- https://www.elsevier.com/books/water-for-the-environment/horne/978-0-12-803907-6

10.3 Social Media

A total of 20 posts to the GB CMA iSpy Facebook page and the GB CMA Facebook page promoted the project, which were viewed over 20,000 times. Associated tweets reached over 10,000 people.

- https://www.facebook.com/gbcmaispyfish
- https://www.facebook.com/gbcma

10.4 Forum

A Forum was held on 25 July, 2017 in Shepparton to outline the aims and the results to date of the Goulburn River LTIM Project. The Forum was attended by 46 people comprised of representatives from government and

NRM agencies, and conservation, recreational, agricultural, environmental water advisory and Traditional Owner groups. In addition, the Victorian State MP Mark Gepp and the Federal MP Damien Drum attended the Forum. The forum was reported in Country news

- http://www.countrynews.com.au/2017/07/27/5916/going-with-the-flows

10.5 Videos

Short web videos were developed to explain environmental and black water and are available for viewing on the GB CMA website. The videos have been viewed a total of 245 and 195 times respectively and have been shared with other water and natural resource management agencies.

- Environmental water: https://www.youtube.com/watch?v=HasFVSC_8h8
- Blackwater: https://www.youtube.com/watch?v=fe8Xl-UlxeU

10.6 Presentations

In June 2017, Dr Angus Webb delivered a presentation to the international Society for Freshwater Science meeting, held in Raleigh, North Carolina. His presentation covered the larger LTIM project, but specifically how hydraulic modelling outputs and fish larval monitoring data are being brought together to generate an ability to predict when golden perch will spawn.

In September, Angus delivered a plenary presentation to the European Inland Fisheries and Aquaculture Advisory Commission (EIFAAC) International Symposium, in Stare Jablonki, Poland. His presentation concentrated on different ways of combining evidence, and used the Bayesian modelling of Goulburn LTIM Project golden perch spawning data as an example.

GB CMA staff presented/provided updates to a number of community and agency groups throughout the year on the project. These groups included:

- GB CMA Indigenous Consultation Group;
- Yorta Yorta Nation Aboriginal Corporation;
- Goulburn-Murray Water;
- Parks Victoria;
- GB CMA partnership group;
- Schools and research institutes;
- Shepparton Irrigation Region People and Planning Integration Committee;
- Goulburn Broken Water Quality Coordination Group;
- Recreational fishing groups and fish management agencies;
- Environmental Water Advisory Groups; and
- Fairley Leadership Group.

In addition, the GB CMA conducted 2 television (WIN News) and 2 radio (ABC) interviews promoting the project.

11. References cited

Abernethy, B., and I. D. Rutherfurd. 2001. The distribution and strength of riparian tree roots in relation to riverbank reinforcement. Hydrological Processes 15:63-79.

Allan, J. D., M. S. Wipfli, J. P. Caouette, A. Prussian, and J. Rodgers. 2003. Influence of streamside vegetation on inputs of terrestrial invertebrates to salmonid food webs. Canadian Journal of Fisheries and Aquatic Sciences 60:309-320.

Bernot, M. J., D. J. Sobota, R. O. Hall, P. J. Mulholland, W. K. Dodds, J. R. Webster, J. L. Tank, L. R. Ashkenas, L. W. Cooper, and C. N. Dahm. 2010. Inter‐regional comparison of land‐use effects on stream metabolism. Freshwater Biology 55:1874-1890.

BoM. 2017. Climate summaries archive. (Available from: http://www.bom.gov.au/climate/current/statement_archives.shtml?region=vic&period=month)

Brooks, S., P. Cottingham, R. Butcher, and J. Hale. 2013. Murray-Darling Basin aquatic ecosystem classification: Stage 2 report. Peter Cottingham and Associates report to the Commonwealth Environmental Water Office and Murray-Darling Basin Authority, Canberra.

Burns, A., and K. F. Walker. 2000. Biofilms as food for decapods (Atyidae, Palaemonidae) in the River Murray, South Australia. Hydrobiologia 437:83-89.

CEWO. 2014. Commonwealth Environmental Water Use Options 2014-15: Victorian Rivers in the Murray-Darling Basin. Commonwealth Environmental Water Office, Canberra.

Chao, A., R. K. Colwell, C. W. Lin, and N. J. Gotelli. 2009. Sufficient sampling for asymptotic minimum species richness estimators. Ecology 90:1125-1133.

Clarke, S. J., L. Bruce-Burgess, and G. Wharton. 2003. Linking form and function: towards an eco-hydromorphic approach to sustainable river restoration. Aquatic Conservation: Marine & Freshwater Ecosystems 13:439-450.

CoA. 2016. Commonwealth Environmental Water portfolio management plan: Victorian Rivers in the Murray-Darling Basin 2016-17. Commonwealth of Australia, Canberra.

Connolly, N. M., M. R. Crossland, and R. G. Pearson. 2004. Effect of low dissolved oxygen on survival, emergence, and drift of tropical stream macroinvertebrates. Journal of the North American Benthological Society 23:251-270.

Cook, B. D., S. E. Bunn, and J. M. Hughes. 2007. A comparative analysis of population structuring and genetic diversity in sympatric lineages of freshwater shrimp (Atyidae: Paratya): concerted or independent responses to hydrographic factors? Freshwater Biology 52.

Cook, R., W. Paul, J. Hawking, C. Davey, and P. Suter. 2011. River Murray Biological (Macroinvertebrate) Monitoring Program - review of monitoring 1980-2009. Final Report prepared for the Murray-Darling Basin Authority. Murray-Darling Freshwater Research Centre, Albury.

Corenblit, D., J. Steiger, A. M. Gurnell, E. Tabacchi, and L. Roques. 2009. Control of sediment dynamics by vegetation as a key function driving biogeomorphic succession within fluvial corridors. Earth Surface Processes and Landforms 34:1790-1810.

Cottingham, P., and SKM. 2011. Environmental water delivery: lower Goulburn River. Report prepared for Commonwealth Environmental Water, Department of Sustainability, Environment, Water, Populations and Communities. Canberra.

Cottingham, P., M. Stewardson, D. Crook, T. Hillman, R. Oliver, J. Roberts, and I. Rutherfurd. 2007. Evaluation of summer Inter-Valley Water Transfers from the Goulburn River. Report prepared by Peter Cottingham and Associates for the Goulburn Broken Catchment Management Authority.

Cottingham, P., M. Stewardson, D. Crook, T. Hillman, J. Roberts, and I. Rutherfurd. 2003. Environmental flow recommendations for the Goulburn River below Lake Eildon. CRC Freshwater Ecology and CRC Catchment Hydrology, Canberra, ACT.

Cottingham, P., G. Vietz, J. Roberts, D. Frood, A. Graesser, J. Kaye, and A. Shields. 2013. Lower Goulburn River: observations on managing water releases in light of recent bank slumping. Report prepared for the Goulburn Broken Catchment Management Authority. Peter Cottingham and Associates, Melbourne.

CSIRO. 2008. Water availability in the Goulburn-Broken. Report for the Australian Government. Commonwealth Industrial and Scientific Research Organisation.

DELWP. 2015. Water measurement information system. Department of Environment, Land, Water and Planning. (Available from: http://data.water.vic.gov.au/monitoring.htm)

Fausch, K. D., C. E. Torgersen, C. V. Baxter, and H. W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52:483–498.

Florsheim, J. L., J. F. Mount, and A. Chin. 2008. Bank erosion as a desirable attribute of rivers. BioScience 58:519-529.

Gawne, B., S. Brooks, R. Butcher, P. Cottingham, P. Everingham, and J. Hale. 2013. Long-term intervention monitoring project: monitoring and evaluation requirements Goulburn River. Murray-Darling Freshwater Research Centre.

GBCMA. 2005. Goulburn Broken Regional River Health Strategy 2005-2015. Goulburn Broken Catchment Management Authority, Shepparton.

GBCMA. 2016. Goulburn River seasonal environmental watering proposal. Goulburn Broken Catchment Management Authority, Shepparton. (Available from: https://www.gbcma.vic.gov.au/downloads/Environmental_Water/2016-05-03_Final_Goulburn_River_Seasonal_Watering_Proposal_2016-17_-_signed.pdf)

GBCMA. 2017. Goulburn River January 2017 blackwater event. Event summary and GBCMA actions. Goulburn Broken Catchment Management Authority, Shepparton.

Gigney, H., J. Hawking, L. Smith, and B. Gawne. 2007a. Murray Irrigation Region Aquatic Ecosystem Monitoring Program Development: 2005 Pilot Study Report. A report for Murray Irrigation Limited. Murray-Darling Freshwater Research Centre, Albury.

Gigney, H., J. Hawking, L. Smith, and B. Gawne. 2007b. Murray Irrigation Region Aquatic Ecosystem Monitoring Program Development: Protocols handbook. A report for Murray Irrigation Limited. Murray-Darling Freshwater Research Centre, Albury.

Grace, M. R., D. P. Gilling, S. Hladyz, V. Caron, R. M. Thompson, and R. Mac Nally. 2015. Fast processing of diel oxygen curves: estimating stream betabolism with BASE (BAyesian Single-station Estimation). Limnology and Oceanography Methods 13:103-114.

Greet, J., J. A. Webb, and B. J. Downes. 2011. Flow variability maintains the structure and composition of in-channel riparian vegetation. Freshwater Biology 56:2514-2428.

Hancock, M. A., and S. E. Bunn. 1997. Population dynamics and life history of *Paratya australiensis* Kemp, 1917 (Decapoda: Atyidae) in upland rainforest streams, south-eastern Queensland, Australia. Marine and Freshwater Research 48:361-369.

Haselmair, A. S., M., M. Zuschin, and B. Riedel. 2010. Behaviour and mortality of benthic crustaceans in response to experimentally induced hypoxia and anoxia *in situ*. Marine Ecology Progress Series 414:195-208.

Horne, A. C., J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman. (Eds.) 2017. Water for the Environment: from Policy and Science to Implementation and Management. Elsevier, Cambridge MA.

King, A. J., D. C. Gwinn, Z. Tonkin, J. Mahoney, S. Raymond, and L. Beesley. 2015. Using abiotic drivers of fish spawning to inform environmental flow management. Journal of Applied Ecology 53:34–43.

Koehn, J., and S. Nicol. 2016. Comparative movements of four large fish species in a lowland river. Journal of Fish Biology 88:1360–1388.

Koehn, J., C. Todd, L. Thwaites, I. Stuart, B. Zampatti, Q. Ye, A. Conallin, L. Dodd, and K. Stamation. 2016. Managing flows and Carp. Arthur Rylah Institute for Environmental Research Technical Report Series No. 255. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Koehn, J. D., C. R. Todd, B. P. Zampatti, I. G. Stuart, A. Conallin, L. Thwaites, and Q. Ye. 2017. Using a population model to inform the management of river flows and invasive carp (*Cyprinus carpio*). Environmental Management in press.

Koster, W., D. Crook, D. Dawson, and P. Moloney. 2012. Status of fish populations in the lower Goulburn River (2003-2012). Arthur Rylah Institute for Environmental Research Client Report, Department of Sustainability and Environment, Heidelberg, Victoria.

Koster, W. M., D. R. Dawson, D. J. O'Mahony, P. D. Moloney, and D. A. Crook. 2014. Timing, frequency and environmental conditions associated with mainstem–tributary movement by a lowland river fish, golden perch (*Macquaria ambigua*). PloS one 9:e96044.

Lammers, J. H., K. Warburton, and B. W. Cribb. 2009. Diurnal refuge competition in the freshwater prawn, *Macrobrachium australiense*. Journal of Crustacean Biology 29.

Lee, C. L., and D. R. Fielder. 1983. Agonistic behaviour and the development of dominance hierarchies in the freshwater prawn, *Macrobrachium australiense* Holthuis, 1950 (Crustacean: Palaemonidae). Behaviour 83:1-16.

Lintermans, M. 2007. Fishes of the Murray-Darling Basin: An Introductory Guide. Murray-Darling Basin Commission, Canberra.

Liu, L. C. 1980. Some aspects of the taxonomy, behaviour and biology of the freshwater prawn, *Macrobrachium australiense* Holthuis 1950) (Crustacea: Decapoda: Palaemonidae). PhD Dissertation. University of Queensland, Brisbane.

Lunn, D., D. Spiegelhalter, A. Thomas, and N. Best. 2009. The BUGS project: Evolution, critique and future directions (with discussion). Statistics in Medicine 28:3049-3082.

Marcarelli, A. M., C. V. Baxter, M. M. Mineau, and R. O. Hall. 2011. Quantity and quality: unifying food web and ecosystem perspectives on the role of resource subsidies in freshwaters. Ecology 92:1215-1225.

Marshall, J. C., N. Menke, D. A. Crook, J. S. Lobegeiger, S. R. Balcombe, J. A. Huey, J. H. Fawcett, N. R. Bond, A. H. Starkey, D. Sternberg, S. Linke, and A. H. Arthington. 2016. Go with the flow: the movement behaviour of fish from isolated waterhole refugia during connecting flow events in an intermittent dryland river. Freshwater Biology:early view.

Miller, K. A., J. A. Webb, S. C. de Little, M. J. Stewardson, and I. D. Rutherfurd. 2015. How effective are environmental flows? Analyses of flow ‐ ecology relationships in the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP) from 2011 ‐ 2014. A report to the Department of Environment, Land, Water and Planning, p. xiv + 342. University of Melbourne, Melbourne.

Milton, D., and A. Arthington. 1984. Reproductive strategy and growth of the crimson-spotted rainbowfish, *Melanotaenia splendida fluviatilis* (Castelnau) (Pisces : Melanotaeniidae) in south-eastern Queensland. Marine and Freshwater Research 35:75-83.

Naiman, R. J., and H. Decamps. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics 28:621-658.

Newson, M. D., and A. R. G. Large. 2006. 'Natural' rivers, 'hydromorphological quality' and river restoration: a challenging new agenda for applied fluvial geomorphology. Earth Surface Processes & Landforms 31:1606-1624.

Ning, N. S. P., R. Petrie, B. Gawne, D. L. Nielsen, and G. N. Rees. 2015. Hypoxic blackwater events suppress the emergence of zooplankton from wetland sediments. Aquatic Science 77:221-230.

O'Connor, J. P., D. J. O'Mahony, and J. M. O'Mahony. 2005. Movements of *Macquaria ambigua*, in the Murray River, south-eastern Australia. Journal of Fish Biology 66:392–403.

Odum, H. T. 1956. Primary production in flowing waters. Limnology and Oceanography 1:102-117.

Oliver, D. R. 1971. Life history of the Chironomidae. Annual Reviews in Entomology 16:211-230.

Osterkamp, W. R., and C. R. Hupp. 2010. Fluvial processes and vegetation -- Glimpses of the past, the present, and perhaps the future. Geomorphology 116:274-285.

Price, A. E., and P. Humphries. 2010. The role of dispersal and retention in the early life stages of shrimp in a lowland river. Canadian Journal of Fisheries and Aquatic Sciences 67:720-729.

R Development Core Team. 2010. R: A language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. (Available from: http://www.r-project.org)

Reynolds, L. F. 1983. Migration patterns of five fish species in the Murray-Darling River system. Marine and Freshwater Research 34:857–871.

Richardson, A., and P. Humphries. 2010. Reproductive traits of riverine shrimps may explain the impact of altered flow conditions. Freshwater Biology 55:2011-2022.

Richardson, A. J., and R. A. Cook. 2006. Habitat use by caridean shrimps in lowland rivers. Marine and Freshwater Research 57:695-701.

Richardson, A. J., J. E. Growns, and R. A. Cook. 2004. Distribution and life history of caridean shrimps in regulated lowland rivers in southern Australia. Marine and Freshwater Research 55:295-308.

Roberts, B. J., and J. P. Mulholland. 2007. In-stream biotic control on nutrient biogeochemistry in a forested stream, West Fork of Walker Branch. Journal of Geophysical Research 112:G04002.

Sheldon, F., and K. F. Walker. 1998. Spatial distribution of littoral invertebrates in the lower Murray-Darling River system. Marine and Freshwater Research 49:171-182.

Song, C., W. K. Dodds, M. T. Trentman, J. Rüegg, and F. Ballantyne. 2016. Methods of approximation influence aquatic ecosystem metabolism estimates. Limnology and Oceanography: Methods 14:557-569.

Stewardson, M., M. Jones, W. Koster, G. Rees, D. Skinner, R. Thompson, G. Vietz, and A. Webb. 2014. Monitoring of ecosystem responses to the delivery of environmental water in the lower Goulburn River and Broken Creek in 2012-13. Report prepared for the Commonwealth Environmental Water Office, p. 244. The University of Melbourne, Melbourne.

Sturz, S., U. Ligges, and A. Gelman. 2005. R2WinBUGS: a package for running WinBUGS from R. Journal of Statistical Software 12:1-16.

Teixeira, M. C., M. P. Budd, and D. L. Strayer. 2015. Responses of epiphytic aquatic macroinvertebrates to hypoxia. Inland Waters 5:75-80.

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

Uehlinger, U. 2000. Resistance and resilience of ecosystem metabolism in a flood-prone river system. Freshwater Biology 45:319-332.

UoM. 2013. Proposal submitted to Department of Sustainability, Environment, Water, Population and Communities. Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project. UoMC Ref: 2013-180. University of Melbourne.

Vietz, G., S. Casanelia, G. Earl, I. Conlan, and C. Johnson. 2016. Knowing then doing, or is it doing then knowing? Environmental flows and bank condition monitoring in the Goulburn River, Australia. Pages Paper 26972 in J. A. Webb, J. F. Costelloe, R. Casas-Mulet, J. P. Lyon and M. J. Stewardson (editors). Proceedings of the 11th International Symposium on Ecohydraulics. The University of Melbourne, Melbourne, Australia. (Available from: http://proceedings.ise2016.org/tracks/1018/abstract/26972.html)

Vietz, G. J., and B. L. Finlayson. 2017. Models of ecological responses to flow regime change to inform environmental flow assessments. in A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter and M. Acreman (editors). Water for the Environment: from Policy and Science to Implementation and Management. Elsevier, Cambridge, MA.

Vietz, G. J., A. Lintern, J. A. Webb, and D. Straccione. early view. River bank erosion and the influence of environmental flow management. Environmental Management:doi: 10.1007/s00267-00017-00857-00269.

Webb, A., B. Baker, S. Casanelia, M. Grace, E. King, W. Koster, K. Lansdown, A. Lintern, D. Lovell, K. Morris, V. Pettigrove, A. Sharpe, K. Townsend, and G. Vietz. 2017. Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Goulburn River Selected Area evaluation report 2015-16. Report prepared for the Commonwealth Environmental Water Office. p. xiv + 160. Commonwealth of Australia, Melbourne.

Webb, A., S. Casanelia, G. Earl, M. Grace, E. King, W. Koster, K. Morris, V. Pettigrove, A. Sharpe, K. Townsend, G. Vietz, A. Woodman, and A. Ziebell. 2016. Commonwealth Environmental Water Office Long Term Intervention Monitoring Project: Goulburn River Selected Area evaluation report 2014-15. p. ix + 107. University of Melbourne Commercial, Melbourne.

Webb, A., A. Sharpe, W. Koster, V. Pettigrove, M. Grace, G. Vietz, A. Woodman, G. Earl, and S. Casanelia. 2014. Long-term intervention monitoring program for the lower Goulburn River: final monitoring and evaluation plan. Report prepared forthe Commonwealth Environmental Water Office. University of Melborne Commercial.

Webb, A., G. Vietz, S. Windecker, S. Hladyz, R. Thompson, W. Koster, and M. Jones. 2015. Monitoring and reporting on the ecological outcomes of commonwealth environmental water delivered in the lower

Goulburn River and Broken Creek in 2013/14. Report prepared for the Commonwealth Environmental Water Office, p. ix + 177. The University of Melbourne, Melbourne.

Williams, W. D. 1977. Some aspects of the ecology of *Paratya australiensis* (Crustacea: Decapoda: Atyidae). Australian Journal of Marine and Freshwater Research 28:403-415.

Windecker, S. M., and G. J. Vietz. 2014. Assessing the influence of environmental flows on physical habitat. Pages 140-142 in G. J. Vietz, I. D. Rutherfurd and R. M. Hughes (editors). Australian Stream Management Conference, Catchments to Coast. University of Melbourne, Townsville, Queensland.

Appendix A. Hydrology and Hydraulics Methods

A.1 Introduction

There are five established flow gauges in the lower Goulburn River that provide data over a long period and generally have good rating curves (Table A-1). The gauges at Goulburn Weir and Murchison provide information about flow rates in Zone 1, and the gauges at Loch Garry and McCoy's Bridge provide flow information for Zone 2. The fifth gauge is at Shepparton, which is close to the boundary between Zone 1 and Zone 2 and can be used to check flow conditions and assumptions for either Zone. An additional established gauge in the lower Broken River is being used to provide flow data for the macroinvertebrate analysis.

Reliable daily and instantaneous discharge records are critical to determine whether the environmental water released from storages meets the target flows throughout the river. These hydrological data are critical to analysing the results of all of the biological and physical monitoring activities taking place in the Lower Goulburn River LTIM Project. The existing flow gauge network in the lower Goulburn River and the small number of large tributaries that flow into it, provide a sufficiently reliable measure of discharge at most points along the river from Goulburn Weir to the Murray River and therefore meet the hydrological monitoring requirements for the LTIM Project.

A.2 What hydrological data have been used for the analysis?

Verified hydrology data have been drawn from the Victorian Water Measurement Information System (http://data.water.vic.gov.au/monitoring.htm). Data were obtained for the sites outlined in Table A-1. Where data were unavailable, unverified (or operational) data were obtained direct from Goulburn-Murray Water (G. Ortlipp, pers. comm.) or via the Victorian Environmental Water Holder (K. Chalmers, pers. comm.), and the verified data sequence infilled with the operational data. Both discharge (ML/day) and level (m AHD) data were available at each gauge for verified data, but only discharge data were available from the operational data.

Table A-1. Available gauge data

Gauge Number	Gauge Name
405204	Goulburn River at Shepparton
405232	Goulburn River at McCoy's Bridge
405253	Goulburn River at Goulburn Weir
405276	Goulburn River at Loch Garry
405200	Goulburn River at Murchison
404222	Broken River at Orrvale
409215	Murray River at Barmah

The gauge at Loch Garry produces the lowest quality data of the set of gauges. Problems with the inlet orifice of the gauge mean that it does not record discharges below ~ 2100 ML/day, which leads to lengthy gaps within the discharge record. This included the entire period of monitoring in this report for the 2015–16 report, plus lengthy periods for the current report. Beyond this, the rating table used to convert stage height to discharge has not been updated since the early 1990s, and recent gaugings undertaken in 2010 suggested quite substantial errors (Tom Candy, Ventia pty ltd., pers. comm.). For analysis of LTIM project ecological responses to flow changes, gaps in the Loch Garry flow data are filled using the regression below, which was developed during Year 1 of the Goulburn River LTIM Project (Webb et al. 2016).

Loch Garry = 0.9297 x McCoy's (next day) + 91.781,

R^2 of 0.9702

McCoy's (next day) represents the discharge at McCoy's on the next day to account for travel time

With Loch Garry being a focus site for monitoring within the Lower Goulburn River LTIM Project, it is important that high quality discharge data are available at this site. The Goulburn Broken CMA is funding the ongoing operation of the Loch Garry gauge, which was removed from the Victorian Surface Water Monitoring Network ~ 2 years ago. The observations above suggest that although data are being collected from Loch Garry, their quality is questionable. We will continue to liaise with the CMA and discharge monitoring provider (Ventia) about how to ensure that the Goulburn River LTIM project has the flow data it needs.

There are several sites where discharge data were not available; these are listed in Table A-2, and the method to derive flows at each location summarised.

An environmental flow series is available from Goulburn Murray Water. This series is only available at McCoy's Bridge gauge and is adapted to other locations using a delay (or time-lag). The flow series from Goulburn Murray Water could be adapted to exclude environmental flows, and was also converted to levels (for vegetation and bank condition analysis) using rating tables at each of the sites.

Table A-2. Discharge data where no gauge exists.

Site	Method for deriving a flow series
Darcy's Track	Flows at Shepparton the next day. This represents the correct magnitude and pattern of flows, when compared to the next downstream site, McCoy's Bridge.
Moss Road	Adopt flow series from Goulburn Weir
Yambuna	Adopt flow series from McCoy's Bridge
Cable Hole	Adopt Goulburn Weir data (same as Moss Road)
Day Road	Adopt Goulburn Weir data (same as Moss Road)

1-Dimensional Hydraulic models are available for several sites, and were adopted as part of the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) monitoring. A summary of these models is in Table A-3. Many of these models have now been superseded by the 2-dimensional hydraulic models developed for the physical habitat assessments.

Table A-3. Hydraulic models available.

Site	Model reference
Loch Garry	VEFMAP site 34
McCoy's	VEFMAP site 36
Moss Road	VEFMAP site 26
Broken River at Orvale	VEFMAP site 9
Darcy's Track	VEFMAP site 32

These models have primarily been used to model inundation depths (levels) under 'no-environmental flow' conditions for vegetation and bank condition analyses. The 2-dimensional hydraulic models are now being used to model more spatially explicit hydraulic parameters, such as velocity, at different points of the river and under different flow conditions (Appendix B).

Appendix B. Detailed Results for Physical Habitat and Bank Condition

B.1 Introduction

Hydraulic conditions, the state of river banks and sediment dynamics, greatly influence fish, vegetation and macroinvertebrate population dynamics. However, the relationships between discharge and river bank condition (sediment dynamics) are not well known. As such, in the physical monitoring program, (i) hydraulic models are being developed to quantify flow-habitat relationships, and (ii) bank condition is being monitored to assess the influence of Commonwealth environmental water flows on erosion and deposition of bank sediments.

Hydraulic conditions specifically refer to metrics such as velocity and depth, rather than flow volume. Whilst, river managers often use flow volume as the main metric of study, it is the hydraulic conditions that influence the biota. For example, slackwater habitats are important nursery areas for fish larvae and juvenile fish, and are also areas of high productivity for zooplankton and macroinvertebrates. As such, flows that maximise the quality and quantity of slackwater habitats at critical times in a particular river system are most likely to trigger a significant ecological response. Measuring changes in the distribution and quality of hydraulic habitats under different flow conditions is therefore important in determining whether specific flow management actions are providing the conditions required for an intended ecological outcome. Such information will improve the interpretation of ecological monitoring results, specifically the attribution of good ecological outcomes to the delivery of Commonwealth environmental water.

Hydraulic models are being used to quantify the relationships between discharge and ecologically relevant hydraulic metrics, to better understand the physical habitats in the Goulburn River. Model results can be used to produce discharge-habitat curves that allow us to predict the quality, quantity and distribution of specific hydraulic habitats under a wide range of flow magnitudes.

River banks influence the velocity of flow, depth of water, and provide the sediment conditions for biota including flora and fauna. For example, some erosion can help streamside and instream vegetation become established, yet, excessive erosion can lead to sediment smothering of bed habitats, and harm to biota. Quantifying the relationship between Commonwealth environmental water and bank condition can assist with identifying critical flow ranges to support specific aquatic biota and ecological processes.

Results and assessment of bank condition has led to various publications: Vietz et al. (early view) for *Environmental Management* and Vietz et al. (2016) for the 11th Symposium on Ecohydraulics. Both of these papers combine inputs from researchers and authorities including the CEWO, VEWH, and the GBCMA. Most recently the physical habitat program has been described in the book *Water for the Environment*, including the chapter by Vietz and Finlayson (2017)

B.2 Methods

Four sites are used for the hydraulic habitat and bank condition monitoring (Table B-1). However, Moss Road is only used for hydraulic habitat monitoring, and Yambuna Bridge is only used for bank condition monitoring. This variation is to maximise the value of the specific questions being posed for each of these monitoring programs.

The methods for monitoring hydraulic habitat and bank condition are described in detail in the Standard Operating Procedures (SOPs) (Webb et al. 2014). Hydraulic data, model development and verification is described in detail in the *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Goulburn River Selected Area evaluation report 2014-15* (Webb et al. 2016). The hydraulic modelling methods are summarised here. Methods for bank condition monitoring were also described in detail in the 2014-15 report and are therefore also summarised here. Statistical analyses have been performed on data collected for the entire program and therefore results are for the three-year period. Observations from the 2016-17 period are described here to highlight changes in this water year.

Table B-1. Goulburn River LTIM physical habitat monitoring sites for physical habitat (hydraulic modelling) and bank condition.

	Site (Component)	Coordinates	Image
1	Moss Road (physical habitat)	E 337458.08 N 5936838.35	
2	Darcy's Track (physical habitat and bank condition)	E 351721.99, N 5966032.91	
3	Loch Garry (physical habitat and bank condition)	E 345932.83 N 5987637.56	
4	McCoy's Bridge (physical habitat and bank condition)	E 330801.78 N 5994732.86	
5	Yambuna Bridge (bank condition)	E 360741.50 N 1450010.78	

B.2.1 Hydraulic habitat model development

Hydraulic habitat (i.e. velocity, depth etc.) is assessed by using a hydraulic model that can be used to characterise hydraulic conditions for particular discharges. The model is two-dimensional (velocity in both x and y directions).

The model requires bed topography as an input, developed using two approaches for above and below water level. Surface topography is obtained from LiDAR (provided by the GBCMA). For the inundated sections bathymetry was captured by Austral Research using a remote-controlled Sonar boat (Z-Boat 1800, Figure B-1, left). These data points are joined in GIS to produce a topographic surface (Figure B-2).

For verification purposes field velocities were measured using an Acoustic Doppler Current Profiler (ADCP) at a range of discharges for model verification (Figure B-1, right).

Figure B-1. Instruments used to collect field data for development and verification of the hydraulic model: (left) Sonar bathymetric survey boat, (right) Acoustic Doppler Current Profiler (tethered to a rope to obtain velocities across fixed cross sections).

B.2.2 Elevation data verification

The same procedure for model development and verification is followed for each of the four sites. For brevity the descriptions here of development, verification and results are presented for one site, Moss Rd.

The bathymetry XYZ file was triangulated in ArcGIS and converted to a 1 m resolution grid. The bathymetry TIN was compared to the LiDAR grid in the areas where they overlapped. The area of overlap was based on visual assessment and clipping out of water surface from LiDAR.

The mean difference between the two datasets was 0.22 m (LiDAR higher than bathymetry) and the standard deviation of differences was 0.36 m, indicating noise in one or both datasets. The median difference was 0.17 m.

B.2.3 Spatial processing

The bathymetry TIN was extended upstream and downstream by approximately 15 m by inserting manually extrapolated points. The TIN was also smoothed to meet the LiDAR on the banks by adding a 3D line draped on the LiDAR as a breakline. The TIN was clipped to this extent. The TIN exhibited a significant amount of noise, due to some points representing non-bed surfaces such as snags. Each noise area was inspected and compared to aerial images and photos to ensure the surface was representative of snags. The bathymetry grid was then mosaicked with the LiDAR data, with preference given to the bathymetry in areas of overlap.

The final LiDAR/bathymetry grid is shown in Figure B-2 below with the raw bathymetry survey overlaid.

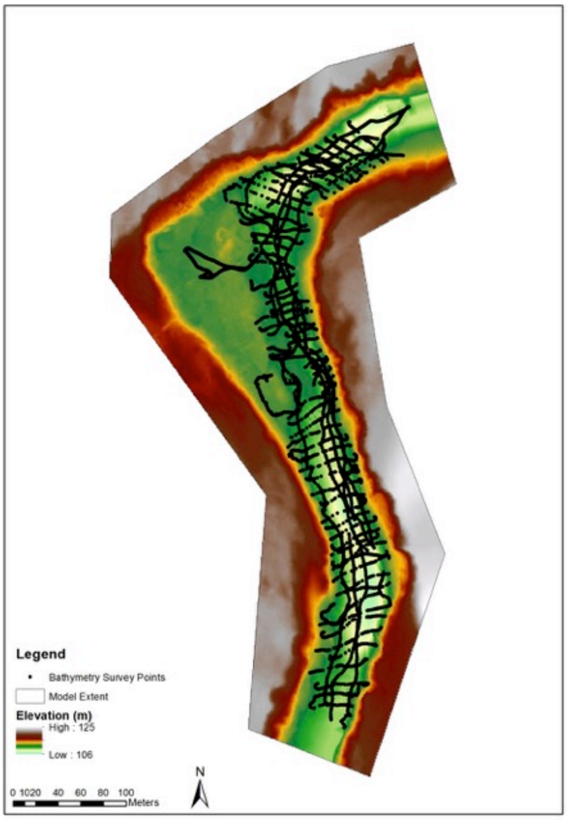


Figure B-2. Topography used to develop the hydraulic model for Moss Rd based on LiDAR and bathymetric survey. The main channel (represented here in green) has the path of the bathymetric survey overlain in black to demonstrate coverage. This includes some verification runs of the boat into the backwater section (already covered by LiDAR).

B.2.4 Mesh Setup

The 1 m LiDAR/bathymetry grid was exported to text format for input to the River 2D program.

The R2DMesh program was used to create a triangular mesh of the following approximate resolution:

- In-channel (bank to bank): 2 m
- Floodplain: 8 m
- Transition: 4 m

An example of the mesh setup within the Moss Road model is shown in Figure B-3.

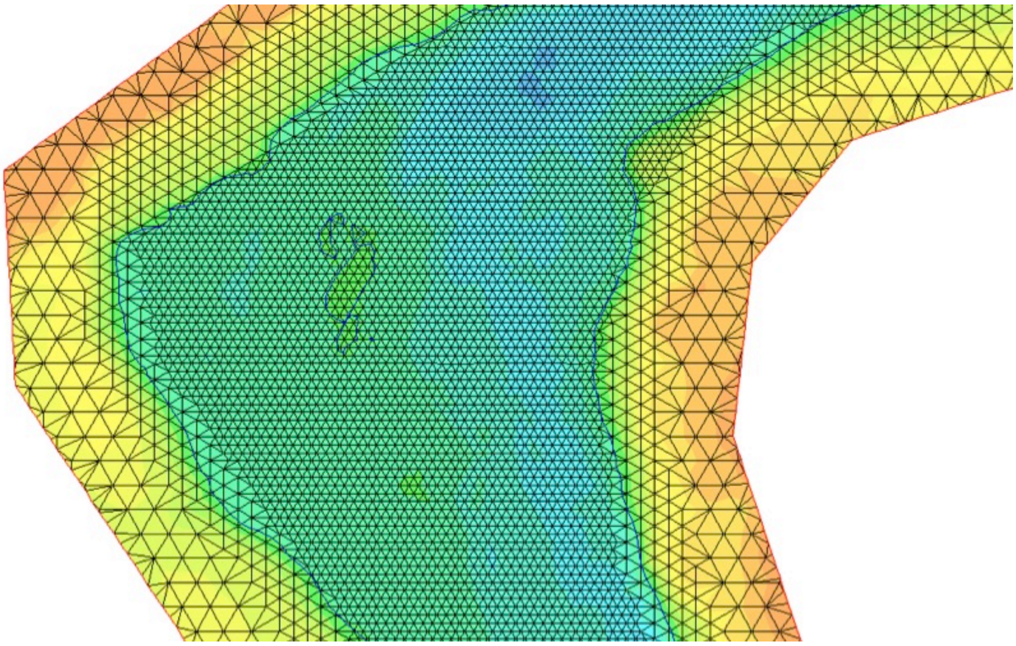


Figure B-3. Example of computational mesh resolution and setup for Moss Road. Greater detail (higher resolution) is provided within the channel to capture small-scale hydraulic variation on the bed of the channel and for lower velocities.

B.2.5 Boundary Conditions

The upstream boundary condition was set to a constant inflow. The downstream boundary condition was set to a constant water level boundary. The tailwater levels corresponding to a range of design flows are shown in Table B-2. The initial water level was set to the same level as the downstream boundary condition to ensure stability.

Table B-2. Design flows and tailwater levels

Flow (ML/d)	Flow (m3/s)	DS water level (m AHD)
300	3.5	111.16
500	5.8	111.36
1000	12	111.79
2000	23	112.36
3000	35	112.80
4000	46	113.13
5000	58	113.47
6000	69	113.75
7000	81	114.02
8000	93	114.28
9000	104	114.51
10000	116	114.75
11000	127	114.95
12000	139	115.17

B.2.6 Roughness

River2D requires the input of a roughness height in metres. A variable roughness height was used for different bed cover types, with the following values:

- Background: 0.2 m
- Rougher channel adjacent to large bar: 0.3 m
- Wood not in bathymetry: 1 m
- Sparse Riparian Vegetation: 0.5 m
- Moderate Riparian Vegetation: 0.8 m
- Dense Riparian Vegetation and Wood: 1.0 m

The roughness zones are shown in Figure B-4.

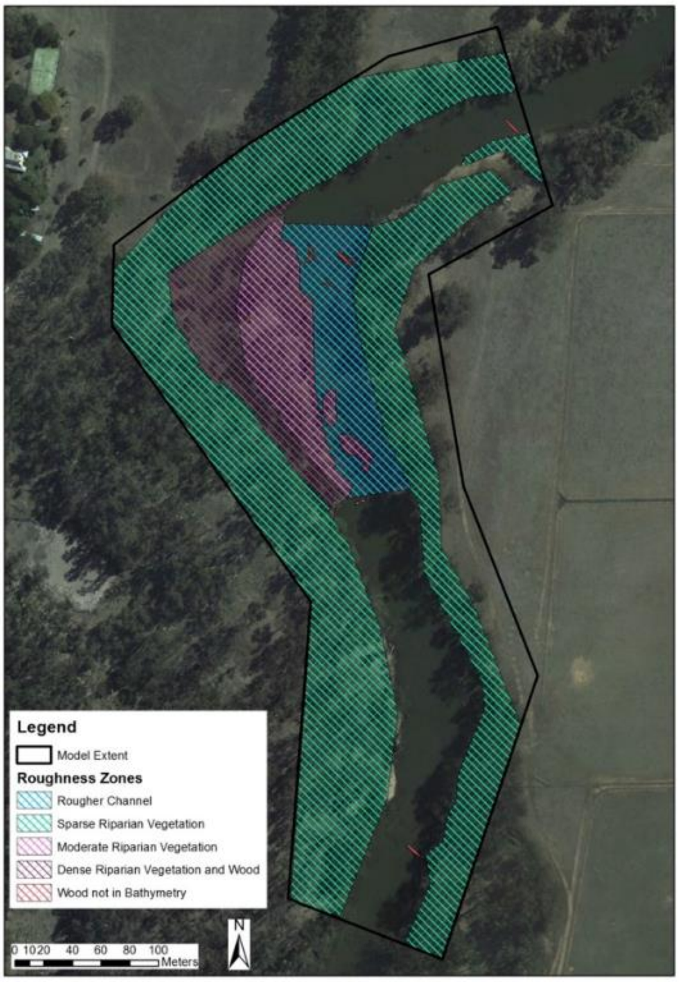


Figure B-4. Roughness zones for Moss Road

B.2.7 Calibration

Two calibration events were available, as summarised in Table B-3. The events were run through the model using the average flow from the ADCP profiles, which were considered more representative at the site than the gauged data at Murchison. The ADCP flows were internally consistent (9–10 m^3/s for the low flow event and 33–40 m^3/s for the high flow event) and reasonably consistent with the gauged flow (0–10% lower for the low flow event and 13–28% lower for the high flow event). The tailwater was calculated from interpolation of the design tailwater levels shown in Table B-2.

Table B-3. Moss Road calibration data

Date	Average flow from ADCP data (m^3/s)	Gauged flow at Murchison (m^3/s)	Observed data	Adopted flow (m^3/s)	Adopted tailwater (m AHD)
12/6/2015	9.4	10.0	ADCP velocity (x, y, magnitude and direction) at 5 sections	9.4	112.8
25/6/2015	37	46	ADCP velocity (x, y, magnitude and direction) at 5 sections	37	111.6

Velocity magnitude results were extracted at each ADCP observation point for comparison. Average differences for each section, as well as standard deviations of the differences and maximum differences, are given in Table B-4. Modelled velocities were generally within +/- 0.1 m with no apparent bias.

Table B-4. Moss Road calibration results

Date	Section	Average difference (modelled – measured) (m/s)	St. dev. of differences (m/s)	Max difference (m/s)
12/6/2015	**4**	-0.01	0.08	-0.17
	6	0.008	0.08	-0.16
	8	-0.04	0.14	-0.32
	9	-0.04	0.04	-0.15
	10	-0.02	0.02	-0.12
	Total	**-0.02**	**0.08**	**-0.32**
25/6/2015	**4**	0.03	0.06	0.18
	6	0.05	0.14	0.32
	8	-0.03	0.19	-0.95
	9	0.005	0.05	0.12
	10	-0.01	0.06	-0.15
	Total	**0.01**	**0.12**	**-0.95**

For the low flow event, a scatter plot showing observed and modelled velocity magnitude values for each section is given in Figure B-5, and a plot showing the velocity differences spatially is shown in Figure B-6. The same plots for the high flow events are given in Figure B-7 and Figure B-8. The observed velocity profile may have been produced by a local but temporary blockage. Localised obstructions (e.g. wood) may be the cause of this variability. Rather than make arbitrary changes to the topography, the calibration was accepted as is, noting that results at the channel margins at low flows may have higher uncertainty than elsewhere.

For the high flow event, Section 8 again had some significant discrepancies between observed and modelled velocities. At three points in particular observed velocities were underestimated by 0.6–0.95 m/s by the model. Given these observed velocities were outside the bounds of any other measured velocities in this event, and much higher than adjacent velocities on the same section, this was attributed to instrument or measurement error.

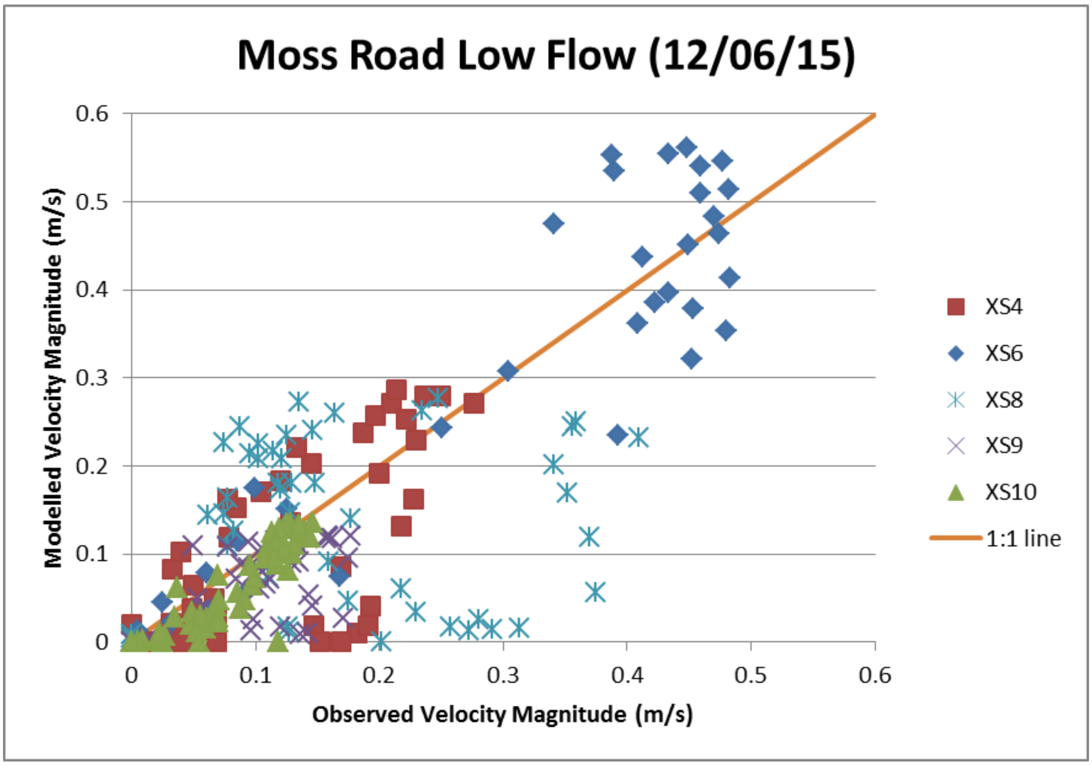


Figure B-5. Calibration results (velocity comparison) for Moss Road low flow event (12/06/15)

Figure B-6. Calibration results (velocity difference) for Moss Road low flow event (12/06/15)

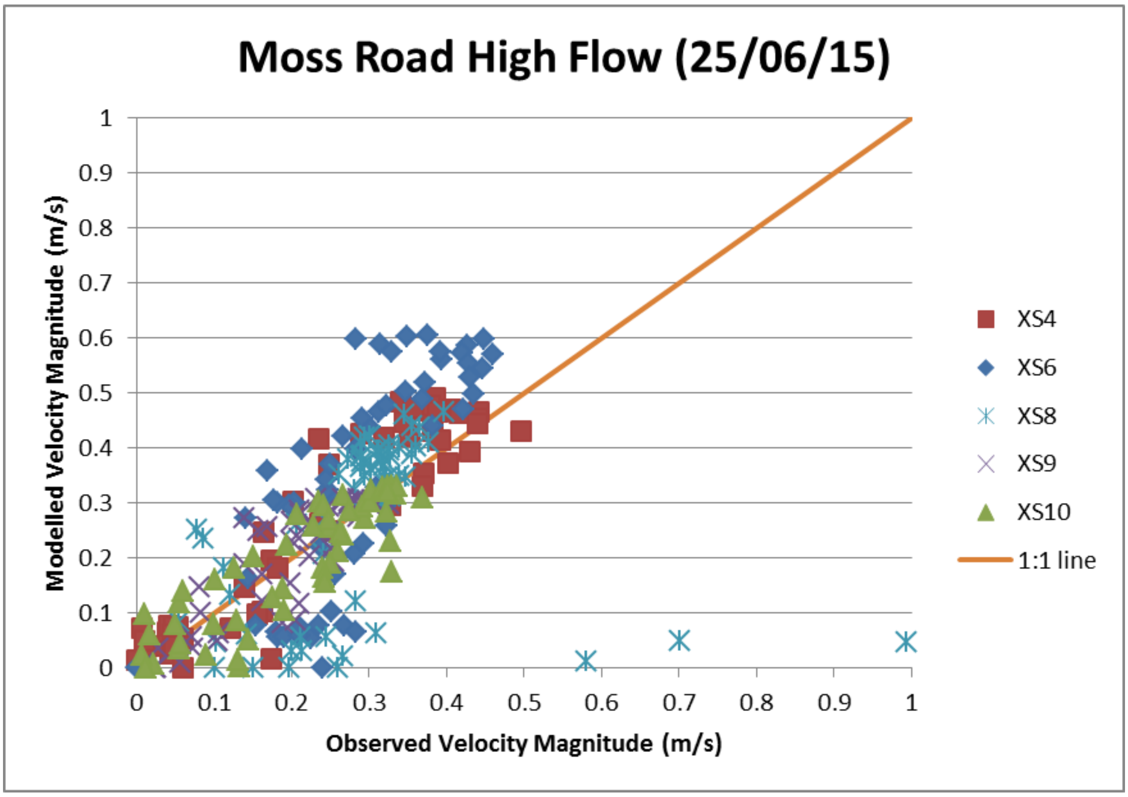


Figure B-7. Calibration results (velocity comparison) for Moss Road high flow event (25/06/15)

Figure B-8. Calibration results (velocity difference) for Moss Road high flow event (25/06/15)

B.2.8 Hydraulic Habitat Results

Results of a range of steady state simulations, from a low flow of 300 ML/d up to approximately bankfull flow of 12,000 ML/d, are given in Table B-5. The results include the total wetted area, the area of pools deeper than 1 m, and the area of pools deeper than 1.5 m (Figure B-9).

Table B-5. Moss Road habitat area results

Flow (ML/d)	Flow (m^3/s)	Wetted area (m^2)	Area of pools > 1.0 m (m^2)	Area of pools > 1.5 m (m^2)	Area of slackwater habitat (D < 0.5 m and V < 0.05 m/s) (m^2)	No. patches of slackwater habitat	Mean patch size of slackwater habitat (m^2)
300	3	24,268	13,849	9,696	3,747	111	34
500	6	26,120	15,632	11,382	3,593	117	31
1,000	12	30,278	20,414	14,792	3,506	140	25
1,500	17	36,288	23,520	18,162	7,085	150	47
2,000	23	41,232	25,962	21,080	7,790	157	50
2,500	29	43,735	28,210	23,411	4,318	168	26
3,000	35	45,070	30,359	25,381	2,742	185	15
4,000	46	46,646	36,951	28,577	2,079	182	11
5,000	58	48,117	42,722	33,539	1,930	185	10
6,000	69	49,236	44,790	39,248	1,829	196	9
7,000	81	50,301	46,151	43,212	1,758	208	8
8,000	93	51,309	47,328	44,963	1,766	222	8
10,000	116	53,116	49,239	47,186	1,687	243	7
12,000	139	54,854	50,885	48,943	1,789	162	11

The area of slackwater habitat (Figure B-10), where depth is less than 0.5 m and velocity is less than 0.05 m/s, increases sharply as discharge increases to around 2,000 ML/d, as large vegetated benches become inundated. Slackwater area decreases and stabilises at around 2,000 m^2 at discharges of 4,000 Ml/d and greater. Mean slackwater patch size is high for discharges less than 2,000 ML/d, is at a maximum for 2,000 ML/d, and is very low for discharges of 3,000 ML/d or greater (Figure B-11). However, the number of slackwater patches increases as discharge increases.

Velocity metrics including the mean velocity and rate of change with flow are identified in Table B-6 and graphed in Figure B-12 and Figure B-13. Consideration of fish triggers, and the relationship between fish movement and velocities, led to investigation of maximal velocities. Maximum velocities (averaged over the reach) and high velocities (the 99th percentile, to remove the potential for extreme values) is presented in (Figure B-14). Figure B-14 demonstrates that maximum velocities can be very high at low velocities (<1000 ML/d) and some very localised maximum velocities can occur. High velocities tend to moderate this pattern.

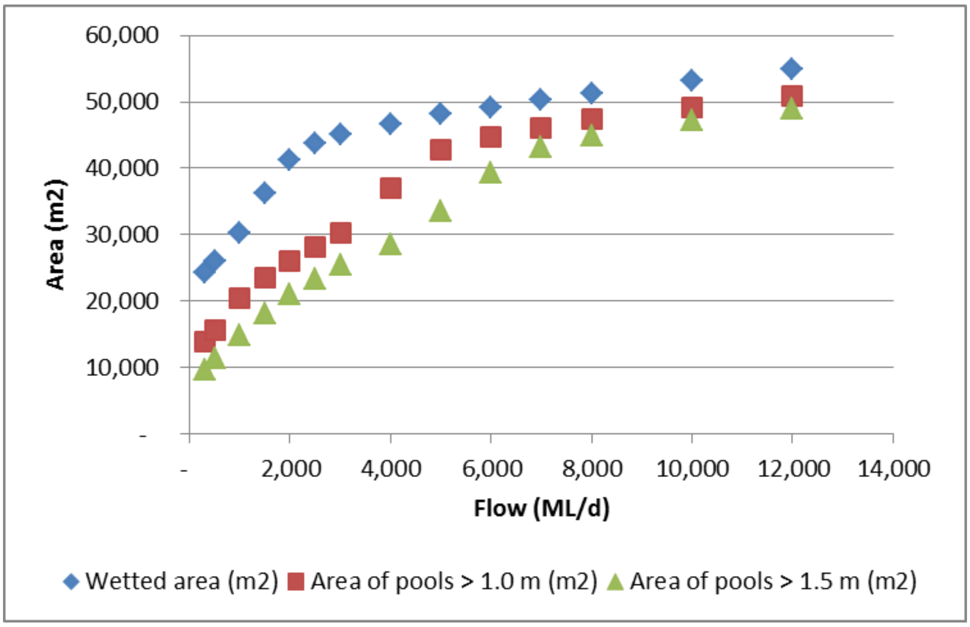


Figure B-9. Results (wetted area and area of pools) for Moss Road

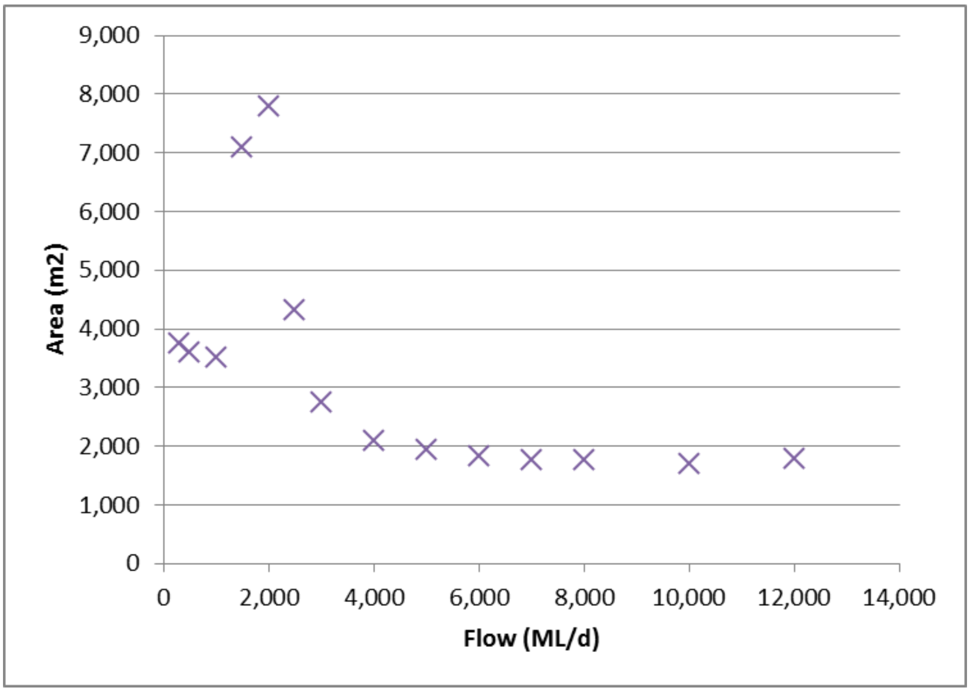


Figure B-10. Results (area of slackwater habitat) for Moss Road

There was a consideration that vegetation may be impacted by maximum velocities. Maximum velocity at vegetation transects was developed by extracting velocity at the specific locations vegetation samples were undertaken (Figure B-15). Relationships between fish spawning and maximum velocities was developed by the team with input from Wayne Koster and analysis by Angus Webb (see Appendix F).

Disturbance of substrates and the potential for particular discharges to mobilise bed sediments is based on shear stress. Figure B-16 demonstrates that coarse-grained sediments such as gravels (>2mm) require discharges of more than 2,500 ML/d before significant bed movement occurs. Medium-grained sized sands (>1mm) are mobilised readily and significantly larger areas of the bed are mobilised as discharge increases up to 5,000 ML/d. The area of sandy bed sediments mobilised is tripled when a fresh of 5,000 ML/d is provided, compared to a baseflow of 1,000 ML/d.

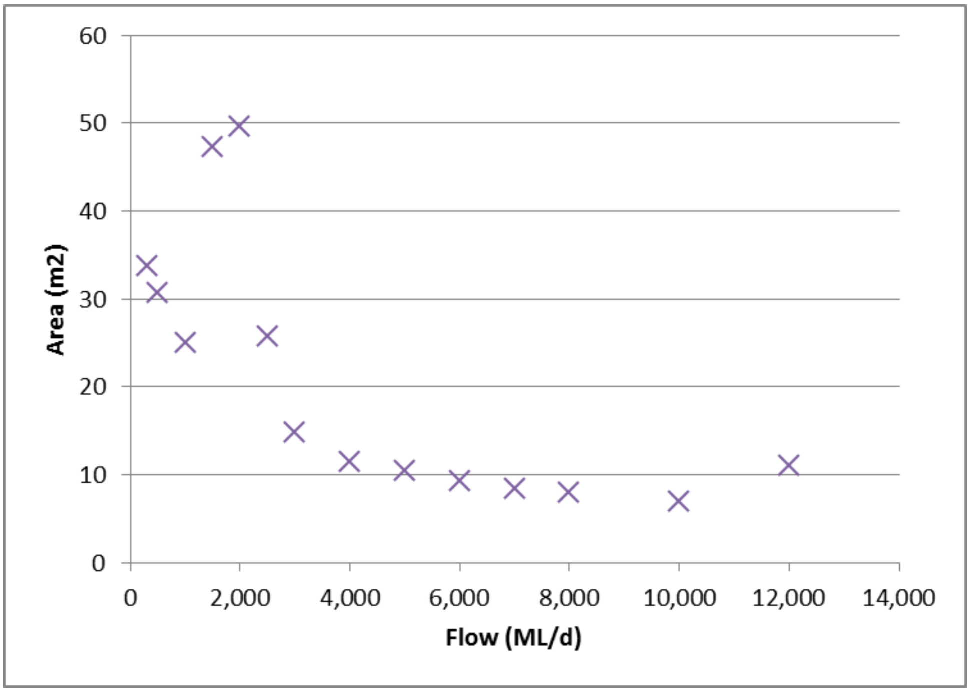


Figure B-11. Results (mean patch size of slackwater habitat) for Moss Road

Table B-6. Moss Road velocity and velocity change results

Flow (ML/d)	Flow (m^3/s)	Mean velocity (m/s)		Flow range (ML/d)	Change in velocity per ML/d change in flow (m/s/(ML/d)*
300	3	0.08		0-300	0.000283
500	6	0.11		300-500	0.000139
1,000	12	0.16		500-1,000	0.000088
1,500	17	0.16		1,000-1,500	0.000008
2,000	23	0.18		1,500-2,000	0.000031
2,500	29	0.20		2,000-2,500	0.000041
3,000	35	0.22		2,500-3,000	0.000039
4,000	46	0.25		3,000-4,000	0.000031
5,000	58	0.27		4,000-5,000	0.000024
6,000	69	0.29		5,000-6,000	0.000020
7,000	81	0.31		6,000-7,000	0.000024
8,000	93	0.33		7,000-8,000	0.000012
10,000	116	0.35		8,000-10,000	0.000014
12,000	139	0.38		10,000-12,000	0.000011

** This metric can be used to estimate the change or rate of change of velocity for a certain change or rate of change of flow, within each flow range. For example, at a flow rate of 6,500 ML/d, an increase of 100 ML/d would produce an increase in velocity of 0.0024 m/s over the same time period.*

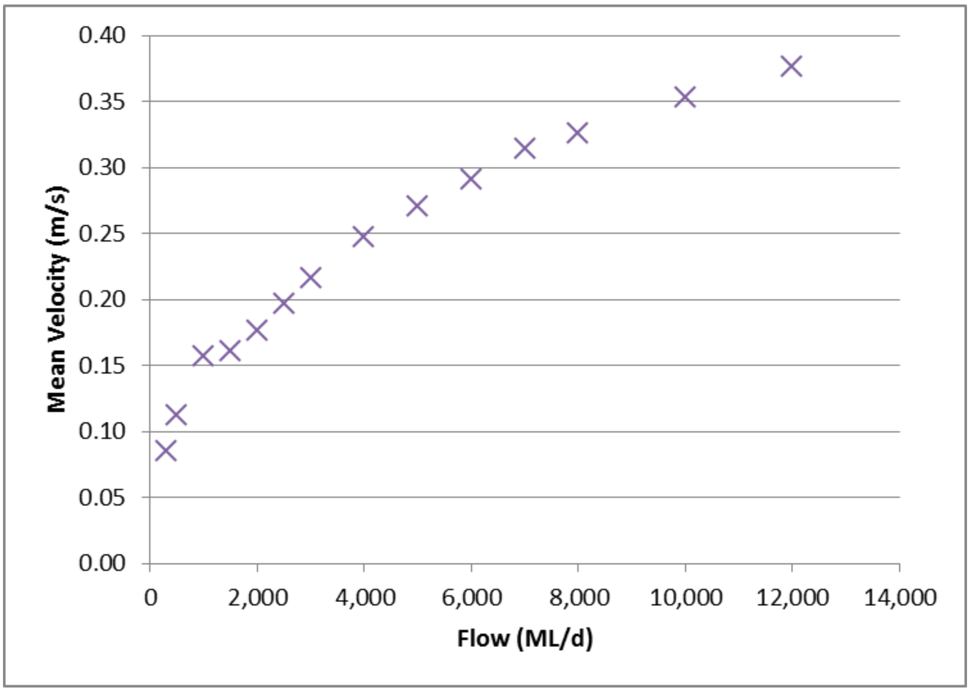


Figure B-12. Results (mean velocity) for Moss Road

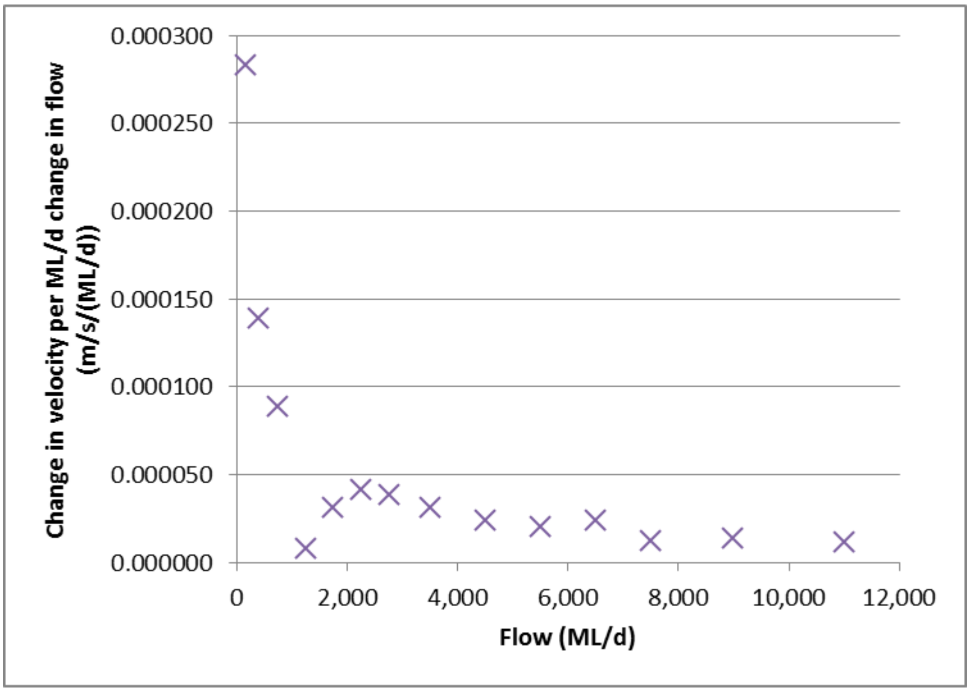


Figure B-13. Results (velocity rate of change with flow) for Moss Road

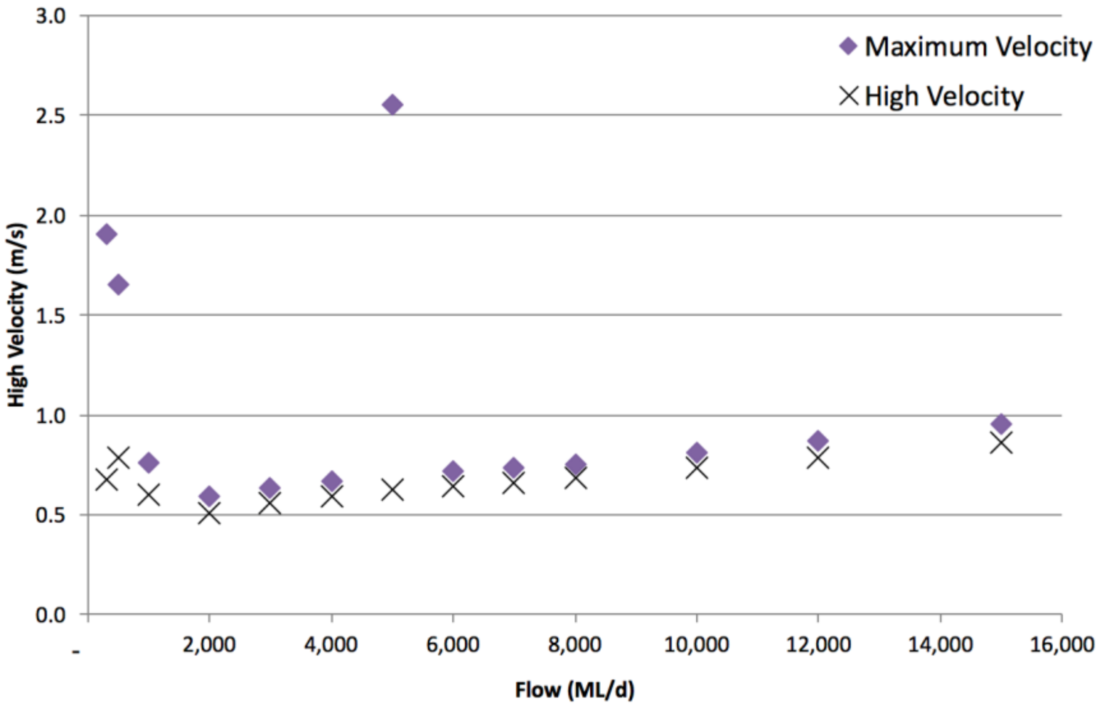


Figure B-14. Results for maximum velocity (purple solid) and high velocity (crosses) relative to discharge for McCoys Bridge

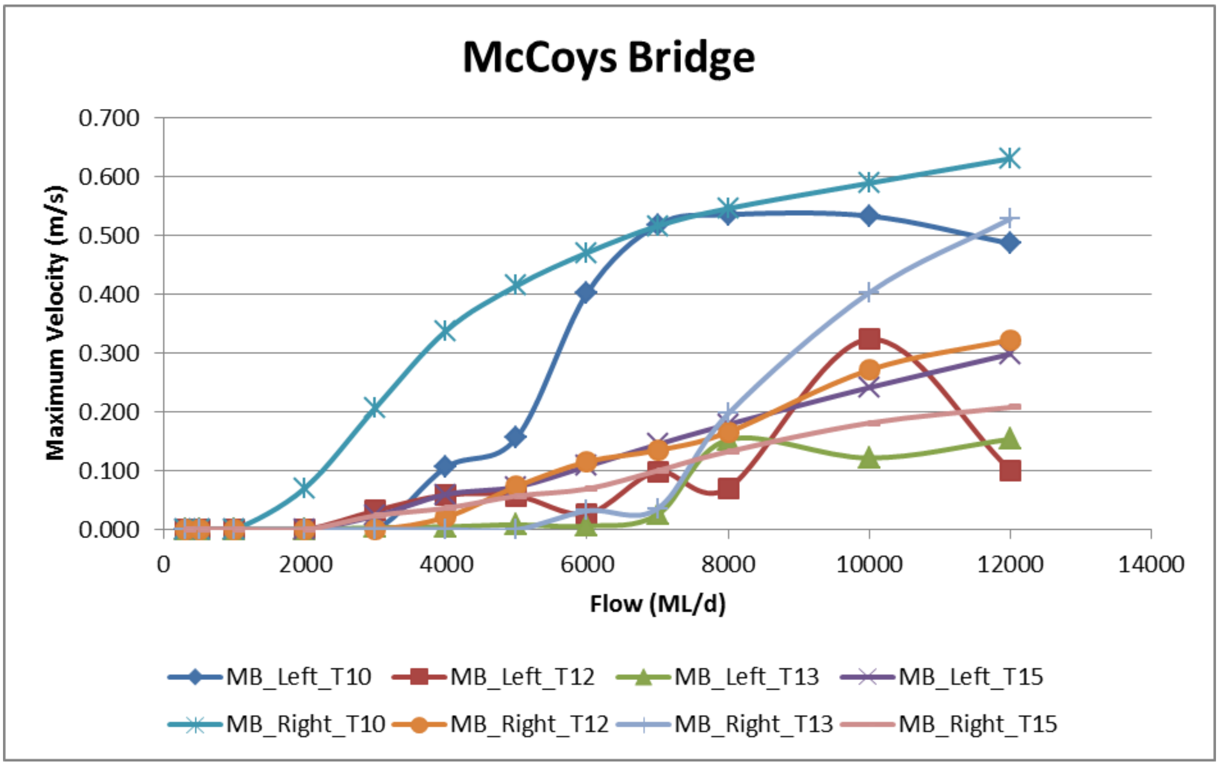


Figure B-15. Maximum velocity at vegetation transects for McCoy's Bridge

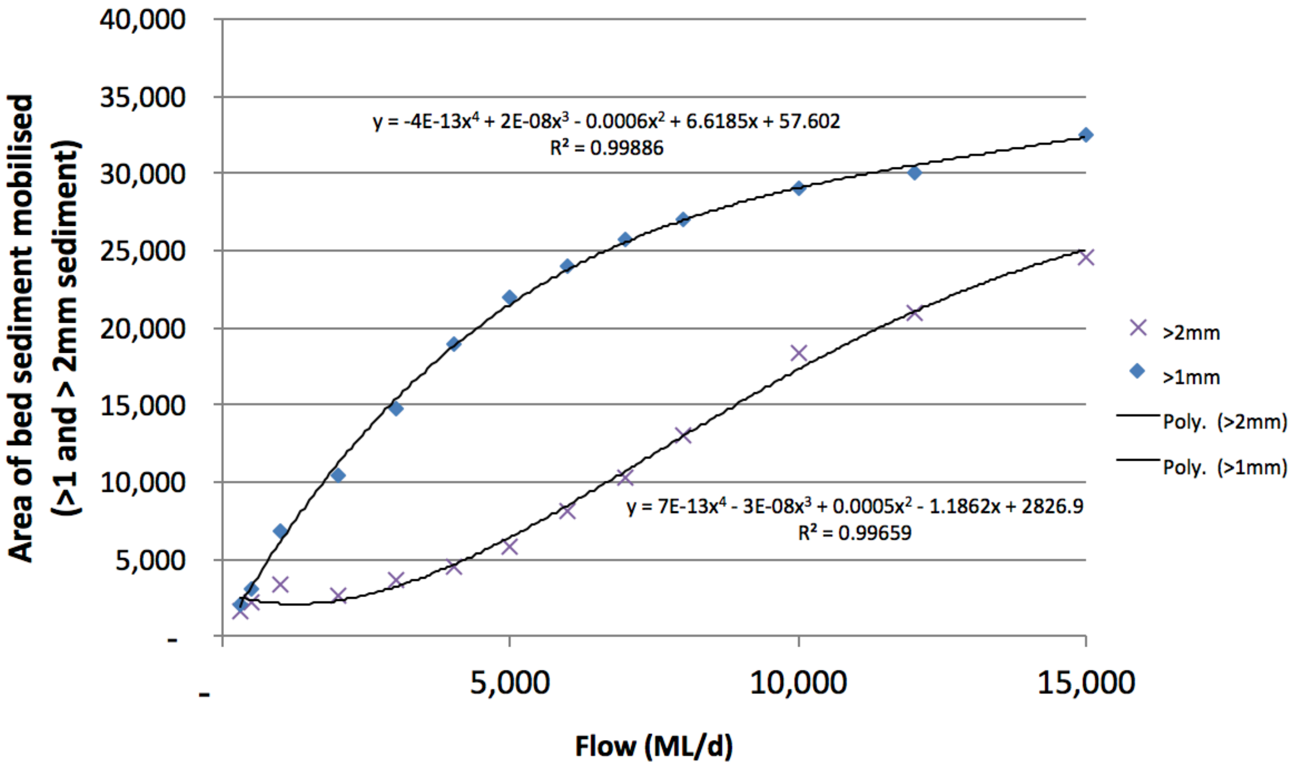


Figure B-16. Bed mobilisation. Area of bed sediment mobilised for gravels (crosses) and medium-grained sands (blue solid) at McCoy's Bridge

B.3 Bank condition

B.3.1 Methods

Equipment used for this monitoring program consists of 200 erosion pins (50 pins at each of the four sites), which are 300 mm long bicycle spokes with colour coded heat shrink (Figure B-17, left). Each pin is inserted into the bank so that 25 mm is exposed. Erosion pins are located at five different elevations (up to approximately bankfull) on each of ten transects at each site. Changes in surface level relative to each erosion pin are made using digital callipers (see Figure B-17, right). Qualitative assessments are also made at each transect on erosion process, failure mechanism, and weakening process (see proforma in the SOP; Webb et al. 2014).

Figure B-17. (left) Colour coded erosion pins inserted at each transect to indicate location/elevation on the river bank and measured by digital callipers, and (right) field placement.

Recordings with positive values (relative to starting position) indicate bank retreat (erosion) and negative values indicate bank aggradation (deposition). Data presented in this report are from the program start (January 2015) to mid-February 2016. Further details on the erosion assessment protocol can be found in (Vietz et al. early view).

B.3.2 Hydrologic variables and statistical analysis

Flow metrics that have been used at this stage to characterise environmental flows are described in Table B-7.

Table B-7. Flow metrics used for comparison with bank erosion measurements

Flow metric	Description	Justification
Duration of inundation	How many days an erosion pin is under water between surveys	The time over which a bank is exposed to inundation and/or flowing water influences bank wetting and saturation, and the effect of cumulative shear stress on erosion. Similarly, deposition may be a function of cumulative time over which sediments can move through the water column to deposit on the bank.
Peak flow magnitude	Peak flow of an event that inundated an erosion pin between surveys (the maximum if multiple peaks are experienced)	Erosion/deposition may be driven by the maximum shear stress associated with an event, with sediment bank sediments being mobilised, or accumulated (if scoured from elsewhere) during the period around peak flows.
Flow volume	Volume of flow of the event above the level of the pin that inundates an erosion pin	A metric that combines duration and magnitude to assess the 'work' being done on the bank by water.
Maximum dry weather period	Maximum number of days without inundation of the pin prior to inundation	Banks may become more sensitive to erosion when inundated if they are allowed to dry out completely, inducing desiccation and cracking of clay-rich sediment particles.
Maximum dry weather period by season **(new for 2016-17)**	Maximum number of days without inundation of the pin prior to inundation by 'hot season' (Nov-Apr) and 'cold season' (May-Oct)	Banks may become more sensitive to erosion when inundated if they are allowed to dry out completely, inducing desiccation and cracking of clay-rich sediment particles. This is hypothesised to be more severe during the hot season when banks can rapidly dry.
Average and maximum rate of drawdown **(new for 2016-17)**	Day 2 discharge divided by Day 1 discharge for the falling limb of a flow event	The rate at which flow recession from an event occurs can impact on bank erosion through surcharging a bank (saturating) and affecting the support provided by the water while the bank is saturated. If the rate of recession is too great mass failure (slumping) can occur, particularly on steep banks.

A hierarchical Bayesian logistic regression model was used to identify the relationship between the flow metrics and bank erosion/deposition. The probability of erosion and deposition was assessed as a function of each metric, as experienced by the erosion pin based on 13 measurements. Other flow characteristics, such as bank notching (a horizontal demarcation in the bank associated with the water level surface), have been considered based on observations but have not, at this stage, been assessed statistically. Details of the statistical analysis can be found in (Vietz et al. early view).

The statistical model is formulated as:

$$y_{ijk} \sim Bern(p_{ijk})$$

$$logit(p_{ijk}) = int + eff.I_k \cdot I_{ijk} + eff.site_k + eff.surv_i + eff.pin_{jk}$$

The occurrence of erosion or deposition (*y*) for pin *j* at site *k* during survey *i* 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 the inundation metric being analysed (*eff.I*) for each site multiplied by the metric value for that survey (*I*). There is a random effect of site (*eff.site*) that acknowledges that local conditions may enhance or retard overall erosion/deposition, a random effect of survey (*eff.surv*) to capture any seasonal or other systematic differences among survey periods in erosion/deposition, and a random effect of pin (*eff.pin*) to account for the repeated measures taken for each pin.

The random effects (*eff.pin, eff.surv, eff.site*) were modelled as normal distributions with a mean of zero, and standard deviations of *s.site*, *s.surv* and *s.pin*, respectively:

$$eff.site_k \sim N(0, s.site^2)$$

$$eff.surv_i \sim N(0, s.surv^2)$$

$$eff.pin_{jk} \sim N(0, s.pin^2)$$

The site-level estimates of *eff.I* were modelled hierarchically and drawn from a normal hyper-distribution with a mean of *mu.eff.I* and standard deviation of *s.eff.I*:

$$eff.I_k \sim N(mu.eff.I, s.I^2)$$

Minimally informative prior distributions were assigned to *int*, *mu.I* (normal distributions with means of 0 and variances of 10) and to *sd.I*, *sd.pin*, *sd. surv*, *sd.site* (uniform distributions with limits of 0 and 10).

The regression models were implemented in OpenBUGS version 3.2.1 (Lunn et al. 2009), using the R2OpenBUGS package (Sturz et al. 2005) in R (R Development Core Team 2010). Three independent Markov chains were used to confirm convergence of chains during model burn-in. Different burn-in periods were employed for different models, with the criterion for establishing convergence being an Rhat value of approximately 1 (Sturz et al. 2005). Different periods were also used for parameter estimation, based upon autocorrelation within the Markov chains. The model was implemented separately for three different thresholds of activity (> 0 mm of erosion, > 30 mm of erosion and < 0 mm of erosion), and for each different flow metric (i.e., total inundation duration, peak flow, flow volume during inundation and maximum dry weather period). The 'step' function in OpenBUGS was used to assess the probability of significant erosion/deposition for individual pins for each analysis.

Posterior predictions were used to assess the effects of environmental flows. Predicted erosion/deposition values and probabilities for individual erosion pins were generated from the fitted model using the observed flow series (including environmental flows) and a counter-factual flow series (from which environmental flow releases had been removed).

B.3.3 Results: Relevant flow components delivered

Flow management and flow events (freshes), including low flow periods, have been well captured by monitoring thanks to good lines of communication (Figure B-18).

B.3.4 Overall bank condition results

Bank erosion and deposition has exhibited similar responses to flow during the 2016-17 period compared to the previous two years. Erosion and deposition are still highly variable both in time and space, but both still occur relatively commonly even at the same location.

The most notable difference in this period was due to the long duration and relatively high magnitude event over winter (June to November). This event was not pre-empted so sampling was not possible immediately prior, and the event did not go below the required 1000 ML/d so a long period of inundation occurred before sampling could recommence. The size of the event (particularly period of time banks were inundated) led to 94% of pins undergoing some activity by either erosion or deposition (compared to an average of 53%). Surprisingly, only 36% of pins underwent erosion, with 53% of pins undergoing deposition. There were greater extremes in erosion with up to 135 mm at one point (and a 90th percentile erosion of 29 mm, compared to 12 mm for the next highest event).

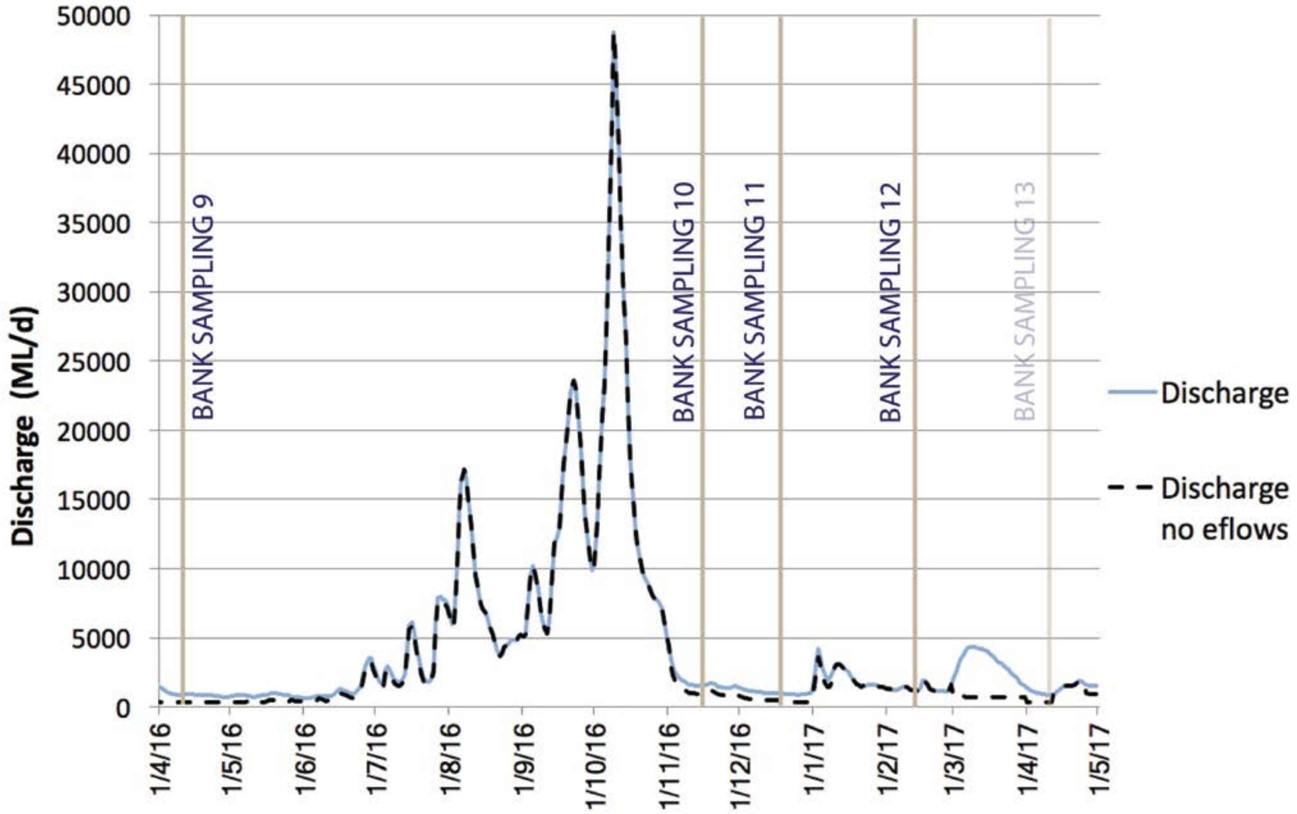


Figure B-18. Bank erosion sampling visits relative to discharge for the period 2016-17 for total discharge (blue) and discharge without eflows (dashed). Data for McCoy's stream gauge. Discharges for other sites vary but the pattern is similar. Note that statistical analysis was undertaken for the full three-year period, but the discussion is focused on this period 2016-17.

For the long winter event there was some evidence of channel changes such as tree fall. Yet, even where tree fall had occurred (for example at Loch Garry) there was surprisingly little erosion evident at the pins on the bank immediately beneath the tree. Bank saturation may have contributed to tree fall, but tree fall does not provide evidence that banks are eroding.

Other than the differences noted for the winter event, erosion and deposition for the 2016-17 period was similar to the 3 year averages.

Significant erosion (>30 mm) was not common, observed in 7 percent or less of pin measurements. No mass failure events occurred at the erosion pin sites, or were observed at the sites more generally. Many erosion pins displayed no erosion or deposition between surveys, especially at the most upstream site Darcy's Track which underwent considerably less erosion than the other sites. For the three most downstream sites bank activity was more common and results were surprisingly consistent. For these sites deposition occurred between 26 and 31% of the time and erosion 33 to 38% of the time (Table B-8). Yambuna Bridge is the most active with more erosion and deposition.

B.3.5 Changes in probability of erosion and deposition with changing flow metrics

Summary findings are as follows (statistics for all regressions are provided in Table B-9).

- As with previous years, it was found that inundation has a positive effect on erosion. This effect is more pronounced for the probability that erosion > 0mm (Figure B-19a,b), compared to the probability that erosion > 30mm (Figure B-19c,d). This can be seen from the fact that the 95 confidence intervals of the linear regression coefficients are all positive for the probability of occurrence of erosion (Table B-9). It is important to note that erosion also occurs in the absence of inundation (note that the intercepts are not at zero).

Table B-8. Results at a glance: Proportion of deposition, no change, erosion, or significant erosion for each erosion pin measurement. The number of erosion pin measurements is given by n. Results for three-year period to February 2017.

Proportion of measurements	Darcy's Track	Loch Garry	McCoy's Bridge	Yambuna
n	574	566	524	566
<0 mm (deposition)	24%	26%	28%	31%
No change	53%	38%	39%	31%
>0 mm (erosion)	23%	36%	33%	38%
>30 mm (significant erosion)	2%	7%	4%	6%

- It was also confirmed that inundation has a negative effect on the probability of occurrence of aggradation (Figure B-20, Table B-9)

- Effects of inundation duration on erosion were weaker for the upstream site at Darcys Track compared to the downstream site of Yambuna Bridge. Effects of inundation duration on erosion and deposition were weaker for the upstream site at Darcy's Track, with the three lower sites (McCoy's Bridge, Loch Garry and Yambuna) responding similarly.

- As with previous years aggradation or erosion is not strongly effected by flow volume (amount of water over the threshold at which an erosion pin is inundated, Figure B-21a) or peak flow (Figure B-21b). This can be seen from the fact that the 95 confidence intervals of the linear regression coefficients are not all positive (for the probability of occurrence of erosion) nor all negative (for the probability of occurrence of aggradation; Table B-8).

- As with previous years maximum ADWP has a strong negative effect on erosion but this effect is more pronounced for the probability that erosion > 0mm compared to the probability of significant erosion (> 30mm; Figure B-22). This can be seen from the fact that the 95 confidence intervals of the linear regression coefficients are all negative (for the probability of occurrence of erosion) and all positive (for the probability of occurrence of aggradation). This is likely due to the cross-correlation between maximum ADWP and inundation duration during the surveys.

- When Maximum ADWP is split by season (hot season versus cold season) the relationship between maximum ADWP and bank erosion are similar to when the assessment is done for the whole year, (Figure B-23). There is a positive relationship between the Maximum ADWP and erosion, and a negative relationship between Maximum ADWP and deposition. Erosion is marginally more likely in the hot season and deposition marginally more likely in the cold season.

- Average and maximum drawdown has a positive effect on erosion (Figure B-24a,b). Average and maximum drawdown also have a positive effect on significant erosion (Figure B-24c,d), although the influence is very small (< 5% chance at the highest rates). Average and maximum drawdown have a negative influence on deposition (Figure B-24e,f).

- Relationships for all sites are very similar, with some slight variability including the higher likelihood of erosion at the Yambuna site with increased flow metrics.

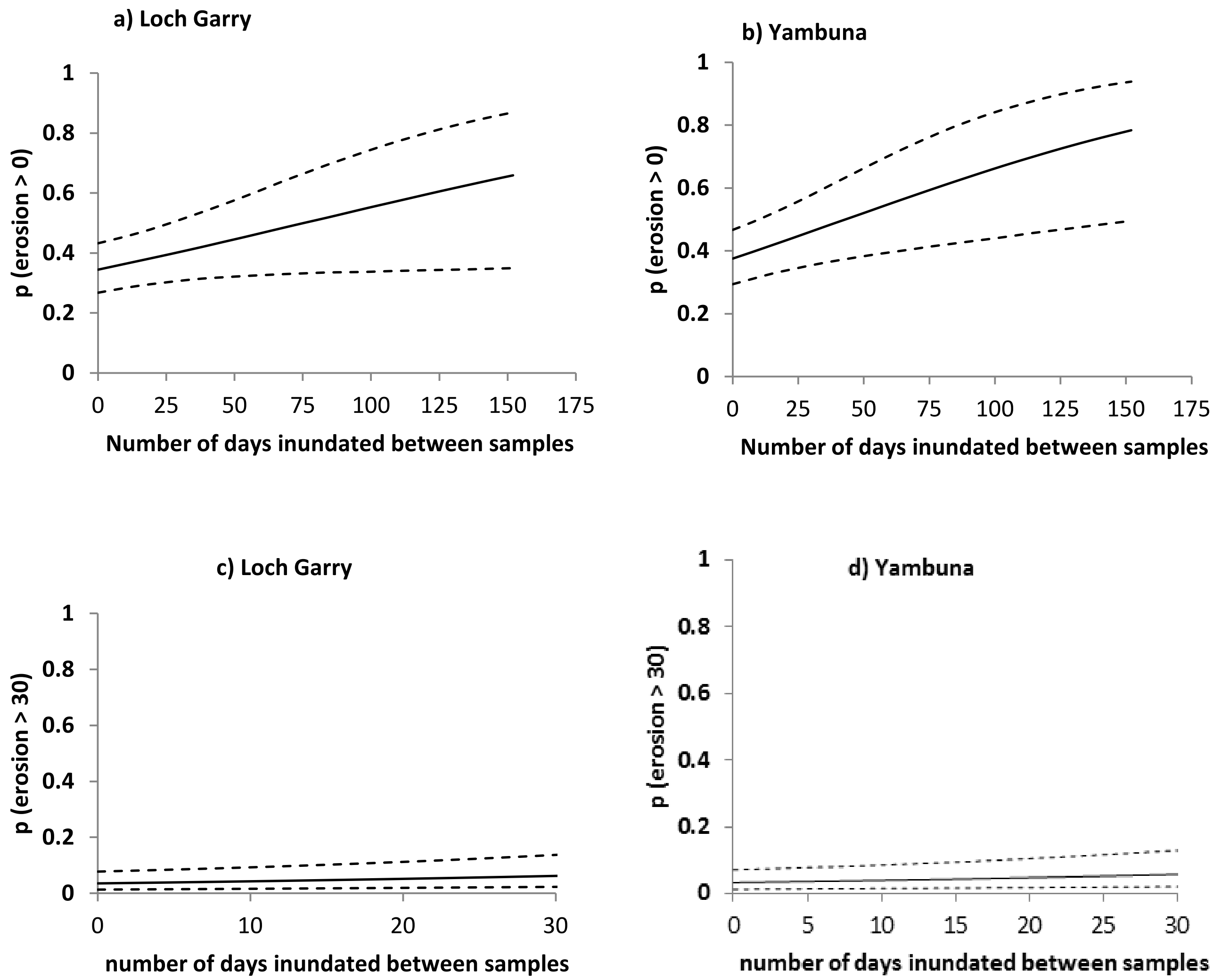


Figure B-19. Probability of erosion of > 0 mm (a, b) and > 30 mm (c, d) with increases in the duration of inundation. Results are shown for two sites, Loch Garry (a, c) and Yambuna (b, d). The solid line is the median probability of erosion with the dotted lines encompassing the 95% credible interval for the estimate.

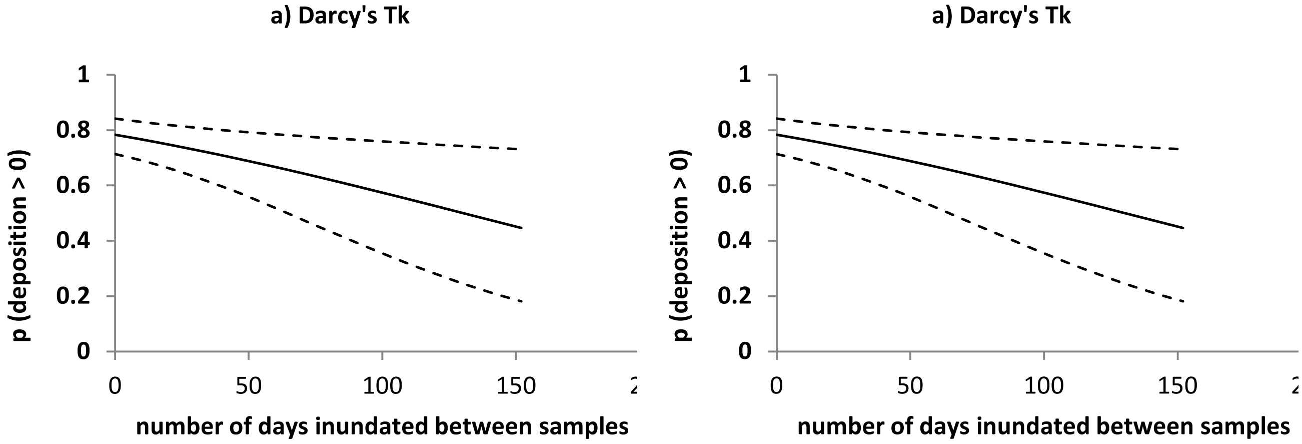


Figure B-20. Probability of deposition of > 0 mm (i.e. negative erosion) for Darcy's Track (a) and Yambuna (b) with increases in duration of inundation.

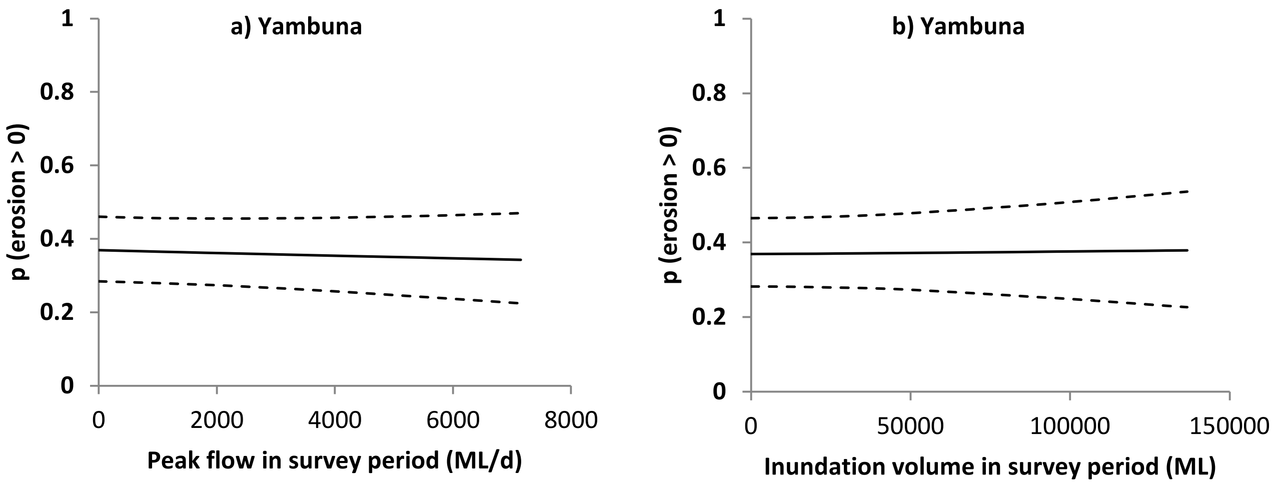


Figure B-21. Peak flow or inundation volume has little influence on erosion. Probability of erosion > 0 mm at Yambuna (the most responsive site in the study) with increasing peak flow (a) and the volume of discharge above the discharge at which an erosion pin is inundated (b). Relationships were similarly lacking for erosion > 30 mm, deposition > 0 mm, and at all other sites.

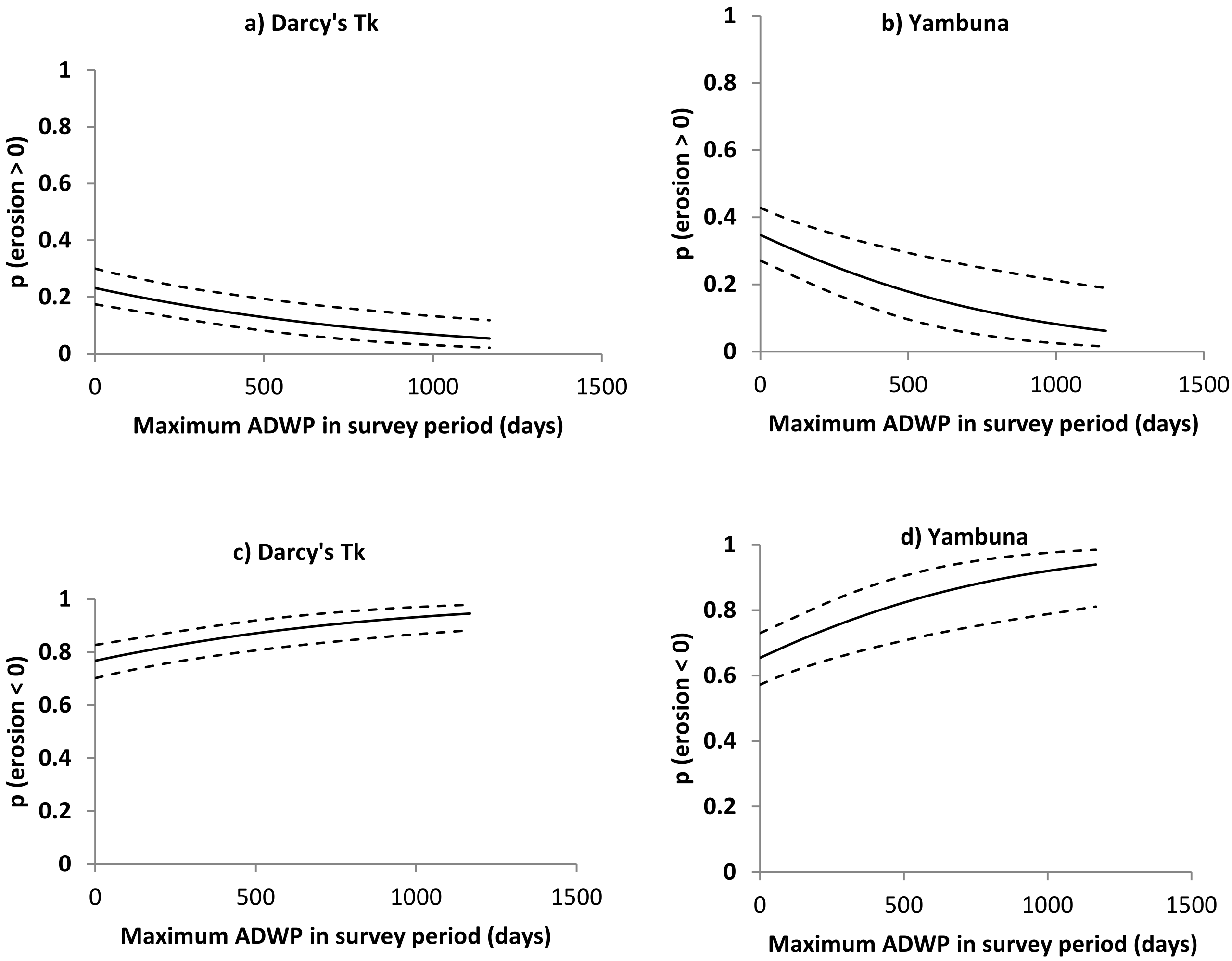


Figure B-22. Probability of erosion > 0 mm (a, b) and deposition (erosion < 0 mm) (b, c) at Darcy's Track (a, c) and Yambuna (b, d) with increasing duration of maximum average dry weather period (Maximum ADWP).

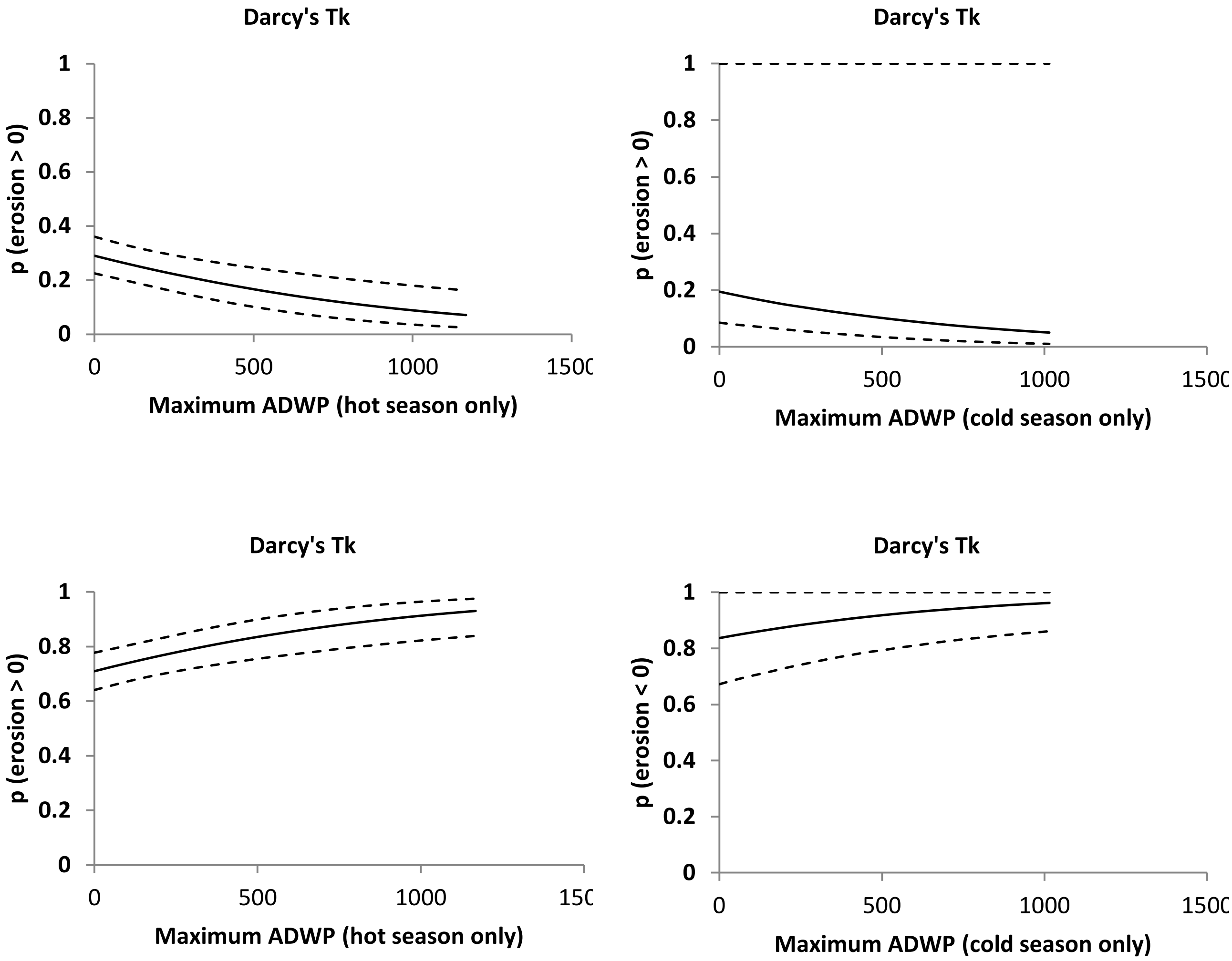


Figure B-23. Probability of erosion > 0 mm and deposition (erosion < 0 mm) for increasing duration of maximum average dry weather period (Maximum ADWP) by hot season versus cold season, for Darcy's Track.

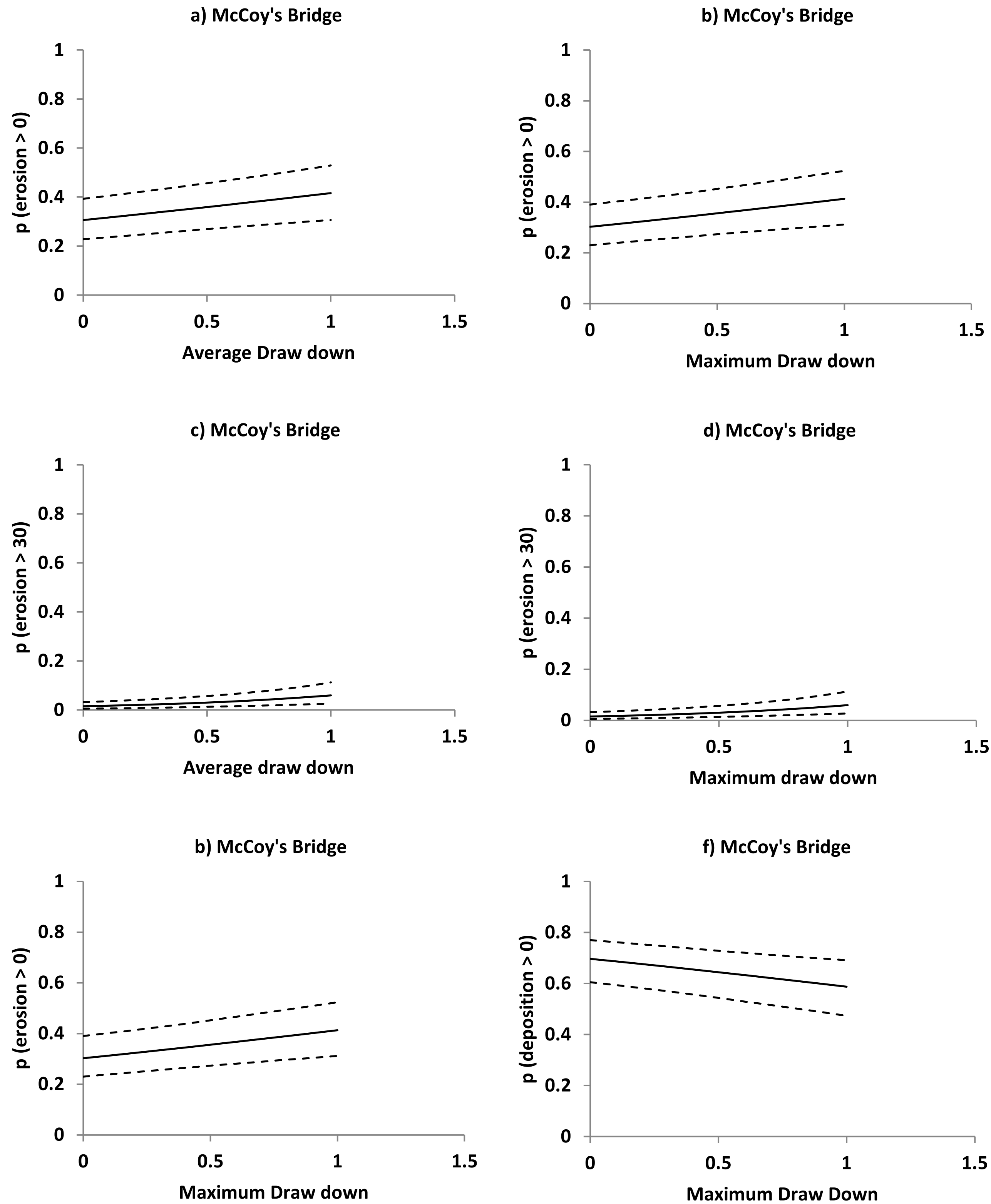


Figure B-24. Probability of erosion > 0 mm, significant erosion (>30 mm) and deposition (erosion < 0 mm) relative to average (a, c, e) and maximum rates of drawdown (b, d, f), for McCoy's Bridge.

Table B-9. 95 percent credible intervals of regression coefficients (Eff.I) for three erosion levels and for each flow metric. Bold values represent instances where there is a relationship between erosion/deposition and flow metric.

Erosion level	**Flow metric**	**Eff.I**									
		Darcy's Track		Loch Garry		McCoy's Bridge		Yambuna		Overall	
Percentile		2.5th	97.5th	2.5th	97.5th	2.5th	97.5th	2.5th	97.5th	2.5th	97.5th
>0 mm	Inundation Duration (days)	**0.07**	**0.48**	**0.01**	**0.43**	**0.09**	**0.50**	**0.10**	**0.55**	**0.02**	**0.53**
	Peak Flow (ML/d)	-0.21	0.15	-0.07	0.25	-0.12	0.20	-0.22	0.10	-0.24	0.27
	Inundation Volume (ML)	-0.13	0.21	-0.15	0.17	-0.03	0.32	-0.17	0.16	-0.20	0.31
	Maximum dry weather period (days)	**-0.64**	**-0.22**	**-2.07**	**-0.51**	**-0.53**	**-0.06**	**-0.86**	**-0.23**	-1.92	0.59
	ADWP Summer (days)	**-0.69**	**-0.20**	**-2.46**	**-0.69**	-0.46	0.06	**-1.04**	**-0.25**	-2.19	0.80
	ADWP Winter (days)	**-0.80**	**-0.17**	**-1.23**	**-0.10**	**-1.02**	**-0.22**	**-0.85**	**-0.05**	**-1.10**	**-0.01**
	Average Drawdown	**0.26**	**0.61**	**0.30**	**0.65**	**0.16**	**0.55**	**0.26**	**0.59**	**0.17**	**0.66**
	Maximum Drawdown	**0.25**	**0.61**	**0.29**	**0.64**	**0.17**	**0.54**	**0.26**	**0.59**	**0.19**	**0.65**
>30 mm	Inundation Duration (days)	**0.21**	**0.93**	**0.17**	**0.90**	**0.22**	**0.95**	**0.14**	**0.91**	**0.14**	**0.95**
	Peak Flow (ML/d)	-0.23	0.60	-0.51	0.20	-0.24	0.52	-0.36	0.28	-0.50	0.60
	Inundation Volume (ML)	-0.06	0.71	-0.37	0.31	-0.06	0.66	-0.29	0.38	-0.44	0.78
	Maximum dry weather period (days)	**-4.63**	**-0.88**	**-5.52**	**-1.61**	**-3.44**	**-0.56**	**-3.16**	**-0.58**	-0.27	1.76
	ADWP Summer (days)	**-5.57**	**-1.31**	**-6.57**	**-2.40**	**-5.18**	**-0.95**	**-5.42**	**-1.66**	**-6.08**	**-0.91**

	ADWP Winter (days)	**-6.36**	**-0.28**	**-6.46**	**-0.37**	**-4.85**	**-0.13**	-2.51	0.71	-5.50	0.90
	Average Drawdown	**0.65**	**1.77**	**0.44**	**1.18**	**0.65**	**1.79**	**0.39**	**1.16**	-4.85	0.07
	Maximum Drawdown	**0.63**	**1.78**	**0.43**	**1.19**	**0.63**	**1.76**	**0.39**	**1.16**	**0.3**	**1.73**
< 0 mm	Inundation Duration (days)	**-0.48**	**-0.06**	-0.41	0.00	**-0.49**	**-0.08**	**-0.55**	**-0.09**	**-0.52**	**-0.02**
	Peak Flow (ML/d)	-0.15	0.21	-0.24	0.07	-0.19	0.12	-0.10	0.22	-0.26	0.24
	Inundation Volume (ML)	-0.21	0.13	-0.16	0.16	-0.32	0.03	-0.16	0.17	-0.30	0.23
	Maximum dry weather period (days)	**0.23**	**0.64**	**0.55**	**2.08**	**0.06**	**0.53**	**0.24**	**0.86**	-0.53	1.90
	ADWP Summer (days)	**0.21**	**0.69**	**0.72**	**2.51**	-0.05	0.48	**0.25**	**1.03**	-0.84	2.26
	ADWP Winter (days)	**0.16**	**0.81**	**0.10**	**1.23**	**0.22**	**0.99**	**0.06**	**0.85**	**0.03**	**1.06**
	Average Drawdown	**-0.62**	**-0.26**	**-0.65**	**-0.30**	**-0.54**	**-0.17**	-0.59	-0.26	-0.65	-0.19
	Maximum Drawdown	**-0.61**	**-0.26**	**-0.64**	**-0.30**	**-0.53**	**-0.16**	**-0.59**	**-0.26**	**-0.65**	**-0.19**

B.3.6 Effects of environmental flows upon probability of erosion and deposition

By focusing on the contribution of environmental water in contributing to bank condition the following have been found:

- There is a slightly higher probability of bank erosion at lower bank elevations with increased inundation due to environmental flows (Figure B-25a,b). This is not surprising considering increased frequency of inundation of the lower banks. The increase is predominantly 10% with a more pronounced effect at Yambuna. The trend is less pronounced for significant erosion (Figure B-25c,d).

- Deposition is also increased due to inundation of the lower banks by environmental flows (Figure B-25e,f).

- This trend is similar for the Maximum ADWP models (all data, hot season and cold season models). There was a minor increase in the probability of erosion following a dry period in the hot season compared to the cold season, but the difference was not significant (<10 %).

- There appears to be no relationship between changes in the probability of erosion occurrence and bank elevation for the peak flow or flow volume models.

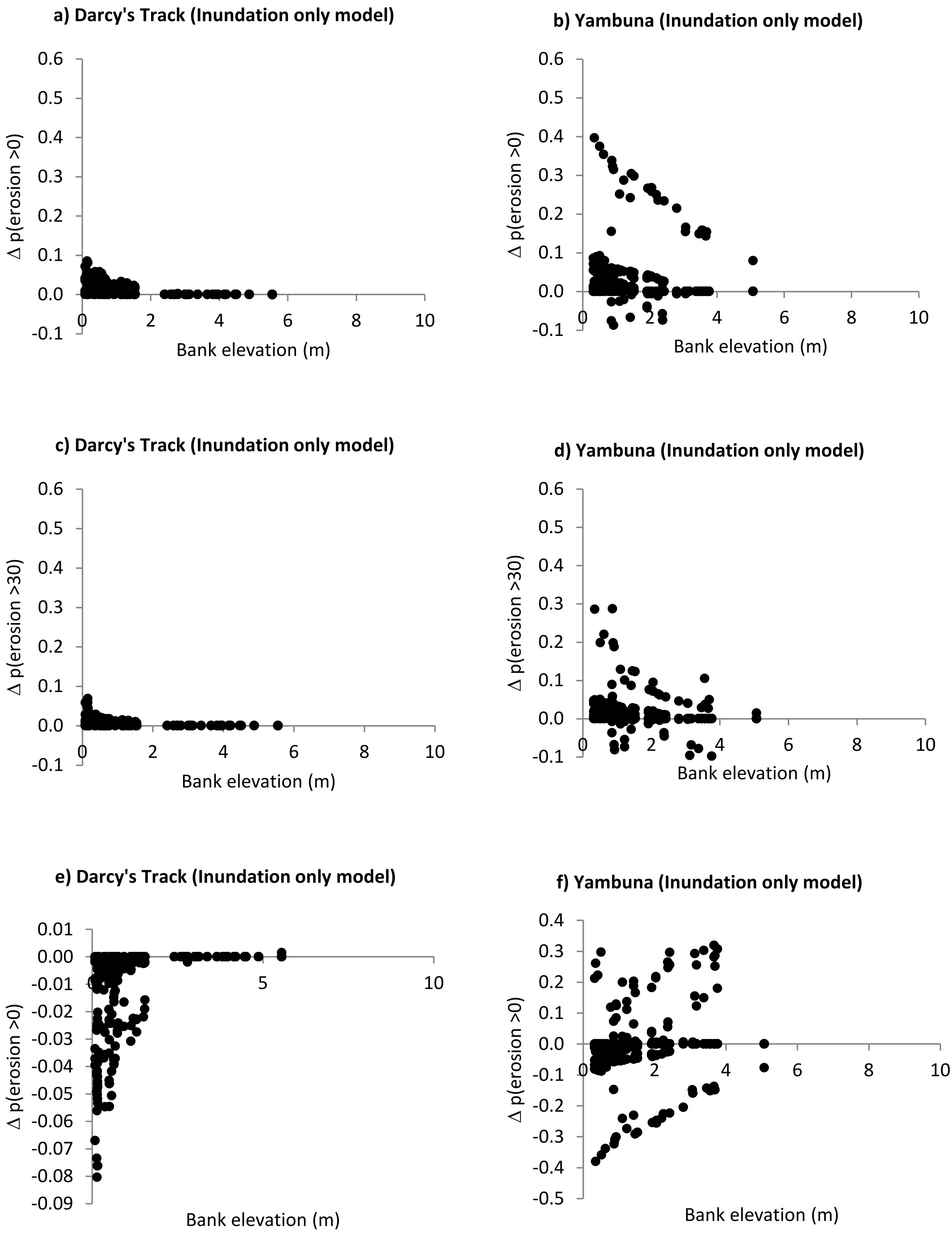


Figure B-25. Effect of the environmental flow component on the probability of erosion (> 0 mm, a and b), significant erosion (> 30 mm, c and d) and deposition (< 0 mm, e and f), at each erosion pin, relative to bank elevation (m) for Darcy's Track and Yambuna (when bank erosion/deposition is modelled as a function of inundation duration).

- There appears to be little change in the probability of bank erosion (>0 mm) for the maximum draw down models for Darcy's Track, Loch Garry and McCoy's Bridge, with a minor influence at Yambuna (Figure B-26b), with a similar trend for deposition (not shown). There is no influence of the maximum rate of drawdown on significant erosion (> 30 mm).

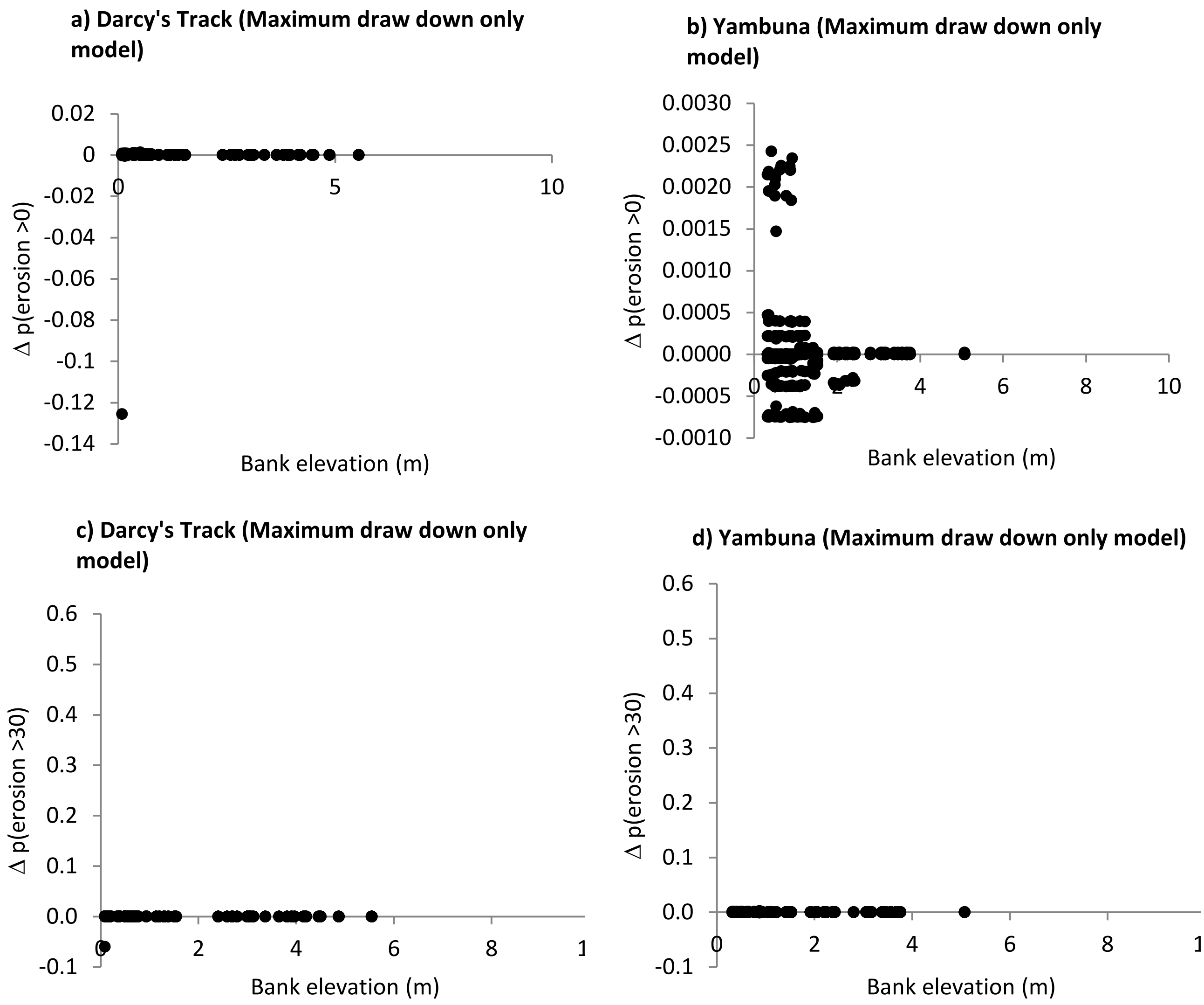


Figure B-26. Effect of the rate of drawdown due to the environmental flow component on the probability of erosion (> 0 mm, a and b) and significant erosion (> 30 mm, c and d) and deposition (< 0 mm, e and f), at each erosion pin, relative to bank elevation (m) for Darcy's Track and Yambuna.

B.4 Discussion of bank condition results

B.4.1 Variability and value of riverbank erosion

Bank erosion and deposition is highly variable with time, with a single point on the bank changing from erosion to deposition with subsequent flow events. Erosion also varies spatially, both along the riverbank and with elevation, often over small spatial scales of centimetres to metres. These findings are not confined to riverbanks on regulated river systems, with riverbanks naturally known to be dynamic with considerable spatial variability (Clarke et al. 2003, Newson and Large 2006).

The variability of active riverbanks has been found to play an important role in the condition of the river ecosystems (Florsheim et al. 2008). Based on observations, bank erosion and subsequent deposition provide niches that encourage regeneration of riparian vegetation (Figure B-27). Vegetation can play a role in the resistance of banks to erosion (Osterkamp and Hupp 2010). Sub-aerial preparation of banks as a result of drying and cracking is exacerbated when vegetation is not available to shade soils, and root wads enhance structural integrity of soils (Abernethy and Rutherfurd 2001). Deposition is also enhanced by vegetation through increased roughness, encouraging further vegetation establishment (Corenblit et al. 2009).

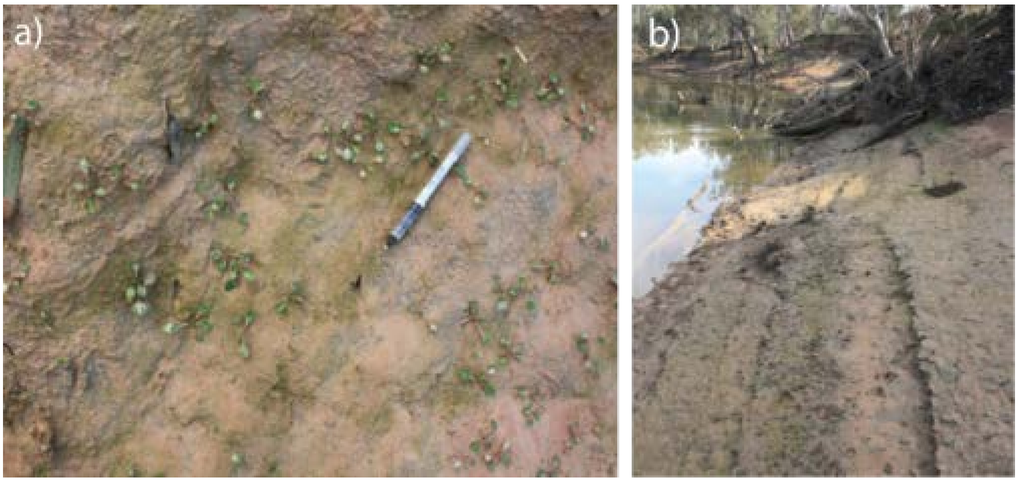


Figure B-27. a) Bank vegetation (*Aster subulatus*) regenerating following mud drapes, and b) the perception of erosion of a bank that has instead experienced deposition (mud drapes during flow recession).

B.4.2 Riverbank erosion and environmental flow management

Riverbank erosion can be related to various characteristics of the flow regime and there are myriad components of a flow event or period that have been assessed. The relationships from the whole program have been further confirmed by monitoring from the 2016-17 period. Components of the flow regime assessed for the first time in the 2016-17 program include the Maximum ADWP (the length of the preceding dry period) and the rate of drawdown. Of the attributes that were considered important to riverbank erosion, the duration of inundation was the most influential, with a positive, mostly linear relationship. For example, doubling the duration of bank inundation from 10 to 20 days leads to a 50% increase in the probability of erosion. Relationships between bank erosion and Maximum ADWP and Drawdown were present but less significant. There was, however, no strong relationship between riverbank erosion and peak discharge or inundation volume, the latter incorporating both flow duration and magnitude.

The effects of environmental flows on top of normal erosion/deposition processes are minor. Probabilities of significant erosion changed very little with environmental flows for the vast majority of samples, and all samples that did show a change were very low on the bank, where inundation profiles were maximally impacted by the removal of environmental flows from the hydrograph. Large-volume environmental flow events (e.g. spring freshes) provide temporary inundation of portions of the bank that might otherwise have been exposed at that time. The erosion pin placement deliberately targets those areas of the bank for which inundation profiles will change by the most, and yet probabilities of erosion were little different with and without environmental flows for almost all pins. The statistical analysis demonstrated that the additional effect of this water on probabilities of significant erosion is very small.

Since peak magnitude and total flow volume were not significantly related to riverbank erosion it can be inferred that the dominant erosion mechanism is not related to high velocities but the influence of inundation on the bank. This supports the role of sub-aerial preparation of bank sediments whereby drying of clay-rich soils (desiccation) leads to cracking and preparation of banks for erosion during subsequent inundation (Figure B-28). This was tested in the 2016-17 period by including the Maximum ADWP by season (a wet and dry season). There was a minor increase in the probability of erosion following a dry period in the hot season compared to the cold season, supporting this hypothesis, but the difference was not significant. This suggests that the visibly cracked clays during the hot season may not lead to increased erosion. There is, however, a question over whether a hot season focused on a shorter period (say December to February) may lead to a significant result.

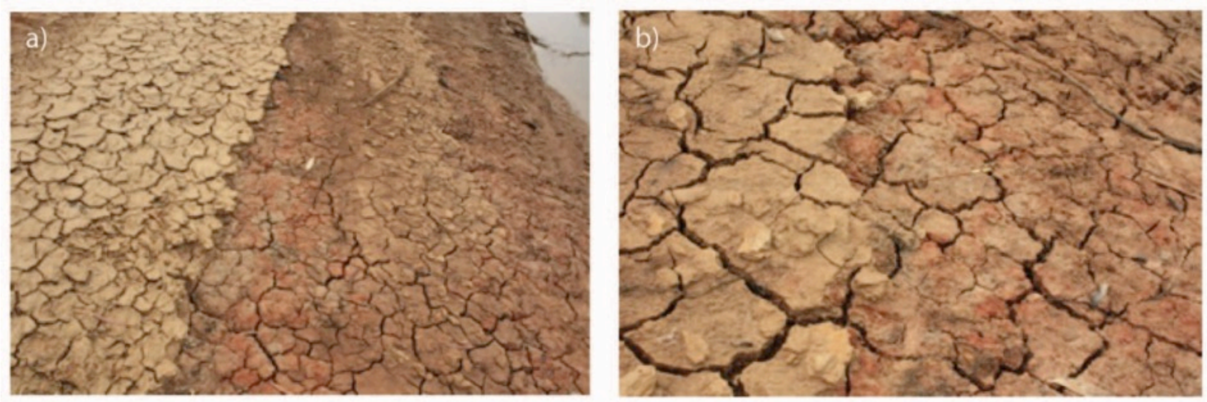


Figure B-28. a) Drying of clay-rich sediments prepares bank materials for removal during subsequent inundation, and b) note erosion pin exposed (centre picture) at the Yambuna site with 54 mm of erosion measured following the first fresh of 3000 ML/d as desiccated sediment was removed.

Significant erosion (>30 mm) was most influenced by inundation duration (similar to erosion >0 mm). A common form of significant erosion was wet flow, whereby saturated bank sediments slumped under the force of gravity, leaving bare roots (rather than broken roots as would be the case with a block mass failure event). It is inferred from this that the longer the period of saturation the greater the chance of significant erosion. Considering the few samples that experienced significant erosion, there is a wide band on the credible intervals of probabilities of erosion. Not surprisingly the location on the bank played a major role, with pins lower on the banks being more influenced by inundation, reflecting increased duration and frequency of inundation.

Deposition was surprisingly common, being observed in 24 to 31 percent of samples at each site. Some deposition was observed to be the result of soil creep under gravity, and this was particularly evident following heavy rainfall events. The majority of bank aggradation was, however, observed to be through mud drapes deposited on the receding limb of the event hydrograph. This may also account for the lower rates of deposition than erosion. The Goulburn River experiences a considerable peak in turbidity on the rising limb of the hydrograph, particularly for natural Spring flow events, with no further increases for increased duration (Windecker and Vietz 2014). Peak flow and volume of inundation had little influence on deposition but deposition was found to increase with MDWP. This may be an artefact of cross correlation (MDWP negatively correlated with inundation) but may also indicate that catchment sediment supply is much greater following long, dry periods, or endogenous sediment supplies (from bank sources) are being redistributed along the channel.

There was some difference between upstream and downstream sites in terms of erosion and deposition, despite all sites receiving similar hydrologic regimes. The most upstream site, Darcy's Track, had the lowest activity (both erosion and deposition), despite it receiving a larger proportion of managed flows, being the only site upstream of the major tributary of the Broken River. The observation that Darcy's Track also had a higher vegetation cover requires quantification before this can be considered as an influencing factor.

B.4.3 Perceptions of riverbank erosion

Despite concerns over excessive bank erosion activity in the Lower Goulburn River, erosion was 2 to 4 times less common than either no change or deposition. Significant erosion, which is considered the perceptible level of erosion (>30 mm), was between 2 and 7 percent of measurements (a maximum at Loch Garry). There were no observations of mass failure erosion at the study sites. Considering the targeted nature of the monitoring (on transects where change was expected to be more likely) the average level of erosion in the Lower Goulburn River will be lower than recorded in this study. The low number of pins impacted by significant erosion (i.e. erosion perceptible by visual assessment) demonstrates that visual perceptions in the absence of monitoring are an unreliable guide.

Perceptions of bank erosion are often misleading, with actual changes often not perceptible by eye. For example, many banks that appeared to be eroding actually experienced deposition because mud drapes (up to 50 mm thick, see Figure B-29a) deposited on the bank during one event, were subsequently dried and cracked in the quiescent period and removed by flowing water during the following flow event. This often left a well-defined linear pattern of erosion that coincided with the maximum flowing water height, and as such appears to be related to flow management. Some riverbanks that appear to be eroding over time are not. For example, an outer bank at McCoy's Bridge, where former wet flows had liberated sediment and left roots and a steep bank (Figure B-29b), appears to be eroding, but has experienced little measurable change during the three year survey period. This was most surprising following the large event in 2016 when measurements of erosion were made in November.

The role of bank erosion relative to bank vegetation has yet to be investigated. Zones of deposition did provide niches for vegetation colonisation. Anecdotally, vegetation plays an important role in the resistance of banks to erosion. Sub-aerial preparation of banks as a result of drying and cracking is exacerbated when vegetation is not available to shade soils. In addition, root wads enhance structural integrity. Deposition is also enhanced by vegetation through increased roughness, encouraging further vegetation establishment. Data from bank condition and riparian vegetation assessments will be synthesised to understand relationships in future reporting.

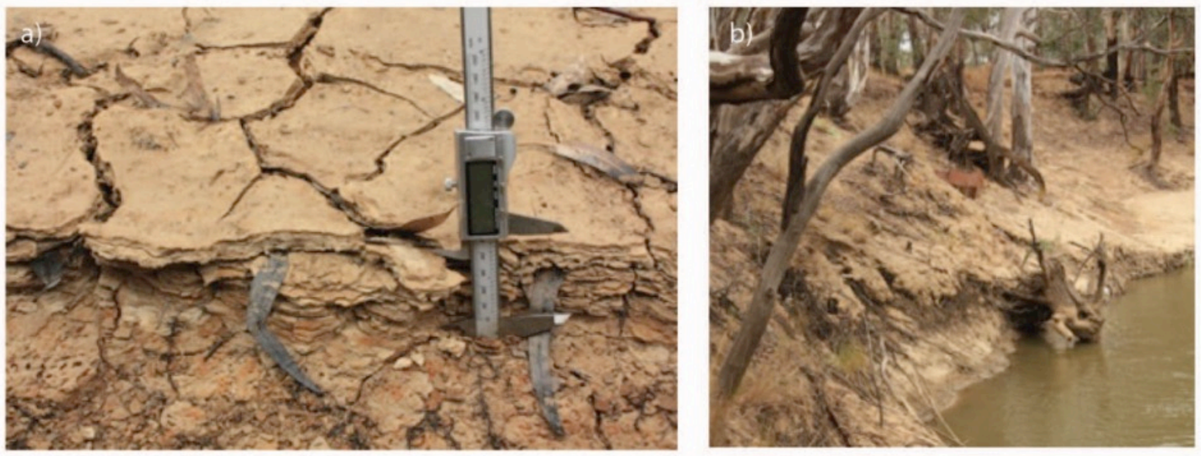


Figure B-29. (a) Sediment drapes (deposition) may be subsequently eroded giving the perception of wholesale bank erosion, but this is episodic, (b). An outer bank at the McCoy's Bridge site that appears to be eroding but where little or no erosion activity has been recorded at the erosion pins.

There are no major issues associated with the physical habitat or bank condition monitoring program.

B.4.4 Adaptive management of river bank erosion

Flow management has been modified through collaboration with researchers during the three years of the Goulburn LTIM project. This includes altering the duration of flows at specific levels so as to increase variability and reduce the potential for bank notching, and managing rates of fall to reduce the potential for bank surcharging and mass failure. The science-practice partnership has two particular advantages in the management of flow. First, researchers have better access to ongoing and up-to-date information on forecasted flows from the water and catchment management authorities to target sampling periods. Second, practitioners see field verification of management intentions, such as managing rates of fall in discharge to avoid bank failure.

An example of this includes the observations made in the early stages of sampling on the Goulburn River that showed that rapid drawdown of river levels that could exacerbate natural erosion processes. In every year of this program water delivery officers regularly sought advice from the Goulburn River LTIM team regarding the design of elevated flows and bank condition. Monitoring of environmental flow events and low rates of erosion suggest that the management regime is effective at reducing the potentially negative impacts on bank condition. Erosion pin measurements also suggested that mud drapes (that encouraged vegetation establishment) were more common during slow rates of recession. Re-establishing bank vegetation had previously been assumed to be driven by spring freshes. Furthermore, observations of bank notching, associated with the water surface level of delivered freshes, suggests that rather than maintaining consistent water levels (such as one discharge rate for a two-week period) variability should be provided to reduce the incidence of notching from sustained water levels.

As a testament to this working relationship, monitoring results for 2014-17 indicate that environmental flow deliveries can proceed with confidence on the Goulburn River, as to date results demonstrate that environmental flows do not considerably increase erosion. A less desirable outcome may have eventuated if the initial hydrograph design had been implemented in the absence of the ground-truthed, catchment-specific advice.

B.5 Conclusions and recommendations

Hydraulic habitat modelling enables us to quantify habitat with respect to discharge. These relationships allow targeted flow delivery to maximise habitat (or prevented reduced habitat). These hydraulic habitat results have been used to identify velocity triggers for fish, and will be developed further for fish, as well as macroinvertebrates and plants.

For bank condition monitoring we expect that five years of monitoring data will be required to develop robust statistical relationships, given the complexity of characterising the flow regime relative to the drivers of riverbank erosion. In particular, this will allow a better understanding of the specific characteristics of flow that affect riverbanks, and enable modifications to reduce impacts of flow management, rather than merely whether environmental flows do or do not have an impact.

The results presented here have already greatly increased our knowledge. Beyond the inundation metrics assessed here, there is a range of flow characteristics that could be included in assessments, such as the role of prolonged flows in facilitating erosional notching. The investigation of the ability of such flow characteristics to explain and predict bank erosion from qualitative assessments is the subject of ongoing research.

The value of the Goulburn bank condition monitoring program at this stage may predominantly be in the relationships developed, whereby practitioners manage environmental flows based on the evolving science, incorporating new knowledge as it becomes available. The bank condition monitoring in the Goulburn River provides a good example where developing knowledge is being used to inform the very environmental flows that are being monitored. At the same time, the monitoring program is benefiting from the flow of information by water managers to ensure a strategic approach to developing the science. This science-practice partnership represents an example of the doing (delivering environmental flows) both enabling, and being undertaken in conjunction with the ‘knowing’ as knowledge is being developed. Essential to this program are the often-informal lines of communication not often captured in reporting. The expected outcome as a result of this close interaction with scientific experts is greater return on investment regarding the application of scarce water resources in the Goulburn system, and more broadly minimising the physical impacts and maximising the benefits of environmental flow management on river systems through explicit understanding of hydrogeomorphic relationships.

Appendix C. Detailed results for stream metabolism

C.1 Background

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

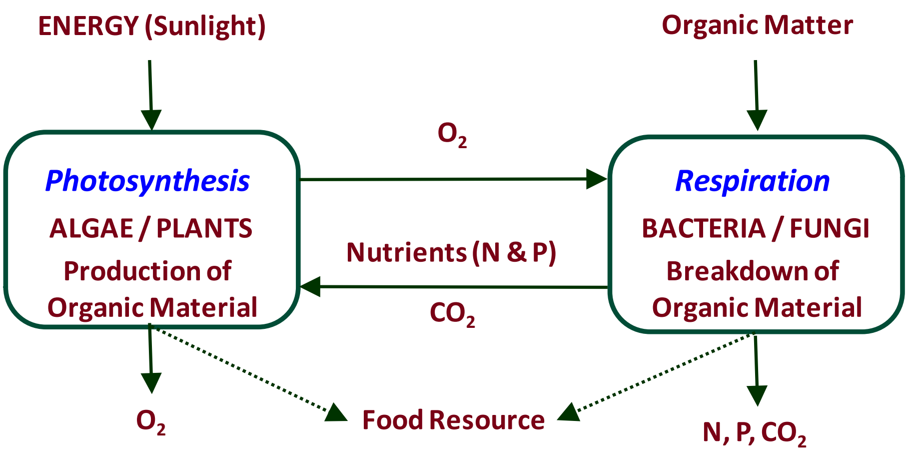


Figure C-1. Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients.

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 and 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). 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 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.

C.2 Methods

The stream metabolism and water quality measurements were performed in accordance with the LTIM Standard Operating Procedure.

Water temperature and dissolved oxygen were logged every ten minutes with one ZebraTech DO logger placed in each of the four sites in zones 1 (Day Rd[1], Darcy's Track) and 2 (McCoy's Bridge, Loch Garry). Data were downloaded and loggers calibrated approximately once per month depending on access. In some months, downloads were delayed by high water levels preventing access to the loggers (too far underwater for safe access). Light (PAR) loggers were also deployed in open fields at Shepparton and Nagambie (Tahbilk); these data were downloaded every few months. The data collected by the DO loggers was also used to calculate daily average temperature (Figure C-2a) and dissolved oxygen concentrations (Figure C-2b) for each of the sites from November 2016 to mid-April 2016.

In accord with the LTIM Standard Protocol, water quality parameters (temperature (°C), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were also measured as spot recordings at two sites within each river reach during deployment and maintenance of the DO loggers.

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

- Total Organic Carbon (TOC)
- Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC)
- Nutrients (Ammonia (NH_4^+), filtered reactive phosphorus (FRP), dissolved nitrate + nitrite (NOx), Total Nitrogen (TN) and Total Phosphorus (TP))

Estimates of Gross Primary Production and Ecosystem Respiration for the 4 sites were produced using a modification of the BASE model (Grace et al. 2015). After discussions at the annual forum in Sydney in July 2016, it was decided that an updated version of the BASE model (BASEv2) would be used for analysing all metabolism data. 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. Acceptance criteria for inclusion of daily results from the BASEv2 model in the data analysis presented here were established at the July 2015 LTIM Workshop in Sydney and refined at the corresponding 2016 Sydney Workshop. These criteria were that the fitted model for a day must have both an r^2 value of at least 0.90 *and* coefficients of variation for all of GPP, ER and K < 50% and $0.1 < PP_{fit} < 0.9$.

C.2.1 Statistical Modelling

Relationships between discharge and gross primary production (GPP), ecosystem respiration (ER) and net ecosystem production (GPP – ER = NEP) were analysed using a hierarchical Bayesian linear regression of the metabolism endpoint against discharge (log transformed) and temperature. First-order auto-regressive terms in the model tested for (and compensated for) the lack of temporal independence in the daily data.

$$y_{ij} \sim N(\mu_{ij}, \sigma)$$

$$(\mu_{ij}) = int_j + eff.Q_j \times \log(Q_{ij}) + eff.Te_j \times Te_{ij} + ac.e^{-eff.d(d_{ij}-d_{i-1,j})}(y_{i-1,j} - (int_j + eff.Q_j \cdot \log(Q_{i-1,j}) + eff.Te_j \cdot Te_{i-1,j}))$$

[1] The site at Day Rd was chosen in 2015-16 to replace the Moss Rd site used in 2014-15. It was found that the Moss Rd site was simply too close to the weir wall and almost no usable data (met acceptance criteria) was obtained.

This code represents metabolism (Gross Primary Productivity, Ecosystem Respiration or Net Primary Productivity, represented by *y*) on day *i* and at site *j* being distributed normally around a mean metabolism of *μ* and standard deviation of *σ*. Mean metabolism on day *i* and at site *j* is a linear function of log of discharge (*Q*), and of temperature (*Te*). The intercept (*int*), and the effect of discharge (*eff.Q*) and of temperature (*eff.Te*) are specific for each site. *int,eff.Q* and *eff.Te* were modelled hierarchically. All prior distributions were minimally informative.

The *ac* term quantifies the extent to which a data point can be estimated from the point preceding it (i.e., autocorrelation). This term is multiplied by a weighted exponential function parameterized by the term *eff.d*, which is the extent to which autocorrelation breaks down with increasing temporal separation of data points (d_i – d_{i-1}). This term was necessary because of the relatively large number of data points that had been deleted from the metabolism time series due to non-compliance with the BASEv2 model acceptance criteria. The bracketed component is simply the residual of the previous data point in the time series.

The effect of environmental flows was estimated by predicting ecosystem metabolism values from the fitted model, but with a synthetic flow series from which environmental allocations had been removed. This resulted in daily ecosystem metabolism values that were then compared to the fitted values from the full model. The total effect of environmental flows over the sampling period was computed as the sum of daily values.

The model was run for scenarios that assumed a lag of between 0 and 20 days, where the lag represents the time between discharge on a day and a resulting effect on metabolism (e.g. time needed for algal populations to increase after an influx of nutrients on a particular day). The optimal lag was determined as the lag at which the coefficient of variation of eff.vel (mean across all four sites) is at a minimum. This indicates the uncertainty in the model. If the model is at its optimum performance, eff.vel would have a higher certainty than a model that is not performing well.

In addition, for the year 3 data we also tested a model of mean metabolism on day i and at site j as a linear function of mean channel velocity (vel), temperature (Te) and light (Light). The intercept (int), and the effect of mean channel velocity (eff.vel), temperature (eff.Te) and light (eff.Light) are specific for each site.

$$y_{ij} \sim N(\mu_{ij}, \sigma)$$

$$(\mu_{ij}) = int_j + eff.vel_j \times (vel_{ij}) + eff.Te_j \times Te_{ij} + eff.Light_j \times Light_{ij} + ac.e^{-eff.d(d_{ij}-d_{i-1,j})}(y_{i-1,j} - (int_j + eff.vel_j \cdot (vel_{i-1,j}) + eff.Te_j \cdot Te_{i-1,j} + eff.Light_j \cdot Light_{i-1,j}))$$

Autocorrelation is as described for the flow model above. int,eff.vel, eff.Te , eff.Light were modelled hierarchically. All prior distributions were minimally informative.

C.3 Results

The periods of data logger deployments are listed in Table C-1 along with the number of days' data that met the extended acceptance criteria (r^2 > 0.90, coefficient of variation for all of GPP, ER and K < 50% and 0.1 < PP_{fit} < 0.9) using BASEv2. The initial 2016-17 deployment of loggers at Day Rd, Darcy's Track and Loch Garry was planned for early-mid August but was delayed until early November by the extremely high water levels. Access to the sites was impossible and required water levels to subside to more 'normal' levels. Data was recorded at McCoy's Bridge from July 1 (this site is logged all year) but inability to access the logger due to floodwaters meant that the scheduled battery replacement could not occur and the logger stopped on August 29, 2016. Unexpected failure of light logger batteries at both sites in autumn 2017 meant that the metabolism data set presented for all sites was truncated at March 30, 2017.

The most important result displayed in Table C-1 is that in 2016-17 there was an increase over 2015-16 in all four sites for the number of days with data that were compliant with the acceptance criteria from the BASEv2 model. In addition, the percentage of total days with data that also met the acceptance criteria increased. These acceptance criteria are conservative, minimizing the likelihood of including metabolic parameter estimates that are unreasonably high or low at the 'cost' of including some data that may have produced reasonable parameter estimates. A key guide is the reaeration rate, which is not affected by biological processes and should be relatively consistent at a particular discharge level. Unusually high (or low) values of K then affect estimates of ER and subsequently GPP. This matter was canvassed extensively in the July 2017 Sydney LTIM meeting. Although the acceptance rate for all four sites was in the range 50-55%, a significant proportion of the unsuccessful fits fell in the period of very low dissolved oxygen concentrations that verged on anoxia for extended periods in spring 2016. This is discussed in more detail below.

Table C-1. DO Logger Deployment and Data Acceptance Information, 2016–17.

Site	First Date	Last Date	Number of Days with data	Compliant Days using BASEv2	% of total days in compliance	Compliant Days 2015-16	% of compliant days 15-16
Day Rd	5/11/16	3/5/17	142	75	55	39	27
Darcy's Track	23/11/16	28/3/17	98	52	53	43	28
Loch Garry	11/11/16	30/3/17	139	70	50	47	33
McCoy's Bridge	1/7/16	30/3/17	223	114	51	92	48

C.3.1 Water Temperature and Dissolved Oxygen

Figure C-2 displays the mean daily water temperature and mean daily dissolved oxygen concentrations, collected from the dissolved oxygen loggers, at all four sites over the entire deployment period. Gaps in the data reflect logger maintenance, data overflow due to high water impeding retrieval and logger failure (Darcy's Track) as noted previously.

The temperature profiles shown in Figure C-2 conform to expected behaviour with the warmest average daily temperatures occurring in mid-late summer. Consistent with the findings from the Year 2 report, the water temperature is noticeably lower at Day Rd and this is most likely the result of the site being relatively close to the outflow from Goulburn Weir. It is a gated weir hence cooler sub-surface water (as well as surface water) is released from the Nagambie Lakes. This temperature difference will be evident especially during daytime in summer when solar irradiance (and hence epilimnetic heating) is at a maximum. This resultant temperature difference between Day Rd and the sites further downstream can be several degrees. This temperature differential is partially overcome by Darcy's Track but does emphasize the generic finding that 'cold water pollution' can extend for large distances downstream of weir structures. The effect is fairly minimal here but definitely identifiable. An additional effect of the weir, elevated reaeration rates, is described in the next section.

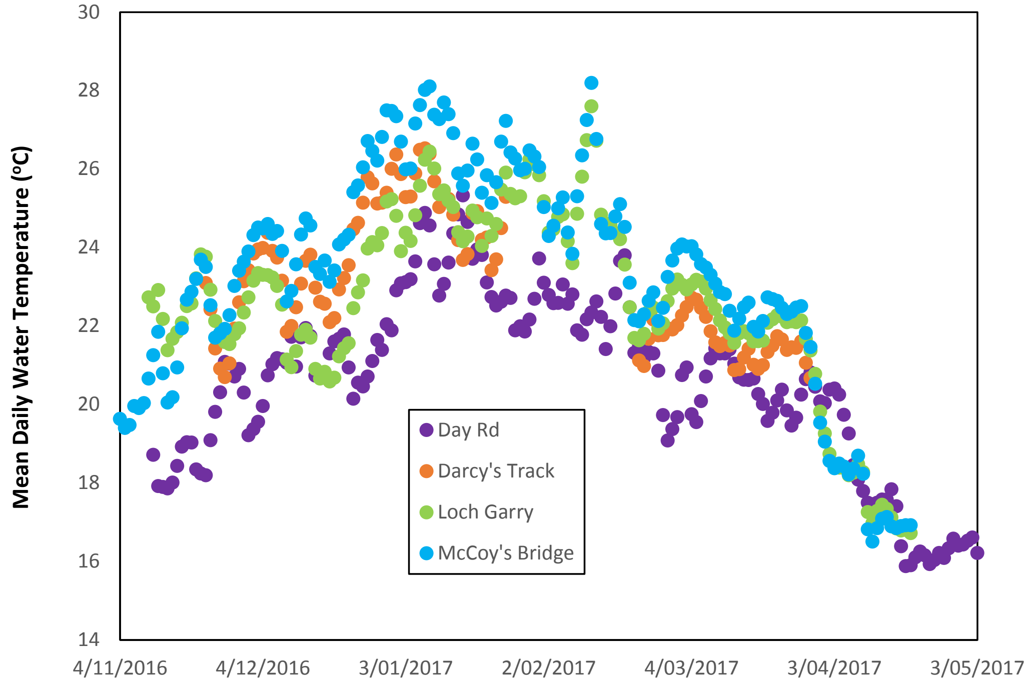
One particularly interesting feature of Figure C-2b) was the pronounced slump in Dissolved Oxygen concentration in all sites except Day Rd in early January 2017. The average daily DO at Loch Garry fell to just 0.85 mg O_2/L on the second of January, with a minimum value of just 0.15 mg O_2/L around 9.30 am on that day. This is clearly far below healthy water quality guidelines as dissolved oxygen concentrations of less than 4 mg O_2/L can be deleterious to aquatic ecosystem health. Recovery to acceptable levels took around 4 days. The cause of the low dissolved oxygen in some of the Goulburn River at this time was attributed by the Goulburn-Broken CMA to a blackwater event in the Pranjip/Castle/Sevens Creeks & Broken River system originating from very heavy rainfall in the region on December 29. This slug of hypoxic/anoxic water entered the Goulburn between the Day Rd and Darcy's Track sites hence no low DO was recorded at Day Rd. The passage of the blackwater down the Goulburn can be seen in Figure C-2b), as there is a temporal delay in the low DO from Darcy's Track to Loch Garry to McCoy's Bridge. Low summertime DO slugs were also noted in December 2015 and extended for about 3 days.

Reasonable estimation of water travel times between the sites (to be done during 2017-18) will allow determination of whether some of these events are independent or simply the same parcel of low DO water travelling slowly downstream. It is beyond the scope of this project to ascertain whether a short duration low DO event caused altered fish movement (e.g. to seek higher DO refuges, perhaps in tributaries?).

C.3.2 Metabolic Parameters

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 4 sites monitored, derived from all days meeting the acceptance criteria, are presented in Table C-2.

a)



b)

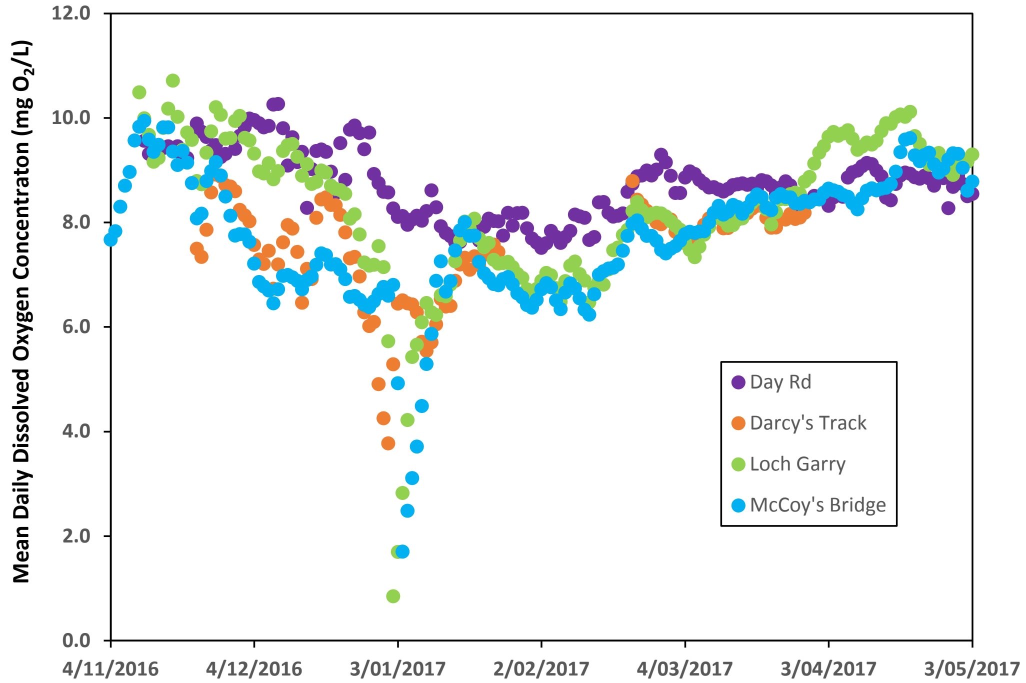


Figure C-2. Daily Mean a) Daily Water Temperature and b) Dissolved Oxygen Concentration for the four study sites from November 2016 to May 2017

Table C-2. Summary of primary production (GPP) and ecosystem respiration (ER) rates, P/R ratios and reaeration coefficients for the four study sites, November 2016 – April 2017.

Parameter	Day Road (n = 78)			Darcy's Track (n = 52)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.82	0.86	8.2	2.25	0.72	5.7
ER (mg O_2/L/Day)	4.55	0.83	16.1	3.87	1.34	9.3
P / R	0.48	0.17	1.3	0.58	0.16	1.2
K (/Day)	6.79	0.44	14.6	2.02	0.44	5.1
Parameter	**Loch Garry (n = 70)**			**McCoy's Bridge (n = 114)**		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.76	0.40	4.0	1.46	0.65	4.1
ER (mg O_2/L/Day)	1.96	0.44	11.9	2.89	0.71	11.1
P / R	0.73	0.16	5.9	0.58	0.13	3.4
K (/Day)	1.70	0.47	7.1	1.53	0.07	5.5

Each metabolic parameter in Table C-2 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. The median GPP values from all four sites fall within a very narrow range of 1.46 (McCoy's Bridge) to 2.25 (Darcy's Track) mg O_2/L/Day. Inter-site differences are not considered significant, as results are also influenced by the period of record – the Zone 2 sites had many more data points in late spring which would drag the median value downwards compared to mostly summertime measurements (Zone 1 sites). There was a larger range in median ER values, varying from 1.96 mg O_2/L/Day at Loch Garry up to 4.55 mg O_2/L/Day at Day Road. There does not appear to be any longitudinal trend in results for either GPP or ER, but this conclusion remains speculative given the significant periods with no data at the different sites.

Figure C-3 to Figure C-6 display the daily rates of GPP, ER and then the GPP to ER (P/R) ratio at all 4 sites. The daily flow data are also plotted in each figure. The P/R ratio indicates the relative importance of oxygen production to oxygen consumption within a river reach on a particular day. As GPP can vary significantly depending on the daily whether, looking at this ratio over only a short period can give misleading results. A ratio of > 1, indicates that more oxygen (and hence organic carbon) is being produced than is being consumed.

The P/R ratios (medians 0.48 to 0.73) were lower than the corresponding values from Year 2 (0.68 to 0.93). The origin of the lower P/R ratios largely lies in higher values for Year 3 ER rather than decreases in GPP. The cause of this change is unclear but might be attributed to the introduction of significant amounts of more labile organic matter during the large spring time floods in 2016. This supposition is supported by much higher TOC concentrations at all 4 sites in spring 2016 compared to long term averages (see Table C-6). The median values indicate that in general and on a daily basis, more oxygen is consumed in these reaches than is produced. However, the maximum P/R ratios indicate that at times, oxygen production is very high in comparison to consumption via ecosystem respiration. As shown in Figure C-3 to Figure C-6, almost all of the 'high' P/R rations (> 1) occurred during spring time and could be attributed to ER at the lower end of the annual range and slightly elevated rates of GPP during this time. It is perhaps placing too much credence on two discrete water quality samples, but the bioavailable phosphorus concentrations at McCoy's Bridge in September (no samples at other sites due to inaccessibility) and November were ten times higher than at other times of the year. This burst of phosphorus may have been sufficient to stimulate primary production in this highly nutrient-limited system. The absence of the higher November concentration at the other 3 sites might be due to the high nutrient water being washed down and out of that river reach. The unfortunate lack of more nutrient data across the flood peak and its decline (and the whole LTIM program) precludes any detailed analysis or modelling of cause and effect between nutrient levels and metabolic responses.

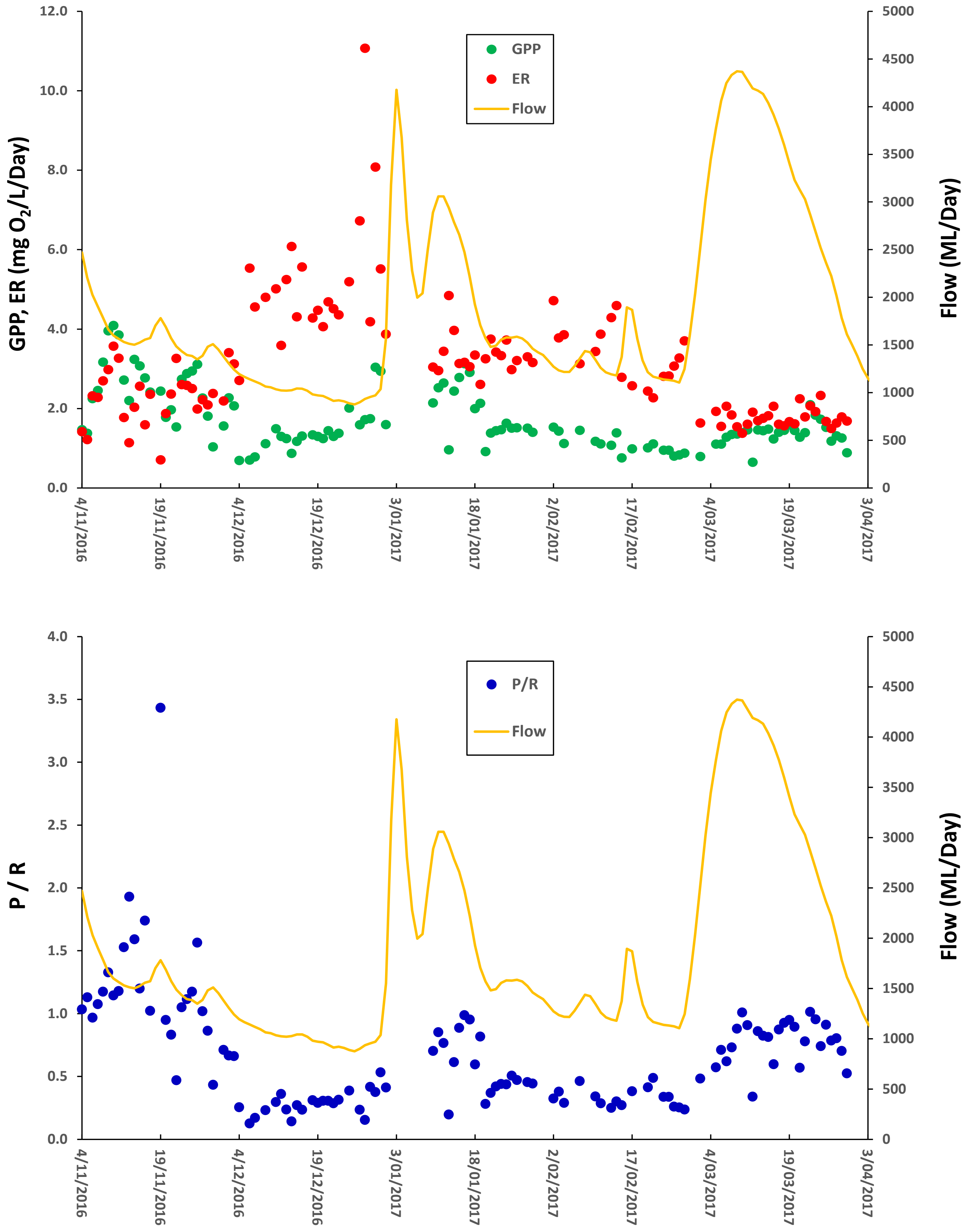


Figure C-3. Stream Metabolism-Flow Relationships for McCoy's Bridge (Zone 2) from November 2016 to April 2017: a) Gross Primary Production and Ecosystem Respiration; b) P / R ratio.

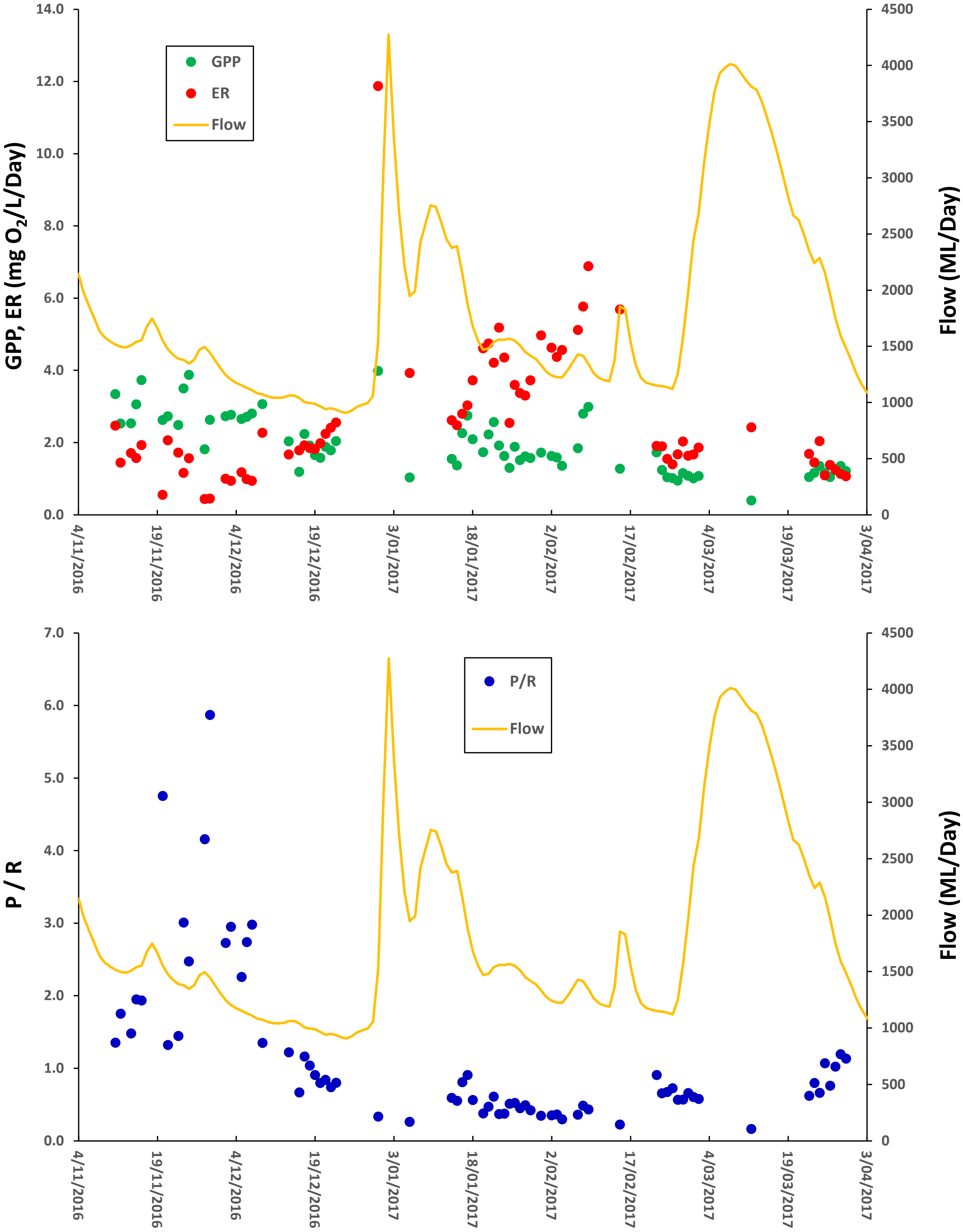


Figure C-4. Stream Metabolism-Flow Relationships for Loch Garry (Zone 2) from November 2016 to April 2017: a) Gross Primary Production and Ecosystem Respiration; b) P / R ratio.

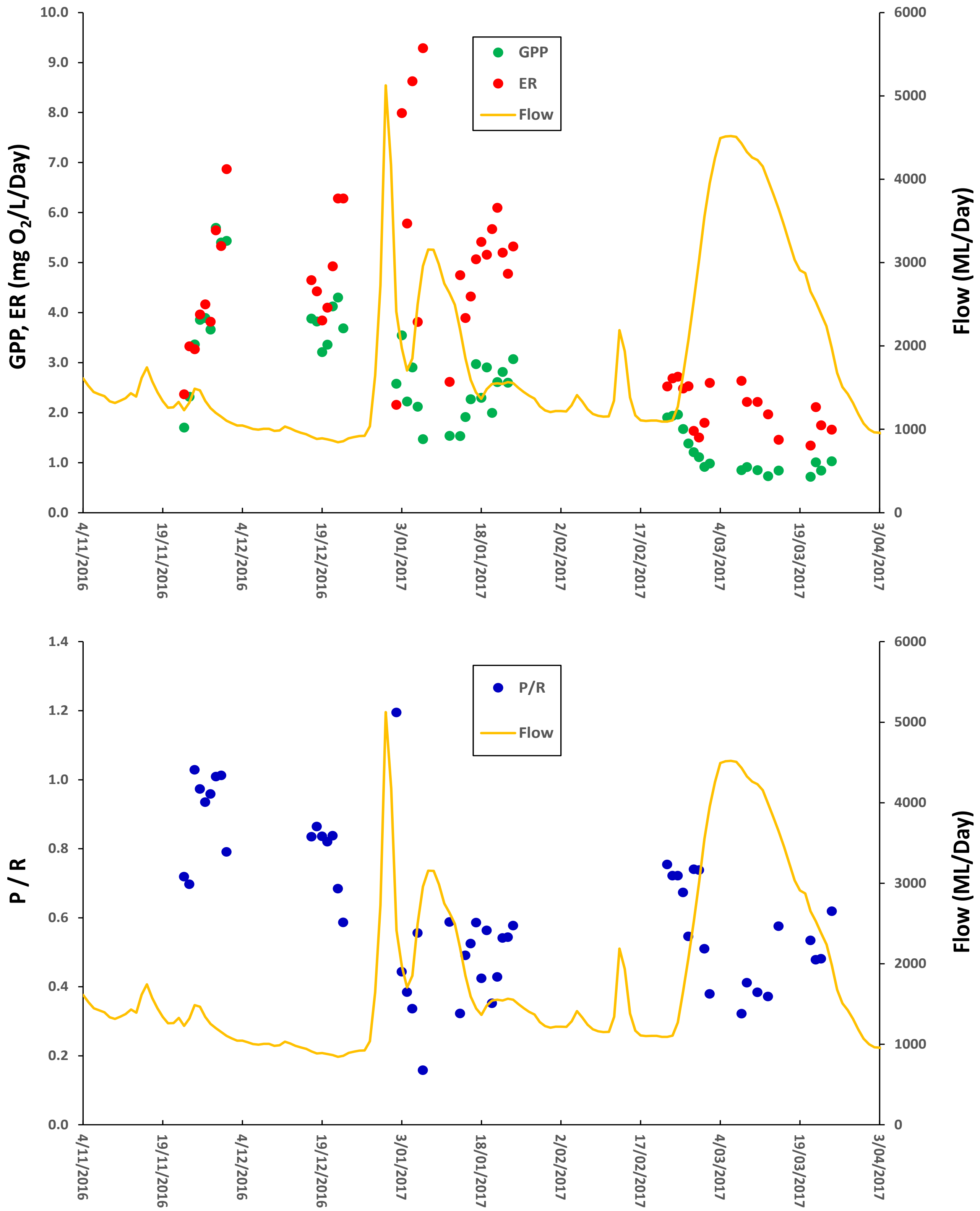


Figure C-5. Stream Metabolism-Flow Relationships for Darcy's Track (Zone 1) from November 2016 to May 2017: a) Gross Primary Production and Ecosystem Respiration; b) P / R ratio.

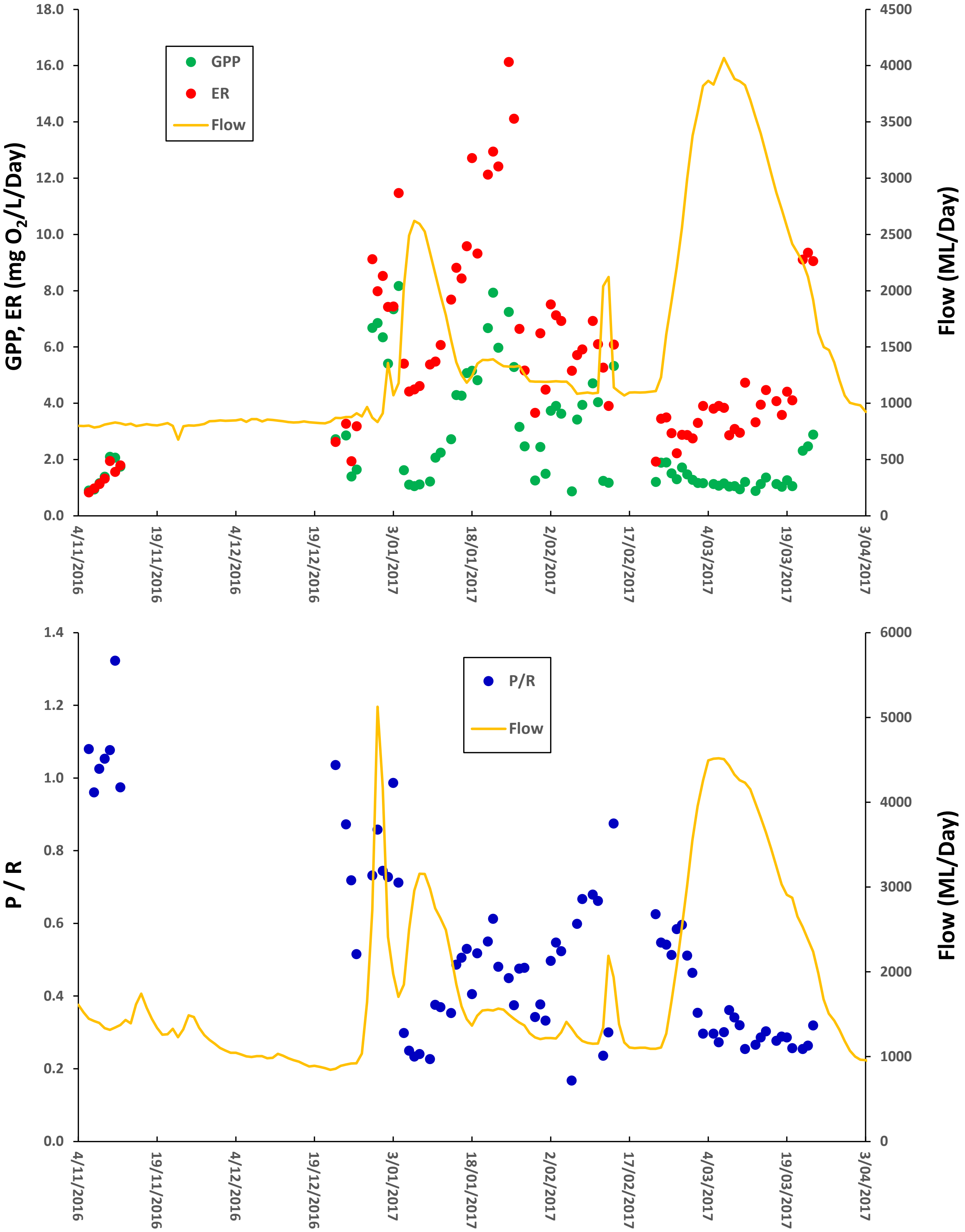


Figure C-6. Stream Metabolism-Flow Relationships for Day Rd (Zone 1) from August 2015 to April 2016: a) Gross Primary Production and Ecosystem Respiration; b) P / R ratio.

To put these metabolic rates into a larger 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 reflect a system under stress or are indicative of 'normal' rates for Australian lowland rivers should become more apparent as LTIM evolves.

Metabolism data collected in 2016-17 has been compared with that from the two previous years. All data presented in Table C-3 below has been calculated using the BASEv2 model and hence comparison is not confounded by use of the original BASE model in 2014-15.

Table C-3. Comparison across the three years of median gross primary production (GPP) and ecosystem respiration (ER) rates, P/R ratios and reaeration coefficients for the three study sites.

Site	Darcy's Track			Loch Garry			McCoy's Bridge			Day Rd		
Year	**14-15**	**15-16**	**16-17**	**14-15**	**15-16**	**16-17**	**14-15**	**15-16**	**16-17**	**15-16**	**16-17**	**14-15**
n	109	43	52	52	47	70	193	92	114	39	78	109
GPP (mg O_2/L/Day)	1.53	1.41	2.25	1.36	2.10	1.76	1.39	1.67	1.46	1.10	1.82	1.53
ER (mg O_2/L/Day)	1.34	2.76	3.87	1.24	2.78	1.96	1.03	1.76	2.89	2.08	4.55	1.34
P/R	1.00	0.70	0.58	1.07	0.90	0.73	1.15	0.68	0.58	0.93	0.48	1.00
K (/Day)	1.45	2.08	2.02	2.11	1.87	1.70	3.02	1.97	1.53	3.38	6.79	1.45

With 3 years of data on median rates (2 years at Day Rd), it is striking to note how small the variation is between sites and across years. The total range of median GPP is just on a factor of 2, from 1.10 mg O_2/L/Day at Day Rd in 2015-16 to 2.25 mg O_2/L/Day in this current year at Darcy's Track. This conformity is despite different periods of missing data. Apart from the significantly higher ER value this year at Day Rd (4.55 mg O_2/L/Day), the range in median ER was again around 2.8. This uniformity is almost certainly derived from the choice of the median as a key summary statistic and from an ecological perspective, the uniformity in bioavailable nutrient concentrations and light climates (related to water depth and turbidity).

An interesting feature of the summary data in Table C-3 is the significantly higher values for the median reaeration coefficient (K) at the Day Road site, especially in 2016-17. It is highly likely that this increased reaeration is due mainly to the impact of the Goulburn Weir. Water leaving through the weir gates is mixed with air in a very turbulent process – especially under higher flows as seen in 2016-17. As the flow becomes less turbulent downstream from the weir discharge, the reaeration rate falls back into the typical 1.5 – 3.0 /Day at the other three sites.

A different approach to assessing any effects of watering actions (and water levels in general) on metabolic parameters is to examine the behaviour of a site over repeated years which obviously is now becoming possible with 3 years of data and will build further in years 4 and 5. Consequently, Figure C-7 and Figure C-8 show GPP and ER data from the McCoy's Bridge site for all three years. Daily discharge is also shown in each plot.

Although there are some differences between years, the most remarkable feature of Figure C-7 and Figure C-8 is the consistency of metabolic rates at the same time period across years. GPP (and ER) rates were consistently highest between days 150 and 200 (December-January) with an increasing trend in GPP over this period, irrespective of year. Relatively small flow peaks in late summer each year were sufficient to drop GPP considerably. The timing of these events varied a little from year to year but the effect was essentially the same. The peaks in GPP around Day 120 (early November) were found in years 2 and 3 but not year 1. This *might* be due to the timing of the peak in year 1 washing out algae and sloughing biofilms. All GPP results in February (from about Day 210) were consistently constrained to the range 1-2 mg O_2/L/Day. It is likely, but the nutrient data are not present to completely validate, that the lack of higher GPP rates in late summer-early autumn is due to very low bioavailable nutrient concentrations depleted through the growing season (and see Table C-6).

There was slightly less uniformity in the ER data displayed in Figure C-8. Apart from elevated rates around Day 120, the year 3 ER values tended to be slightly lower than the other years in the December-January period, however few data points were available over this period in year 2. Year 2 ER was higher than year 1 for the late autumn-early winter period but these values were commensurate with the lowest values found at times throughout the rest of the year.

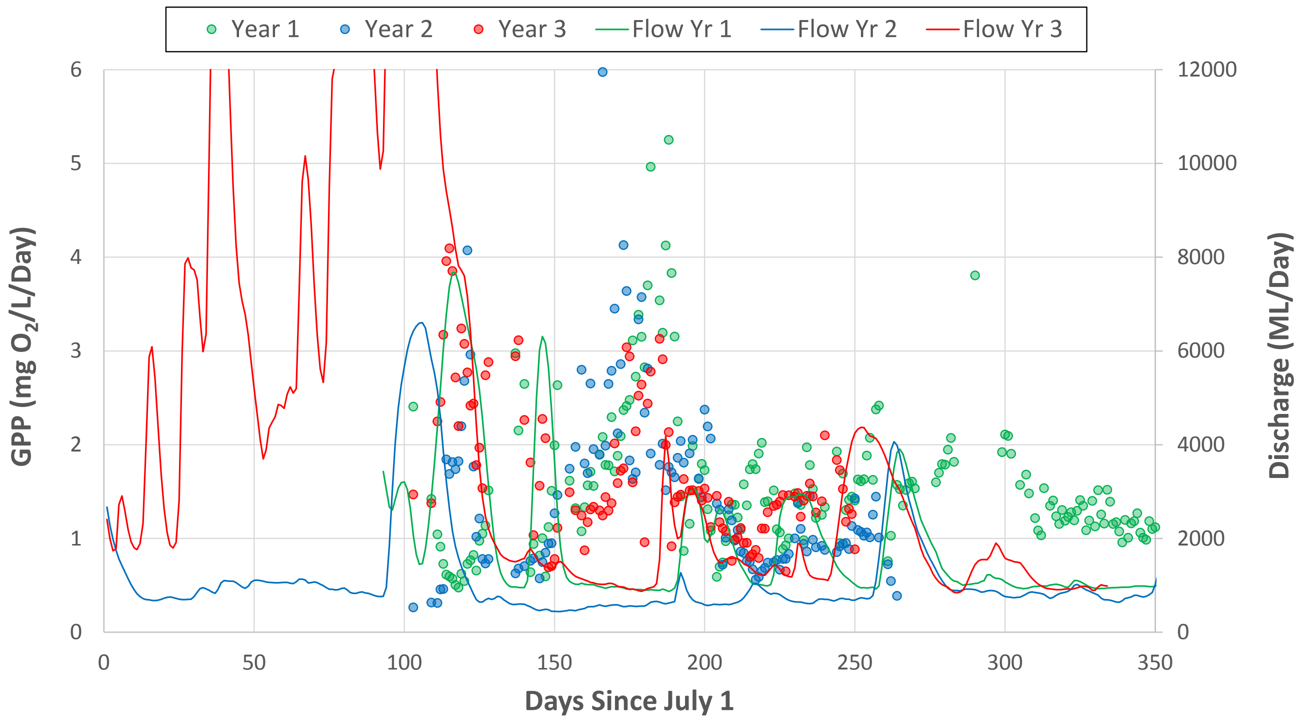


Figure C-7. GPP-Flow Relationships for McCoy's Bridge over the 3 years of the LTIM program. As a guide, Day 100 is October 8, Day 150 is November 27, Day 200 is January 16 and Day 250 is March 7 (in non-leap years).

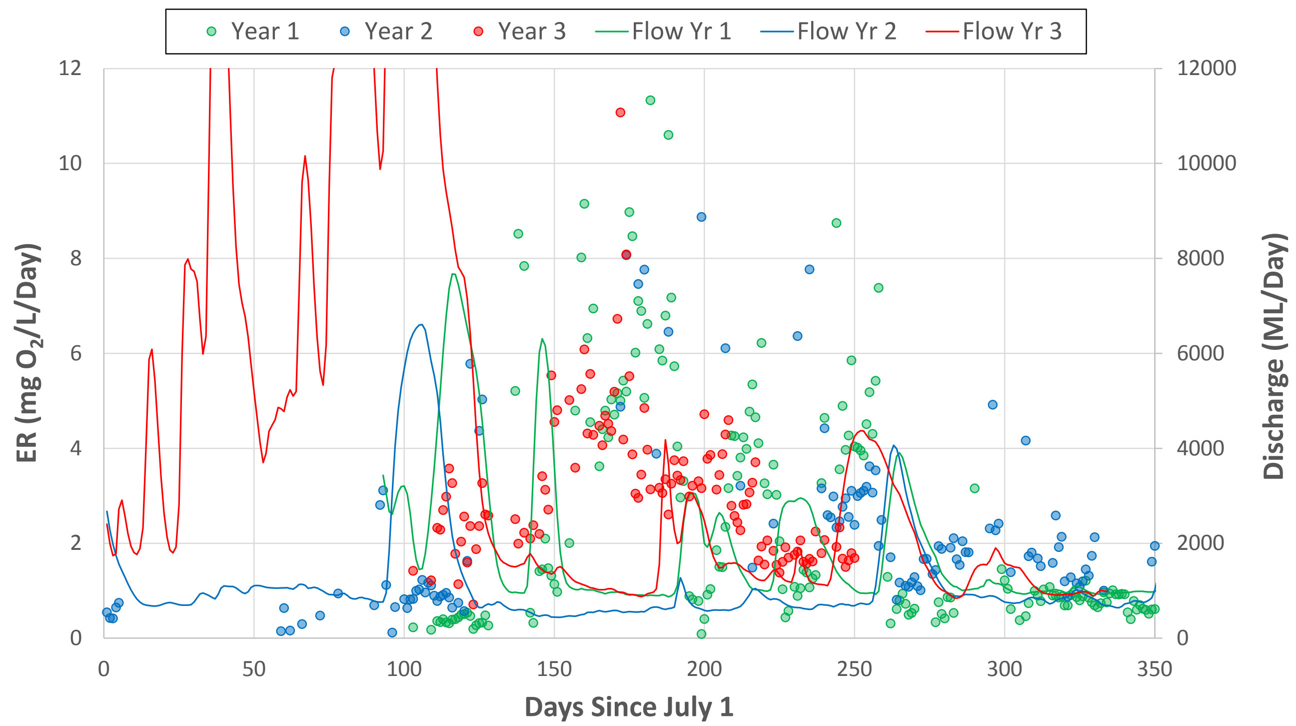


Figure C-8. ER-Flow Relationships for McCoy's Bridge over the 3 years of the LTIM program. As a guide, Day 100 is October 8, Day 150 is November 27, Day 200 is January 16 and Day 250 is March 7 (in non-leap years).

What these figures show is that the metabolic rates are affected in a reasonably predictable manner by season and then flow events can alter the rates for periods of time (weeks to a month). As more data becomes available over the next two years, this picture should become even clearer. In addition, the full five years data set should offset the lack of data at the other 3 sites from time to time.

C.3.3 Oxygen Loads – A comparison of O_2 Production and Consumption

The total amount of oxygen (and hence organic carbon) created by photosynthesis or consumed by respiration is determined by the daily load. This load is simply the mathematical product of the metabolic rate in mg O_2/L/Day multiplied by the flow in L/Day. The result is in mass of O_2 produced or consumed on that day. The most convenient unit is Tonnes O_2 (per day). Table C-4 summarizes the GPP and ER loads for each of the sites. The table shows that although the rates of oxygen production and consumption were lower in Zone 2 (Loch Garry and McCoy's Bridge) than at the two more upstream sites, the difference was not statistically significantly different given the very large daily variability. Given this high variability around similar load values, no specific importance, or ecological significance is therefore drawn to inter-site differences. The one caveat to this statement is the higher oxygen consumption in Zone 1, especially at Day Road. This might be attributed to more labile organic carbon originating from Lake Nagambie (and perhaps upstream of that too).

Table C-4. Mean Daily Oxygen Production and Consumption Data for the 4 sites within the Goulburn River from November 2016 until April 2017.

Zone & Site	n	O_2 Production (Tonnes)	sd	O_2 Consumption (Tonnes)	sd
McCoy's Bridge, Zone 2	143	2.8	2.3	4.4	2.3
Loch Garry, Zone 2	70	2.9	1.2	4.0	3.0
Darcy's Track, Zone 1	52	3.8	1.3	7.0	4.1
Day Rd, Zone 1	78	4.1	2.2	9.6	5.2

Of more diagnostic value is to look at the relationships between flow and oxygen production and consumption. An example of these plots is shown for the McCoy's Bridge site in Figure C-9. This site was chosen as it has the most data available.

Unlike 2015-16 when there was a pronounced peak in the highest amounts of oxygen production and consumption occurring around 1000 ML/Day. Figure C-9 demonstrates that oxygen loads from both GPP and ER increase with flow across the observed discharge range. The important finding in this figure is that even though added discharge (e.g. through watering actions) tends to decrease the actual rates of GPP and ER through dilution, the sheer extra volume of water means that the total mass of oxygen created through GPP and consumed through ER increases i.e. the greater water volume is more important than the dilution effect when determining the mass of oxygen (and hence organic carbon) being produced or consumed.

This raises the issue of concentration versus load. A concentration is important to biota in the immediate vicinity (utilizing that oxygen). Two loads that are the same but one has a 10 mg O_2/L concentration and a flow of 1000 ML/Day will provide a healthy environment for a fish (ignoring other factors affecting fish health) yet the same load constituted of 1 mg O_2/L DO and 10,000 ML/ Day could be fatal if the fish cannot find safe (higher DO) refuge. The load is important as the mass of material (in this case, Oxygen) transported downstream. This could for example determine the total amount of oxidation that the water body could perform.

C.3.4 Investigating the Basal Drivers for Metabolism

As noted in previous annual reports, primary production is expected to depend upon temperature and light (PAR) while respiration is also expected to increase with increasing temperature. Consequently, linear regressions were performed between the two metabolic parameters and the anticipated explanatory variables. The results of these regressions are presented in Table C-5.

As expected, GPP and ER daily rates were positively correlated with mean daily water temperature (Table C-5), with the exception of GPP at Loch Garry and Darcy's Track where no statistically significant relationship was found (this lack of a statistically significant relationship at Loch Garry was also found in years 1 and 2). Figure C-10 represents this relationship across the three years of data at McCoy's Bridge. Despite a significant amount of variability with individual points, the slopes of the linear trend-lines for each year are remarkably consistent.

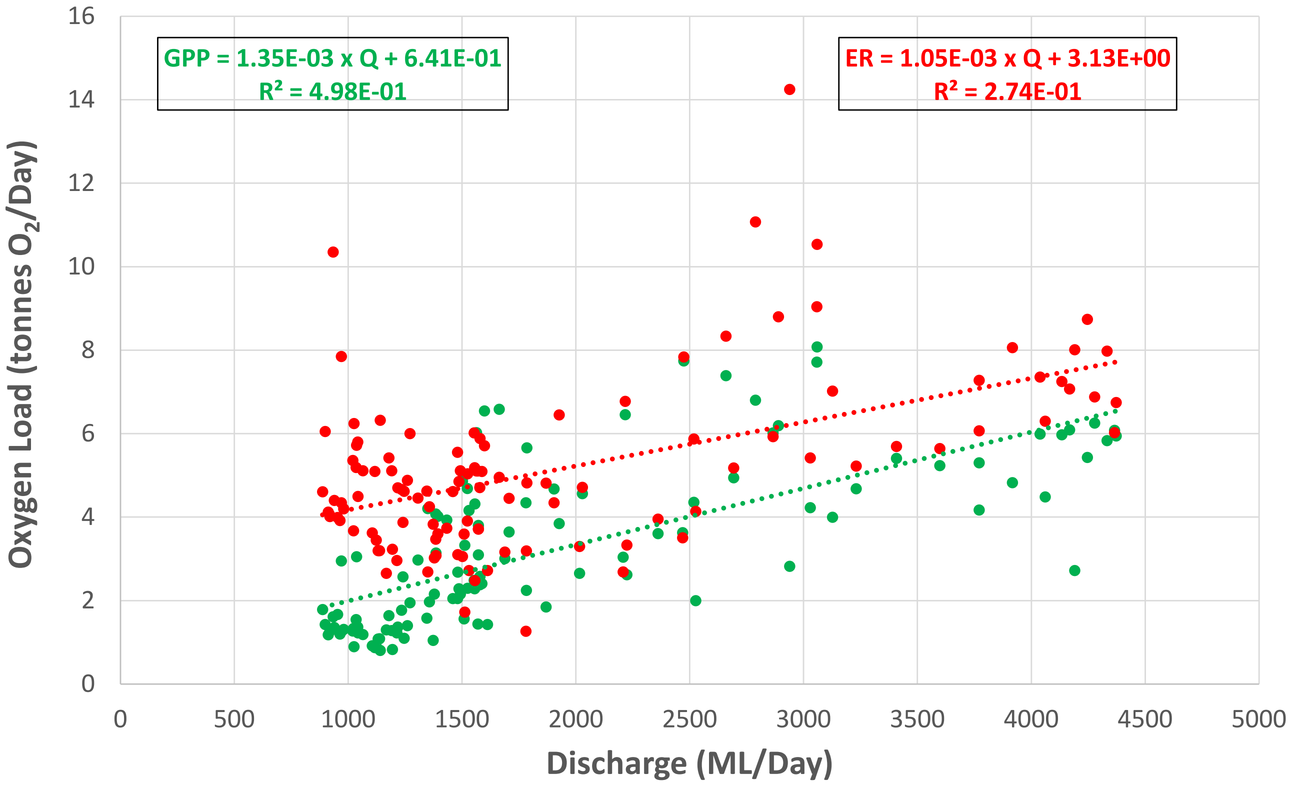


Figure C-9. Mean daily oxygen production created by photosynthesis (GPP, green points and trendline) and consumption through aerobic respiration (ER, red points and trendline) over the period November 2016 to April 2017.

Table C-5. Exploration of Linear Relationships between the metabolic parameters (GPP and ER) and Light and Temperature for the four study sites, Nov 2016 - Apr 2017. Statistical significance was inferred at $p < 0.05$.

Site		GPP vs Temp	GPP vs Light	ER vs Temp	Temp vs Light
Loch Garry	r^2	0.002	0.041	0.44	0.051
	p	0.73	0.09	< 0.001	0.06
	slope	-	-	0.77	-
McCoy's Bridge	r^2	0.076	0.15	0.27	0.42
	p	< 0.001	< 0.001	< 0.001	< 0.001
	slope	0.049	0.10	0.19	0.42
Darcy's Track	r^2	0.04	0.19	0.45	0.04
	p	0.15	0.001	< 0.001	0.15
	slope	-	0.35	0.79	-
Day's Rd	r^2	0.23	0.074	0.26	0.002
	p	< 0.001	0.016	< 0.001	0.71
	slope	0.55	0.31	0.96	-

Although there was also a large degree of variability (scatter) in the regression plots of GPP versus total daily light ($Es/m^2/Day$) shown in Figure C-11, there was positive slope to the regression for each of the three years displayed. As long as there are sufficient concentrations of bioavailable nutrients, then an increase in light should result in higher GPP. If nutrients are limiting growth then an increase in light will result in no further increase in GPP. It is considered very unlikely that, apart perhaps from very shallow marginal zones, light in the water column or at the benthic surface would be sufficient to engender significant photoinhibition. Unsurprisingly, plots of Light versus Water Temperature were strongly positively correlated. 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 into account this covariance.

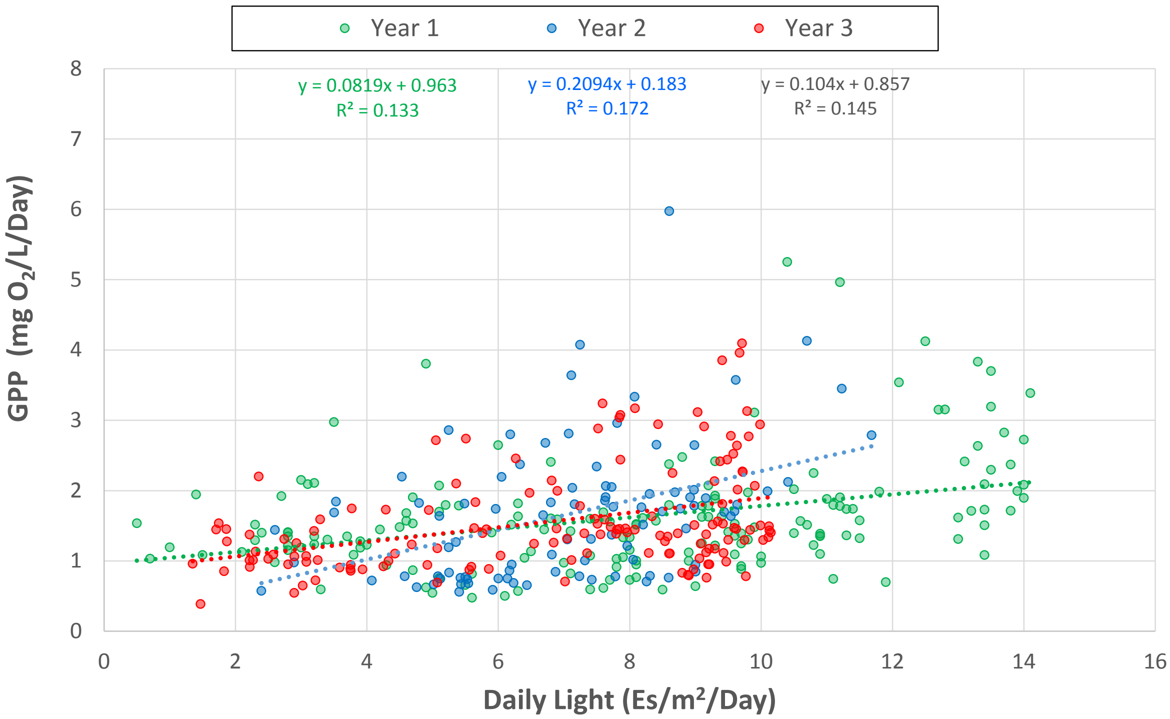


Figure C-10. The Relationship between Daily Gross Primary Production and Average Daily Water Temperature at the McCoy's Bridge site over the three year period of record for LTIM.

As found in previous years, as the sampling period progressed from spring into summer, GPP rates generally increased due to a combination of longer days (more sunlight) and warmer temperatures. Rates then declined during March, into April and then May. This is best exemplified by the decline in GPP and ER rates at McCoy's Bridge (Figure C-7, Figure C-8). A key point is that although the GPP rates varied with time (season) and location, the magnitude of the variability was very small. Rates were constrained within a narrow range (Table C-2).

Nutrient concentrations from the four sites were determined on the samples that were collected approximately monthly during the DO probe deployment, downloading and maintenance. These data are presented in Table C-6. Also included in the table are data from the long term monitoring program at McCoy's Bridge (DELWP 2015). Dating back to 1990, data was collected weekly up until December 2013, when monthly sampling was instituted. The key finding from Table C-6, is that, consistent with 2014-15 and 2015-16, the concentrations of bioavailable nutrients in the Goulburn River at all 4 sites are very low. In particular, the bioavailable phosphorus concentration FRP, is consistently below 0.01 mg P/L with a couple of exceptions 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, which by necessity is during low flow periods. As noted above, the only values of elevated FRP were measured at McCoy's Bridge in September 2016 (during the high water event) and in November.

It is interesting to note that the nitrate concentrations at Day's Rd were on average much higher than the other sites, indicating that the outflow from the Goulburn Weir is a source of nitrate (but certainly not phosphate). This nitrate was often largely consumed by the time water reaches Darcy's Track and definitely by Loch Garry. As noted with FRP, elevated nitrate concentrations were associated with the high flow event and persisted through November. It is likely this nitrate loss is due to both denitrification by sediment bacteria and assimilation of the nitrate into plant material (algae, macrophytes).

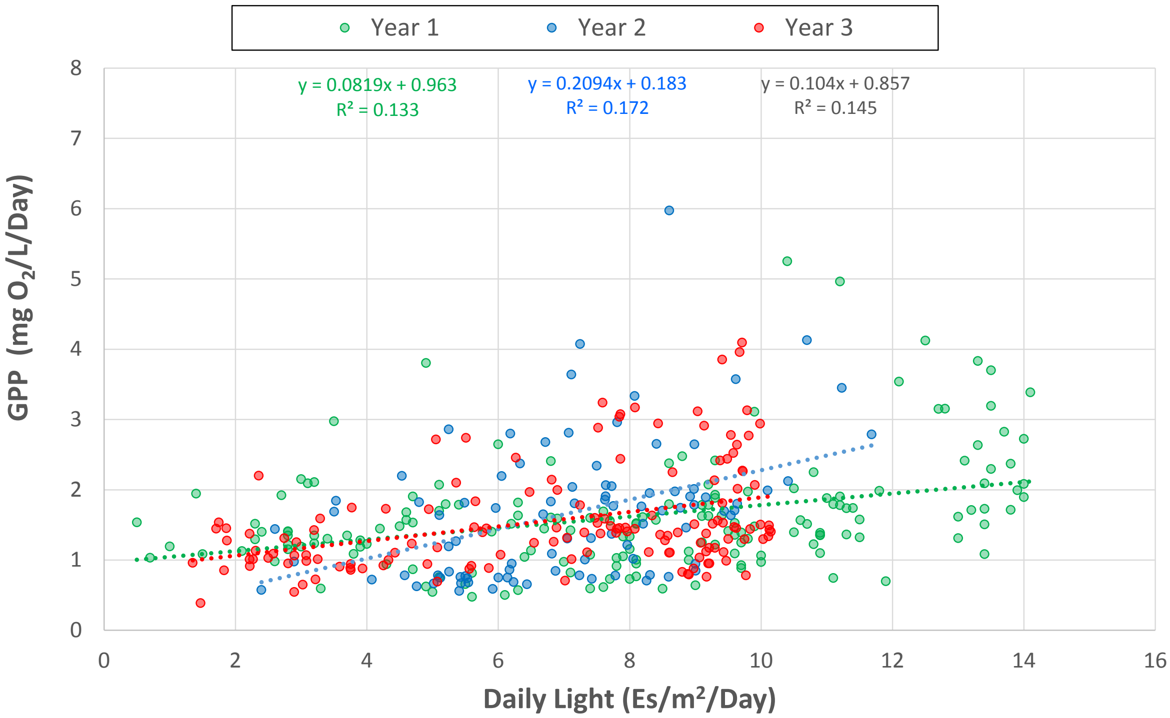


Figure C-11. The Relationship between Daily Gross Primary Production and Total Daily Light at the McCoy's Bridge site over the three year period of record for LTIM.

C.3.5 Organic carbon production and consumption per km of stream reach

A new way to examine the ecological benefits arising from watering actions on metabolic rates is to estimate the amount of organic carbon produced per day (via GPP) over a stream reach of a particular length. The calculation is conceptually simple: it involves multiplying the daily rate of GPP (or ER) in mg O2/L/Day (equivalent to g O2/m3/Day) by the cross-sectional stream area for that daily discharge at the gauging station (unit = m2). A conversion factor of 12/32 is used to convert oxygen to (organic) carbon; this is the ratio of the atomic mass of carbon divided by the molecular mass of oxygen gas (O_2). The resultant unit is then g C/m/Day, which is equivalent to kg C/km/Day: the mass of organic carbon produced by GPP (or consumed by ER) per longitudinal stream km per day. This then opens up the possibility of relating this daily food supply per stream km to the viable fish population in that same km. That is for future discussion and modelling.

There is a valid argument that this calculation assumes a 100% efficiency in conversion of oxygen to organic carbon. In reality it is typically around 80-90% efficient. Nevertheless, what we are examining is patterns and responses in organic carbon production associated with changing water levels, hence the exact number is far less important.

Figure C-12 and Figure C-13 display the relationship between stream discharge and the amount of organic carbon fixed per stream km; the second figure is over a smaller discharge range (0-4000 ML/Day) and includes linear fits to the data.

These plots have two major features. Firstly they show that at lower discharges, around 1000 ML/Day, there is a large variation in the amount of organic carbon fixed. This is attributed to seasonal and daily variations in GPP rates brought about by weather, light and temperature conditions on that particular day. The second point is that although there is this variation at a particular flow, in general the amount of organic carbon fixed in that stream reach per day increases with flow from base flow up until about 4000 ML/Day (Figure C-13). At even higher flows the amount fixed stays within the range 40-80 kg org C/km/Day (Figure C-12). **The most obvious and profound conclusion from this data is that there *is* an ecological benefit in even small, in-stream flow increases**. These smaller events result in additional organic carbon being created per stream kilometre. *This is the first time within the LTIM program that benefits of small flow increases have been able to be documented*.

Table C-6. Nutrient (N, P & C) concentrations of water samples collected from the four study sites over the period September 2016 to April 2017. Long term data from McCoy's Bridge are also included. Due to flooding, McCoy's Bridge was the only accessible site for water quality sampling in September 2016.

Site	Date	Total P	Total N	NPOC measured	NH_3	FRP	NOx	Chl-a
		mg/L P	mg/L N	as TOC mg/L-C	mg/L N	mg/L P	mg/L N	ug/L
Darcy's Track	11/18/2016	0.04	0.52	5.2	0.001	0.004	0.088	27
	12/16/2016	0.04	0.34	3.1	0.002	0.002	0.0005	9
	1/25/2017	0.04	0.31	2.9	0.002	0.002	0.0005	10
	2/21/2017	0.03	0.33	2.1	0.003	0.001	0.026	7
	4/11/2017	0.03	0.32	4.2	0.002	0.002	0.061	< 5
Day Rd	11/10/2016	0.03	0.65	6.1	0.012	0.002	0.20	13
	12/22/2016	0.03	0.30	3.3	0.005	0.002	0.050	< 6
	1/27/2017	0.03	0.27	2.9	0.002	0.002	0.002	13
	2/21/2017	0.02	0.27	2.5	0.013	0.001	0.066	6
	4/11/2017	0.03	0.31	4.5	0.004	0.003	0.084	6
Loch Garry	11/4/2016	0.06	0.81	29	0.001	0.002	0.065	24
	12/16/2016	0.06	0.44	4.8	0.001	0.003	0.0005	< 9
	1/25/2017	0.06	0.39	4.3	0.0005	0.003	0.0005	< 7
	2/21/2017	0.04	0.32	5.5	0.0005	0.001	0.0005	< 9
	4/11/2017	0.03	0.29	11	0.001	0.003	0.0005	7
McCoy's Bridge	9/27/2016	0.14	1.6	15	0.067	0.025	0.31	< 6
	11/3/2016	0.13	1.2	9.4	0.020	0.023	0.24	< 9
	12/16/2016	0.06	0.51	5.5	0.003	0.003	0.001	< 14
	1/27/2017	0.07	0.39	4.0	0.003	0.003	0.0005	< 11
	2/21/2017	0.04	0.35	2.9	0.002	0.002	0.0005	< 10
	4/11/2017	0.03	0.25	5.0	0.002	0.003	0.001	7
Long Term Mean	*Oct 2004*	0.067	-	6.9	-	0.008	0.133	
Long Term Median	*to*	0.059	-	5.0	-	0.004	0.050	
n	*Apr 2015*	493	-	456	-	493	493	

It is anticipated that this analysis will become more sophisticated over the next few years as using GPP rates adjusted for e.g. daily weather will allow better evaluation of the specific effects of flow. Figure C-13 also shows that there is a different positive response depending on the year. Whether this is due to the availability of data (e.g. almost no spring time data in year 3) or biogeographical/climatic differences across years should become more obvious.

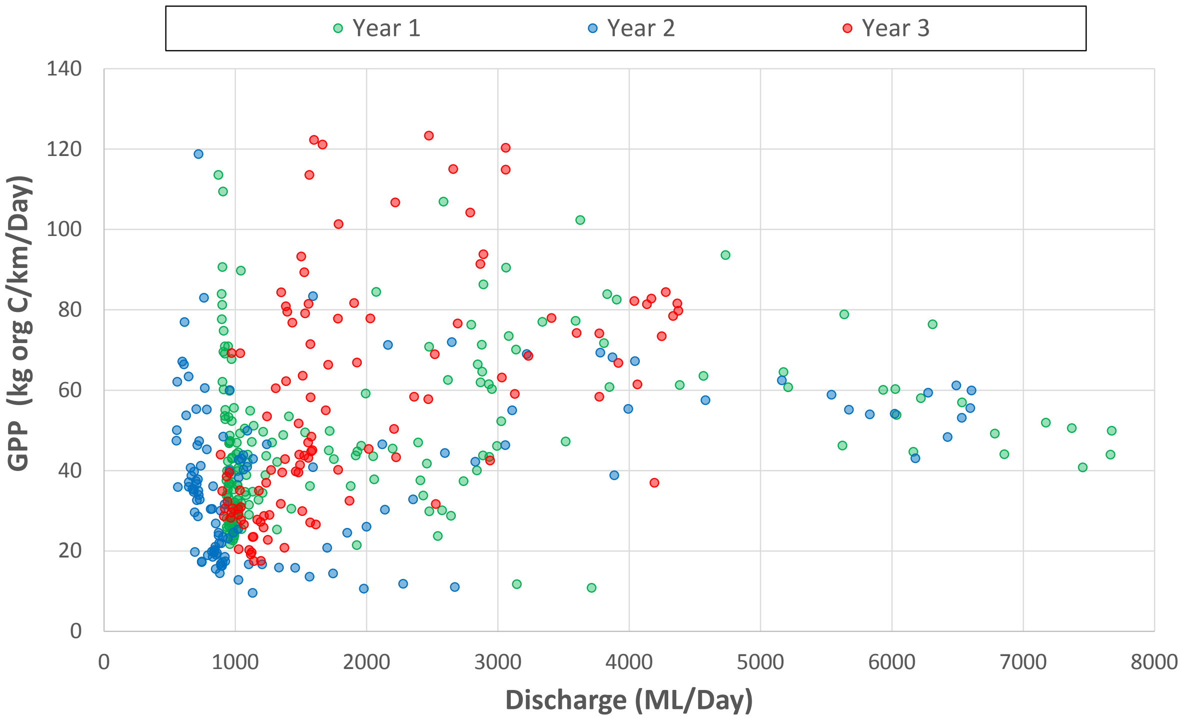


Figure C-12. The Relationship between the amount of organic carbon created in a 1 km stream reach by photosynthesis and stream discharge. The data presented here is from all data collected at McCoy's Bridge that met the acceptance criteria for GPP in BaseV2.

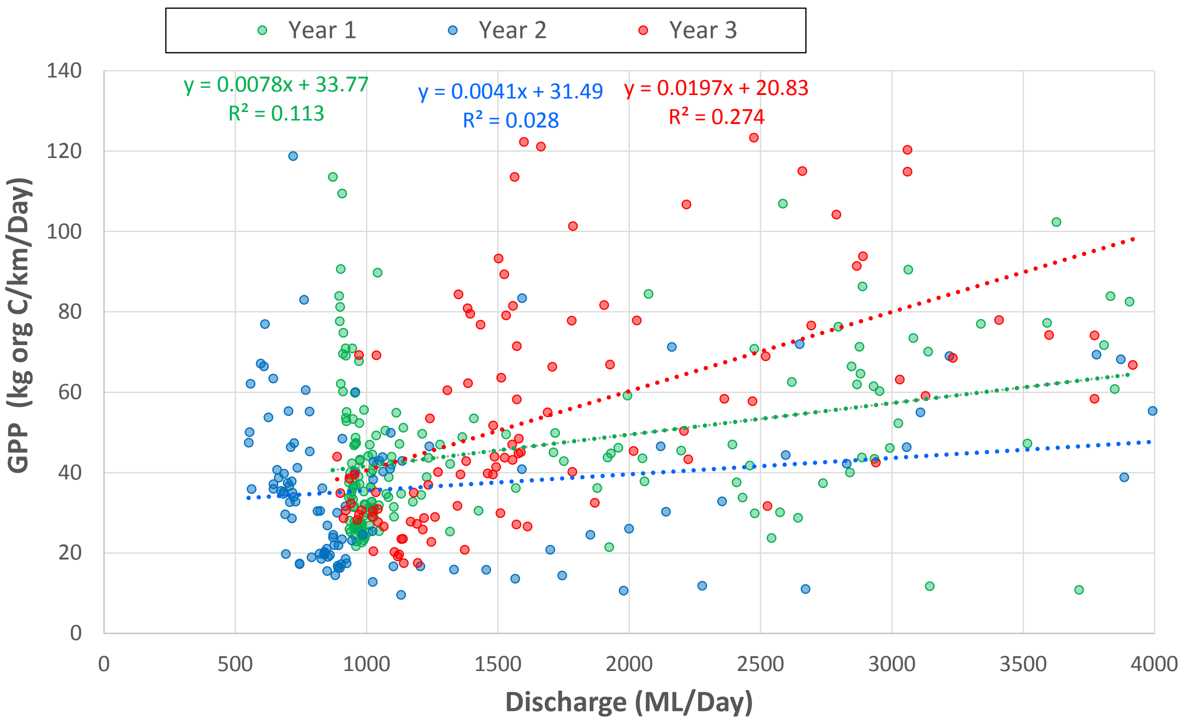


Figure C-13. The Relationship between the amount of organic carbon created in a 1 km stream reach by photosynthesis and stream discharge up to 4000 ML/Day. The data presented here is from all data collected at McCoy's Bridge that met the acceptance criteria for GPP in BaseV2. The linear trend-lines and equations match the colour coding of the years.

C.3.6 Temporal lag between flow and stream metabolism

Two major modelling activities were performed with the stream metabolism data from 2016-17: i) Modelling Flow and Temperature versus metabolic responses (as per 2015-16), specifically examining the role of higher flows resulting from environmental watering including watering actions and natural flow events by contrasting with the counterfactual; and ii) Modelling Light, Temperature and Velocity versus metabolic responses. The purpose was to provide a more sophisticated data treatment, including allowing for multiple factors and autocorrelation, than was presented in the simple linear regressions described above. Both approaches have their benefits, so both are presented. An important difference between the approach used here and the single factor linear regressions in Section C3.4 is how "statistical significance" is established. With the linear regressions, it is the typical $p < 0.05$ for the slope term. With this Bayesian modelling, the 95th percentile confidence interval (between 2.5% and 97.5%) should not include 0. If 0 falls within the confidence interval, the regression is considered non-significant.

C.3.6.1 Effects of Discharge and Temperature on GPP and ER rates

Figure C-14 displays the outcomes from the Bayesian modelling of GPP and ER versus environmental flows (including watering actions). See Section C2.1 for details of how this modelling was performed. This analysis shows that watering actions (and other elevated flow events) are not having a significant effect on the rates of either GPP or ER (the 95th confidence intervals include 0). A similar plot for NEP (not shown) has the same finding.

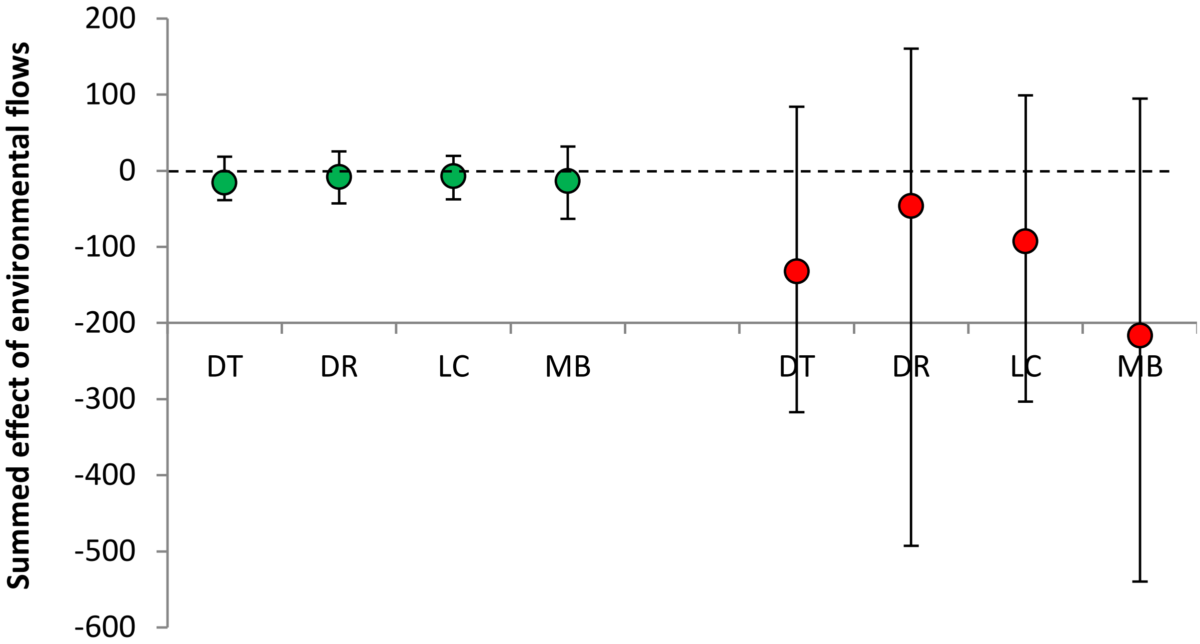


Figure C-14. Effects of Environmental Flows (inc watering actions) on rates of GPP (green points) are ER (red points). The error bars represent the 95% confidence intervals. DT = Darcy's Track, DR = Day Road, LC = Loch Garry, MB = McCoy's Bridge.

Although there were no statistically significant effects of enhanced flows on GPP and ER, all median values (the coloured circles) were below zero, suggesting a suppression of metabolic rates with increased flow. Other metrics for assessing effects of elevated flows will be examined in years 4 and 5 e.g. repeating this analysis with oxygen loads or organic carbon per stream kilometre (from GPP and ER).

C.3.6.2 Effects of Light, Temperature and Water Velocity on GPP and ER rates

The effect of introducing a lag phase into the potential relationship between water velocity and metabolism was explored. The lag is the number of days from the mean velocity reading on Day 0 to the values for GPP and ER on day X. The optimal lag was determined as the lag at which the coefficient of variation of effect of mean channel velocity (mean across all four sites) is at a minimum. The results of this modelling are shown below in Table C-7.

Table C-7. Coefficients of variation in the relationships between mean water velocity and the rates of GPP and ER as a function of lag (in days).

	GPP CV (%)	ER CV (%)
Lag	**Mean**	**Mean**
0	167.8	156.0
1	211.2	145.9
2	168.5	202.4
3	521.6	185.0
4	317.9	168.0
5	757.6	158.0
6	185.4	136.5
7	410.0	159.1
8	2985.7	131.9
9	636.0	124.8
10	216.7	115.0
11	208.9	109.8
12	275.8	104.6
13	225.0	100.8
14	239.4	99.3
15	230.1	97.2
16	241.2	97.4
17	222.6	91.7
18	240.3	91.0
19	210.4	91.4
20	**79.9**	**83.1**

The results shown in Table C-7 indicate that the 'best' model has a lag of 20 days between the measurement of water velocity and the estimates of both GPP and ER. In the case of GPP, the 20 day lag model was greatly superior to all others tested. A lag of 20 days was also best for modelling ER but the differences with other days is far less pronounced. A 20 day lag can be rationalized in terms of time needed to build up populations of primary producers for GPP, but is much harder to rationalize for ER where microbial communities can change in numbers very rapidly in response to (for example) influx of labile organic carbon.

Table C-8 uses the Bayesian model described in Section C2.1 to investigate relationships between GPP or ER and Total Daily Light and Average Daily Water Temperature. A key feature of this model compared to single linear regressions is the incorporation of temporal autocorrelation.

Table C-8. Regression coefficients from Bayesian modelling of relationships between discharge and GPP or ER. Bolded values represent regressions significantly different from 0. ρ is the coefficient of the autocorrelation term.

	GPP vs Light			**ER vs Light**		
	2.5%	median	97.5%	2.5%	median	97.5%
Day Road	0.08	0.15	0.22	0.01	0.14	0.28
Darcy's Track	0.05	0.09	0.13	-0.07	0.01	0.09
Loch Garry	0.05	0.10	0.15	-0.12	-0.02	0.09
McCoy's Bridge	0.04	0.07	0.11	-0.16	-0.09	-0.02
ρ	0.75	0.80	0.85	0.83	0.88	0.94
	GPP vs Temperature			ER vs Temperature		
	2.5%	median	97.5%	2.5%	median	97.5%
Day Road	0.03	0.12	0.28	0.17	0.29	0.65
Darcy's Track	0.01	0.09	0.19	0.13	0.24	0.38
Loch Garry	-0.02	0.05	0.12	0.11	0.21	0.29
McCoy's Bridge	-0.01	0.05	0.10	0.13	0.22	0.30
ρ	0.72	0.78	0.85	0.75	0.81	0.88

Unsurprising perhaps, the findings shown in Table C-8 are in good agreement with those presented from the single factor regressions in Table C-5, albeit with some differences. In the single factor models, no significant relationship was found between GPP and Light at Loch Garry, no significant relationship was found between GPP and Temperature at Darcy's Track and a significant relationship was found between the same two parameters at McCoy's Bridge. There was significant autocorrelation for all relationships except between GPP and Temperature. This autocorrelation is interpreted as the previous day's conditions influencing GPP or ER. This could readily be mediated though current populations of primary producers for example.

As noted above, these relationships are expected due to the extremely well-known effects of light on GPP and of temperature on both GPP and ER. No major ecological significance is attached to the positive (Day Road) and negative (McCoy's Bridge) regression coefficients for the effect of light on ER. Increasing light can induce greater GPP (as already demonstrated here) and in turn, higher GPP can result in elevated ER through such factors as enhanced algal exudates which then fuel microbial respiration.

C.4 Discussion

Rates of GPP and ER were constrained within a fairly narrow range throughout 2016-17. Median rates from each site were very similar suggesting no major geographical effect. The one partial exception to this generalization was the higher median rates of ER and reaeration at the Day Road site. This is almost certainly due to the influence of the Goulburn Weir on reaeration and probably a slightly elevated supply of labile organic carbon from the Nagambie Lakes. The other major spatial discontinuity in the data occurred in early January 2017 when a black-water event in the Pranjip/Sevens/Broken system resulted in severely depressed oxygen readings from Darcy's Track downstream, yet Day Road continued to experience typical mid-summer rates. These very low dissolved oxygen concentrations (almost anoxic at times) persisted for several days at each site before being washed downstream. The downstream water movement can be tracked by the passage of the low dissolved oxygen front. DO was certainly low enough to pose a critical risk to biota that could not escape.

The small but important event in January was preceded of course by the major flooding in Spring 2016. This precluded collection of metabolism (and water quality) data due to site inaccessibility. Data was lost from the in situ McCoy's Bridge logger as it could not be downloaded and the batteries replaced in time. The data that was available was generally not conducive to modelling using BASEv2 due to the lack of any appreciable increase in

%DO saturation during the daytime. All other metabolism models would suffer the same fate as they rely on a response in dissolved oxygen to daylight.

The data presented in Figure C-3 to Figure C-6 did not indicate a strong relationship between GPP and flow events. It is clear however that the immediate effect of a flow pulse 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 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. The relationship between GPP (and ER) with velocity as a surrogate for discharge suggested the largest response in GPP and ER occurred with a lag of 20 days. This was the longest lag investigated and perhaps needs to be extended even further (a lag of 0-10 days was modelled in 2015-16). However, finding ecological relevance of very long lag phases seems to be a fraught task. An alternative approach of considering antecedent conditions prior to an event will be considered. It is quite reasonable to surmise that a second event of similar magnitude following reasonably shortly after a first one would have a much smaller effect as nutrients and organic carbon would have already been washed into the main channel and would not have had time to re-establish before the next event.

It is extremely likely that the absence of significant growth of primary producers, manifest in the constrained rates of GPP, 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 did seem to increase 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.

Comparison of the three years of data at McCoy’s Bridge did show that GPP especially and ER to a slightly lesser extent behave in a reproducible fashion across the year, peaking in value in late January-early February after rising through summer. Flow spikes induced immediate decreases in GPP and ER through dilution as noted above. Consideration of the similarity in GPP patterns across the years will enable better estimates of counterfactual conditions (i.e. what would the GPP value be if that higher discharge hadn’t occurred at that time). Another outcome of this type of analysis is that the large flood hydrograph did not appear to have any extended effect on rates of GPP or ER when considering the actual rates of these two processes as the parameter of interest.

Moving beyond the rates of GPP and ER, we have used two additional metrics to investigate the influences of flow increases (including watering actions) on stream ecosystem functioning: i) the load (mass) of oxygen created by GPP and consumed by ER, and ii) the mass of organic carbon created or consumed by the same processes on a per kilometre stream reach basis. Both of these metrics indicated that flow increases, even if they are constrained within the river channel, can have a positive effect on food and nutrient resource availability for higher levels of the food chain. This is a major change in perspective from earlier reports where it was written that there is relatively little benefit in adding water to the Goulburn River if the water does not get into backwaters, flood-runners and even the floodplain. There clearly IS an ecological benefit in adding more water, even relatively small amounts when upstream water availability might be constrained by other needs and considerations. The reconnection of backwaters and flood-runners should however still be an ecologically beneficial target for watering actions.

Appendix D. Detailed results for Macroinvertebrates

D.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 the lower Goulburn River, macroinvertebrate responses have been measured to increase our understanding of how Commonwealth environmental water (CEW) affects these organisms. The aims of the macroinvertebrate monitoring program are to answer the following questions:

- What did Commonwealth environmental water contribute to macroinvertebrate diversity and abundance in the lower Goulburn River? Specifically, what combination of freshes and low flows are required to maximise macroinvertebrate abundance and biomass in the river?
- What did Commonwealth environmental water contribute to macroinvertebrate emergence in the lower Goulburn River?

Above average rainfall conditions, including record wet weather, during winter and spring of 2016 resulted in elevated water levels in the lower Goulburn River and its tributaries (BoM 2017). This included moderate flooding, overbank flows and reconnection of riparian wetlands to the river channel. As a result, Commonwealth environmental water was not delivered as a spring fresh and the macroinvertebrate monitoring program was adjusted to meet these altered conditions

D.2 Methods

The methods used for monitoring macroinvertebrates are given in Webb et al. (2014), with modifications described in Webb et al. (2017). Briefly, three methods were employed at two sites in the region: the impacted site (Goulburn River at McCoys Bridge) and the control site (Broken River at Shepparton East). The first method used artificial substrates (adapted from (adapted from Cook et al. 2011), which are plastic mesh cylinders containing an artificial substrate (onion bags) that are deployed at each site for four to six weeks, allowing macroinvertebrates to colonise these during that time. The second method involves conducting Replicated Edge Sweep Sampling (RESS) at each site. This method is modified from that of Gigney et al. (2007a, 2007b) and involves taking five replicate sweep samples across the different types of edge habitat at each site. The third method involves measuring the presence and abundance of insects and other arthropods in the riparian habitat at each site by deploying yellow sticky traps over a week. Monitoring typically occurs before Commonwealth environmental water delivery (usually a spring fresh) and after environmental water delivery for each method. However, the normal sampling protocol could not be conducted in 2016-17 and instead an adaptive monitoring approach was applied.

Due to above average rainfall conditions and moderate flooding during winter and spring of 2016, Commonwealth environmental water was not delivered as a spring fresh and the macroinvertebrate monitoring program was adjusted to meet these altered conditions. Pre-fresh monitoring could not be conducted due to safety and site access issues while river heights were elevated. Instead, only post-fresh (or in this case, “post-flood”) sampling was conducted.

It was observed that crustacean abundances in RESS samples appeared greater than in previous years, so a decision was made to re-allocate the resources from pre-fresh sampling to monitor this increase in productivity. To achieve this, 20 bait traps were used monthly from December to March and were deployed overnight at two sites on the Goulburn River (Loch Garry and McCoys Bridge). At each site, the bait traps were divided among four habitat types (bare, coarse organic particulate matter/depositional areas, macrophytes and snags) to determine if crustacean abundance was affected by habitat. Upon retrieval, all crustaceans were removed from the bait traps and stored in 100% ethanol, with the exception of yabbies (*Cherax* sp.), which were counted, weighed and released back into the river. The preserved crustaceans 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, then dried in the oven at 60°C for a further 24 hours before being weighed so that biomass could be calculated. Additional RESS samples were taken from both Loch Garry and McCoys Bridge when bait traps were being retrieved. These samples were preserved in 100% ethanol and crustaceans were picked from these in the laboratory. Crustaceans from RESS samples were also identified, measured, dried and weighed for biomass.

It should be noted that significant rainfall in the Goulburn and Broken River catchments during late December resulted in significant volumes of organic-rich water entering the lower Goulburn River downstream of Goulburn weir. This blackwater caused dissolved oxygen levels to plummet, with stressed and dying aquatic organisms (fish and crustaceans) noticed within Shepparton and further downstream. Although environmental water was released to alleviate the issues caused by blackwater, it is likely the blackwater event impacted macroinvertebrate responses in January and potentially in later months. The timing of monitoring, along with significant events in the catchment, are given in Table D-1.

Table D-1. Macroinvertebrate sampling times and significant events in the Goulburn River and Broken River during 2016-17 compared to previous years. CEW = Commonwealth Environmental Water delivered as spring freshes. BR = Broken River at Shepparton East; GM = Goulburn River at McCoys Bridge; GL = Goulburn River at Loch Garry.

		Sampling dates						
Activity/event	Sites	September	October	November	December	January	February	March
Natural events		Elevated flows	Elevated flows		Elevated flows and blackwater (late December)	Elevated flows and blackwater (early Jan)		
RESS	GM			Post-flow 24/11				
	BR			Post-flow 25/11				
Artificial substrates	GM			Post-flow deployed 24/11		Post-flow retrieved 10/1		
	BR			Post-flow deployed 25/11		Post-flow retrieved 11/1		
Yellow sticky traps	GM			Post-flow deployed 24/11	Post-flow retrieved 2/12			
	BR			Post-flow deployed 25/11	Post-flow retrieved 2/12			
RESS (crustaceans)	GM, GL				Conducted 21/12	Conducted 24/1	Conducted 24/2	Conducted 25/3
Bait traps	GM, GL				Overnight 20/12 – 21/12	Overnight 23/1 – 24/1	Overnight 23/2 – 24/2	Overnight 24/3 – 25/3
Previous years								
RESS	BR, GM	Pre-CEW			Post-CEW			
Artificial substrates	BR, GM	Pre-CEW deployed		Pre-CEW retrieved	Post-CEW deployed	Post-CEW retrieved		
Yellow sticky traps	BR, GM	Pre-CEW deployed and retrieved		CEW deployed and retrieved	Post-CEW deployed and retrieved			

D.2.1 Data analysis

Data from 2016-17 were only compared to data from post-flow sampling in previous years. Macroinvertebrate abundances and biomass from the artificial substrates, along with biomass from RESS samples, were modelled as a linear function of flow within a Bayesian framework. The model is structured as follows:

where yi~norm(mui,tau)

mui = int + eff.Q * Qi + eff.River[Riveri]

The abundance of macroinvertebrates (y) for artificial substrate i has a normal distribution with an expected value of mui and precision of tau. mui is modelled using a linear function and is driven by the global intercept (int), and the median flow in the previous three months before sampling, normalised by the river's bankfull flow rate (Qi). In addition, there is a random effect of the river in which the artificial substrate was placed.

When modelling biomass as a function of flow, yi represents the log-transformed biomass in either artificial substrate i or reef edge sample i.

The models for both macroinvertebrate biomass and abundance were implemented in OpenBUGS version 3.2.1 (Lunn et al. 2009), using the R2OpenBUGS package (Sturz et al. 2005) in R (R Development Core Team 2010). Three independent Markov chains were used to confirm convergence of chains during model burn-in. Different burn-in periods were employed for different models, with the criterion for establishing convergence being an Rhat value of approximately 1 (Sturz et al. 2005). Different periods were also used for parameter estimation, based upon autocorrelation within the Markov chains. The abundance model was implemented separately for families or species of macroinvertebrates.

Data from other components of the project were visually compared to data from previous years.

D.3 Results

D.3.1 Artificial substrates

Compared to previous years, the diversity (taxonomic richness) of macroinvertebrates in artificial substrates was lower at both sites (Figure D-1a). Similarly, average macroinvertebrate abundance was much lower in the Goulburn River at McCoys Bridge than in previous years, while it was higher in the Broken River, though highly variable between substrates (Figure D-1b). There was no linear relationship between macroinvertebrate abundance and median flows for the preceding three months (Figure D-1c).

The effects of flows on the abundances of common taxa were variable and differed between taxa. Midge fly larvae (Family Chironomidae) were among the most common taxa in the artificial substrates. Of these, only one genus, *Rheotanytarsus* sp., showed positive response to increasing flows (Figure D-2a), with the probability that eff.Q value of the model (33.9) was positive 100% of the time (i.e. p.eff.Q = 1.0). This relationship was largely driven by an increase in abundance in the Broken River after the large flows of 2016-17 (Table D-2). In contrast, other Chironomidae had negative relationships with flows. The abundance of *Cladotanytarsus* sp. had a weak negative association with median flows for the preceding three months (Figure D-2b). The eff.Q value (-2.9) in the model of *Cladotanytarsus* sp. abundances and flow was only positive 11% of the time (p.eff.Q = 0.11), indicating the relationship is negative 89% of the time. Similarly, *Tanytarsus manleyensis* abundances were negatively associated with flow (Figure D-2c), with the eff.Q value (-15.2) negative 100% of the time (p.eff.Q = 0, or positive 0% of the time). For both *Cladotanytarsus* sp. and T. *manleyensis*, neither species was present during 2016-17 (the year with the highest median preceding three month flows), which may explain the negative relationship between flows and abundances (Table D-2). There was a strong negative relationship between *Procladius* sp. abundance and the median flow for the preceding three months (Figure D-2d), with the eff.Q term of -26.1 negative 100% of the time (p.eff.Q = 0). The abundance of this genus was much lower in the Goulburn River in 2016-17 than in previous years (Table D-2). *Parakiefferiella* sp. were much less abundant at both sites in 2016-17 than the previous year (Table D-2), resulting in a linear model that showed a negative relationship between *Parakiefferiella* sp. abundance and preceding median flows (Figure D-2e). The eff.Q value (-5.3) in the model for this genus was positive less than 1% of the time; i.e. over 99% of the time the eff.Q was negative (p.eff.Q = 0.009). The abundance of *Cryptochironomus* sp. had no clear relationship with preceding flows (Figure D-2f; eff.Q = -0.7; p.eff.Q = 0.31).

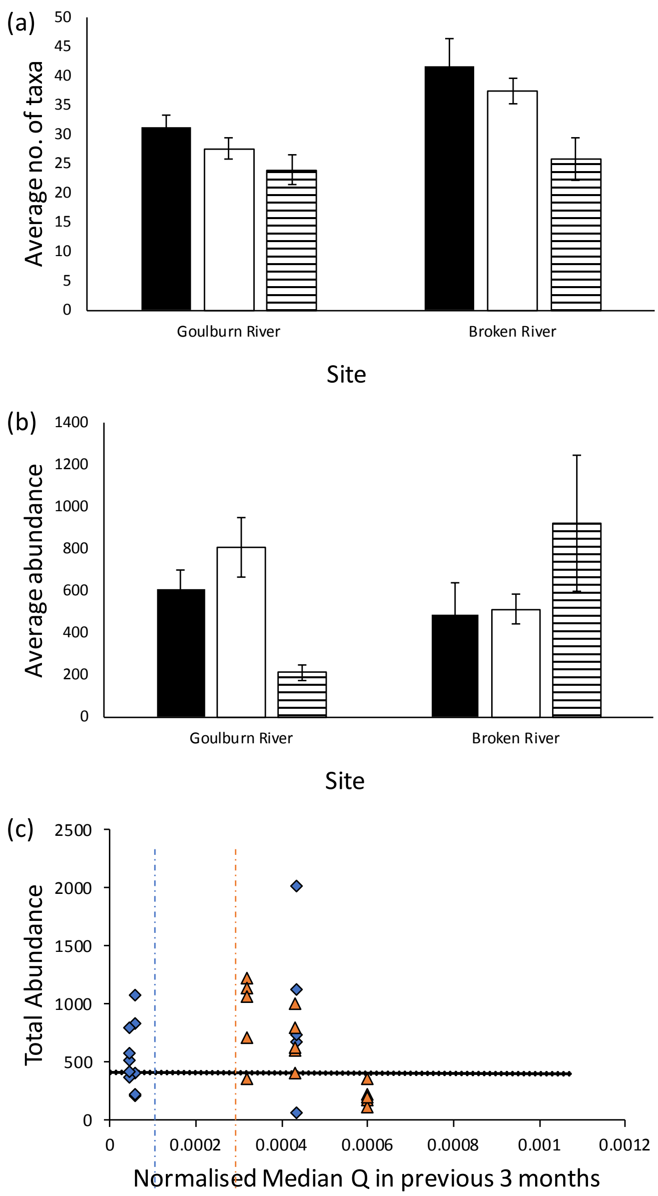


Figure D-1. (a) Average number of taxa, (b) average abundance of macroinvertebrates and (c) modelled linear relationship between macroinvertebrate abundance and normalised median flows (Q; ML/day/m^2) for the three months prior to sampling in artificial substrates deployed in the Goulburn River and Broken River. In the bar charts: black columns = post-CEW spring fresh data from 2014-15; white columns = post-CEW spring fresh data from 2015-16; striped columns = post-spring flood data from 2016-17; error bars = standard error of the mean. For the flow vs abundance plot: blue broken line = Broken River baseflow of 0.000116 ML/day/m^2; orange broken line = Goulburn River baseflow of 0.000289 ML/day/m^2; solid black line = modelled linear relationship between abundance and median Q; black broken lines = 97.5th and 2.5th percentiles; blue diamonds = abundance data from Broken River; orange triangles = abundance data from Goulburn River.

Two species of caddisflies belonging to the genus *Ecnomus* were relatively common. There was a negative relationship between *E. pansus* abundance and the median flow of the previous three months (Figure D-3a), with the probability of the eff.Q value from the model (-25.2) being positive 0% of the time (i.e. negative 100% of the time; p.eff.Q = 0). This was largely due to a decline in the abundance of *E. pansus* in the Goulburn River during 2016-17 (Table D-2). *Ecnomus continentalis* abundance was also negatively associated with increasing median flows for the preceding three month period (Figure D-3b). Here, the eff.Q value from the model (-5.3) was only positive < 1% of the time (i.e. the relationship was negative over 99% of the time; p.eff.Q = 0.009), and the model appeared to be driven by a decrease in *E. continentalis* in the Broken River during 2016-17 when that river experienced large, natural flows (Table D-2).

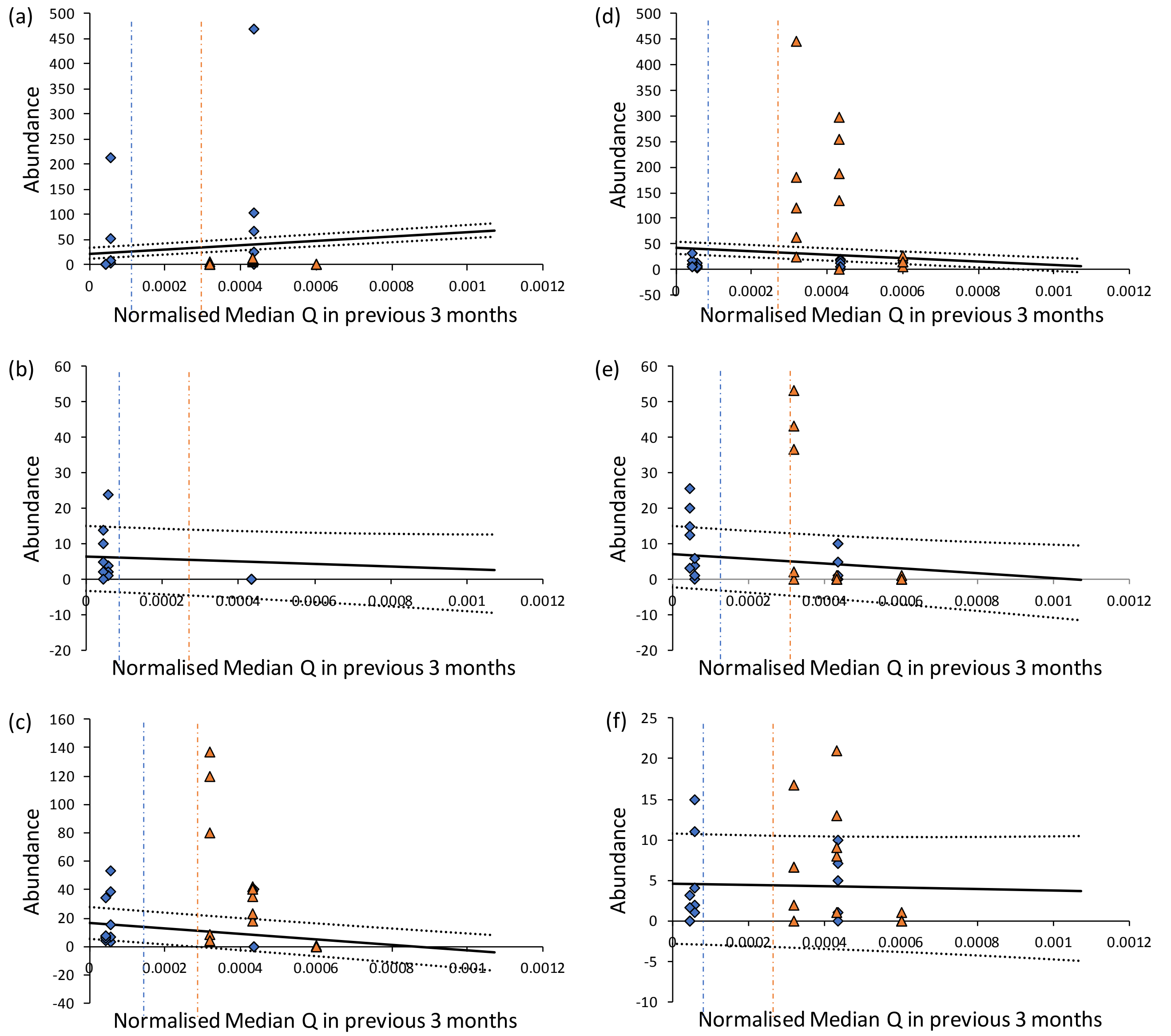


Figure D-2. Modelled macroinvertebrate abundance in artificial substrates compared to the median flow of the previous three months (Median Q; ML/day/m^2) for the Chironomidae (a) *Rheotanytarsus* sp., (b) *Cladotanytarsus* sp., (c) *Tanytarsus manleyensis*, (d) *Procladius* sp., (e) *Parakiefferiella* sp. and (f) *Cryptochironomus* sp. Blue broken line = Broken River baseflow of 0.000116 ML/day/m^2; orange broken line = Goulburn River baseflow of 0.000289 ML/day/m^2; solid black line = modelled linear relationship between abundance and median Q; black broken lines = 97.5th and 2.5th percentiles; blue diamonds = abundance data from Broken River; orange triangles = abundance data from Goulburn River.

Although large macroinvertebrate biomass was reduced in 2016-17 compared to previous years, the results was quite variable between substrates and there was no clear association between median 3 month preceding flows and biomass (p.eff.Q = 0.20, Figure D-4a). The three common groups that dominated large macroinvertebrate biomass (Crustacea, EPT or Ephemeroptera, Plecoptera and Trichoptera, and Odonata) all showed reduced biomass or were absent from artificial substrates in 2016-17 compared to previous years, regardless of site (Figure D-4b-d).

Table D-2. Average abundance (± standard error of the mean) of common taxa caught in artificial substrates in post-flow sampling in the Lower Goulburn River.

		Year		
Taxon	**Site**	**2014-15**	**2015-16**	**2016-17**
Diptera (Chironomidae)				
***Rheotanytarsus* sp.**	Goulburn River	11 (2)	1 (1)	<1
	Broken River	54 (40)	<1	133 (86)
***Cladotanytarsus* sp.**	Goulburn River	29 (7)	5 (4)	0
	Broken River	7(4)	6 (3)	0
Tanytarsus manleyensis	Goulburn River	32 (5)	70 (28)	0
	Broken River	23 (10)	12 (6)	0
***Procladius* sp.**	Goulburn River	175 (52)	167 (75)	17 (4)
	Broken River	7 (1)	14 (5)	11 (4)
***Parakiefferiella* sp.**	Goulburn River	32 (5)	70 (28)	0
	Broken River	23 (10)	12 (6)	0
***Cryptochironomus* sp.**	Goulburn River	10 (3)	7 (3)	<1
	Broken River	7 (3)	1 (1)	5 (2)
Trichoptera				
Ecnomus pansus	Goulburn River	37 (17)	134 (54)	3 (1)
	Broken River	75 (17)	83 (9)	77 (30)
Ecnomus continentalis	Goulburn River	1 (1)	6 (4)	2 (1)
	Broken River	20 (6)	11 (3)	6 (3)

D.3.2 Replicated Edge Sweep Samples

As the methods used in the first year of sampling differed from later years, only the post-flow results from the last two years were compared, and insufficient data were available for robust statistical analyses to be performed. Compared to 2015-16, the diversity (richness) and abundance of macroinvertebrates in RESS samples was much higher in 2016-17 (Figure D-5a,b).

As with the previous year, the responses of individual taxa varied. Some taxa appeared to respond positively to the large flow events of 2016-17 compared to spring freshes in the previous year. For example, the shrimp *Paratya australiensis* was much more abundant in the Goulburn River in 2016-17, and was present in the Broken River (compared to being absent in the previous year) (Figure D-6a). Similarly, the prawn *Macrobrachium australiense* was slightly more abundant in edge samples in 2016-17 than 2015-16 (Figure D-6b). Oligochaeta (worms) also showed a positive response to natural flows at McCoys Bridge, with greater abundance in 2016-17 at this site (Figure D-6c).

The natural flow events appeared to cause a seasonal shift in abundance for some taxa, with the fly larvae *Austrosimulium furiosum*, *Cricotopus parbicinctus* and *Parakiefferiella* sp. appearing in post-flow samples in 2016-17, whereas in 2015-16 they were only present in pre-flow samples and were absent during post-CEW monitoring (Figure D-6d, Figure D-7a,b). Further evidence that the large, unregulated flows of 2016-17 had a different effect on macroinvertebrates that the CEW spring freshes came from the Broken River. This site was affected by the natural events of 2016-17 but did not receive environmental water in previous years. The midge fly larva *Tanytarsus manleyensis* appeared to benefit from the increased flows in Broken River in 2016-17; it was absent from the Broken River in 2015-16 but present this year (Figure D-7c). In contrast, the mayfly *Tasmanocoenis rieki* was adversely affected by conditions in the Broken River, becoming absent from RESS samples in 2016-17 (Figure D-7e). However, it is not clear if this was simply an effect of flows, as its abundance increased in the Goulburn River during this period. The response of the midge fly *Cryptochironomus* sp. was similar to the previous year, remaining absent from the Goulburn River in post-CEW and post-flood samples but increasing in abundance in the Broken River (Figure D-7d).

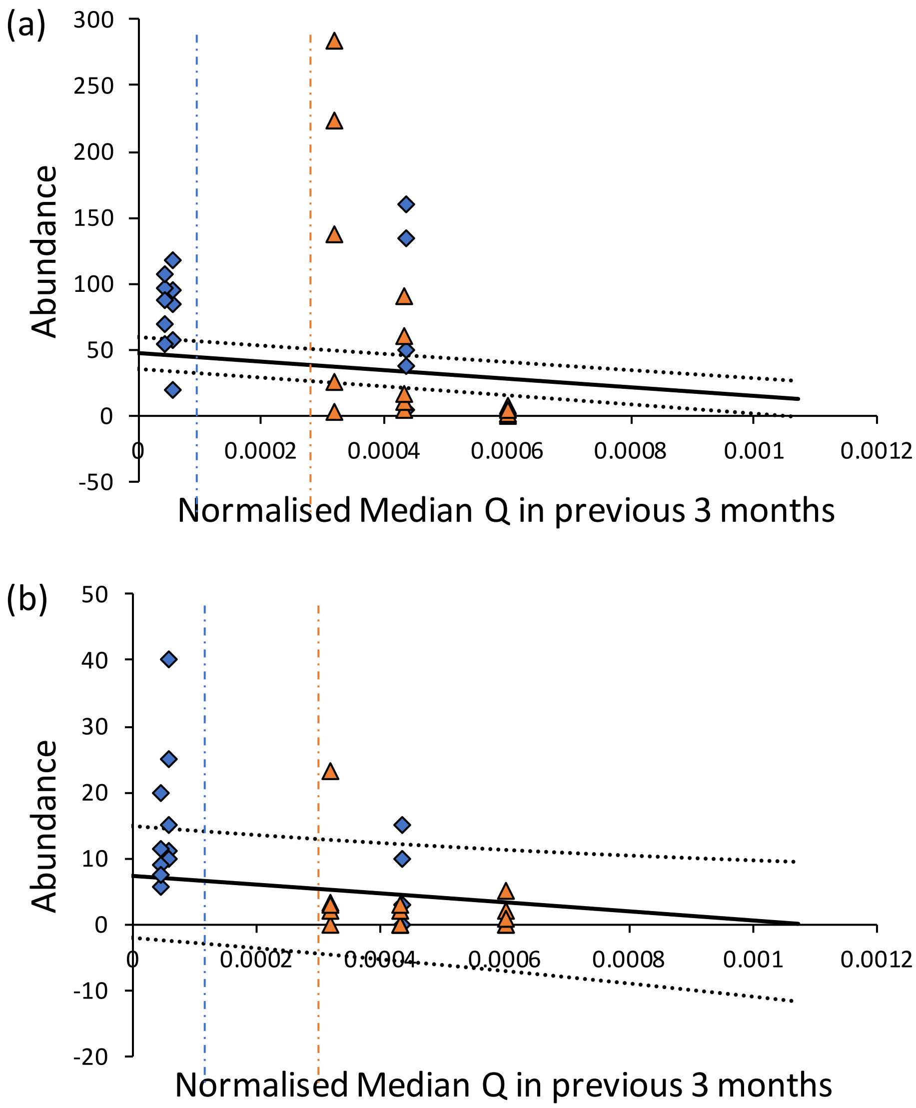


Figure D-3. Modelled macroinvertebrate abundance in artificial substrates compared to the median flow of the previous three months (Median Q; ML/day/m^2) for the Trichoptera (a) *Ecnomus pansus* and (b) *Ecnomus continentalis*. Blue broken line = Broken River baseflow of 0.000116 ML/day/m^2; orange broken line = Goulburn River baseflow of 0.000289 ML/day/m^2; solid black line = modelled linear relationship between abundance and median Q; black broken lines = 97.5th and 2.5th percentiles; blue diamonds = abundance data from Broken River; orange triangles = abundance data from Goulburn River.

There was a positive relationship between macroinvertebrate biomass and flow in the RESS samples (p.eff.Q = 0.99, Figure D-8a). This was evident with an increase in large macroinvertebrate biomass at both sites in 2016-17 compared to the previous year (Figure D-8b, largely due to an increase in crustacean biomass at both sites (Figure D-8c). However, the crustaceans contributing to increased biomass differed between sites. In the Goulburn River, shrimp *P. australiensis* biomass was much greater in 2016-17 than 2015-16 (Figure D-8d). In contrast, prawn *M. australiense* biomass was greater in the Broken River in 2016-17 than the previous year (Figure D-8e). The biomass of EPT was also greater in the Broken River this year (Figure D-8f).

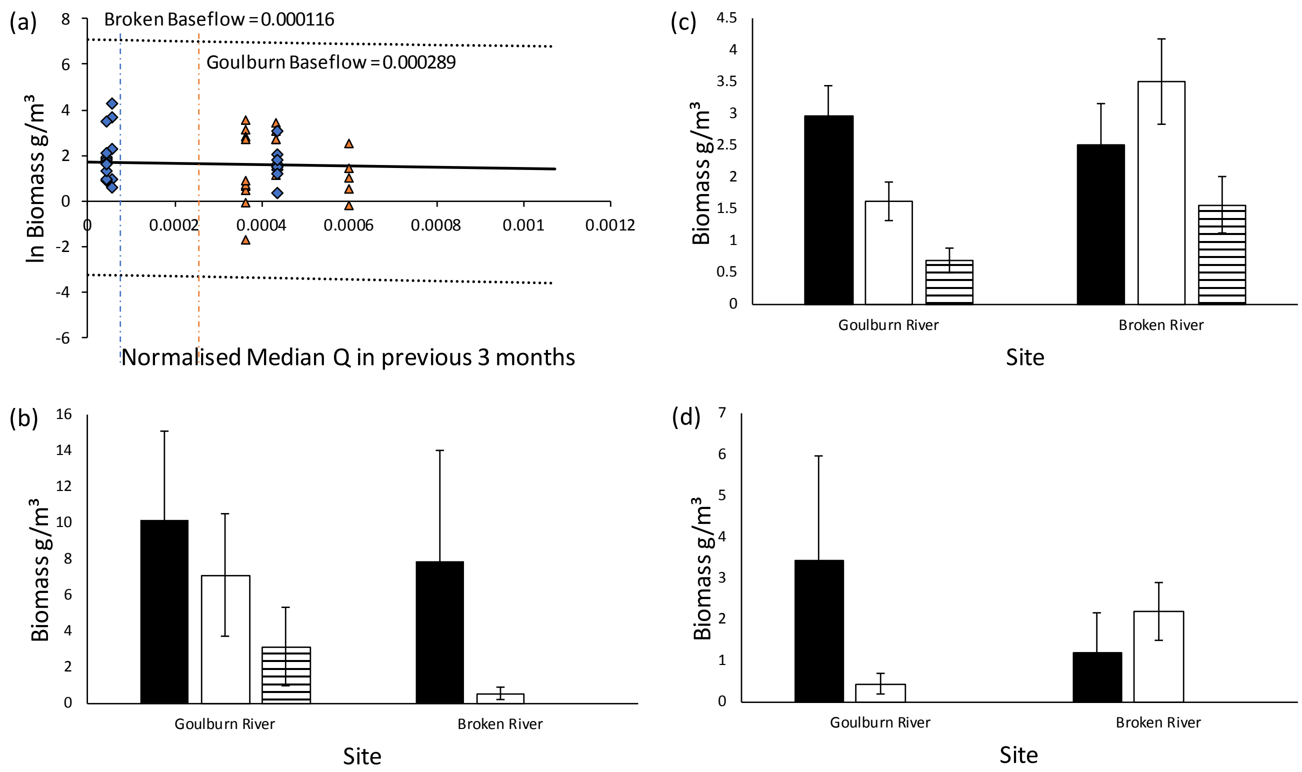


Figure D-4. (a) Modelled linear relationship between large macroinvertebrate biomass and normalised median flows (Q; ML/day/m^2) for the three months prior to sampling in artificial substrates deployed in the Goulburn River and Broken River, (b) average biomass of crustaceans, (c) average biomass of Ephemeroptera, Plecoptera and Trichoptera and (d) average biomass of Odonata in artificial substrates from post-flow sampling only. For the flow vs biomass plot: blue broken line = Broken River baseflow of 0.000116 ML/day/m^2; orange broken line = Goulburn River baseflow of 0.000289 ML/day/m^2; solid black line = modelled linear relationship between biomass and median Q; black broken lines = 97.5th and 2.5th percentiles; blue diamonds = biomass data from Broken River; orange triangles = biomass data from Goulburn River. In the bar charts: black columns = post-CEW spring fresh data from 2014-15; white columns = post-CEW spring fresh data from 2015-16; striped columns = post-spring flood data from 2016-17; error bars = standard error of the mean.

D.3.3 Yellow Sticky Traps

When the yellow sticky traps were deployed in November, 2016, it was observed that debris from the floodwater was stuck on cages at both sites, indicating that water heights during the late winter and early spring flood events were well above bank level. Without the equivalent of pre-CEW and during-CEW sampling conducted in 2016-17, only post-flow sampling was conducted once water levels receded. This was compared to post-CEW data from the previous two years to determine if the effects of large, natural overbank flows on riparian invertebrates differed to that of spring freshes in previous years.

The total abundance of invertebrates caught on the yellow sticky traps compared to post-CEW sampling in previous years did not indicate a strong effect of increasing flows on riparian invertebrates (Figure D-9a). Similarly, the abundances of thrips (Thysanoptera), bugs (Hemiptera) and spiders (Araneae) did not indicate a positive or negative response to the overbank flows of 2016-17 compared to lower flows of previous years (Figure D-9b,e,g respectively). Flies (Diptera) abundances was much higher in riparian habitat near the Goulburn River in 2016-17 compared to previous years, but it is not clear if this was a response to wetter conditions and overbank flows as a similar pattern was not observed at the Broken River site (Figure D-9d). Hymenoptera (wasps, bees and ants) showed similar responses at both sites, with abundances reduced each year of the study (Figure D-9c). Beetles (Coleoptera) appeared to be negatively impacted by overbank flows, with much lower abundances at both sites in the current year compared to previous years (Figure D-9f).

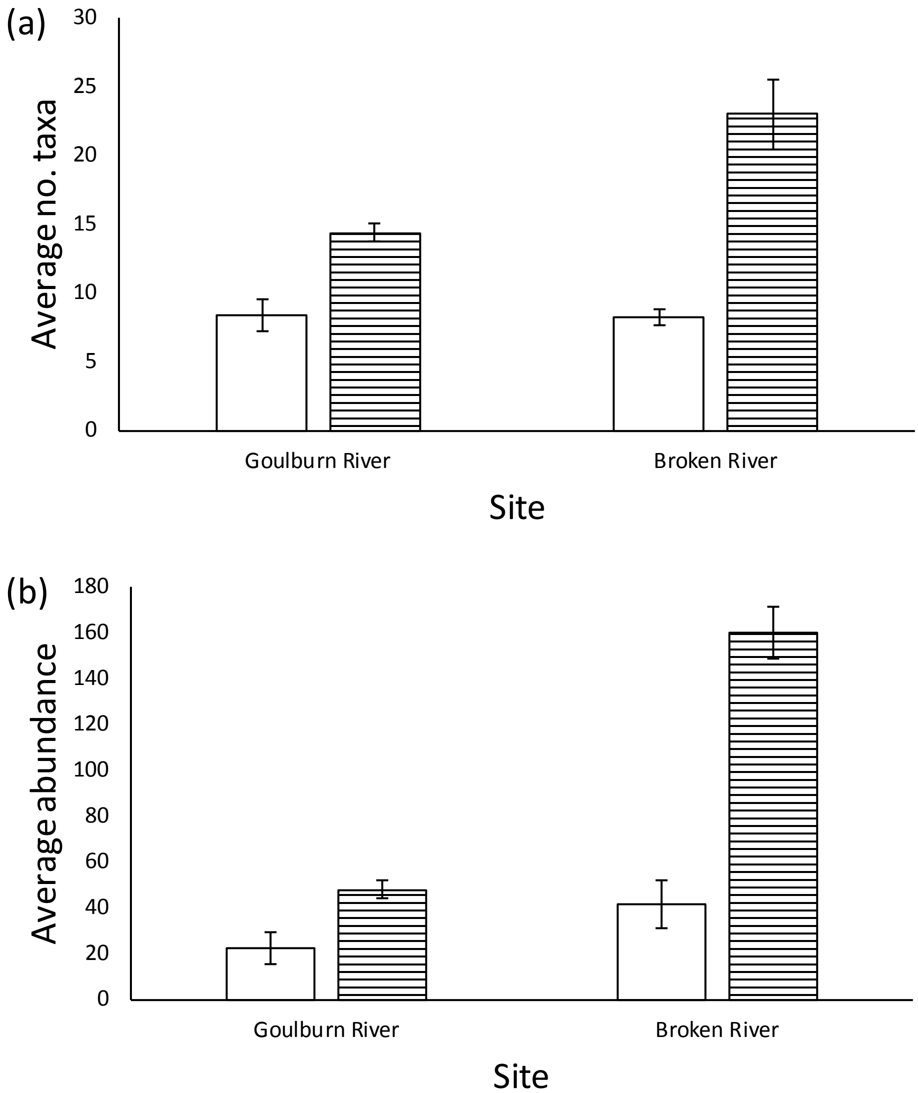


Figure D-5. (a) Taxonomic richness and (b) macroinvertebrate abundance (average ± standard error of the mean) in replicated edge sweep samples. White columns = post-CEW data from 2015-16; striped columns = post-flood data from 2016-17.

The abundance of insects with aquatic life stages increased at both sites in 2016-17 compared to 2015-16 (Figure D-10a). It was difficult to determine if this was an effect of flows as one species, the midge fly *Corynoneura australiensis*, dominated aquatic insect abundance in 2014-15 in the Broken River, obscuring patterns that might be observed with other insects. Excluding this species showed a different pattern that would indicate aquatic insects were positively responding to the larger flows in 2016-17, with greater abundances at both sites this year than previous years Figure D-10b). This was particularly evident at Broken River.

The most commonly occurring taxa with aquatic life stages were Diptera. Very few mayflies (Ephemeroptera) and caddisflies (Trichoptera) were caught, while stoneflies (Plecoptera) were very rare and no dragonflies or damselflies (Odonata) were caught on the sticky traps. Within the Diptera, three families were commonly caught. Of these, the abundances of biting midges (Ceratopogonidae) were not showing clear responses to the increased flows of 2016-17 compared to previous years (Figure D-10c). There was some evidence that the overbank flows in 2016-17 created favourable conditions for drain flies (Psychodidae) in the Goulburn River, but the responses in the Broken River indicated that overbank flows were not the only factors benefitting this species, with increased abundances observed in the Broken River in 2015-16 also (Figure D-10d).

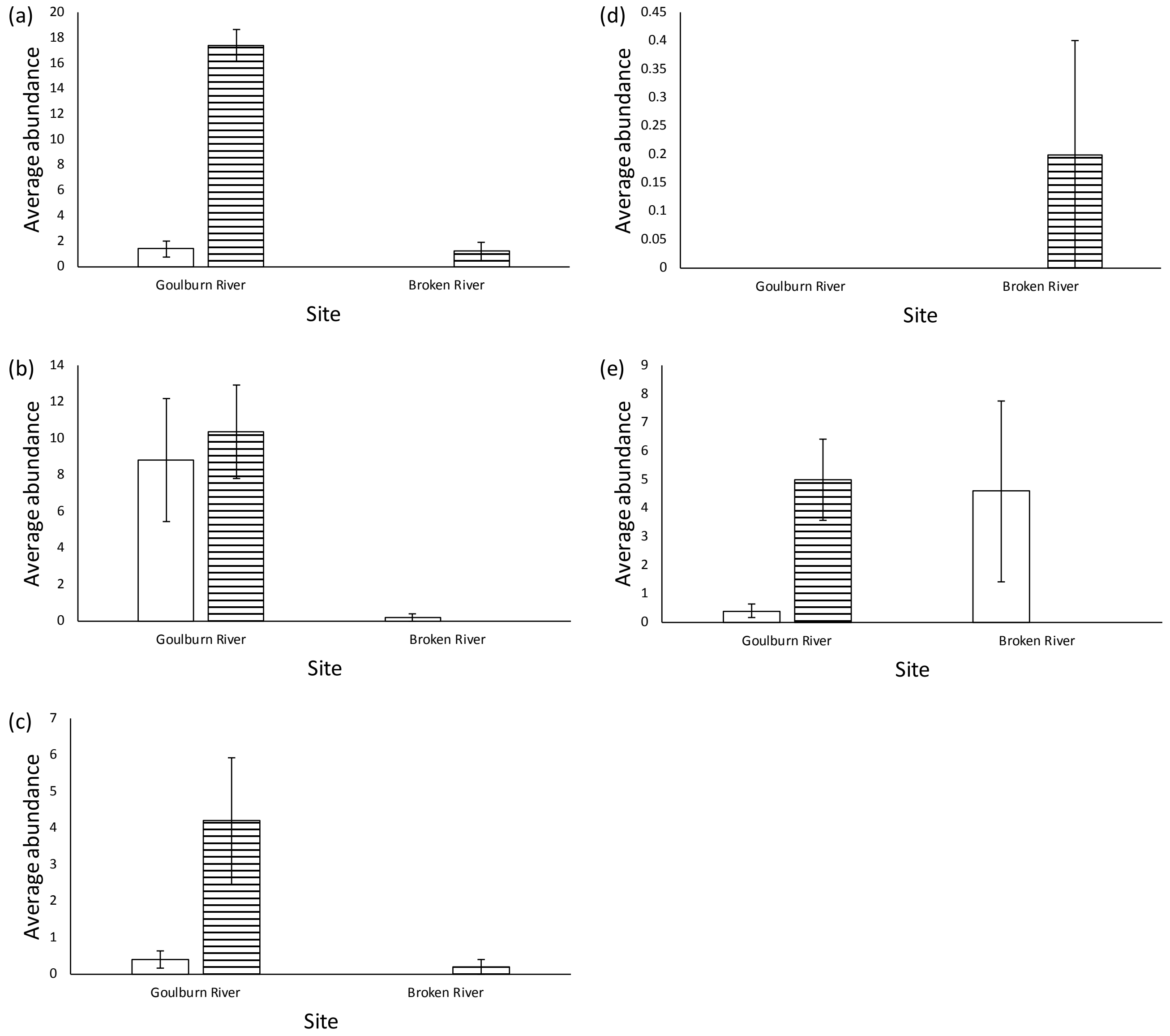


Figure D-6. Average abundance (± standard error of the mean) of (a) *Paratya australiensis*, (b) *Macrobrachium australiense*, (c) Oligochaeta, (d) *Austrosimulium furiosum* and (e) *Tasmanocoenis rieki* in replicated edge sweep samples. White columns = post-CEW data from 2015-16; striped columns = post-flood data from 2016-17.

The abundances of adult midge flies (Chironomidae) did not appear to be affected by flows, with similar low abundances in 2016-17 compared to the previous year (Figure D-11a). Again, extremely high abundances of *Corynoneura australiensis* in the Broken River in 2014-15 obscured the responses of other aquatic taxa. Excluding this species showed that the natural, large flows of 2016-17 did not appear to have an effect on the abundances of aquatic Chironomidae in the Goulburn River, but abundances of Chironomidae were much higher in the Broken River than in previous years (Figure D-11b). There was not a consistent effect of natural flows compared to environmental water on taxonomic richness of Chironomidae, with richness relatively similar in the Goulburn River across all years (Figure D-11c). However, taxonomic richness was much lower in the Broken River in 2016-17 compared to previous years, indicating Chironomidae richness in a river that had not received large freshes in previous years were adversely affected by wetter conditions and overbank bank flows in the current year.

Common Chironomidae species showed different responses to the flows. Only *Tanytarsus palmatus* positively responded to increased flows in 2016-17, with greater abundances at both sites compared to previous years (Figure D-12a). Both *Cricotopus parbicinctus* and *Microcricotopus parvulus* showed negative responses to increased flows and were either absent or had reduced abundances compared to previous years (Figure D-12b&c respectively). However, this cannot be solely attributed to increased flows as abundances of both species were reduced in post-flow sampling in 2015-16 compared to the first year also. The abundances of other species did not provide strong or consistent evidence that large natural flows were any more beneficial to these than the spring freshes provided in previous years (Figure D-12d-f; *Thienemanniella trivitatta*, *Parakiefferiella varigatus* and *Corynoneura australiensis*).

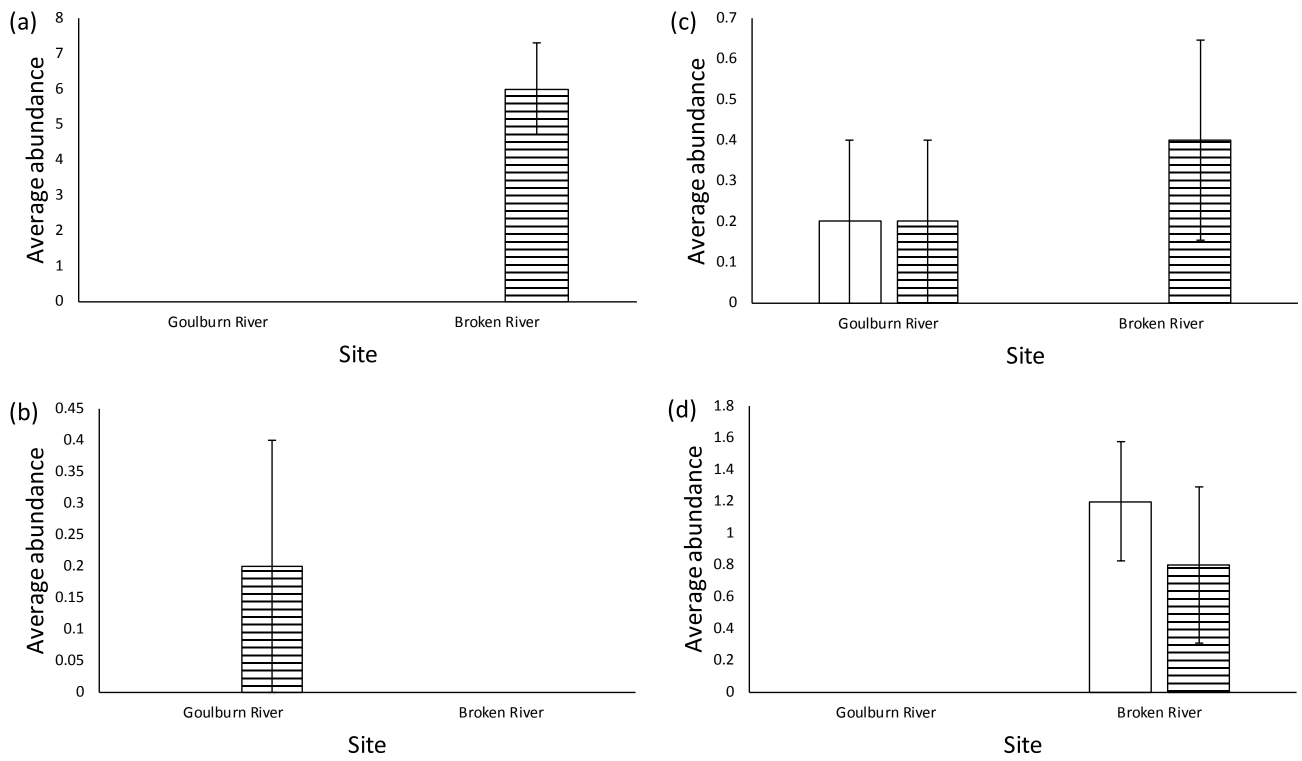


Figure D-7. Average abundance (± standard error of the mean) of the Chironomidae larvae (a) *Cricotopus parbicinctus*, (b) *Parakiefferiella* sp., (c) *Tanytarsus manleyensis* and (d) *Cryptochironomus* sp. in replicated edge sweep samples. White columns = post-CEW data from 2015-16; striped columns = post-flood data from 2016-17.

D.3.4 Additional crustacean survey: Replicated Edge Sweep Samples (RESS)

Three species of crustaceans were commonly caught in the additional RESS samples collected at Loch Garry and McCoys Bridge during 2016-17. Immature crustaceans (which could not be identified further) were among the most commonly caught crustaceans. These were more abundant in samples taken in January and February (Figure D-13a). *Paratya australiensis* were the most abundant identified taxa in RESS samples. There was evidence that the blackwater event in early January negatively impacted the abundance of these at both Goulburn River sites, but populations appeared to recover again in February then decreased again in March (Figure D-13b). In any month, very few captured *P. australiensis* were ovigerous, and by March no egg-bearing females were captured (Figure D-13c).

Macrobrachium australiense were less abundant in edge habitats than *P. australiensis* and showed a clear preference for site, with higher abundances at McCoys Bridge than upstream at Loch Garry (Figure D-13d). There was no strong evidence that the blackwater event severely impacted *M. australiense* populations in edge habitats at either site; instead, changing season seemed to have a greater effect, with abundances reduced at McCoys Bridge in February and March. Only a low percentage of *M. australiense* were ovigerous, and breeding was limited to early summer, with no egg-bearing females captured in February or March (Figure D-13e).

Yabbies *Cherax* sp. were rarely caught in RESS samples, making it difficult to determine if the large flows in spring, blackwater event in summer or changing seasons were affecting the abundance of these over the sampling period (Figure D-13f).

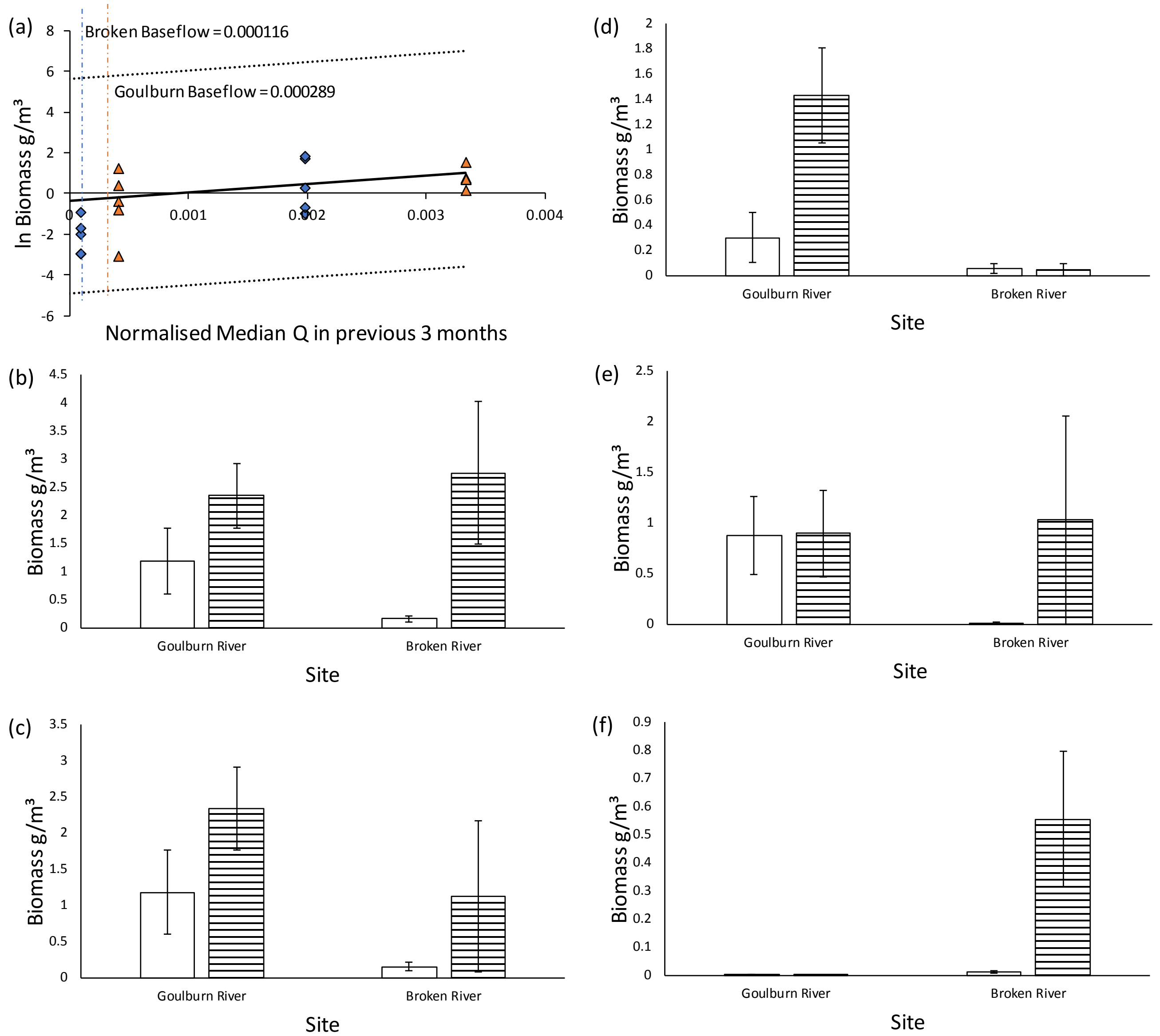


Figure D-8. (a) Modelled linear relationship between macroinvertebrate large and normalised median flows (Q; ML/day/m^2) for the three months prior to sampling, and average (± standard error of the mean) biomass for (b) total macroinvertebrates, (c) crustaceans, (d) *Paratya australiensis*, (e) *Macrobrachium australiense* and (f) Ephemeroptera, Plecoptera and Trichoptera in replicated edge sweep samples. For the flow vs biomass plot: blue broken line = Broken River baseflow of 0.000116 ML/day/m^2; orange broken line = Goulburn River baseflow of 0.000289 ML/day/m^2; solid black line = modelled linear relationship between biomass and median Q; black broken lines = 97.5th and 2.5th percentiles; blue diamonds = biomass data from Broken River; orange triangles = biomass data from Goulburn River. In the bar charts: white columns = post-CEW spring fresh data from 2015-16; striped columns = post-spring flood data from 2016-17.

Carapace lengths of *P. australiensis* and *M. australiense* were measured to understand the size range (and age) of individuals making up populations of crustaceans at each site. On average, *P. australiensis* caught in edge habitats at McCoys Bridge were larger than those at Loch Garry, but there was a lot of overlap in the size of individuals caught (Figure D-14a). The greatest variability in shrimp sizes was at McCoys Bridge in March, indicating animals from different cohorts were present at the site during this month. Regardless of month or size, females carrying eggs were of a similar size with average carapace lengths between 8mm to 10mm. The smallest ovigerous females had 8mm carapace lengths, while the largest had a 17mm carapace.

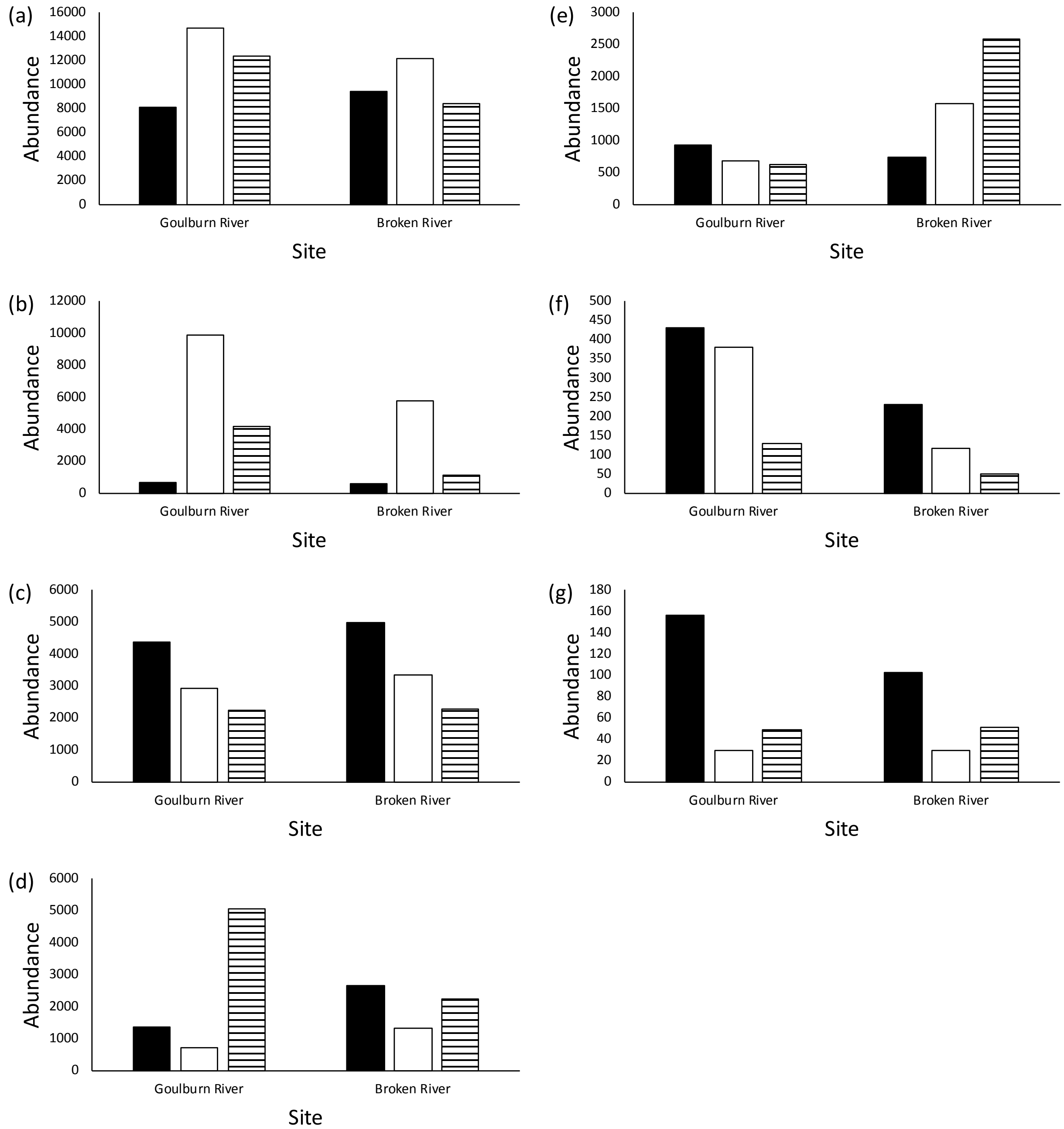


Figure D-9. Total abundance of (a) all invertebrates, (b) Thysanoptera, (c) Hymenoptera, (d) Diptera, (e) Hemiptera, (f) Coleoptera and (g) Araneae on yellow sticky traps. Black columns = post-flow data from 2014-15; white columns = post-flow data from 2015-16; striped columns = post-flow data from 2016-17.

The length and variability in size of *Macrobrachium australiense* carapace lengths was similar across both sites regardless of month (Figure D-14b), except at Loch Garry in January where there was much greater variability in the size of *M. australiense* captured. Ovigerous females were larger than average for each site and month, with carapaces ranging from 14mm to 17mm (compared to the average carapace length which ranged from 9mm to 14 mm).

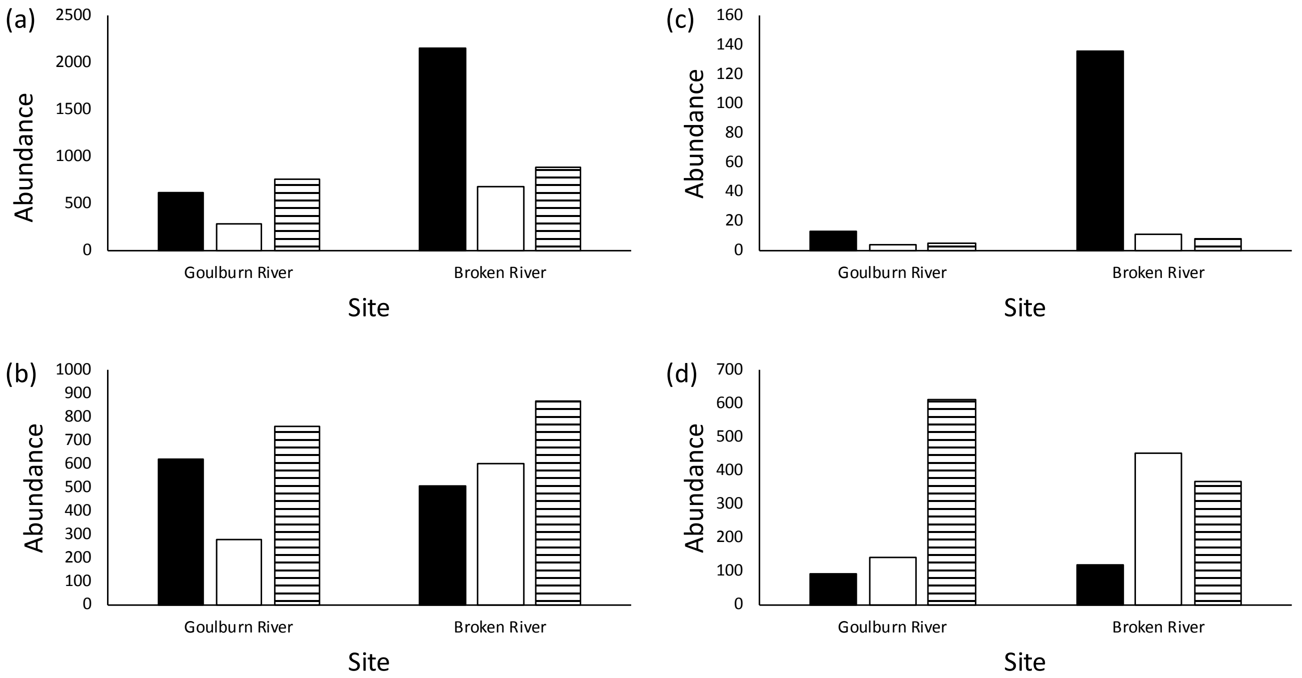


Figure D-10. (a) Aquatic insect abundance, (b) aquatic insect abundance excluding *Corynoneura australiensis*, (c) Ceratopogonidae abundance and (d) Psychodidae abundance on yellow sticky traps. Black columns = post-flow data from 2014-15; white columns = post-flow data from 2015-16; striped columns = post-flow data from 2016-17.

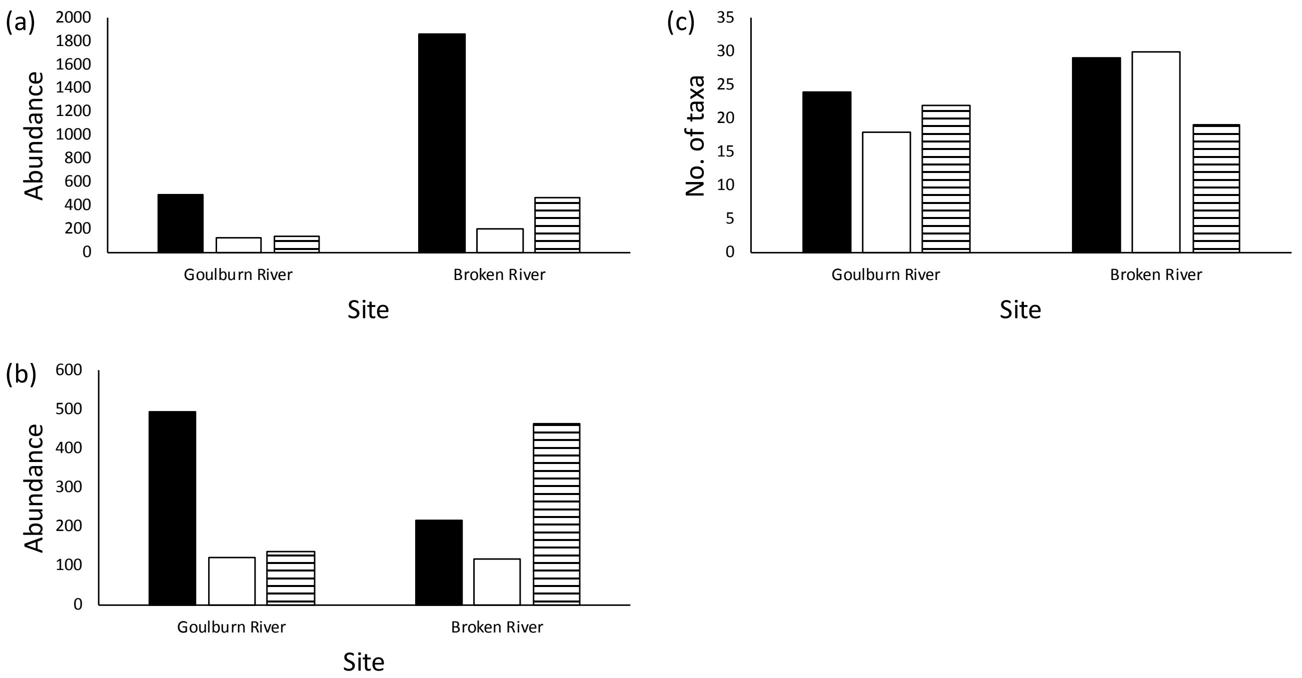


Figure D-11. (a) Aquatic Chironomidae abundance, (b) aquatic Chironomidae abundance excluding *Corynoneura australiensis* and (c) taxonomic richness of aquatic Chironomidae caught on yellow sticky traps. Black columns = post-flow data from 2014-15; white columns = post-flow data from 2015-16; striped columns = post-flow data from 2016-17.

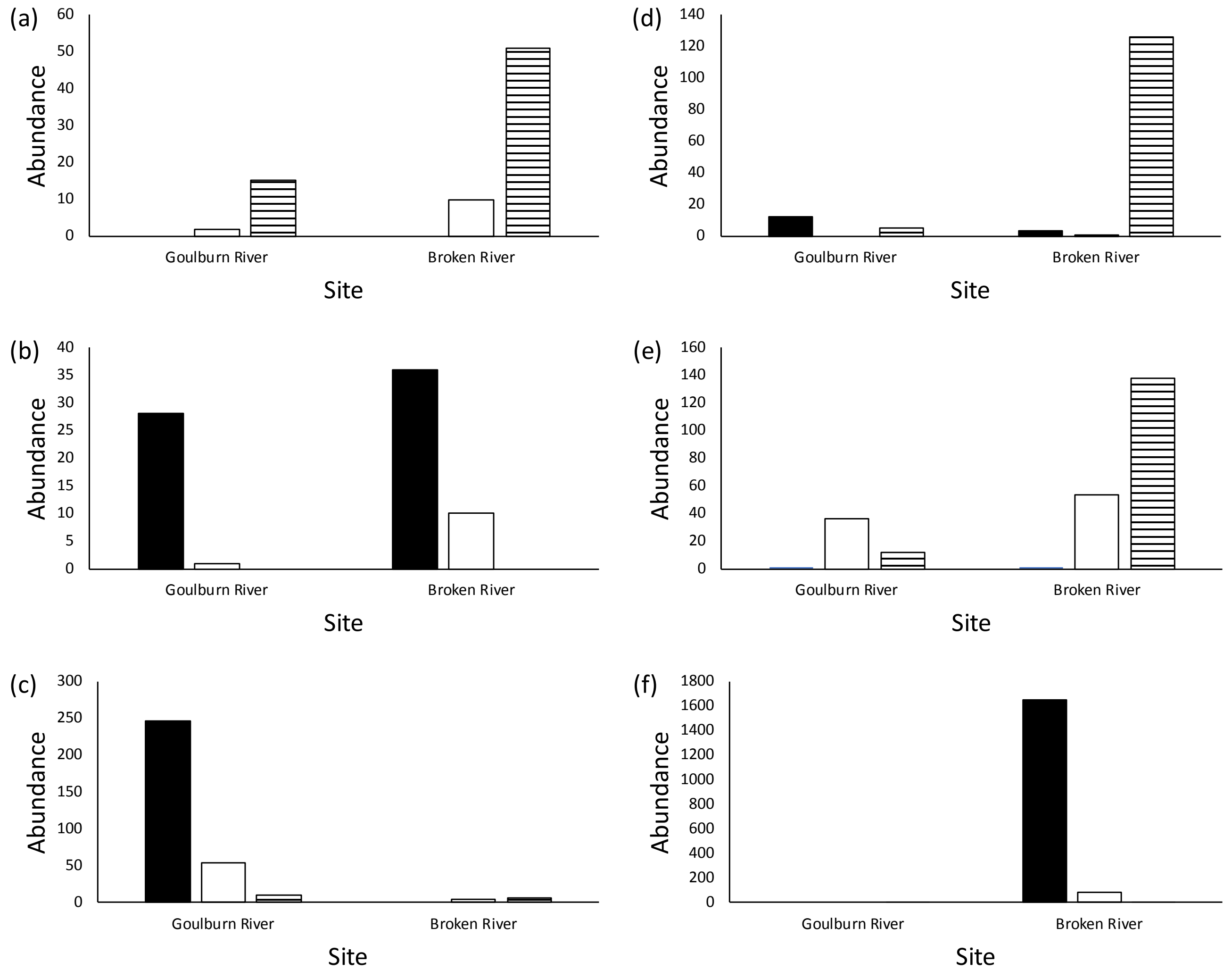


Figure D-12. Abundance of (a) *Tanytarsus palmatus*, (b) *Cricotopus parbicinctus*, (c) *Microcricotopus parvulus*, (d) *Thienemaniella trivittata*, (e) *Parakiefferiella varigatus* and (d) *Corynoneura australiensis* on yellow sticky traps. Black columns = post-flow data from 2014-15; white columns = post-flow data from 2015-16; striped columns = post-flow data from 2016-17.

Despite dominating crustacean abundance, immature crustaceans contributed little to biomass in edge samples due to their small size (Figure D-15a). Their biomass followed a similar pattern to their abundance, with the greatest biomass observed in January and little difference in biomass between sites regardless of month. *Paratya australiensis* biomass was usually greater at McCoys Bridge than at Loch Garry (Figure D-15b). This species appeared to be positively affected by the large natural flows in spring, with much greater biomass at McCoys Bridge in November of 2016-17 compared to post-CEW sampling in the previous year (Figure D-16a). However, it was also evident that the blackwater event in late December 2016 also impacted biomass, with declines observed in January (Figure D-15b, Figure D-16a). Although they were not as abundant as *P. australiensis* or immature crustaceans, *M. australiense* dominated the crustacean biomass of the RESS samples due to their larger size. The biomass of this species was always greater at McCoys Bridge than at Loch Garry (Figure D-15c), reflecting the fact *M. australiense* was also more abundant at this site. Its biomass was greatest in December at both sites and declined in subsequent months. However, this species did not respond as rapidly to natural flows as *P. australiensis* did, with biomass in November 2016-17 similar to that of post-CEW sampling in the previous year (Figure D-16b). The effect of the blackwater event was also less clear, with no sharp drop in abundance in January and instead a steady decline over the months (Figure D-15c). *Cherax* sp. contributed little to biomass at each site in the RESS samples (Figure D-15d), which demonstrates the RESS method is not very suitable for capturing crayfish such as *Cherax* sp., and those individuals caught tend to be quite small and young (personal observation).

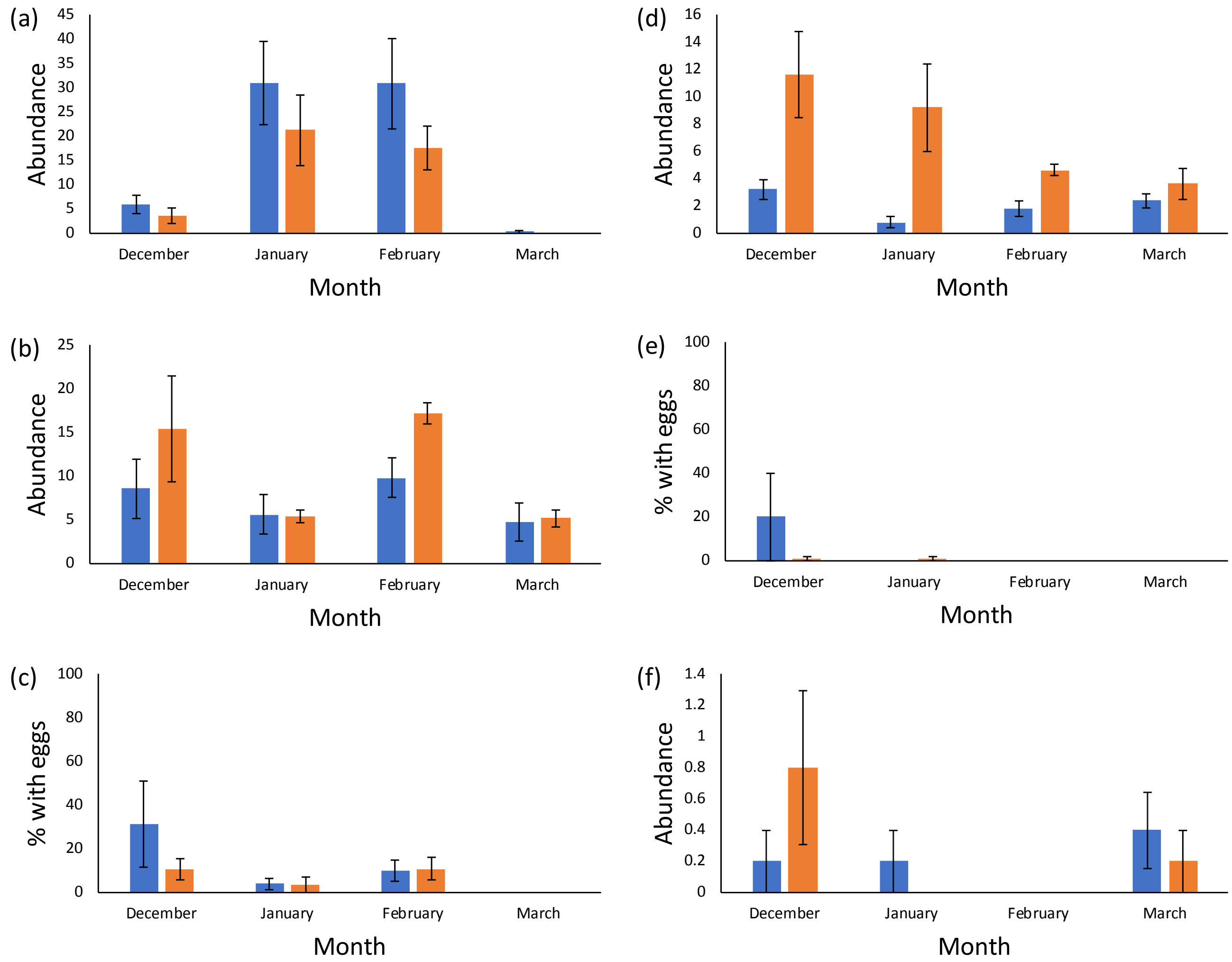


Figure D-13. Average (± standard error of the mean) (a) abundance of immature crustaceans, (b) abundance of *Paratya australiensis*, (c) % of *P. australiensis* with eggs, (d) abundance of *Macrobrachium australiense*, (e) % of *M. australiense* with eggs and (f) abundance of *Cherax* sp. caught in replicated edge sweep samples from the Goulburn River in 2016-17. Blue columns = the Goulburn River at Loch Garry; orange columns = the Goulburn River at McCoys Bridge.

D.3.5 Additional crustacean survey: bait traps

Macrobrachium australiense were the most abundant crustaceans caught in the bait traps. The average abundance of *M. australiense* was similar between sites for each month, and was greatest during the December sampling period (Figure D-17a). Abundances markedly decline during January and remained low for the following sampling events. *Macrobrachium australiense* showed no clear preference for habitat at either site (Figure D-17b,c). Very few (< 4%) of *M. australiense* carried eggs at either site in any month, with no egg-bearing females captured in February or March.

Paratya australiensis were not very abundant in the bait traps at either site, making it difficult to observe differences in abundance across months (Figure D-17d). There did not seem to be a strong preference for habitat at the Loch Garry site (Figure D-17e), while at McCoys Bridge *P. australiense* were more abundant in bait traps deployed in macrophytes and depositional areas (Figure D-17f). Very few *P. australiensis* caught in bait traps carried eggs at either site in any month (<10%), with no egg-bearing females captured in March.

Although yabbies (*Cherax* sp.) were occasionally caught in bait traps their abundances were very low, with most traps empty. As a result, these were not compared among habitats.

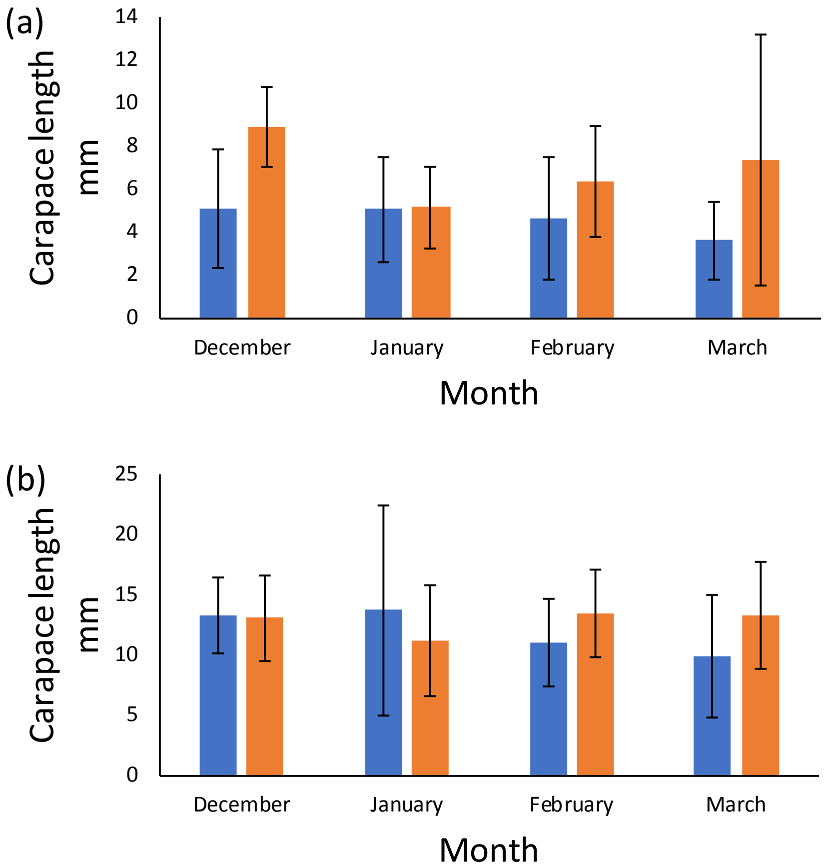


Figure D-14. Carapace lengths of (a) *Paratya australiensis* and (b) *Macrobrachium australiense* (average ± standard deviation) from replicated edge sweep samples in the Goulburn River in 2016-17. Blue columns = Goulburn River at Loch Garry; orange columns = Goulburn River at McCoys Bridge.

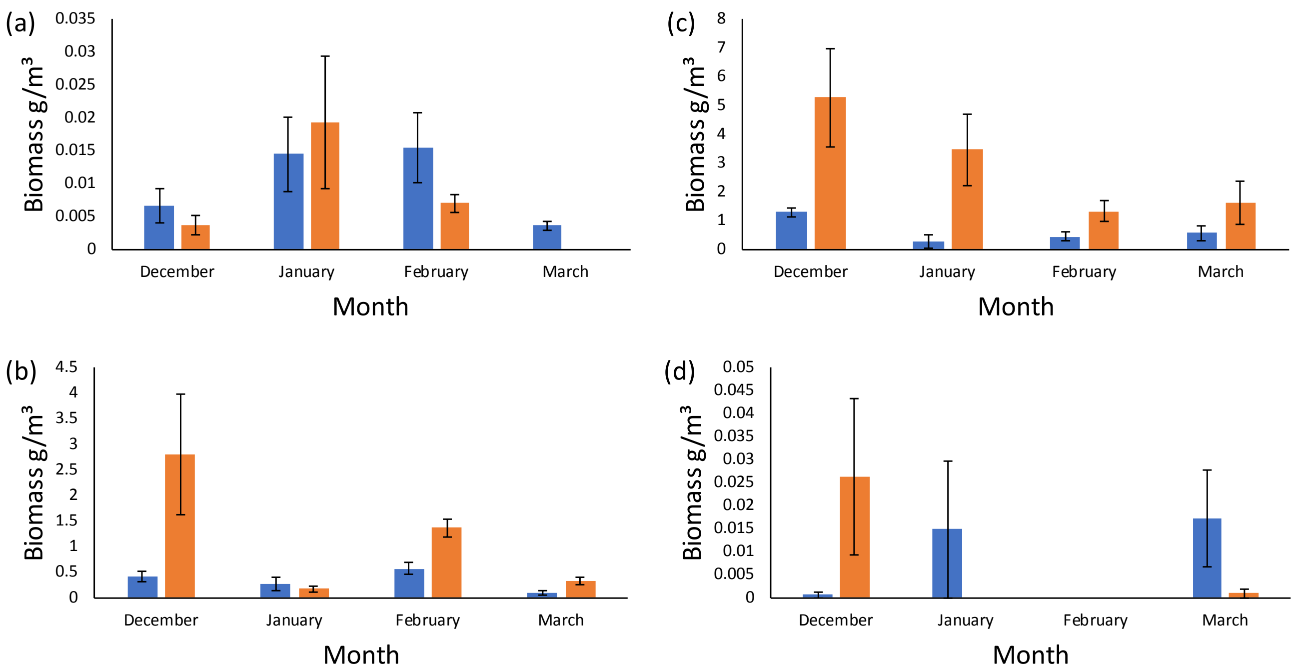


Figure D-15. Biomass of (a) immature crustaceans, (b) *Paratya australiensis*, (c) *Macrobrachium australiense* and (d) *Cherax* sp. (average ± standard error of the mean) in replicated edge sweep samples from the Goulburn River in 2016-17. Blue columns = Goulburn River at Loch Garry; orange columns = Goulburn River at McCoys Bridge.

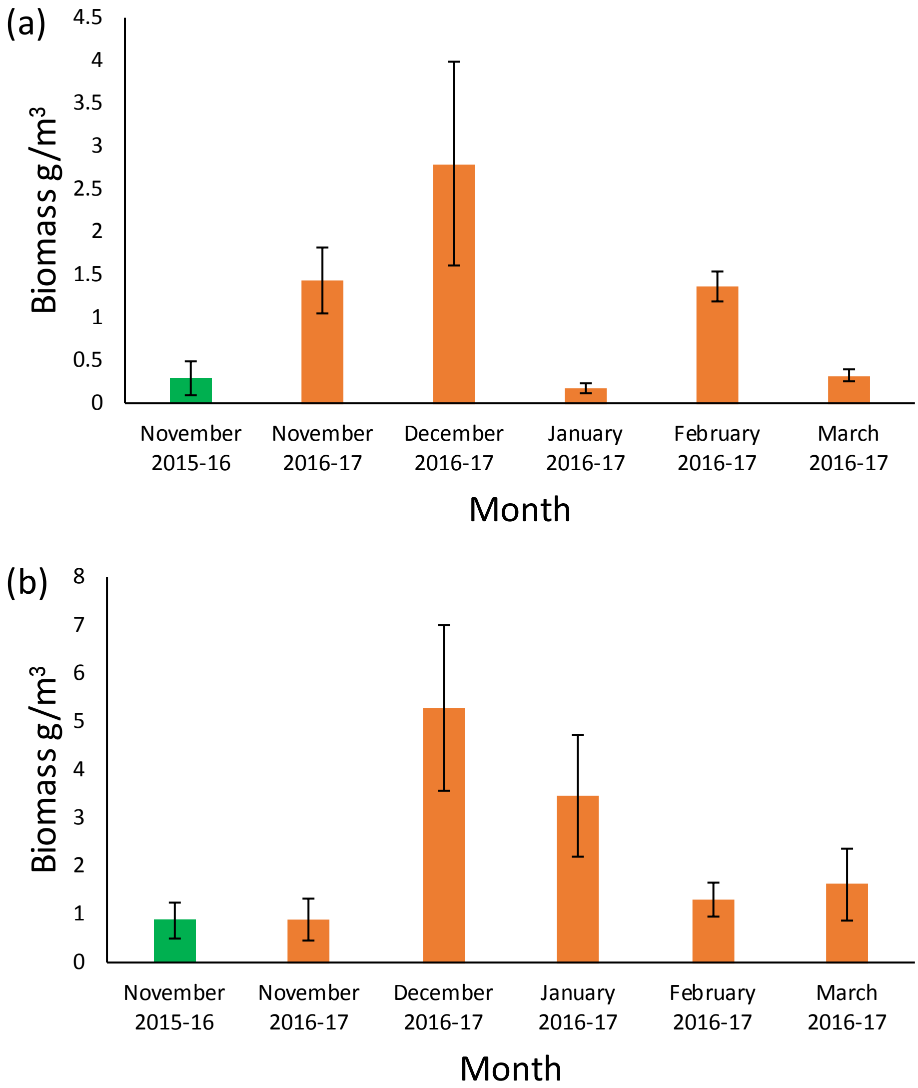


Figure D-16. Biomass of (a) *Paratya australiensis* and (b) *Macrobrachium australiense* (average ± standard error of the mean) in replicated edge sweep samples from the Goulburn River at McCoys Bridge. Green column = data from post-Commonwealth Environmental Water sampling in 2015-16; orange columns = data from post-flood sampling in 2016-17.

The size (carapace lengths) of *M. australiense* caught in the bait traps were generally similar regardless of site or season (Figure D-18a). A similar pattern was evident with *P. australiensis* in the bait traps, with captured individuals of a similar size across both sites and all months (Figure D-18b).

Macrobrachium australiense contributed the most to crustacean biomass in the bait traps. Their biomass at each site mirrored that of their abundance, with a large reduction in biomass at both sites during January and for the remaining months of the survey (Figure D-19a). The biomass of *P. australiensis* also closely reflected their abundance at each site and month (Figure D-19b), again demonstrating that individuals caught in the bait traps were of a similar size and therefore abundance, rather than the size of individuals was the factor determining biomass. Although *Cherax* sp. were not very abundant, the individuals caught in the bait traps were much larger than other crustaceans, thus contributing substantially to crustacean biomass at each site (Figure D-19c). Their biomass was highly variable at each site and in each month, except in February when biomass was very low compared to other months.

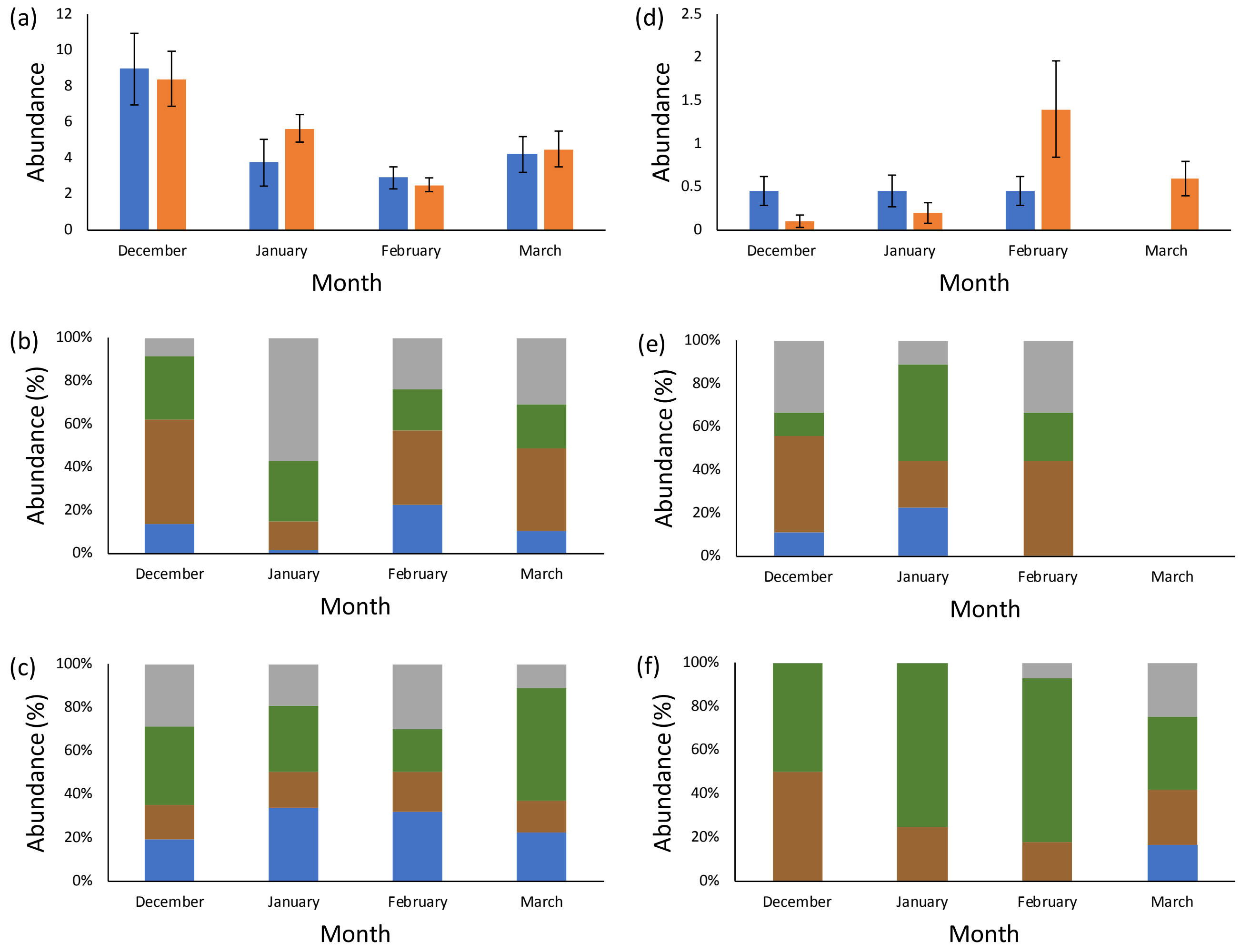


Figure D-17. Abundance of crustaceans caught in bait traps in the Goulburn River: *Macrobrachium australiense* (a) average abundance ± standard error of the mean, (b) expressed as the percentage occurring in different habitat types at Loch Garry, (c) expressed as the percentage occurring in different habitat types at McCoys Bridge; and *Paratya australiensis* (d) average abundance ± standard error of the mean, (e) expressed as the percentage occurring in different habitat types at Loch Garry and (f) expressed as the percentage occurring in different habitat types at McCoys Bridge. In Figures (a) and (d) blue columns = Loch Garry and orange columns = McCoys Bridge. In Figures (b), (c), (e) and (f) colours indicate habitat where bait traps were deployed, where blue = bare, brown = depositional area, green = macrophytes and grey = snags.

D.4 Discussion

The 2016-17 monitoring period was characterised by record-breaking rainfall in parts of the Goulburn River catchment, resulting in moderate flooding, overbank flows and filling of riparian wetlands in some areas. As a result, Commonwealth Environmental Water (CEW) was not delivered as spring freshes. Macroinvertebrates showed stronger responses to larger, natural flows than to the spring freshes of previous years, but these responses were not always positive and there was not a clear relationship between increasing flows and macroinvertebrate responses.

The strongest evidence that increasing flows positively affected macroinvertebrates came from increased macroinvertebrate diversity, abundances and biomass in RESS samples and bait traps following the spring floods. These responses were much greater than in previous years, suggesting increased flows contributed to increased macroinvertebrate productivity. Compared to baseflows, floods can massively elevate fine particulate organic matter and coarse organic particulate matter transport in both regulated and unregulated rivers (Fuller et al. 2014). In the Goulburn and Broken River catchments, elevated flows in spring that caused moderate flooding, overbank flows and riparian wetland filling may have entrained more organic matter into river channels than would occur during spring freshes. This could potentially increase microbial and algal productivity in the river, translating into beneficial effects for organisms that consume these, including macroinvertebrates. Among groups that would benefit from increased organic matter were detritivores such as the prawn *Macrobrachium australiense*, the shrimp *Paratya australiensis* and worms (Oligochaeta), all of which increased in abundance and/or biomass following the spring flows.

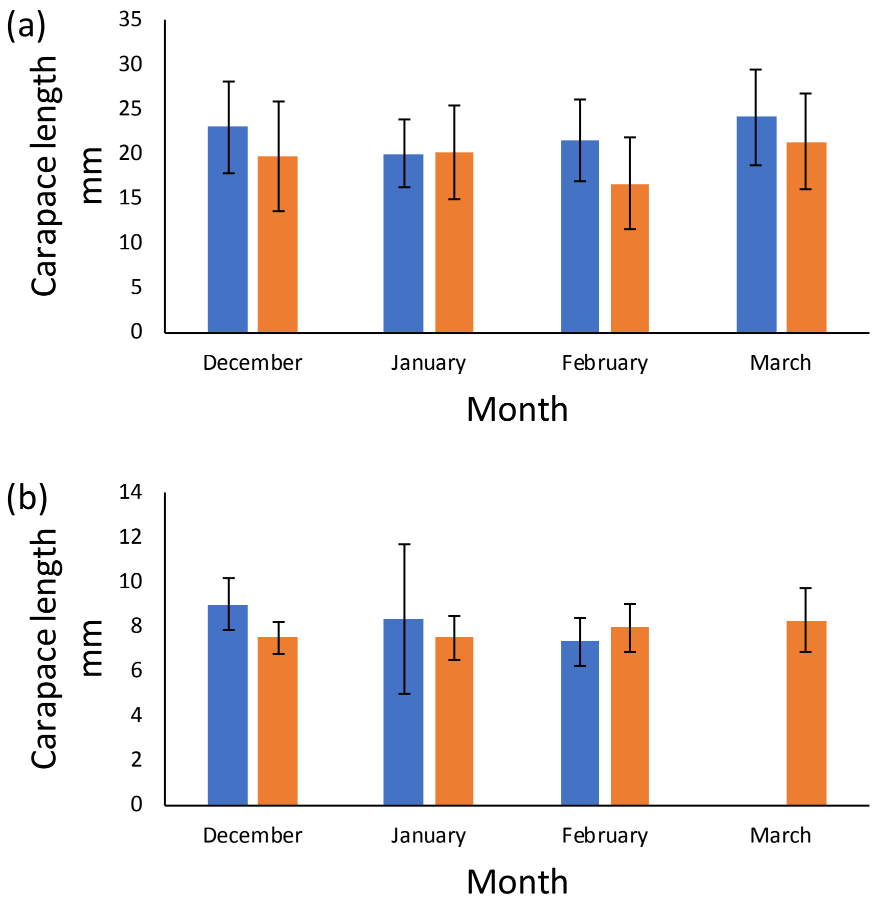


Figure D-18. Average (± standard deviation) carapace lengths of (a) *Macrobrachium australiense* and (b) *Paratya australiensis* caught in bait traps in the Goulburn River. Blue columns = Goulburn River at Loch Garry; orange columns = Goulburn River at McCoys Bridge.

In addition, elevated flows may have provided more suitable habitats for some macroinvertebrates. This could include an increase in slackwater and still littoral habitats, and the reconnection of riparian wetlands to the river channel. Slackwater and still littoral habitats are particularly important to *P. australiensis* and *M. australiense* larvae, and research suggests breeding females from these species move into slackwater habitats to hatch eggs (Price and Humphries 2010).

The riparian zone is important for river functioning by influencing channel morphology and stability, contributing organic matter and other materials (including sediment) to the channel, acting as ecological corridors, buffering the channel from surrounding land use activities and providing shelter (shading) (Naiman and Decamps 1997). Riparian vegetation is an important habitat for many invertebrates, both terrestrial and aquatic species that have terrestrial life stages. Invertebrates from the riparian zone form an important part of aquatic species' diets; for example, terrestrial invertebrates formed around 50% of the prey eaten by Coho salmon in Alaska (Allan et al. 2003). River flows are important factors in determining the composition and structure of riparian habitats; even small fluctuations in river heights can affect riparian vegetation (Greet et al. 2011).

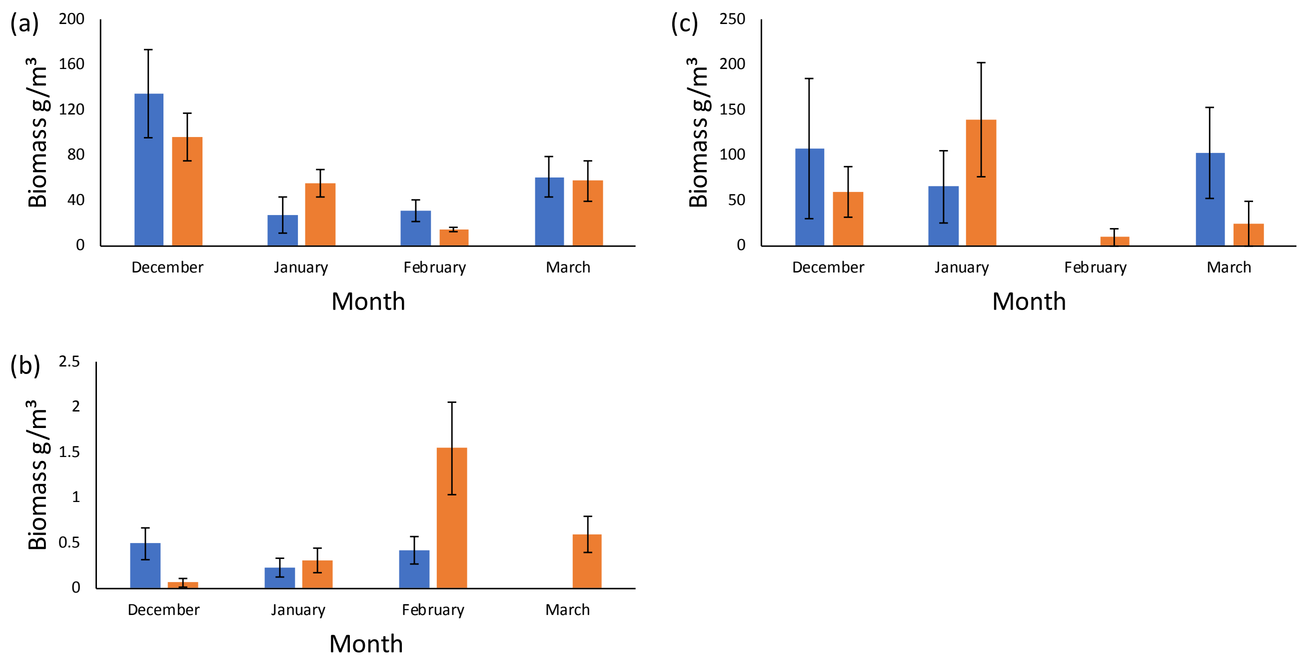


Figure D-19. Biomass (average ± standard error of the mean) of (a) *Macrobrachium australiense* (dry weight), (b) *Paratya australiensis* (dry weight) and (c) *Cherax* sp. (wet weight) caught in bait traps deployed in the Goulburn River. Blue columns = Goulburn River at Loch Garry; orange columns = Goulburn River at McCoys Bridge.

It was obvious that the riparian zone had been impacted by elevated flows in 2016-17. We personally observed more bank vegetation at the Goulburn River than we had seen in previous years, though much of this had died back, presumably due to prolonged inundation. Despite the fact it seemed like larger flows had affected bank vegetation, there was no strong evidence that this in turn had a greater impact on riparian invertebrates than in previous years. Only a few taxa showed what may have been a weak response to the flows. For example, Coleoptera were less abundant at both sites after the flood compared to previous years, perhaps due to displacement or drowning as a result of overbank flows. Aquatic insect abundance also increased on the sticky traps compared to previous years (when the most abundant species, *Corynoneura australiensis*, was excluded as its elevated abundance at the Broken River in 2014 obscured the responses of other taxa). Larger flows may have provided more slackwater habitats and food resources such as detritus, benefitting taxa with aquatic larvae such as Psychodidae (drain flies) (MDFRC n.d.). Two Chironomidae (midge fly) species (*Cricotopus parbicinctus* and *Microcricotopus parvulus*) were absent or had reduced abundances on sticky traps in 2016-17 compared to post-CEW in previous years; however, it seemed that the natural flows affected the timing of their emergence rather than reducing their abundance, as their larval abundance was greater in post-flood samples this year than in post-CEW samples in previous years. Although Chironomidae species have different developmental rates, the development of most is affected by temperature and development times are shorter when water temperatures increase (Oliver 1971). The development rate of these two species in 2016 may have been delayed compared to previous years due to colder water temperatures associated with the larger flows; hence a lower number of adults were present in the riparian zone when we sampled in 2016-17.

The flooding that occurred in late December, 2016, also impacted macroinvertebrates through introducing organic matter into the river channel. However, unlike with the spring floods, the large volumes of organic-rich water entering the Goulburn River had the immediate impact of reducing dissolved oxygen levels, with stress and mortality in fish and crustaceans observed as far downstream as McCoys Bridge (GBCMA 2017). There was an obvious decline in macroinvertebrate abundances and biomass after this blackwater event, including samples for artificial substrates, bait traps and additional RESS surveys.

Blackwater events are characterised by high concentrations of dissolved organic carbon and low concentrations of dissolved oxygen (hypoxia). Hypoxia can directly affect macroinvertebrates by causing stress and mortality. In crustaceans, decreasing oxygen levels can elicit a behavioural response, with individuals moving towards areas with higher oxygen concentrations (Haselmair et al. 2010). Such effects were observed in the Goulburn

River, with stressed crayfish, shrimp and prawns seen out of the water (GBCMA 2017). At very low concentrations of dissolved oxygen, sublethal effects (e.g. immobility) and mortality will occur (Haselmair et al. 2010). Although many aquatic taxa can withstand some level of hypoxia, significant mortality will occur at very low oxygen concentrations (Connolly et al. 2004). Near lethal concentrations of dissolved oxygen can also induce a drift response in macroinvertebrates (Connolly et al. 2004), and can indirectly affect macroinvertebrates by reducing the diversity and abundance of their prey items, such as zooplankton (Ning et al. 2015).

Not all invertebrates showed negative responses to the blackwater event. Some macroinvertebrates are less susceptible to hypoxia than others. For example, Teixeira et al. (2015) found some Chironomidae (midge flies) and Amphipoda (water fleas) were more resistant to hypoxia than gastropods (snails) and Zygoptera (damselflies), due to their natural association with a low oxygen habitat. Connolly et al. (2004) also found Chironomidae were relatively resistant to hypoxia, whereas Baetidae (mayfly nymphs) were highly sensitive. Such variability in responses could indicate why one genus in the artificial substrates, the midge *Rheotanytarsus* sp., showed a positive response to flows (including blackwater), while others had negative responses.

Immature crustaceans actually increased in abundance in January after the blackwater event. The increase coincides with the middle of the *P. australiensis* and *M. australiense* breeding season, i.e. warmer months (Williams 1977, Hancock and Bunn 1997, Richardson et al. 2004, Richardson and Humphries 2010). It also reflects the fact that breeding in both species tends to be greatest earlier in the season, (November to December) (Richardson et al. 2004), resulting in an increase in immature crustaceans in the following month. Previous flooding in spring probably increased and sustained a large number of immature crustaceans by increasing food resources (female M. australiense fecundity is strongly affected by food; Liu 1980) and suitable low velocity habitats, which are crucial for larvae of both species (Richardson et al. 2004, Richardson and Cook 2006, Price and Humphries 2010).

Increased abundance of immature crustaceans after the blackwater event might indicate that these young individuals were tolerant of low dissolved oxygen concentrations in the river, but this is unlikely. Their presence and unexpected abundance in the affected area is probably due to drift from unaffected sites upstream due to water releases from Goulburn Weir. Both *P. australiensis* larvae and *M. australiense* larvae are dispersed in flows, even in low flow events (Price and Humphries 2010). Flows are important for dispersal of *P. australiensis* populations (Cook et al. 2007), but it should also be noted that larvae of *P. australiensis* can be adversely affected by increased flows, with reduced recruitment (Hancock and Bunn 1997).

In addition to providing information about the positive and negative effects of natural floods, data from bait traps and additional RESS surveys also confirmed what is known about the biology of *P. australiensis* and *M. australiense*. For example, ovigerous females from both species were most common in December, with none present in March, which supports the breeding patterns described in other studies (Williams 1977, Liu 1980, Hancock and Bunn 1997, Richardson and Humphries 2010).

In other ways, data from these surveys contributed to understanding previous hypotheses we had. For instance, in 2015-16 *M. australiense* appeared to be moving out of the channel and increasing in abundance in edge habitats post-CEW. We hypothesised that particular edge habitats may be more appealing to this species than others, perhaps due to an increase in the quality or quantity of biofilms in these areas after spring freshes. However, the bait trap data from 2016-17 failed to show that *M. australiense* had a preference for any habitat type. This was somewhat surprising, as other studies have shown *M. australiense* to be selective of habitats based on their age and sex, with adults preferring moderate current velocity channels (Richardson and Cook 2006) and silt and snag microhabitats (Sheldon and Walker 1998), ovigerous females moving into slackwater habitats to breed (Price and Humphries 2010) and larvae preferring slackwater habitats (Richardson and Cook 2006, Price and Humphries 2010). Unrelated to habitat, some traps appeared to “attract” a larger number of *M. australiense* than others (personal observation). It is not clear why this occurred, but reasons could include cues from predation (i.e. if a *M. australiense* killed a small fish or shrimp in the trap, it may have released chemical cues to attract other *M. australiense*) or complex social interactions. *Macrobrachium australiense* display quite involved agonistic social behaviours and have three tier dominance hierarchies (Lee and Fielder 1983, Lammers et al. 2009); increasing numbers of *M. australiense* in a trap may have provided stronger social cues to other individuals, with the attractiveness of these traps increasing in a “snowball effect” as more animals were caught. Interestingly, *M. australiense* caught in bait traps had much lower variability in size than those caught in RESS samples, indicating smaller individuals were not attracted to or were more likely to avoid bait traps. It is unlikely that cannibalism was an attracting factor for this species, as it is not known to be cannibalistic, even during moulting when individuals are more vulnerable (Liu 1980).

Paratya australiensis were more commonly caught in edge samples than *M. australiense* and were much less common in bait traps, highlighting the preference this species has for edge habitats regardless of life stage (Richardson et al. 2004, Richardson and Cook 2006, Richardson and Humphries 2010). Unlike *M. australiense*, *P. australiensis* were more commonly caught in bait traps placed in vegetated and depositional areas, reflecting their preference for vegetated habitats (Williams 1977) and silt (Sheldon and Walker 1998). These habitats are also likely to be food rich for *P. australiensis*, which are detritivores that also graze on algae and biofilms (Burns and Walker 2000). It is not clear why such a pattern was only evident at McCoys Bridge and not Loch Garry.

D.5 Conclusions

Despite the disruption of the normal sampling routine, the data gained from the 2016-17 provided important insights into how flows of different magnitudes can affect macroinvertebrates in the lower Goulburn River. Two very different responses to increasing flows occurred, both of which can probably be linked back to increasing carbon inputs into the stream channel with increasing flows. The first response was an increase in macroinvertebrate productivity, particularly an increase in freshwater shrimp and prawn abundances. The second was a sharp decline in macroinvertebrate productivity as a result of hypoxia in a blackwater event. Both these types of responses showed that large, overbank flows elicited much stronger responses in macroinvertebrates than CEW spring freshes did; however, while these responses were stronger they were not always positive. Unlike natural flood events, CEW spring freshes are delivered to the Goulburn River in such a controlled way that large, negative impacts on stream biota are avoided. In the future, to increase the value of environmental water some of the beneficial aspects of large natural flows could be incorporated into how environmental water is delivered. For example, environmental water is relatively “clean” compared to flood water; if environmental water could be enriched with some organic matter, such as by reconnecting wetlands to the river channel, this may have greater positive impacts on macroinvertebrates.

Appendix E. Detailed results for Vegetation

E.1 Introduction

Riparian and aquatic vegetation underpins 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 drought and floods have reduced the quantity, quality and diversity of riparian and bankside vegetation over the last 10-15 years. Minimum summer and winter low flows and periodic freshes are recommended to help rehabilitate and maintain vegetation along the lower Goulburn River. The recommended flow components shape aquatic plant assemblages by influencing (1) inundation patterns in different elevation zones on the bank and hence which plants can survive 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 has been monitored at four sites in the lower Goulburn River every two years since 2008 as part of the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP; Miller et al. 2015), and has been assessed for the Commonwealth Short Term Monitoring Projects (STIM; Stewardson et al. 2014, Webb et al. 2015). Vegetation diversity monitoring in the LTIM Project at two sites in the lower Goulburn River is extending those data sets and allowing the effect of different flow components to be assessed in wet and dry climatic conditions. The results will be 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. The results will also be used to broadly inform appropriate water management in other systems recovering from extreme events.

E.2 Methods

E.2.1 Sampling

Elevation surveys

Vegetation responses to flow are expected to vary with elevation as this determines the depth and duration of inundation experienced under a particular flow. To support more targeted monitoring, elevation profiles were obtained at 1 m intervals along all transects in December 2014 using a high-precision RTK GPS. These were used to target sampling locations along each transect in 2015-16 to ensure an optimal range of elevations was sampled along each transect.

Elevation profiles were surveyed again in December 2016 following the recession of floodwater to ensure accurate inundation histories of sampling locations. Elevation survey in December were supported by the GBCMA with funding by VEFMAP.

Vegetation sampling

Vegetation was sampled on both banks at Loch Garry and McCoy's Bridge, before and after the delivery of spring freshes in 2014-15 and 2015-16 (Table E-1, Figure E-1). In 2016 spring freshes were not delivered due to the large natural high 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 again 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.

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 CEWH 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.

Table E-1. Summary of vegetation survey dates, sampling locations and transects.

Year	Sampling event	Date	Sites sampled	Transects sampled North bank	Transects sampled South bank
2014-15	Pre-fresh	23 Sept & 3 Oct	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
	Post-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	Pre-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
	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	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
	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
	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

At each sampling location 20 points are surveyed along a horizontal transect to give estimates of cover for each species (see details in standard operating procedures in Webb et al. 2014). 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.

Soil moisture recording

One of the objectives for environmental flows is to recharge soil bank moisture stores to support vegetation growth and reproduction over summer. The influence of flows and antecedent conditions on bank soil moisture stores has not be assessed. To address this knowledge gap soil moisture probes were installed at an upper and lower elevation at Loch Garry and McCoy's Bridge in December 2016 supported by the GBCMA and VEFMAP. Each probe recorded soil moisture and temperature every hour, at 10cm depth intervals from 5 cm to 85cm.

The data gathered will inform the following questions.

- How deep does the water penetrate the soil?
- How do flow influence bank soil moisture through the soil depth profile between 5-85 cm?
- How long is soil moisture retained over the soil depth profile?
- How does rainfall and temperature influence soil moisture stores in the bank?

E.2.2 Analyses

Monitoring data collected over the three years of the LITM program provides insights into the responses of vegetation to particular environmental flow events and in to longer term hydrologic regimes. Qualitative and quantitative approaches have been applied to evaluate vegetation responses.

Qualitative approaches include the following:

- Examination of species lists and total number of native and exotic species at each site and sample dates.
- Examination of mean percent foliage projective cover (FPC %) 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 (FPC %) of different taxa across the elevation gradient at each sample date at each site.

Quantitative approaches were developed to (*i*) evaluate response of vegetation to the March fresh and (*ii*) develop relationships between hydrologic variables and vegetation cover and occurrence that is more transferrable to other sites and support a more predictive approach.

We concentrated much of the evaluation on particular species. This was because many species had low occurrences, and species level analysis was limited to those species with sufficient occurrences to reveal responses to inundation. More specifically, *Persicaria* spp., *Alternanthera denticulata* and *Poa labillardierei* 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). *Cyperus eragrostis* was included even though it is an introduced species, as it was considered to be representative of key ground-layer dominants of 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 *Poa labillardierei* occurred with high enough frequency to warrant species level analyses.

Statistical Model: A. Responses to the March fresh 2017

Hierarchical Bayesian logistic models were developed to assess responses to the 2017 March fresh. These models assessed the probability of occurrence of different vegetation types across the elevation profile and corresponding number of days inundated in the past year at each site in December 2016 and February 2017, prior to flow delivery, and again in April 2017, after flow delivery. The model assessed changes in presence of vegetation vs elevation and corresponding day inundated prior to sampling in response to the March fresh 2017.

The models described below for both vegetation presence and abundance were implemented in OpenBUGS version 3.2.1 (Lunn et al. 2009), using the R2OpenBUGS package (Sturz et al. 2005) in R (R Development Core Team 2010). Three independent Markov chains were used to confirm convergence of chains during model burn-in. Different burn-in periods were employed for different models, with the criterion for establishing convergence being an Rhat value of approximately 1 (Sturz et al. 2005). Different periods were also used for parameter estimation, based upon autocorrelation within the Markov chains.

$$veg.before \sim Bernoulli(probability.before_i)$$

$$logit(probability.before_i) = int + slope.before_j \times I.365_{\ i} + eff.site_j + eff.unit_k + eff.transect_{\ l}$$

$$veg.after \sim Bernoulli(probability.after_i)$$

$$logit(probability.before2_i) = int + slope.after_j \times I.365_i + \ eff.site_j + eff.unit_k + eff.transect_{\ l}$$

$$veg.after2 \sim Bernoulli(probability.after2_i)$$

$$logit(probability.after1_i) = int + slope.after2_j \times I.365_i + \ eff.site_j + eff.unit_k + eff.transect_{\ l}$$

The presence or absence of vegetation (all species, or specific vegetation species) is assumed to be drawn from the Bernoulli distribution, and is modelled using a logit link function. The probability of the presence of vegetation in December (*before*), February (*before 2*) and in April (*after 1*) are modelled separately. The occurrence of vegetation in December (veg.before) is a function of the global average across all sites in the absence of inundation (int), and the effect of inundation in the previous year (slope. before) on each site. There is also a random effect of the site, the sampling unit and the sampling transect.

The occurrence of vegetation in February (veg.after) is a function of the global average across all sites in the absence of inundation (int), the effect of inundation in the previous year (slope.after) on each site. There is also a random effect of the site, the sampling unit and the sampling transect. The occurrence of vegetation in April (veg.after2) is a function of the global average across all sites in the absence of inundation (int), the effect of inundation in the previous year (slope.after2) on each site. There is also a random effect of the site, the sampling unit and the sampling transect. All random effects are drawn from a normal distribution with mean 0. Site level estimates of slope.before and slope after were modelled hierarchically. All other parameters had non -informative prior distributions. This is also modelled using the inundation duration during a counterfactual scenario where there are no environmental flows.

Statistical Models: B. Relationships between hydraulic variables and vegetation

The data collected so far by the LTIM program represents an array of inundation histories at each sampling location generated by: (i) the range of elevation profiles sampled and (ii) differences in river discharge prior to vegetation sampling. A range of hydrological variables can be derived for each sampling time and location and used to characterise the hydrological envelope of vegetation.

Using the data collected by the LTIM program relationships between the total number of days inundated in the year prior to sampling and (i) vegetation abundance (% FPC) and (ii) the probability of occurrence of selected species/groups was examined. To enhance the dataset LTIM and VEFMAP data were combined in models of long-term relationships between vegetation abundance and the number of days inundated in the year prior to sampling. Analyses using combined LTIM and VEFMAP data was carried out only for grouped aquatic species and total vegetation cover as the relationship between VEFMAP data and LTIM data was not strong for individual species.

The models described below for both vegetation presence and abundance were implemented in OpenBUGS version 3.2.1 (Lunn et al. 2009), using the R2OpenBUGS package (Sturz et al. 2005) in R (R Development Core Team 2010). Three independent Markov chains were used to confirm convergence of chains during model burn-in. Different burn-in periods were employed for different models, with the criterion for establishing convergence being an Rhat value of approximately 1 (Sturz et al. 2005). Different periods were also used for parameter estimation, based upon autocorrelation within the Markov chains.

i) Model of vegetation presence/absence and number of days inundated

Vegetation presence/absence and was modelled as a non-monotonic function of flow within a Bayesian framework. The model is structured as follows:

$$\text{where } y_i \sim Bernoulli(p_i)$$

$$logit(p_i) = int + eff.Q * (Q_i^{\alpha} -1)/\alpha + eff.Q2 * [(Q_i^{\alpha} -1)/\alpha]^2 + eff.Transect[Transect_i]$$

The presence/absence of vegetation species or groupings (y) for site i has a Bernoulli distribution with a probability of pi. pi is modelled using a non-monotonic function and is driven by the global intercept (int), and the number of days that the sampling site is inundated in the previous year (Qi), with α determining the shape of the function. In addition, there is a random effect of the transect in which the sampling site is located. When modelling vegetation abundance as a function of Q, yi represents the cover (FPC) and is drawn from a normal distribution with an expected value of mui and precision of tau. mui is modelled using the same non-monotonic function as above.

$$\text{where } y_i \sim norm(mu_i , tau)$$

$$mu_i = int + eff.Q * (Q_i^{\alpha} -1)/\alpha + eff.Q2 * [(Q_i^{\alpha} -1)/\alpha]^2 + eff.Transect[Transect_i]$$

Int, eff. Q, α, eff. Transect were all drawn from uninformative normal distributions and Tau was drawn from an uninformative uniform distribution. This is also modelled using the inundation duration during a counterfactual scenario where there are no environmental flows.

ii) Model of vegetation cover and number of days inundated

The model structure to assess relationship between total vegetation cover and total aquatic cover and number of days inundation in the year prior.

coveri~norm(mui, tau.toti)

*mui = int + eff.Q * (Qi α -1)/α + eff.Q2 * [(Qi α -1)/α]2 +eff.Transect[Transecti]*

Vegetation cover at site i is drawn from a normal distribution with an expected value of mu and precision of tau.tot. mu is modelled using a non-monotonic function and is driven by the global intercept (int), and the number of days that the sampling site is inundated in the previous year (Qi), with α determining the shape of the function. In addition, there is a random effect of the transect in which the sampling site is located. int, eff.Q, α, eff.Transect were all drawn from uninformative normal distributions.

Tau.tot at sample i was used to represent the total prediction of the vegetation cover at site i. This is the inverse of the total variance at site i, which is a function of (i) the variance due to the model of vegetation cover as a function of hydrology (v.fit), and (ii) the variance in the VEFMAP data (v. vefmap; due to the conversion from cover classes to absolute over):

tau.toti = 1/v.toti

v.toti = v.fit + v.vefmapi

v. vefmapi is provided in the dataset, being greater than 0 for the pre-2014 data and 0 for the post-2014 data. v.fit is drawn from an unimformative uniform distribution.

E.3 Monitoring results and observations

E.3.1 Relevant flow components delivered to the lower Goulburn River

2014-15 spring fresh: Commonwealth environmental water was delivered to the Goulburn River for vegetation objectives over 3 weeks from mid-October to early November in accordance with seasonal watering plans. A maximum discharge of ~7700 ML/d was released (Figure E-1 upper panel). A further release of Commonwealth environmental water occurred over 3 weeks, from mid-November to early December, in accordance with seasonal watering plans, primarily to meet fish objectives and with a secondary objective of maintaining bank soil moisture stores.

2015-16 spring fresh: Commonwealth environmental water was delivered to the Goulburn River for vegetation objectives over approximately 3 weeks commencing the 2 October and finishing on the 26 October in accordance with seasonal watering plans (Figure E-1 middle panel). A maximum discharge of ~6200 ML/d was released. In contrast to 2014 there were no further releases to meet fish objectives.

2017: *summer fresh*: Commonwealth environmental water was delivered to the Goulburn River in response to a black water event that commenced on 1 January 2017. A maximum discharge of 3000 ML/d was released (CEWO, unpubl.).

2016-17 autumn fresh: Commonwealth environmental water was delivered to the Goulburn River for fish and instream vegetation objectives over approximately 4 weeks commencing 27 February and finishing on 30 March (Figure E-1 lower panel). A maximum discharge of ~ 4372 ML/d was released. There were no bankside vegetation objectives identified for this flow event but vegetation was monitored to evaluate (i) recovery of vegetation following the extended natural flooding and (ii) responses to the March fresh to inform future flow planning.

E.3.2 Vegetation trajectories and flow

Changes in mean cover over time for all grass species and all aquatic species across sampling locations at each site is shown in Figure E-2. Temporal patterns in mean cover differ for all grasses and all aquatics but patterns for each group are the same at Loch Garry and McCoy's Bridge.

The mean cover of grasses decreased between September and December in both 2014 and 2015, suggesting that spring freshes limit the cover of grasses. It was not possible to sample vegetation in September 2016 due to natural flooding but the cover of grasses in December 2016 was similar to that recorded in December 2014 and 2015. This suggests that natural flooding may have produced a similar suppression of grass cover over spring and early summer.

Figure E-1. Goulburn river discharge (ML/d) for McCoy's Bridge (green) in 2014-15 (upper panel) and 2015-16 (middle panel) and 2016-17 (bottom panel) showing spring freshes and autumn freshes. Blue arrows indicate timing of vegetation sampling.

Vegetation sampling in February and April 2017, before and immediate after the March fresh, respectively, found that the mean cover of grasses was increasing over time, despite the fresh delivered in March 2017. This suggests freshes later in the growing season when grasses are more mature may favour their growth.

The mean total cover of all water dependant species showed the opposite pattern to grasses and increased between September and December in 2014 and 2015, suggesting that spring freshes contributed to increasing cover. Increase cover following spring freshes in 2014 were not maintained and returned to similar levels in Spring 2015. This may partly be attributed to a drier year. In December 2016 following natural flooding the cover of water dependant species was lower than measured in December 2015.

Water dependent species differ in their hydrologic preferences. Patterns of mean cover for several water dependant taxa are shown in Figure E-3 and reveal that the cover of creeping knotweed (*Persicaria prostrata)*, lesser joyweed (*Alternanthera denticulata* and sedges (Cyperaceae) all increased between sampling in September and December in 2014 and 2015 following spring freshes. This suggests that spring freshes maybe contributing to increase cover of these taxa, however it is uncertain how much change is due to seasonal patterns of plant growth that would occur in the absence of spring freshes.

Climatic conditions and unregulated river flows also influence vegetation and can override responses to environmental watering. In 2014-15 dry climatic condition and low unregulated flows over the year prior to monitoring in September 2015 was associated with reduced cover of lesser joyweed (*A. denticulata*) while flooding in 2016-17 was associated with increased cover. In contrast, mean cover of sedges (Cyperaceae) did not decline over dry conditions in 2015-16 but was severely reduced in response to the prolonged flooding in 2016. The cover of creeping knotweed (*P. prostrata*) appears more resilient to variations in flow and climate conditions, particularly at Loch Garry where it has slowly increased in cover over time. A similar steady increase in cover of creeping knotweed has not been observed at McCoys Bridge. Similarly, the mean cover of all taxa examined was consistently lower at McCoy's Bridge compared with Loch Garry.

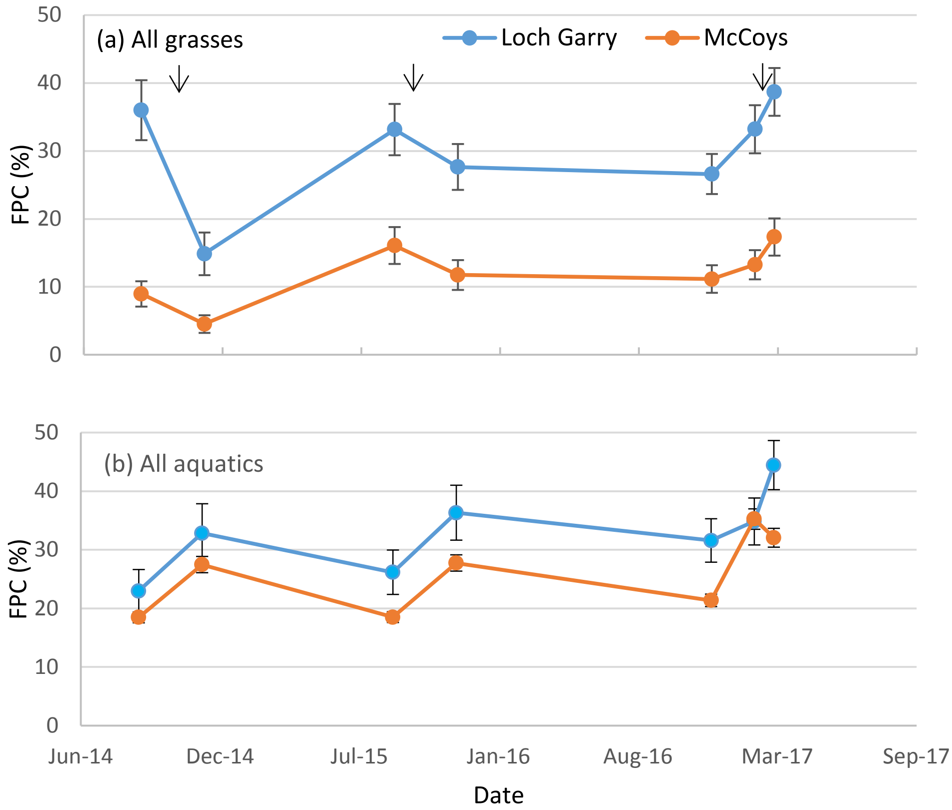


Figure E-2. Mean foliage projected cover (FPC, %) (± SE) across all sampling locations at Loch Garry and McCoy's Bridge at each sample date for all grass species (upper panel) and all aquatic species (lower panel). Black arrows indicate environmental watering events that were monitored.

Changes in patterns of species distribution along the elevation gradient

Species are not evenly distributed on the bank face but occur in zones that reflect each species tolerances to the hydrologic regimes experienced at different elevations along the bank face (Figure E-4). During periods where inundation experienced at a particular elevation on the bank is not favourable, the occurrence and or cover of the species may decline at that location but be maintained or increased at other locations on the bank that experience more favour inundation regimes. Characterising the inundation regime at differ elevations along the bank face over time provides insights into the hydrological envelope of each species.

The distribution of dominant species along the elevation gradient at all sample periods at McCoys Bridge and Loch Garry is shown in Figure E-4. The examined taxa differ in their patterns of distribution along the bank face differs patterns are similar at both sites. Common tussock grass (*Poa labillardieri*) occupies the highest elevations sampled on the bank face and achieved highest cover at elevations above the level typically reached by spring freshes. Creeping knotweed (*P. prostrata*) occurs across a wide range of elevations but has the highest cover at mid elevations with cover declining above elevations typically reached by spring freshes. Lesser joyweed (A. denticulata) and sedges (Cyperaceae) occupy comparatively lower elevations where inundation is more frequent indicating a greater dependence on water availability.

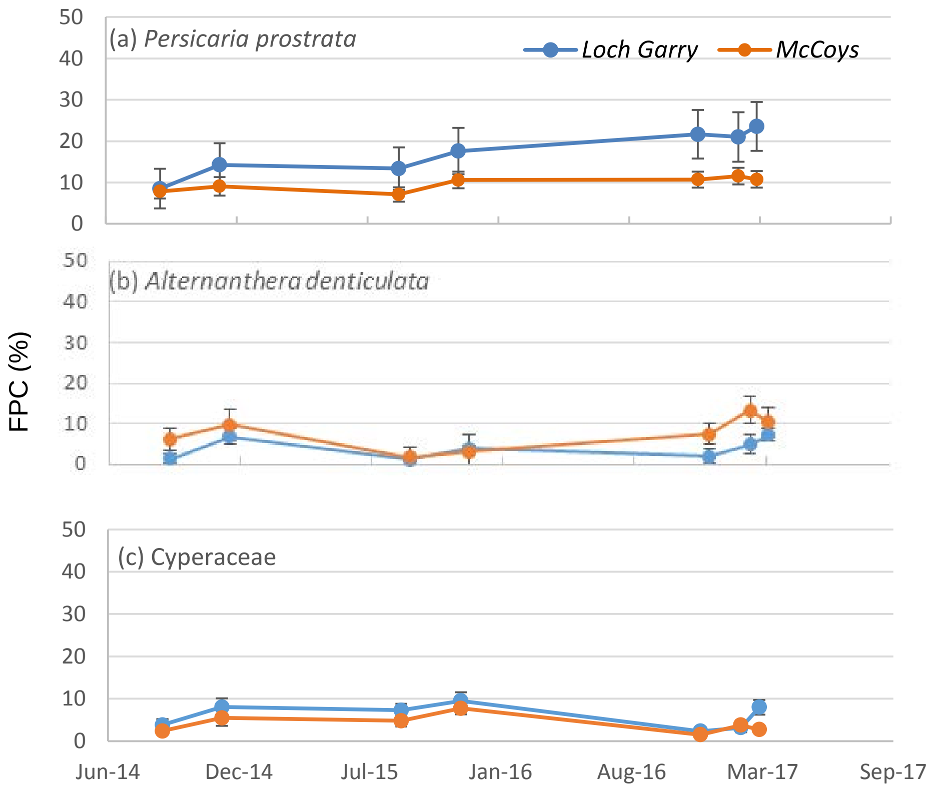


Figure E-3. Mean FPC (%) (± SE) across all sampling locations at Loch Garry and McCoy's Bridge at each sample date for creeping knotweed (*Persicaria prostrata*) (upper panel), lesser joyweed (*Alternanthera denticulate*) (middle panel) and sedges (Cypercaeae) (lower panel). Black arrows indicate environmental watering events that were monitored.

The occurrence and cover of some species along the elevation profile were dynamic and shifted over time as shown in Figure E-5. The distribution of for lesser joyweed *(A. denticulata*) shifted to lower elevations during drier condition in 2014-15 but increased again after the recession of flood water in 2016-17 (Figure E-5a,b). In contrast the occurrence and cover of sedges (Cyperaceae) increased at lower elevations during the drier conditions in 2014-15 but decreased following prolong flooding in 2016-17 (Figure E-5c,d). The pattern of distribution of cover of creeping knotweed (*P. prostrata*) along the elevation profile did not differ substantially over time.

Modelled responses to of vegetation to hydrologic variables

Pattern of change in vegetation cover and occurrence with total number days inundated in the year prior to sampling for selected taxa is shown in Figure E-6 and Figure E-7. The data represent modelled patterns using all LTIM data collected (seven sampling periods between 2014-2017). Patterns of cover with inundation were also modelled including past VEFAMP data for all aquatic and total cover, resulting in a minor reduction in model uncertainty Figure E-6.

Modelled patterns of FPC for all species as a group in response to days inundated the prior year is shown in Figure E-6. The model outputs for the LTIM data only show that FPC for all species as a group declines rapidly as the days inundated increases to 20, after which cover gradually increases. This pattern most likely reflects response of species that differ in their response to inundation. Where the number of days inundated is < 20 days, FPC and probability of occurrence of the aquatic group is low and the pattern for all species as a group is likely to be dominated by grasses. In contrast, as total inundation increases above 20 days the response to days inundated is dominated by aquatic species (see Figure E-7b,d,e). This demonstrates that care must be taken in interpreting grouped responses of diverse taxa. Even grouping aquatic taxa can be misleading as responses to inundation days differ as shown in Figure E-7, with some species preferring longer periods of inundation which is not represented when responses of all aquatic species are grouped (Figure E-6).

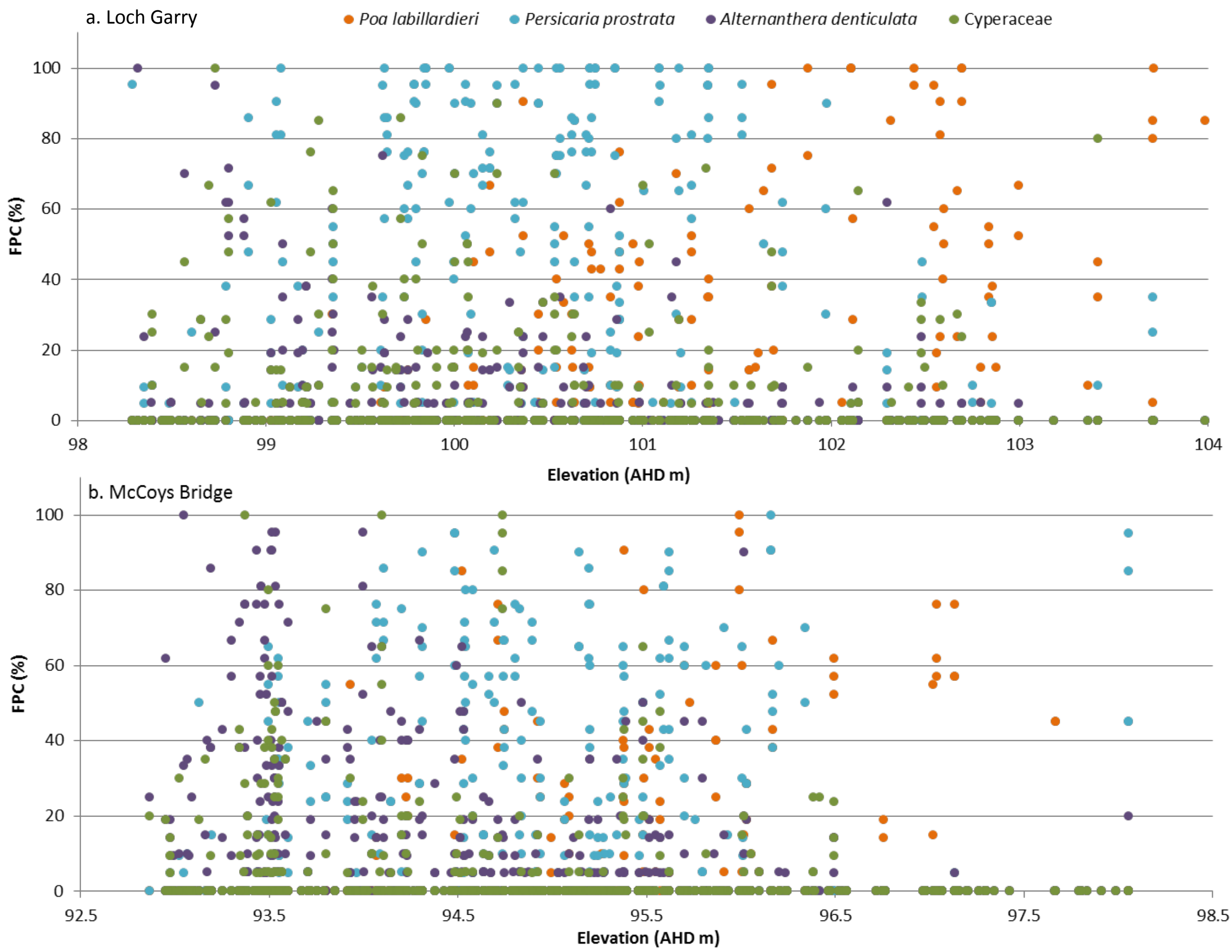


Figure E-4. Foliage projected cover (%) of *Poa labillardieri* (green circles) creeping knotweed (*Persicaria prostrata*) (blue circles), lesser joyweed (*Alternanthera denticulata*) (purple circles) and Sedges (Cypercaeae) (green circles) at Loch Garry (upper panel) and McCoy's Bridge (bottom panel) at each sample date.

Responses of cover to inundation duration the year prior to sampling using LTIM data only, or LTIM and VEFMAP data, were similar for aquatic species but differed for total cover Figure B-6. Difference observed for total cover may be due to differences in sampling times between the two monitoring program, where VEFMAP data were generally collected in early summer only, In contrast LTIM data are collected in Spring before spring freshes and in Summer, after spring freshes.

Modelled probabilities of occurrence and cover of a number of species/groups to days inundated in the prior year shows that optimal inundation requirements vary for each species/group examined. In most cases patterns for the relationship between probability of occurrence or cover and days inundated are similar, except for lesser joyweed (*A. denticulata*). For this species the probability of occurrence decreases as days inundated increased above 200 days, albeit with high uncertainty, while cover continues to increase with increasing inundation. Decreased probability of occurrence at higher inundation most likely reflects the ability of this species to rapidly colonise wet areas upon drawdown of flood waters and its limited ability to persist as the area dries. This is consistent with the high level of uncertainty in model predictions for occurrence as days inundated increases. Model outputs may be improved by including days since inundation in the model, and this should be considered in future analyses.

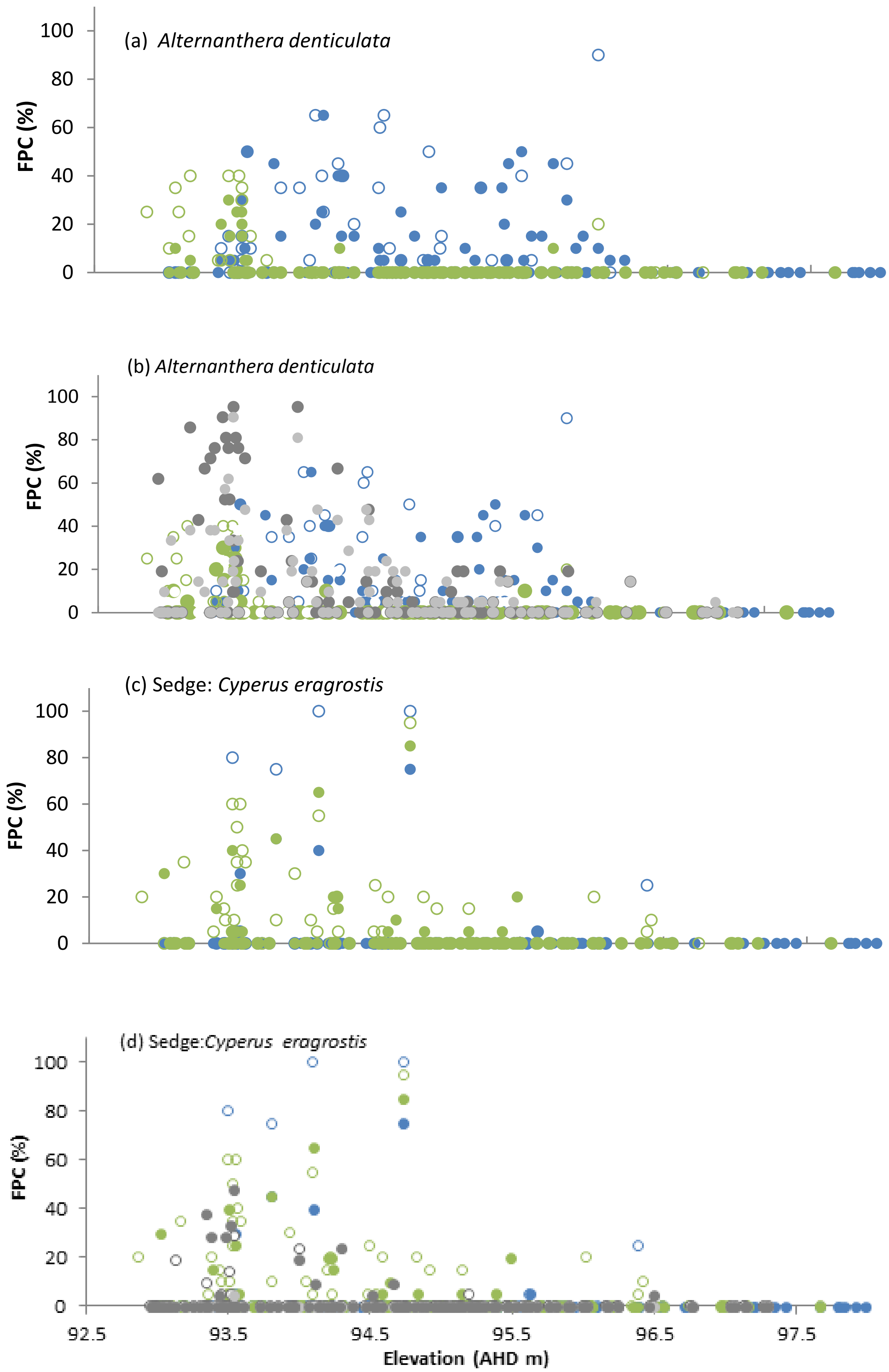


Figure E-5. Foliage projected cover (%) of lesser joyweed (*Alternanthera denticulata)* (a. b) and Sedges (Cyperaceae) (c,d) at each sampling location across the elevation gradient at each sample date at McCoys Bridge. Blue circles = 2014–15; green circles = 2015–16; grey circles = 2016–17. Filled circles are before flow events, and open circles are after flow events.

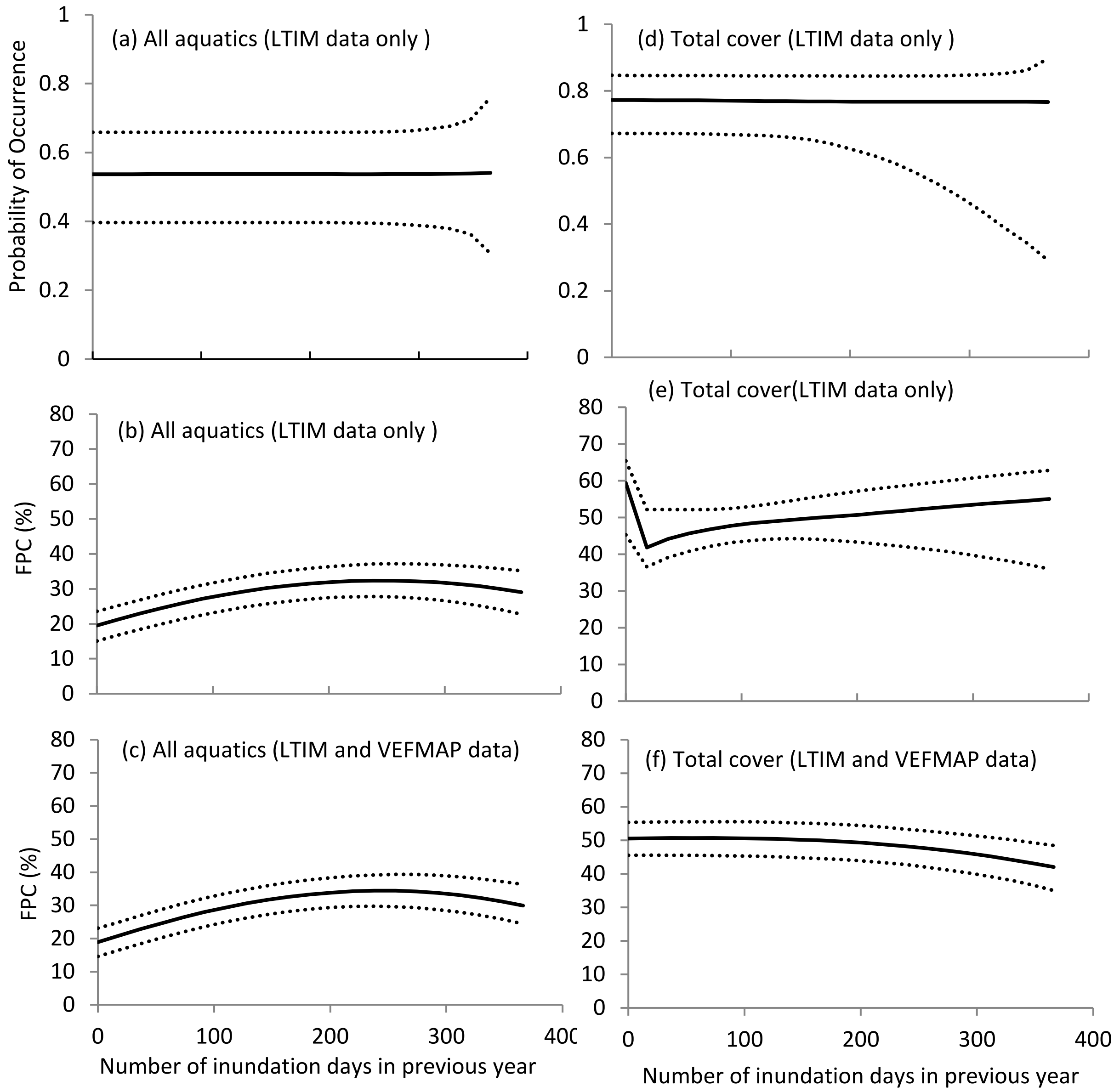


Figure E-6. Modelled probability of occurrence (a, d) and foliage projected cover (FPC %) (b, c, e, f) for grouped aquatic species (a. b. c) and all species (d, e, f) in response to number of inundation days in the previous year using all LTIM data and modelled FPC using all LTIM and VEFMAP data (c, d).

These models have considerable potential significance for management applications, as they will allow change in occurrence and cover of these taxa to be predicted under flow regimes with and without environmental water.

The modelled probability of occurrence of selected taxa with inundation days in the prior year at McCoys Bridge only differed substantially across sample dates only for lesser joyweed (*A. denituculata*) where it increased in occurrence. The data suggests that the March 2017 fresh had no strong influence on the probability of occurrence of selected taxa. However, the level of uncertainty around the model outputs is high and limits inferences on vegetation responses. The increased occurrence lesser joyweed (*A. denituculata*) is consistent with the ability of this species to rapidly colonise wet sites upon drawdown of water levels. A similar pattern was found at Loch Garry.

E.3.1 Species

Comparison of species number before and after freshes are difficult to interpret as they are likely to be confounded by the seasonal growth of annual herbs and grasses. An evaluation of long term changes in community assemblages in a particular season may be more informative, and could be undertaken as part of the basin scale evaluation or included in the selected area analysis next year.

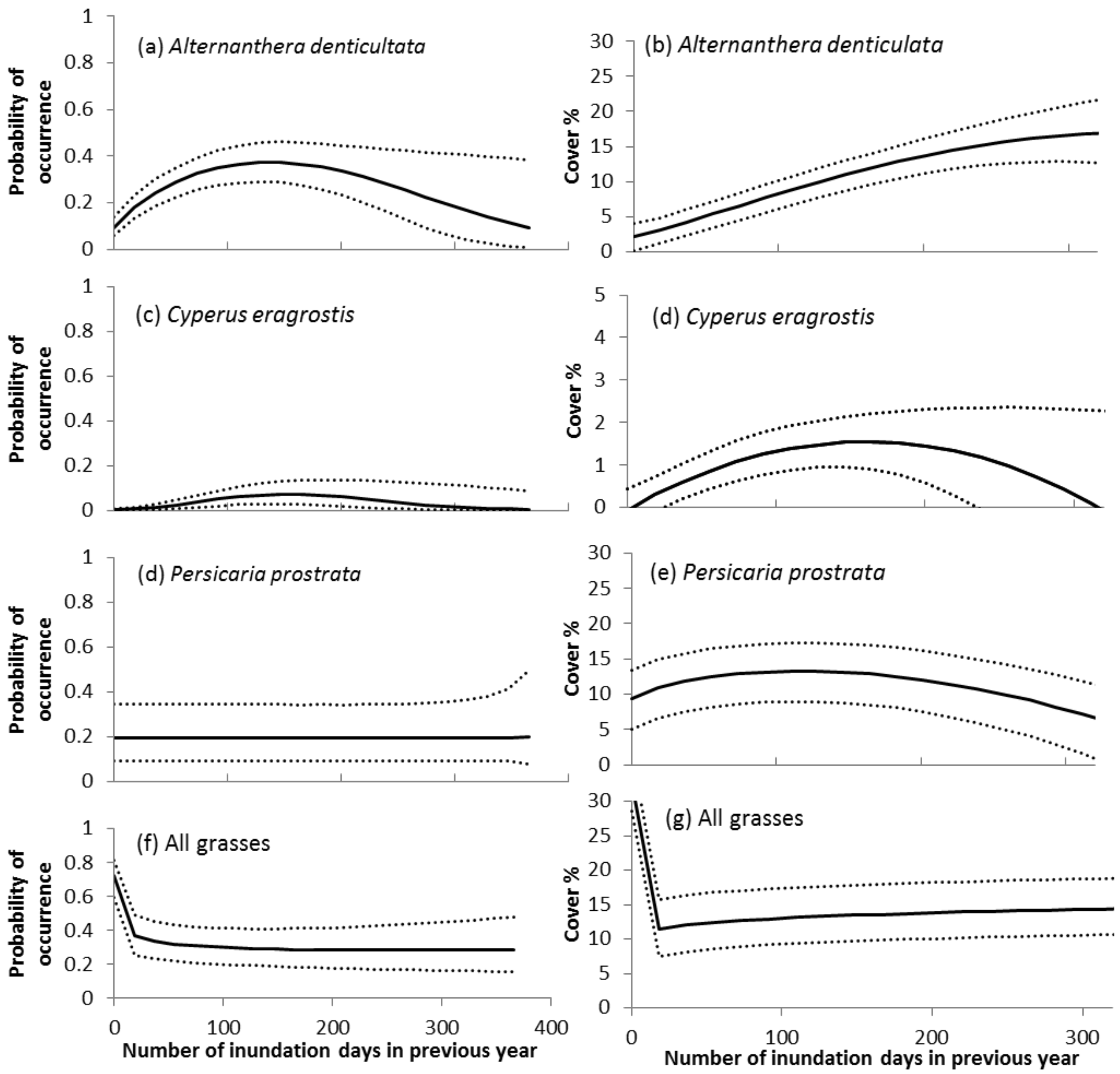


Figure E-7. Modelled probability of occurrence (a, c, d, f) and foliage projected cover (FPC %) (b, d, e, g) in response to the number of inundation days in the prior year for lesser joyweed (*Alternanthera denticulata*) (a, g) and sedges (*Cyperus eragrostis*), (c.d) , creeping knotweed (*Persicaria prostrata*) (d, e) and grasses as a group (f, g).

A full species list for each site and each sample date is provided in Table E-2 and the total number of native and exotic taxa are summarised in Table E-3 for sampling carried out in 2015-16 and 2016-17. Species data collected in 2014-15 are not included as higher elevations were initially surveyed to link to VEFMAP data and required surveys at higher elevation which included more terrestrial species not represented in subsequent surveys. The number of sampled locations differs among sites and complicates an assessment of species number. For each sampling event species accumulation curves and Chao analyses (Chao et al. 2009) can be undertaken in future analyses to assess how well our sampling effort captures species richness at each site.

In 2016, following natural flooding over June to November 2016 the number of taxa identified in December 2016 was lower than recorded at the same time in 2015 after the delivery of spring freshes lasting 3 weeks. Taxa number however increased over February and March 2017 and suggests that the natural fresh may have delayed seasonal patterns of growth.

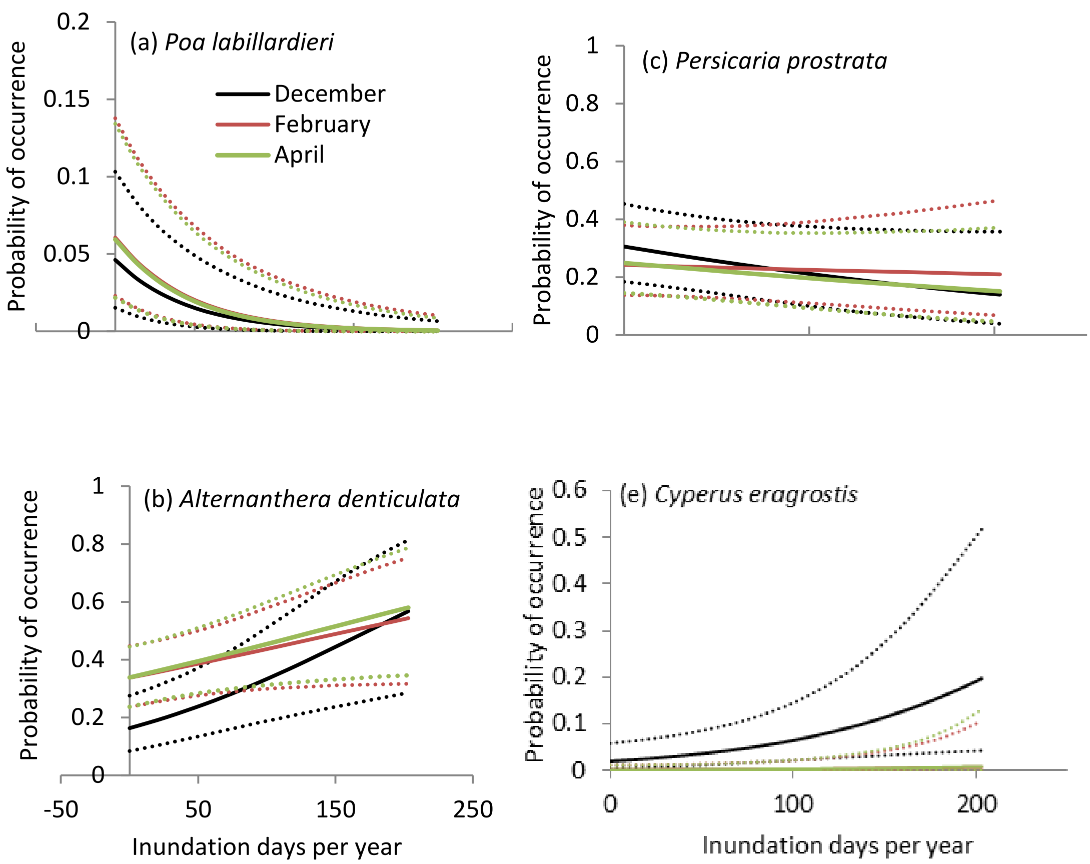


Figure E-8. Modelled probability of occurrence for selected species at McCoys Bridge for selected taxa in response to number of inundation days in the prior year across sample dates: December 2016 and February 2017, before the March fresh, and again in April 2017 immediately after the March fresh. Selected taxa: (a) *Poa labillardieri*, (b) *Alternanthera denticulata*, (c) *Persicaria prostrata* and (e) Umbrella sedge (*Cyperus eragrostis).*

Table E-2. Species identified at McCoys Bridge (MB) and Loch Garry (LG) across all sample dates. Current species names based on the Natural Herbarium of Victoria are provided and old species names still in use by the NSW herbarium are given in parentheses. Species present are assigned as N (native) or E (exotic) or Y (present but status of native or exotic not determined). An asterisk in species list indicates an exotic species. Superscript A indicates an aquatic species, and superscript G indicates a grass species.

Species	Sept 2015		Dec 2015		Dec 2016		Feb 2017		April 2017	
	MB	LG	MB	LG	MB	LG	MB	LG	MB	LG
Acacia dealbata	N	N	N	N		N		N		N
Acetosella vulgaris*										E
Alternanthera denticulata^{A}	N	N	N	N	N	N	N	N	N	N
Anthosachne scabra^{G}		N								
Arctotheca calendula*	E	E								
Aster subulatus*	E		E						E	
Avena barbata*^{G}			E	E						
Avena sp.*^{G}	E									

Species	Sept 2015		Dec 2015		Dec 2016		Feb 2017		April 2017	
Bromus diandrus*[G]	E	E								
Bromus sp.*[G]				E						
Callistemon sieberi		N		N				N		N
Calotis scapigera	N				N		N		N	
Carex appressa[A]	N	N	N							
Carex sp.[A]	Y	Y	Y	Y		Y		Y		
Carex tereticaulis[A]			N	N	N	N	N	N	N	N
Cenchrus clandestinus*	E									
Centipeda cunninghamii[A]	N	N	N	N	N	N	N	N	N	N
Cirsium vulgare*	E	E	E	E		E	E	E	E	E
Crassula decumbens		N								
Cuscuta australis								N	N	N
Cynodon dactylon var. dactylon *			E							
Cyperus eragrostis*[A]	E	E	E	E	E		E		E	E
Cyperus exaltatus[A]	N			N			N	N	N	N
Cyperus sp.[A]	Y	Y	Y	Y						Y
Dysphania ambrosioides* (Chenopodium ambrosioides)	E		E						E	
Dysphania pumilio* (Chenopodium pumilio)			E	E	E	E	E	E	E	
Eclipta platyglossa			N							
Ehrharta longiflora*[G]	E			E						
Elatine gratioloides[A]						N				
Epilobium sp.		N								
Eragrostis elongata[G]		N		N		N		N		N
Erigeron bonariense* (Conyza bonariensis)	E	E					E	E	E	E
Erigeron sp.*(Conyza sp.)	E		E							
Erigeron sumatrensis* (Conyza albida)				E						
Eucalyptus camaldulensis	N	N	N	N	N	N	N		N	N
Euchiton involucratus					N					
Euchiton sp.		N				N			N	
Euphorbia sp.					Y					
Galium aparine*	E	E								
Gamochaeta sp.*		E								
Gnaphalium polycaulon			N	N						
Haloragis aspera				N	N					
Haloragis heterophylla			N						N	
Helichrysum luteoalbum (Pseudognaphalium luteoalbum)			N				N			
Helminthotheca echioides*	E		E					E		E
Holcus sp.*[G]	E	E								

Species	Sept 2015		Dec 2015		Dec 2016		Feb 2017		April 2017	
Hypochaeris glabra*						E				
Hypochaeris radicata*	E	E		E				E		E
Juncus amabilis[A]	N	N	N	N					N	N
Juncus aridicola[A]		N					N	N		
Juncus flavidus[A]				N						
Juncus sp. [A]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Juncus subsecundus[A]			N							
Juncus usitatus[A]	N	N	N	N	N	N			N	
Kickxia elatine subsp crinita*							E		E	E
Lachnagrostis filiformis[G]	N	N	N	N				N		N
Lactuca serriola*	E	E				E	E	E	E	E
Lactuca sp.*				E						
Leontodon taraxacoides subsp taraxacoides				E						
Lolium loliaceum*[G]				E						
Lolium perenne*[G]						E		E		
Lolium sp.* [G]	E	E	E	E		E				
Lysimachia sp.*	E									
Lythrum hyssopifolia	N	N	N	N						N
Mentha australis					N		N		N	
Mentha sp.	Y									
Oxalis exilis		N		N					N	N
Oxalis perennans				N					N	N
Oxalis sp.	Y	Y	Y	Y	Y	Y	Y	Y		
Panicum coloratum*[G]	E	E	E	E	E	E	E	E	E	E
Paspalidium jubiflorum[G]	N	N	N	N	N	N	N	N	N	N
Paspalum dilatatum*[G]	E		E						E	
Persicaria decipiens[A]			N							
Persicaria hydropiper[A]							N		N	N
Persicaria prostrata[A]	N	N	N	N	N	N	N	N	N	N
Phragmites australis[A]									N	
Piptatherum miliaceum*[G]	E	E								
Plantago lanceolata*		E		E				E		E
Poa annua*[G]	E									
Poa labillardierei[G]	N	N	N	N	N	N	N	N	N	N
Polygonum aviculare*	E		E				E	E	E	E
Rorippa sp.*		E	E							
Rumex brownii						N				
Rumex sp.		Y	Y							
Rytidosperma sp. (Danthonia sp.)							N			

Species	Sept 2015		Dec 2015		Dec 2016		Feb 2017		April 2017	
Senecio quadridentatus			N						N	
Senecio sp.		Y								
Sigesbeckia australiensis								N		N
Solanum nigrum*								E		
Solanum sp.						Y	Y	Y		Y
Sonchus asper*	E									
Sonchus oleraceus*	E	E	E	E	E	E		E		E
Sonchus sp.		Y				Y				
Stellaria media*	E									
***Themeda triandra*[G]**		N		N		N		N		N
***Unidentified Cyperaceae sp.* [A]**					Y	Y	Y	Y	Y	
***Unidentified Pocaeae*[G]**						Y		Y		Y
Unidentified seedling					Y	Y	Y		Y	
Verbena officinalis	N		N						N	
Vicia sp.*	E									
Wahlenbergia gracilis		N	N	N						
Xanthium spinosum*								E		

Table E-3. Summary of the total number of taxa, number of native and exotic and unidentified taxa at McCoys Bridge (MB) and Loch Garry (LG) between September 2015 and April2017.

	Sample date and site									
	Sept 2015		Dec 2015		Dec 2016		Feb 2017		April 2017	
Summary of taxa recorded	MB (*n*=123)	LG (*n*=97)	MB (*n*=131)	LG (*n*=105)	MB (*n*=131)	LG (*n*=106)	MB (*n*=132)	LG (*n*=106)	MB (*n*=133)	LG (*n*=99)
Total taxa recorded	47	45	42	41	21	30	27	34	35	37
Total native species	15	22	22	22	12	14	14	15	21	20
Total introduced species	27	16	15	15	4	8	8	13	11	12
Records unable to assign to either native or Introduced	5	7	5	4	5	8	5	6	3	4

E.3.2 Soil moisture

Changes in soil moisture over the sampled depth gradient at McCoys Bridge at upper and lower elevations on the bank is shown in Figure E-9. Probes installed at the lower elevation were inundated by high flows delivered in January 2017 in response to low dissolved oxygen levels and in March 2017 for fish objectives. These flows influenced soil moisture stores to the maximum measured depth of 85 cm at both sampled elevations. At the lower elevation, increased soil moisture was maintained between the two flow events (~ 40 days) at depths greater than 45 cm. The effects of inundation extended to the high elevation but only at depths > 25 cm and the effects were smaller in magnitude and shorter in duration; persisting ~ 10 days.

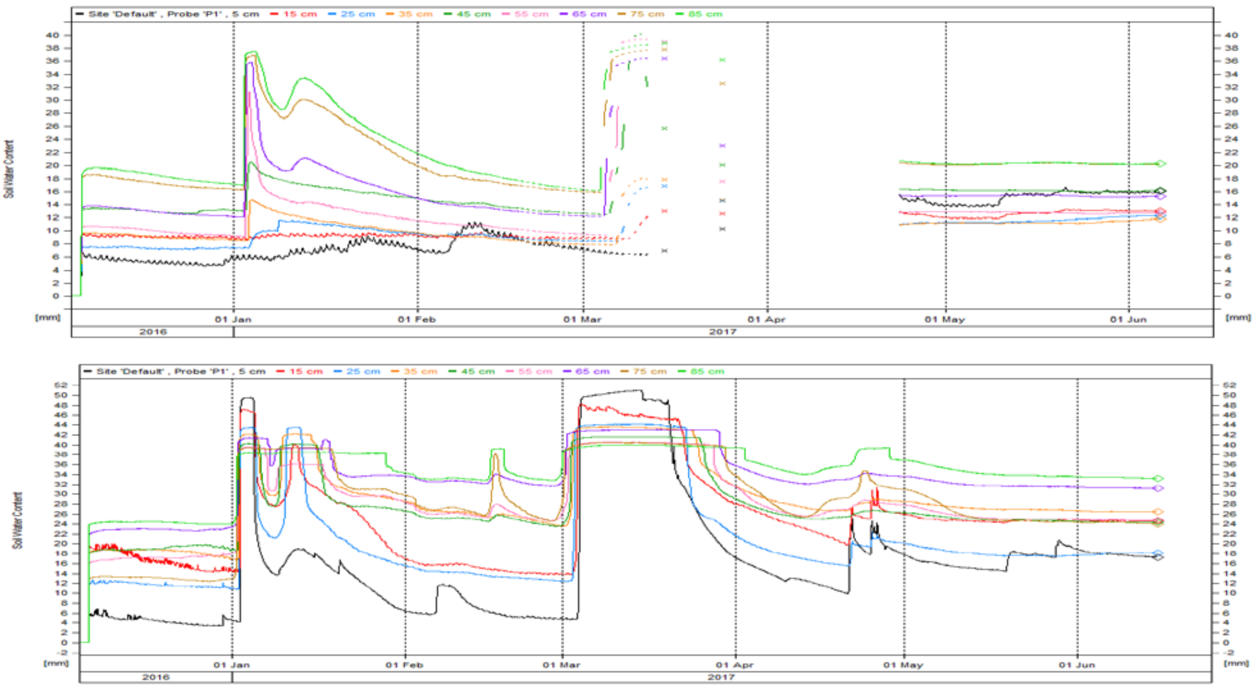


Figure E-9. Soil moisture across the depth profile at McCoys Bridge (a) upper elevation (b) lower elevation.

E.1 Discussion

It was not possible to evaluate responses of vegetation to environmental water delivered for vegetation objectives in 2016-17 due to natural flooding. Instead responses of vegetation following the recession of flood waters was assessed by monitoring carried out in December and February 2017 and again in April 2017 to a March fresh delivered for fish and instream vegetation objectives were assessed. Responses of vegetation to environmental water and natural flow events over time and across the elevation profile using data gathered so far have been examined quantitatively and qualitatively. A summary and discussion of the key findings so far are given below.

- Temporal patterns of cover for grasses show a repeated pattern on decreasing following spring freshes in 2014-15 and 2015-16. Monitoring over summer–autumn found the cover of grasses increased steady over December, February and April 2017 and suggests grasses potentially benefited from the late season watering.

- The cover for water dependant taxa examined show a repeated pattern of increasing following spring freshes in 2014-15 and 2015-16. While this pattern is correlated with spring freshes it is not known what portion of the increase in cover 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 was correlated with the distribution and cover of vegetation along the bank face. A number of plant species associated with wet habitats including lesser joyweed (*A. denticulata*), creeping knotweed (*Persicaria prostrata)* and sedges (mostly *Cyperus eragrostis*) are more prevalent and had higher cover at elevations inundated by spring freshes. In contrast, the perennial native grass common tussock grass (*Poa labillardierei*) is restricted in its distribution to elevations at or above the level inundated by spring freshes. Although *Cyperus eragrostis* is not native to Victoria it serves a similar functional role as other emergent littoral vegetation by stabilising the banks and providing food resources and habitat for aquatic fauna.

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

- Climatic conditions and non-regulated flows can exert strong effects on vegetation and have the potential to influence the outcomes of environmental water delivery. In drier years the cover of lesser joyweed is reduced and its distribution becomes restricted to lower elevations. Under wet conditions its cover increased and becomes more widely distributed over the elevation profile. In contrast the occurrence of Sedges (Cyperaceae) increased during drier conditions and declined follow prolonged inundation over spring.

- Some species such as lesser joyweed, (*A. denticulata*) can opportunistically respond to wet condition on the receding arm of high flows and showed a dynamic pattern of occurrence and cover both spatially and temporally. Other species such as creeping knotweed (*P. prostrata*) are less dynamic and maintain a more stable position along the elevation gradient possibly supported by a persistent woody root stock.

- Changes in the cover of examined taxa over time are similar at Loch Garry and McCoys Bridge but the cover of all taxa examined was lower at McCoys and the gradual increase in cover of creeping knotweed (*P. prostrata*) over time observed at Loch Garry was not evident at McCoys Bridge. The reason for differences in cover at the two sites is not known by may reflect differences in channel shape, 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 with McCoys which also has more human activity and goat grazing on *P.prostrata* (*pers*. *obs.* D. Lovell, GBCMA). Soil moisture probes installed at both sites in December 2016 by the GBCMA with VEFMAP funding will help assess if patterns of soil moisture stores differ between sites.

- Models of changes in the occurrence and cover of common taxa with the number of days inundated the year prior reveal different hydrologic requirements of the taxa examined. Is it expected that further development of these models will support the evaluation of environmental watering scenarios and provide a valuable planning tool.

Further monitoring and evaluation of the data is needed to: (i) extend on the range of hydrological variables included in models representing relationships between vegetation and hydrological variables. (ii) understand how flows contribute to soil moisture stores, (iii) understand long term trajectories of change at both sites and causes of underlying differences between sites, and (iv) understand how hydraulic habitat and the dynamics of bank erosion and deposition influence vegetation.

E.1.1 Further research

Research is needed to improve understanding of:

- The contribution of the soil seed bank, propagule transport and deposition, and propagule retention on vegetation community assemblages at the sites.

- If the distribution of instream and littoral vegetation along the river length is influenced by hydraulic variables.

- The influence of mud drapes on recruitment.

- If features such as logs and extant vegetation promote seed deposition and facilitate establishment of vegetation.

- The vegetation monitoring program is meant to answer questions regarding diversity, but a focus on species numbers would not be helpful because there are more terrestrial species and a possible relationship between species richness and environmental flows. Moreover, it is not possible to determine the influence of spring freshes on species number as differences before and after freshes will be confounded by seasonal patterns of plant growth, which alter species composition and detectability. An evaluation of changes in community assemblages would prove more valuable and could be undertaken as part of the basin scale evaluation or included in the selected area analysis next year.

E.2 Conclusion

- The means cover of water dependant vegetation across all sampling locations at both sites repeatedly increased following spring freshes in 2014-15 and 2015-16. In contrast the mean cover of all grasses repeatedly decreased.

- The extent and duration of inundation provided by spring freshes is correlated with the distribution and cover of vegetation along the bank. Several native plant species that have an affinity for wet habitats have higher cover and probability of occurrence in regions of the bank inundated by spring freshes.

- The recruitment of woody species, specifically silver wattle (*Acacia dealbata* and river red gum (*Eucalyptus camaldulensis*) are generally restricted to higher areas of the bank which experience shallow and less frequent inundation.

- Climatic conditions and non-regulated flows can exert a strong influence on vegetation and potentially influence the outcomes of environmental water. Drier conditions in 2014-15 resulted in the recruitment of sedges along the river margin at base flow but a reduction in the cover and spatial extent of lesser joyweed *A. denticulata*). In contrast, prolonged natural flooding in 2016-17 caused a significant decline in the cover and occurrence of establishing sedges but increase the cover and distribution of lesser joyweed, (*A. denticulata*) and to a lesser extent common sneezeweed *(C. cunninghamii*).

- Lesser joyweed, (*A. denticulata*) and common sneezeweed *(C. cunninghamii*) can respond rapidly to wet conditions on the receding arm of high flows.

Models of change in cover and the probability occurrence of selected taxa with the number of days inundated the year prior demonstrate that the hydrologic requirements of the taxa examined differ. It is expected that further improvements to these models will support the evaluation of (i) the contribution of environmental water to the cover and probability of occurrence of select taxa and (ii) evaluation of environmental watering scenarios.

Appendix F. Detailed results for Fish

F.1 Introduction

Supporting native fish populations is a key element of the Basin Plan's goal to protect biodiversity. The Goulburn River supports a diverse native fish fauna with high conservation and recreational angling value. Species of conservation significance include trout cod, Murray cod, silver perch, golden perch, Murray River rainbowfish and freshwater catfish. Conservation of the fish fauna of the Goulburn River has been recognised as a high priority by fisheries management and natural resource management agencies. In particular, the provision of environmental flows to support native fish populations has been identified as a key environmental watering objective for the Goulburn River (Cottingham and SKM 2011). Indeed, in terms of Commonwealth water being invested for environmental objectives, flow allocation for native fish represents a major investment of water (e.g. 58 GL for fish habitat maintenance, 138 GL for fish breeding/movement). Given this investment, it is critical that the LTIM Project evaluates the effect that Commonwealth environmental water has on native fish populations in the lower Goulburn River. Quantifying relationships between fish populations (e.g. abundance, distribution, population structure) and environmental flows in the lower Goulburn River will help the adaptive management of environmental flows in the Goulburn River and support decisions regarding environmental flows for fish throughout the Murray-Darling Basin.

The fish monitoring being carried out in this program builds upon 10 years' worth of monitoring and research assessing the status of fish populations in the Goulburn River (Koster et al. 2012) as well as monitoring undertaken since 2006 as part of the Victorian Environmental Flows Monitoring and Assessment Program. When complete, the Goulburn River fish LTIM Project will represent one of the longest continuous sets of fish monitoring data collected in the Murray Darling Basin. Moreover, it will cover a wide range of climatic conditions including record drought, record floods, and a major blackwater event that contributed to widespread fish kills. LTIM project monitoring through to 2019-20 will be particularly important in assessing the ongoing recovery of fish populations from those extreme disturbances.

The Goulburn River fish LTIM Project is also crucial to informing and interpreting the results of monitoring in other parts of the Basin. Golden perch have the capacity to disperse throughout the Basin and there is potentially a high level of connectivity between populations in the lower Goulburn River, lower Murray River, Edward-Wakool system, and Murrumbidgee River (the southern connected Basin). Coordinated monitoring across these four regions may be used to assess the influence of environmental flows in one area (e.g. spawning in the Goulburn River) on fish populations in other areas (e.g. recruitment in lower Murray).

The three fish monitoring methods employed in the Goulburn River LTIM Project (annual adult fish surveys, larval surveys, fish movement) complement each other, and increase the number of evaluation questions and associated research questions that can be answered through the program.

F.1.1 Annual fish surveys

Annual fish surveys in the river channel are part of the LTIM Project Standard Methods for fish monitoring that will provide critical information for the Basin-scale evaluation of Commonwealth environmental water. When added to the existing fish survey data for the lower Goulburn River it will provide a record of how the fish community has changed over a period of 15 years and how those changes relate to river flow. Moreover, annual surveys will help to determine whether fish spawning (detected through larval surveys), or fish movement that may be triggered by environmental flow releases, result in successful recruitment.

F.1.2 Larval fish surveys

The larval surveys for the lower Goulburn River are collecting larvae of all fish species, but will be designed more specifically to detect golden perch spawning. Golden perch is one of only two fish species (along with silver perch) in the Murray Darling Basin for which there is strong evidence of the need for increased discharge to initiate spawning. Indeed, environmental flows in the Goulburn River are explicitly used to promote spawning and recruitment of golden perch; one of the key flow objectives is to deliver freshes to promote the spawning of golden perch (Cottingham and SKM 2011).

The annual adult fish surveys can be used to identify any young-of-year golden perch in the lower Goulburn River, but given golden perch can move long distances, direct egg/larval surveys are required to determine whether high flows released into the lower Goulburn River actually trigger fish spawning.

The larval fish program will build on and add to an existing 10 year data set monitoring the spawning responses of fish to flows in the Goulburn River (Koster et al. 2012) and will represent one of the longest continuous sets of larval fish data collected in the Murray Darling Basin. Relatively few golden perch spawning events have been recorded in the lower Goulburn River to date. That is mainly thought to be due to the lack of large flows during the Millenium Drought (2001–2009). The managed flow releases in spring 2013 and 2014 (which used Commonwealth environmental water) triggered the most significant golden perch spawning that has been recorded in the lower Goulburn River in recent years. Ongoing monitoring as part of the LTIM Project should aim to more reliably determine the specific timing, magnitude and duration of flows that are needed to trigger spawning events. That information can then be used to help the Goulburn Broken Catchment Management Authority actively manage environmental flows in the future.

The larval fish program will also inform and complement monitoring in other Selected Areas. Fish have the capacity to disperse throughout the Basin and there is potentially a high level of connectivity between regions, particularly the Goulburn, lower Murray, Edward-Wakool and Murrumbidgee rivers. That connection means that environmental flows in one area (e.g. spawning in the Goulburn River) has the potential to influence outcomes in other areas (e.g. recruitment in lower Murray). In other words, monitoring of fish spawning responses in the Goulburn River may help to explain changes in recruitment and abundance in other selected areas. Thus, the Goulburn River larval fish LTIM Project will contribute to a comparison and contrast of spawning and recruitment responses of golden perch at sites across much of the Murray Darling Basin, thereby informing Basin-level responses.

F.1.3 Fish movement

Biotic dispersal or movement is critical to supporting connectivity of native fish populations, which is a key element of the Basin Plan's goal to protect ecosystem function. In particular, movement within and between water-dependent ecosystems (i.e. connectivity) can be crucial for sustaining populations by enabling fish to recolonise or avoid unfavourable conditions. For some fish species, movement also occurs for the purposes of reproduction and therefore contributes to the Basin Plan's goal to protect Biodiversity.

The Goulburn River fish movement program targets golden perch and will build on the existing six-year acoustic telemetry project monitoring movement of native fish in the Goulburn and Murray rivers that was funded by Commonwealth Environmental Water Office (as part of their Short Term Intervention Monitoring Program) and Goulburn Broken Catchment Management Authority (Koster et al. 2012). The Goulburn River fish movement program complements monitoring of fish movement being undertaken as part of the LTIM Project in the Edward-Wakool and Gwydir rivers. In particular, it will enable a comparison and contrast of the movements of native fish at sites across much of the Murray Darling Basin thereby informing Basin-level responses. Fish have the capacity to disperse throughout the Basin and there is potentially a high level of connectivity between regions, particularly the Goulburn, lower Murray, Edward-Wakool and Murrumbidgee rivers. Therefore, the influence of environmental flows in one area has the potential to strongly influence outcomes in other areas. In other words, monitoring of fish movement within the Goulburn River might help to explain changes in fish abundance within other selected areas.

The LTIM Project is providing a unique opportunity to co-ordinate fish movement monitoring across the southern connected Murray-Darling Basin. A focus is to investigate whether individual golden perch move between any of the selected areas over the course of the LTIM project, and considering whether particular flow events triggered or facilitated that movement.

F.2 Methods

F.2.1 Monitoring

A detailed description of the sampling methods can be found in the Standard Operating Procedures available as part of the Monitoring and Evaluation Plan. Briefly, electrofishing (Figure F-1) was conducted at 10 sites in the

Goulburn River during April and May 2017 (Table 2-1). Sampling was conducted at each site during daylight hours using a Smith–Root model 5 GPP boat–mounted electrofishing unit. 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. Nets were set in late afternoon and retrieved the following morning.

A total of 89 adult golden perch were collected from the Goulburn River and tagged with acoustic transmitters in autumn 2014-16. Twenty-one acoustic listening stations were also deployed in the Goulburn River between Goulburn Weir and the Murray River junction as part of this and other monitoring programs. Four listening stations were also deployed in the Murray River near the Goulburn River junction.

Drift nets were used to collect fish eggs and larvae in the Goulburn River at four sites (Pyke Road, Loch Garry, McCoy's Bridge, Yambuna) every week from October to December 2016 using 3 nets set at each site. The nets were set in late afternoon and retrieved the following morning.

Figure F-1. ARI staff completing electrofishing survey in the Goulburn River in 2017

F.2.2 Statistical analysis

The data collected in the drift net surveys and in the fish movement monitoring were statistically modelled to identify the impact of hydrology (and therefore, environmental flows) on fish spawning and movement through the Goulburn River.

Spawning (golden perch) statistical analyses

The golden perch spawning data (2014-2016 data combined) were analysed with a hierarchical logistic regression (probability of spawning):

$$\mathrm{y_i} \sim \mathrm{Bernoulli}(\mathrm{probability_i})$$

$$\mathrm{logit}(\mathrm{probability_i}) = \mathrm{int} + \mathrm{Inc_i} \times \ \mathrm{eff.Q_j} \times \mathrm{Q_i} + \mathrm{eff.site_j} + \mathrm{eff.net_k} + \mathrm{eff.survey_m}$$

$$\mathrm{Inc_i} \sim \mathrm{Bernoulli}(\mathrm{e.Temp_i})$$

$$\mathrm{logit}(\mathrm{e.Temp_i}) = \mathrm{int.Temp} + \mathrm{eff.Temp} \times \mathrm{Temp_i}$$

The occurrence of spawning (count of eggs) normalised to the discharge through the net (y) for drift net j at site k during year (or survey) m and deployment i is driven by a global average across all sites (int), plus the effect of discharge (eff.Q). However, this effect of discharge is only relevant when temperatures exceed certain levels, as determined by an inclusion term (Inc). This inclusion term is drawn from a Bernoulli distribution, with a probability of e.Temp. e.Temp is driven by an intercept term (int.Temp) and the effect of temperature (eff.temp).

There is a random effect of site (eff.site) that acknowledges that local conditions may enhance or retard spawning overall, plus a random effect of each drift net location (eff.net) to account for the repeated measures taken for each net location, and a random effect of each year (eff.survey) to account repeated measures taken in each year.

The random effects were drawn from a normal distribution with mean zero. The site-level estimates of eff.Q were modelled hierarchically and drawn from a hyper-distribution. All prior distributions for parameters were assigned as minimally informative.

We also modelled fish spawning occurrence as a function of mean channel velocity.

Fish movement statistical analyses

The fish movement data (2014-2016 data combined) were also analysed with a hierarchical logistic regression (probability of occurrence of downstream movement). The occurrence of downstream movement was defined as the detection of an individual fish at multiple acoustic listening stations, as repeated detections of a fish at a single listening station does not imply movement away from a home range. The model structure is as follows:

$$\mathrm{move_i} \sim \mathrm{Bernoulli(probability.move_i)}$$

$$\mathrm{logit(probability.move_i) = int + eff.Q \times Q_i + eff.day1 \times day_i^2 + eff.day2 \times day_i + eff.Temp_k \times temp_i + eff.Fish_j}$$

The occurrence of downstream movement (move) for fish j on day i is driven by the global average across all sites in the absence of flow (int) ,the effect of discharge (eff.Q) , the effect of temperature (eff.Temp), and the effect of the time of year (eff.day1 and eff.day2). There is also a random effect of the fish j (eff.Fish). The effect of temperature has been modelled at a 'year-level'. This is to take into account the fact that the relationship between temperature and the occurrence of fish movement during a set time period can vary depending on the specific hydrological conditions of the time period.

eff.Fish was modelled hierarchically, being drawn from a normal distribution with the hyperprior (mu.eff.fish) modelled as a function of the fish length (in mm). This is to take into account the fact that young fish tend to move less than mature fish.

$$\mathrm{eff.Fish_j \sim N(mu.eff.fish_j, t.eff.fish)}$$

$$\mathrm{mu.eff.fish_j = int.fish + eff.Size \times Size_j}$$

The effect of fish length (eff.Size) on the hyperprior (mu.eff.fish) and the global intercept (int.fish) was drawn from a normal distribution with a mean of 0.

eff.Temp was also modelled hierarchically, being drawn from an uninformative normal distribution with mean of 0 and precision of 0.01. int, eff.day1 and eff.day2 are drawn from a normal distribution with mean 0.

We also modelled fish movement occurrence as a function of mean channel velocity and all data were averaged over a moving 5-day timestep. It should be noted that the daily temperature data at various spatial points in the river (Darcy's Track, Day Rd and Loch Garry) averaged over the moving 5-day timestep, were estimated by applying a conversion factor (that vary according to season) to daily water temperature data at McCoys Bridge throughout the fish movement monitoring period. The seasonally varying conversion factors were determined by comparing the surface water temperature data at Darcy's Track, Day Rd, Loch Garry and McCoys Bridge collected as part of the stream metabolism monitoring. The stream metabolism monitoring period is shorter than that of fish movement.

Finally, the model was run using a counterfactual flow series without environmental flows, and the probability of downstream fish movement under the two scenarios (i.e., real scenario and no environmental flows scenario) was compared.

F.3 Results

F.3.1 Monitoring results and observations

Annual surveys (electrofishing and netting)

A total of 1287 individuals comprising nine native and three exotic species were collected from the annual electrofishing surveys (Table F-1). Species of conservation significance collected were Murray cod, silver perch and Murray River rainbowfish. Similar to previous surveys, Australian smelt was the most abundant species collected, comprising 42% of the total abundance for all species, followed by the introduced carp (30%) and Murray River rainbowfish (17%) (Table F-2).

Murray River rainbowfish, silver perch and bony herring were collected in higher numbers compared to previous surveys (Table F-2). Trout cod, recorded in the first 2 years (2015 and 2016) of the LTIM Project, were not collected in 2017. Murray cod were collected in lower numbers compared to previous surveys, largely due to fewer individuals at Zeerust (2015, n =14; 2016, n = 14, 2017, n = 3).

Table F-1. Numbers of individual fish species collected from the Goulburn River in electrofishing and fyke net surveys in 2017. Asterisk denotes native fish species.

Species	Electrofishing	Fyke Netting	Total
Silver Perch *Bidyanus bidyanus* *	15		15
Goldfish *Carassius auratus*	14		14
Carp *Cyprinus carpio*	388		388
Eastern gambusia *Gambusia holbrooki*	5	5225	5230
Carp gudgeon *Hypseleotris sp.* *	18	651	669
Trout cod *Maccullochella macquariensis* *			
Murray cod *Maccullochella peelii* *	53		53
Golden perch *Macquaria ambigua* *	30	1	31
Murray River rainbowfish *Melanotaenia fluviatilis* *	214	152	366
Bony herring *Nematalosa erebi* *	12		12
Flatheaded gudgeon *Philypnodon grandiceps* *		2	2
Australian smelt *Retropinna semoni* *	538	60	598
Total number of individuals	**1287**	**6091**	**7378**

A total of 6091 individuals comprising five native species and one exotic species were collected from the annual netting surveys (Table F-1). The introduced eastern gambusia comprised the bulk of the catch (86%) and was collected in much higher numbers (n = 5225) than previous surveys (2015, n = 0; 2016, n = 6). The majority (94%) of eastern gambusia collected were from a single site, Stewarts Bridge. Carp gudgeon was the next most abundant species, comprising 11% of the total abundance for all species.

Length frequency histograms are presented for three of the six selected target species: Murray cod, golden perch and silver perch. One of the target species, river blackfish, was not collected. This species however appears to be rare in the lower Goulburn River. Lengths of the two other target species, carp gudgeon and Australian smelt, no longer need to be measured (Rick Stoffels, pers. comm.).

Table F-2. Numbers of individual fish species collected from the Goulburn River in electrofishing, fyke net and bait trap surveys combined in 2015, 2016 and 2017.

Species	2015	2016	2017	Total
Silver Perch *Bidyanus bidyanus* *	2	5	15	22
Goldfish *Carassius auratus*	8	22	14	44
Carp *Cyprinus carpio*	107	264	388	759
Eastern gambusia *Gambusia holbrooki*	1	6	5230	5237
Carp gudgeon *Hypseleotris sp.**	185	452	669	1306
Trout cod *Maccullochella macquariensis* *	1	4		5
Murray cod *Maccullochella peelii* *	79	83	53	215
Golden perch *Macquaria ambigua* *	31	44	31	106
Murray River rainbowfish *Melanotaenia fluviatilis* *	186	208	366	760
Bony herring *Nematalosa erebi* *		3	12	15
Flatheaded gudgeon *Philypnodon grandiceps* *		1	2	3
Australian smelt *Retropinna semoni* *	276	350	598	1224
Total number of individuals	**876**	**1442**	**7378**	**9696**

Murray cod

The size of Murray cod collected in the 2017 surveys ranged from 47 mm in length and 1.2 g in weight to 720 mm in length and 5.5 kg in weight (Figure F-2, Figure F-3). The vast majority of the population were below the minimum legal size (550 mm) for Murray cod. Five young-of-year (YOY) Murray cod (i.e. <100 mm in length) were collected.

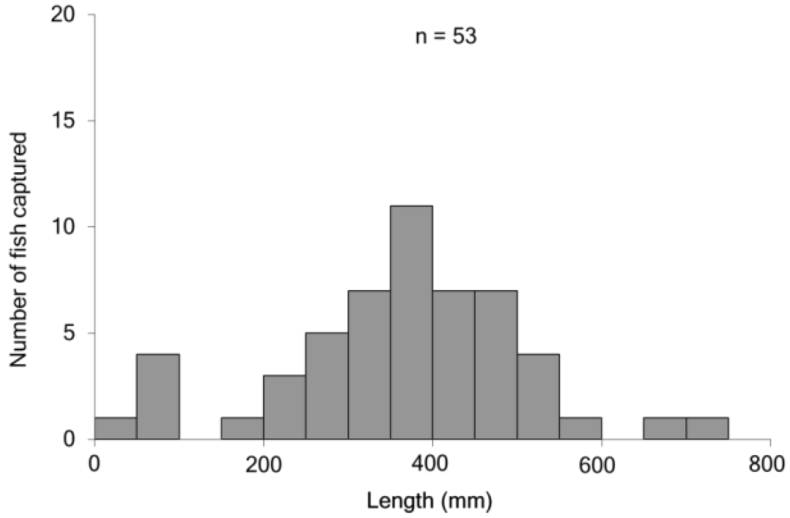


Figure F-2. Length frequency (total length) of Murray cod collected in the Goulburn River in 2017

Golden perch

The size of golden perch collected in the 2017 surveys ranged from 116 mm in length and 21.9 g in weight to 525 mm in length and 2.6 kg in weight (Figure F-4, Figure F-5). No YOY golden perch were collected, although two fish between 100-200 mm in length were captured, which are likely 1-2 years old.

Figure F-3. A Murray cod being released into the Goulburn River after capture

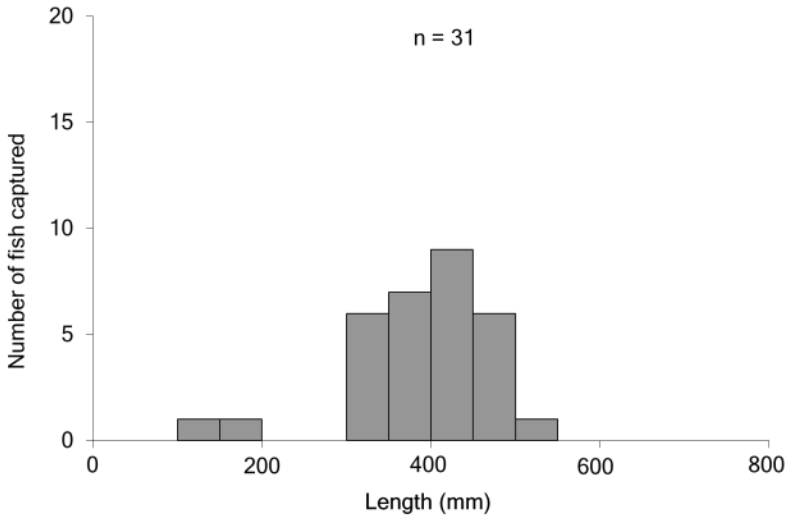


Figure F-4. Length frequency (total length) of golden perch collected in the Goulburn River in 2017

Figure F-5. A golden perch being released into the Goulburn River after capture

Silver perch

The size of silver perch collected in the 2017 surveys ranged from 124 mm in length (fork length) and 20 g in weight to 287 mm in length and 342 g in weight (Figure F-6, Figure F-7). No YOY silver perch were collected, although six fish between 100-200 mm in length were captured, which are likely 1-2 years old (Figure F-7). These may be fish that have migrated in to the Goulburn River from the Murray River, but this would need to be confirmed by otilith microchemical analysis.

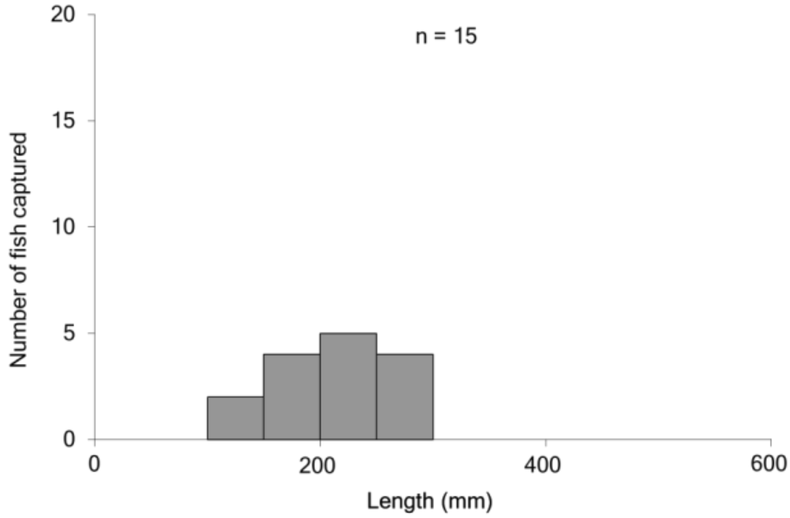


Figure F-6. Length frequency (fork length) of silver perch collected in the Goulburn River in 2017

Figure F-7. A juvenile silver perch collected in the Goulburn River in 2017

Surveys of eggs and larvae (drift nets)

A total of 1045 individuals representing six native species and one exotic species were collected in the drift net surveys between October and December (Table F-3). Murray cod was the most abundant species collected, comprising 85% of the total abundance for all species. This is an unusually high abundance for this species, which is not believed to respond to flows in terms of spawning.

Golden perch eggs were collected in late October and early November on the falling limb of a natural flow event (Figure F-8). Water temperature at these times was about 16.3-18.5 °C. The majority (99%) of eggs were collected in early November. Discharge and water temperature at this time was about 3500 ML day and 18.5

°C, respectively. Silver perch eggs were also collected during the natural flow event in mid-November on the falling limb of the hydrograph. Water temperature at this time was 20.7 °C (Figure F-9).

Carp larvae were collected between late October and early November also on the falling limb of the natural flow event during the natural flow event (Figure F-10). Water temperature at these times was about 14.8-18.5 °C. The majority (96%) of larvae were collected in early November. Discharge and water temperature at this time was about 3500 ML day and 18.5 °C, respectively.

Table F-3. Numbers of eggs (e) and larvae (l) of fish species collected in drift net surveys from the Goulburn River in 2016. Species with asterisk are native species.

Species	Pyke Rd	Loch Garry	McCoy's Bridge	Yambuna	Total
Silver perch*			34e		34
Murray cod*	174l	404l	200l	114l	892
Golden perch*	1e	24e	3e	19e	47
Common carp	2l		5l	11l	18
Australian smelt*	23e	4e	7e	1l	35
Flathead gudgeon*	16l		2l		18
Carp gudgeon*	1l				1
Total number of individuals	**174**	**432**	**251**	**145**	**1045**

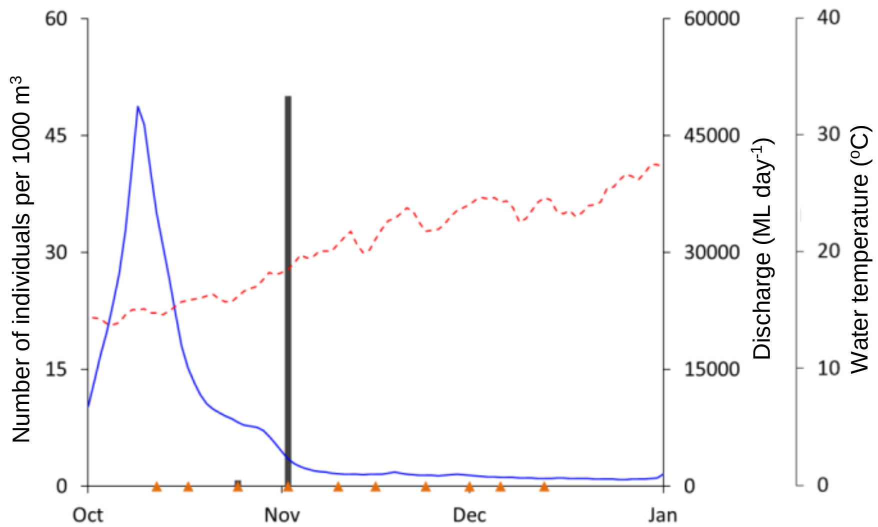


Figure F-8. Adjusted total density of golden perch eggs (grey bar) per 1000m³ collected in drift nets in the Goulburn River. Mean daily discharge (blue line) and water temperature (broken red line) of the Goulburn River at McCoy's Bridge. Orange triangles indicate sampling dates.

The statistical analyses of the counts of golden perch eggs indicate a positive relationship between the probability of spawning, and discharge (Figure F-11). The 95th confidence interval bounds tighten at higher temperatures. Similarly, there was a positive relationship between the probability of spawning and mean channel velocity (Figure F-12).

Movement of golden perch

Of the 89 golden perch tagged, 81 have been detected by the listening stations. Over half (44 out of 81) of the fish detected have undertaken long-distance movements (i.e. > 20 km); the other 37 fish had no detectable movement (i.e. > 20km).

Movement was strongly seasonal, being most prevalent during the spawning season (spring to early summer), and occurred primarily in a downstream direction into the lower river reaches, typically followed by return upstream movements (Figure F-13). Twenty eight golden perch moved downstream into the Murray River. Of these fish, twenty returned to the Goulburn River (Figure F-13). Most long-distance downstream movements coincided with increases in flow, including spring 'freshes' (Figure F-13).

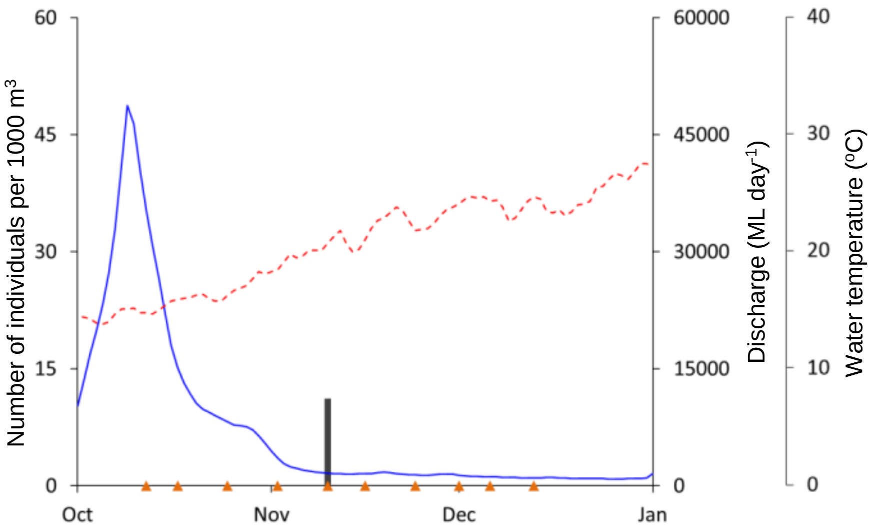


Figure F-9. Adjusted total density of silver perch eggs (grey bar) per 1000m^3 collected in drift nets in the Goulburn River. Mean daily discharge (blue line) and water temperature (broken red line) of the Goulburn River at McCoy's Bridge. Orange triangles indicate sampling dates.

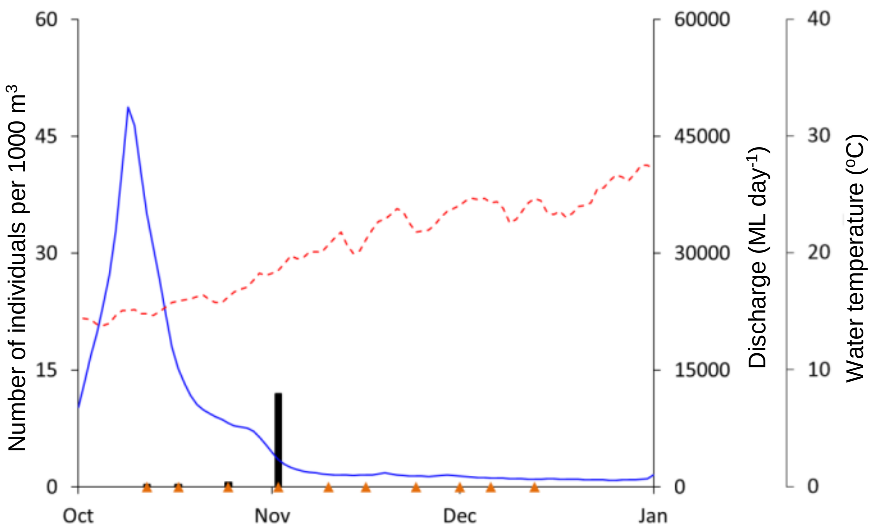


Figure F-10. Adjusted total density of carp larvae (grey bar) per 1000m^3 collected in drift nets in the Goulburn River. Mean daily discharge (blue line) and water temperature (broken red line) of the Goulburn River at McCoy's Bridge. Orange triangles indicate sampling dates.

The percentage of tagged fish detected migrating to the lower reaches varied between years: 40% in 2014, 4% in 2015, and 35% in 2016. The timing of downstream movements also varied between years: in 2014 and 2015 all downstream movements occurred in October-November, while in 2016, 45% occurred in October-November and 45% occurred slightly earlier in August-September.

In the 2014 and 2016 spawning seasons, the occurrence of golden perch eggs in the lower reach corresponded with the movements of tagged fish into the lower reaches of the river (Figure F-13). In 2015, few fish undertook long distance movements, and no golden perch eggs were collected.

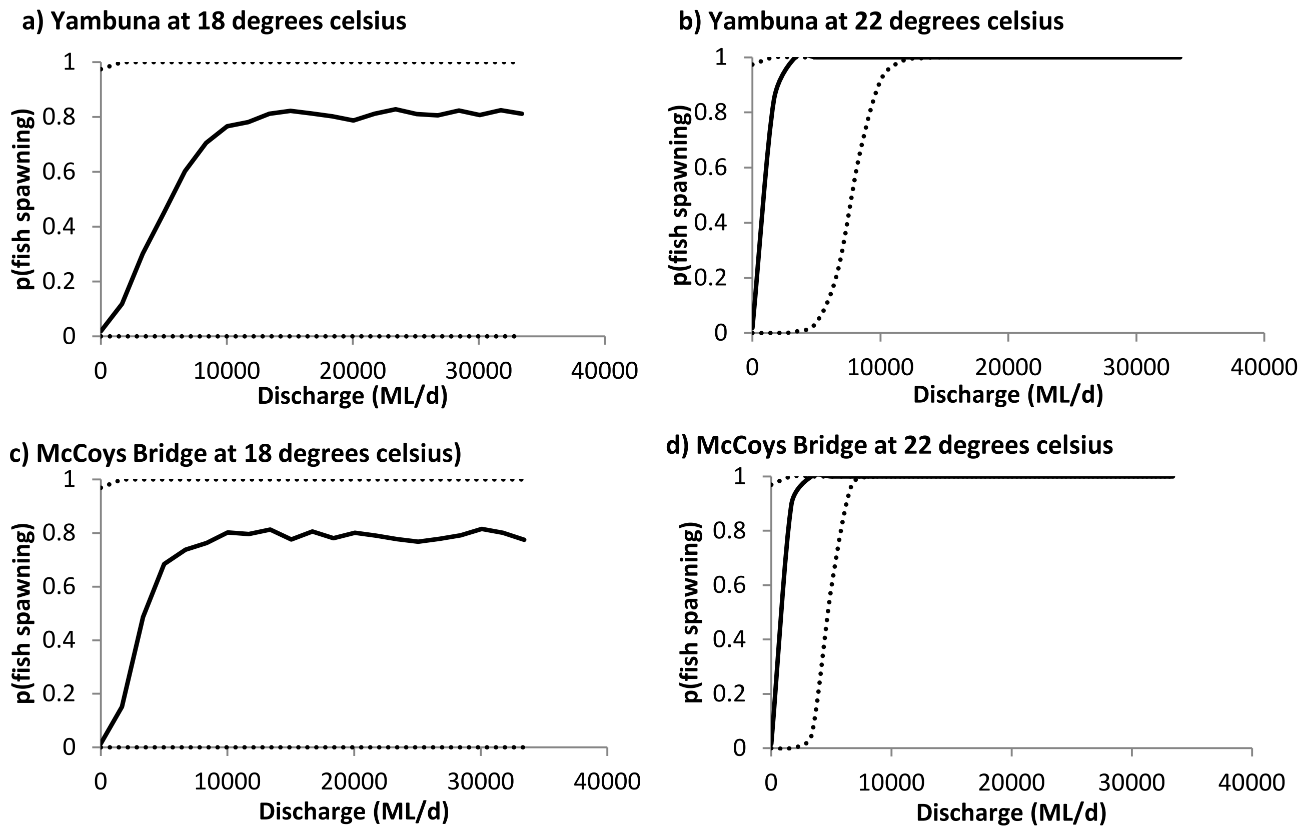


Figure F-11. Relationship between the probability of occurrence of spawning and discharge (ML/d).

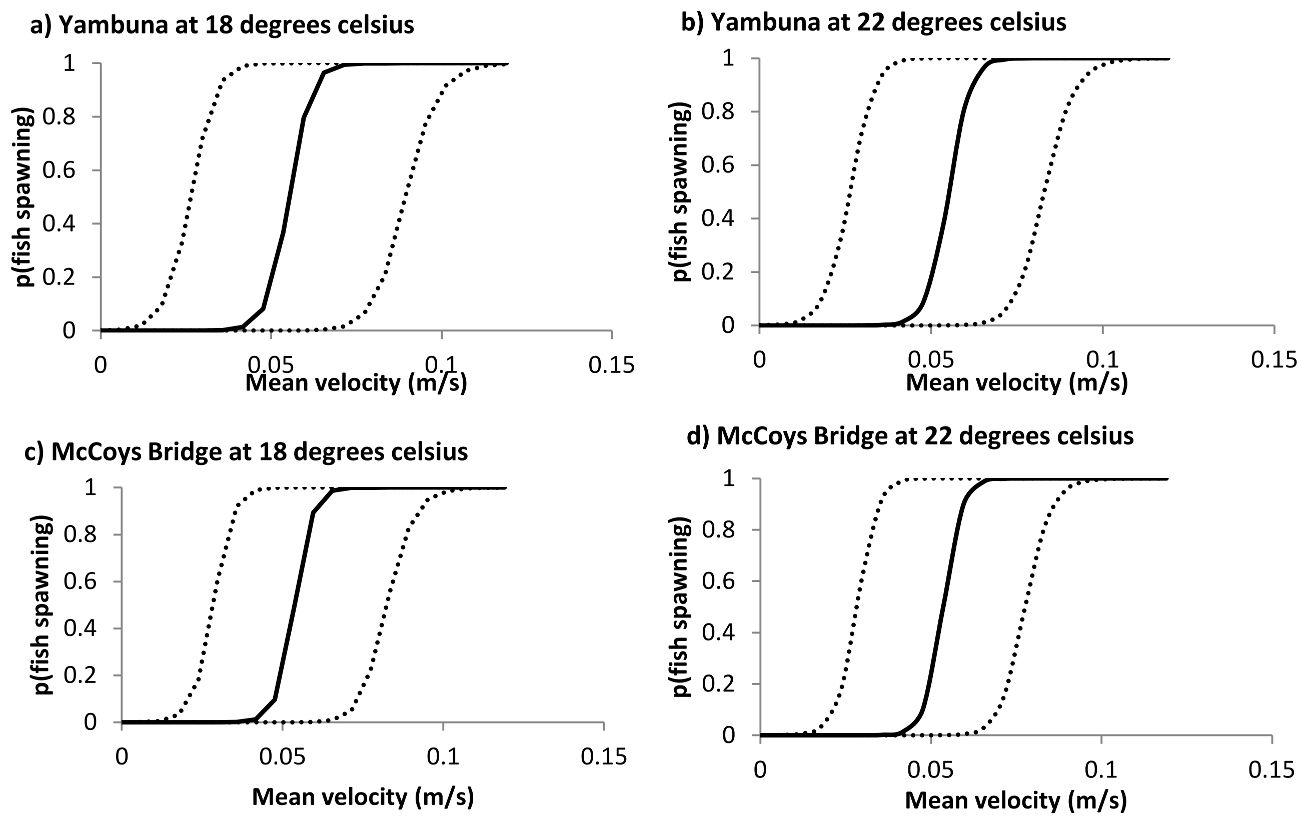


Figure F-12. Relationship between the probability of occurrence of spawning and mean channel velocity (m/s).

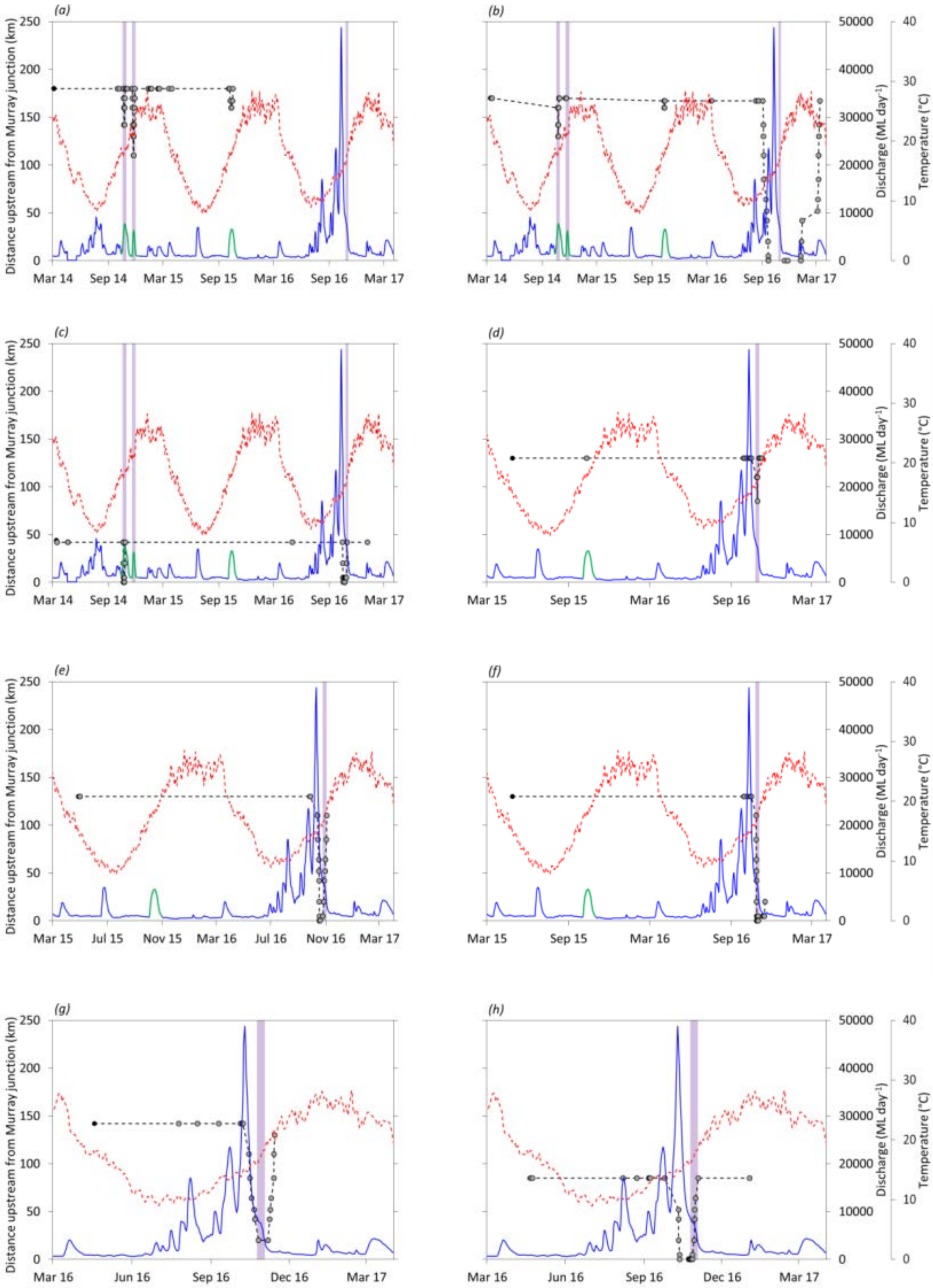


Figure F-13. Examples of the movement patterns of individual golden perch tagged in the Goulburn River in 2014 (a-c), 2015 (d-f) and 2016 (g, h). Black circles show the date and location of tagging and grey circles show detections of tagged fish on the listening stations. Mean daily discharge (blue line) and water temperature (broken red line) of the Goulburn River at McCoy's Bridge. Green line denotes spring environmental flow 'freshes'. Coloured purple bars represent times when golden perch eggs were collected.

Similarly, the statistical analyses indicated a positive relationship between both discharge and mean channel velocity and downstream fish movement in the Goulburn River. This is indicated by the positive regression coefficients for the discharge and velocity term (eff.Q) in the models (Table F-4). In addition, it is evident that the effect of temperature on the probability of occurrence of fish movement varies significantly between years, with the regression coefficient of the temperature term (eff.temp) being negative in year 3 only. This suggests that only in year 3 the relationship between temperature and the occurrence of downstream fish movement is negative. This is likely due to the unusual hydrological conditions witnessed in this year. It should also be noted that the size of the fish has a positive effect on the probability of occurrence of downstream fish movement also (Table F-4).

Table F-4. Regression coefficients of fish movement statistical model.

	Flow (ML/d)			Mean Velocity (m/s)		
	2.5th percentile	50th percentile	97.5th percentile	2.5th percentile	50th percentile	97.5th percentile
eff.Q	0.36	0.44	0.52	0.15	0.26	0.38
eff.temp (year1)	0.43	0.80	1.14	0.41	0.72	1.07
eff.temp (year2)	-1.26	-0.93	-0.59	-1.24	-0.95	-0.63
eff.temp (year3)	-0.74	-0.50	-0.25	-0.70	-0.45	-0.21
eff.Size	-2.71	2.08	7.33	-5.43	1.46	3.91
int	1.64	3.59	6.25	-0.89	1.79	4.68

However, the models indicate that the movement behaviour of fish varies significantly depending on the individual fish, both when the probability of occurrence of downstream movement is modelled as a function of discharge, and as a function of mean channel velocity. For example for a discharge to 7120 ML/d, at 20 degrees and in summer, some fish can demonstrate no movement at all, whilst some fish have a probability of downstream movement of greater than 0.4 (Figure F-14).

It should be highlighted that the probability that the occurrence of fish movement downstream will increase with environmental flows, due to the increase and change in timing of discharge (ML/d) is 0.53. The probability of increase of downstream fish movement due to an increase and change in the timing of mean channel velocity (m/s) with environmental flows, is 0.49. As such, it appears that the probability that there will be an increase in fish movement with environmental flows is approximately 50%.

F.4 Discussion

Annual surveys (electrofishing and netting)

An important finding of the recent surveys was that the nationally endangered silver perch was collected in higher numbers compared to the last two years. Further, electrofishing catch per unit effort of silver perch in the current surveys (1.9 fish per hour) was considerably higher than in most surveys in the Goulburn River from 2003 to 2014 (average 0.9 fish per hour) (Koster et al. 2012; Koster unpublished data). It is possible that this increase was driven by recent immigration of silver perch from the Murray River. As part of an acoustic telemetry study funded by MDBA and DELWP, juvenile silver perch tagged in the Murray River were detected moving into the Goulburn River and other tributaries in March-April 2017 coinciding with environmental flow freshes in the tributaries (Koster unpublished data).

The Murray River rainbowfish, listed as threatened in Victoria, was also more abundant in 2017 compared to the last two years. One factor which may have contributed to this increase in abundance could be the recent recruitment of semi-aquatic vegetation along the banks of the Goulburn River. The species has been documented to use aquatic vegetation for spawning (Milton and Arthington 1984). Furthermore, Murray River rainbowfish were also observed in high abundance in areas with aquatic vegetation (ARI unpublished data). Thus, an increase in this habitat may have enhanced feeding opportunities, survival as well as breeding of the species. Notwithstanding, for small-bodied schooling species such as Murray River rainbowfish, occasionally large schools are encountered, possibly by chance, thus contributing to unusually high catches on occasions. This patchiness places limitations on interpretation of the data and needs to be considered when examining variation in numbers of these small schooling species.

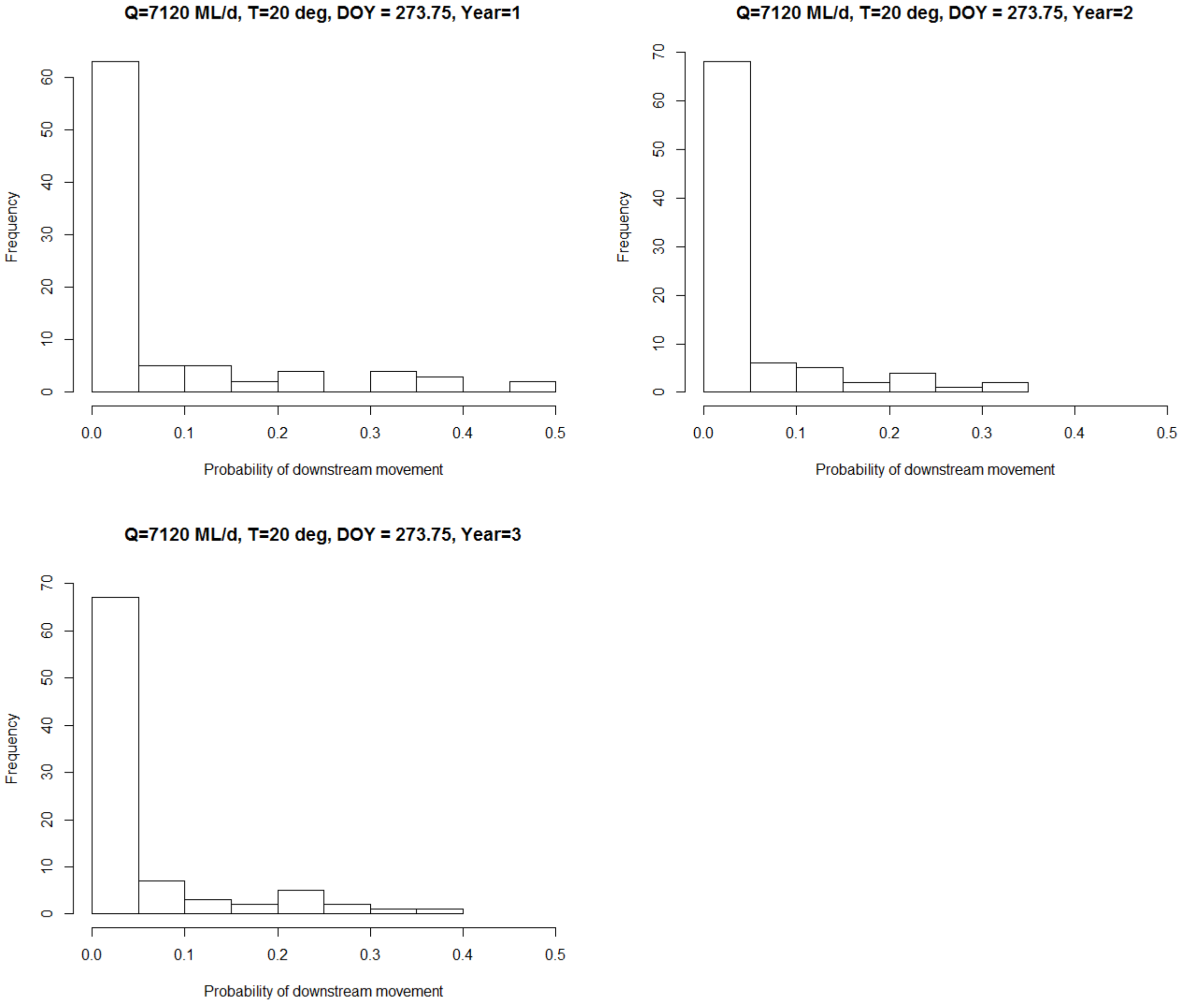


Figure F-14. Histograms showing the distribution of the probability of occurrence of downstream fish movement under different flow and temperature conditions.

Bony herring was also more abundant in 2017 compared to the last two years. Bony herring have rarely been collected in surveys in the Goulburn River conducted since 2003 (Koster et al. 2012; Koster unpublished data). Bony herring are not tolerant of low water temperatures (Lintermans 2007) and this may limit their occurrence in the Goulburn River. Bony herring in the Goulburn River likely represent transient fish that occasionally enter the Goulburn River from other areas when conditions are suitable.

Another species of conservation significance, trout cod, was not collected in the current surveys. Surveys in the first 2 years (2015 and 2016) recorded the species between Zeerust and Loch Garry, and indicated a more widespread distribution than previously thought and possibly a recent range expansion. A blackwater event in January 2017 in the Goulburn River resulted in fish deaths between Shepparton (just upstream of Zeerust) and Loch Garry and may explain the absence trout cod. Following a 2004 fish kill below Goulburn Weir, it took many years before trout cod were collected again in the Goulburn River (Koster et al. 2012). Numbers of Murray cod were also lower compared to the last two years, largely due to fewer individuals at Zeerust. A decrease in the abundance of Murray cod in the Goulburn River was also observed after a blackwater event in 2010 (Koster et al. 2012).

Golden perch and silver perch spawned in the Goulburn River in spring 2016, but no young-of-year fish were collected in surveys in autumn 2017. Similarly, golden perch and silver perch spawned in the Goulburn River each year between 2010 and 2014 (except in 2012 for silver perch), but no young-of-year fish were collected in surveys in each of the following autumns (Koster et al. 2012; Koster unpublished data). These result suggests that spawning may not necessarily translate into immediate recruitment of young-of-year fish in the Goulburn River. Given that golden perch and silver perch eggs are semi-buoyant and drift downstream, potentially over large distances, it is possible that eggs drift downstream into the Murray River, and that any recruitment into the Goulburn River occurs at a later stage by older fish re-entering the system. Determining whether golden perch in the Goulburn River were spawned locally, or have migrated into the system from elsewhere, and relating this to patterns of flow, will be investigated as part of the LTIM project using otoliths of fish collected for the annual ageing component of this project (UoM 2013).

Two pest species, carp and eastern gambusia, were collected in much higher numbers compared to the last two years. In each of the last two years, high numbers of young-of-year carp have been recorded, indicating recent successful spawning and juvenile recruitment. Whether this result is due to spawning events in the Goulburn River, or immigration of fish into the system from elsewhere, is unknown. Reasons for the increase in numbers of eastern gambusia are unclear, although high natural flows in spring 2016 might have facilitated their dispersal from offstream habitats into the river.

Surveys of eggs and larvae (drift nets)

The results of the drift sampling between 2014–2016 show that spawning of golden perch was related to higher flows during the spawning season. In particular, golden perch spawned only in association with bankfull flows or within-channel flow pulses (i.e. spring 'freshes') in late October-November, whilst during lower and stable flows, no spawning was detected. The results also suggest that water temperature influences the strength of spawning, with the greatest spawning outcomes at water temperatures ≥18° C. Similarly, in surveys conducted from 2003–2013 in the Goulburn River, peak egg abundances of golden perch were collected coinciding with flow pulses in November at temperatures around 19–20° C (Koster et al. 2012; Koster unpublished data). These findings confirm the importance of a rise in river flow for golden perch spawning coupled with appropriate water temperature (Koster et al. 2014, King et al. 2015), and serve to demonstrate the benefit of restoring key components (e.g. spring-summer freshes) of the flow regime for golden perch spawning in regulated rivers.

Silver perch spawning has also been detected in two out of the last three years (2014 and 2016), with eggs collected during a within-channel fresh in late November 2014, and in early November 2016 following a bankfull flow, at water temperatures of around 20–24 ° C. Similar to golden perch, this result demonstrates that environmental flows can promote silver perch spawning in regulated rivers.

Carp spawning has also been detected in the last two years (2015 and 2016), with carp larvae collected during the within-channel fresh delivered for vegetation objectives in mid-October 2015, and between mid-October and early November 2016 following a bankfull flow. In contrast, carp spawning was rarely detected in the river in surveys conducted from 2003–2013 (Koster et al. 2012; Koster unpublished data). This result might reflect recent re-establishment of vegetation on the banks of the Goulburn River that may have provided enhanced spawning opportunities for carp (Koehn et al. 2016). The longer-term contribution of these events to the carp population is unknown, although recent modelling indicates that within-channel flows have relatively little effect on carp recruitment (Koehn et al. 2017).

Movement of golden perch

The results of the acoustic telemetry demonstrate the importance of a rise in streamflow for golden perch movement, in agreement with previous studies on the movement of this species (Reynolds 1983, O'Connor et al. 2005, Koehn and Nicol 2016, Marshall et al. 2016). The results also revealed that environmental flows in the Goulburn River, especially in spring, promote movement (and spawning) of this species.

Golden perch movement increased during the spawning season and often coincided with the presence of golden perch eggs in drift samples. This result provides a rare example where telemetry data and direct observations of spawning have been integrated to examine the role of reproduction as a driver of riverine fish movement behaviour, and suggests that at least some of the long-distance movements are related to reproduction (Reynolds 1983, O'Connor et al. 2005).

Temporal patterns of movement differed among years, with all downstream movements in 2014 and 2015 in October-November, while in 2016, downstream movements mostly occurred between August and November. These results likely reflect differences in prevailing hydrological conditions; 2016 was characterised by high river flows throughout August-November, while in 2014 and 2015 rises in streamflow were largely confined to October-November.

Golden perch moved between the Goulburn and Murray rivers. In most cases, Goulburn to Murray movements were characterised by temporary occupation, with fish returning to the Goulburn River. However, about 30% of tagged fish did not return to the Goulburn River. The patterns of movement observed have important implications for management and conservation of golden perch. In particular, the relatively common occurrence of movement between the Goulburn and Murray rivers highlights that fish populations do not necessarily conform to artificially constrained management units, and demonstrates the need to consider connectivity among fish populations in river networks (Fausch et al. 2002).

The transmitters implanted into fish in 2014, 2015 and 2016 should continue to transmit until 2017, 2018 and 2019, respectively. This will enable more conclusive analysis regarding golden perch movement patterns to be undertaken and improve our capacity to develop and implement targeted management strategies for the species.

F.5 Conclusion

- There is evidence of increased abundance of the nationally endangered silver perch in the Goulburn River in the latest surveys. This likely reflects immigration of silver perch from the Murray River into the Goulburn River.
- Recruitment of semi-aquatic vegetation on the banks of the Goulburn River may have benefited Murray River rainbowfish by providing improved littoral habitats and spawning opportunities
- Streamflow plays an important role as a driver of long-distance movement and spawning in golden perch. In particular, golden perch migrate and spawn in the Goulburn River in response to bankfull flows and within-channel flow pulses, including targeted managed flows (i.e. spring 'freshes').
- Both golden perch and silver perch spawn in the Goulburn River in responses to flow events, but there appears to be little or no recruitment of young-of-year of either species in the river. Recruitment sources outside of the Goulburn River such as the Murray River possibly act as a key source of recruits for golden perch and silver perch in the Goulburn River.
- Elevated spring flows coupled with improved littoral habitat may have benefited carp spawning and juvenile recruitment.

Appendix G. Examples of stakeholder communications

Figure G-1. Invitation to the Goulburn River LTIM Project community forum, July 2017

Figure G-2. Advertisement in the Shepparton Adviser, February 2017

4 Country News week of Tuesday, February 21, 2017 www.countrynews.com.au

A big flush of fresh water

The Goulburn River is about to get a big dose of fresh water as part of the Goulburn Broken Catchment Management Authority's program for environmental watering.

Depending on natural conditions, including rainfall, the CMA could be applying up to 60 Gl of water.

The extra flow is designed to provide plants on the banks of the lower Goulburn River a well-needed late summer drink and encourage golden perch to migrate from the Murray River to the Goulburn.

Goulburn Broken CMA environmental water manager Simon Casanelia said an environmental water "fresh" would be delivered along the Goulburn River below the Goulburn Weir from late February and through March.

"The annual monitoring that we've been conducting shows that using environmental water to 'top up' the water that is being delivered to irrigators and other users at this time of the year has helped bank-stabilising plants establish along the lower Goulburn," Mr Casanelia said.

"And, because of this vegetation, we saw far less bank slumping and erosion during the natural flooding we experienced late last year than we did during 2010 to 2012."

Water for the increased flow is due to be released from Goulburn Weir from February 26, with the peak of about 4600 Ml/day reaching McCoy's Bridge by March 9.

The flow will be well below minor flood level. In the event of heavy rain, the timing and size of the environmental flow could change.

The water will come from an Inter-Valley transfer and from Commonwealth and Victorian environmental water.

If the water from the transfer is low, about 60 Gl of environmental water could be used, or if the water available from the transfer is high, then only 14 Gl may be required.

The CMA said these estimates were assuming no rainfall and no inflows from tributaries such as the Broken River, so they were at the highest possible range of water required to be released.

The environmental water will improve water quality and provide food and shelter for water bugs and native fish.

"During the hot, dry weather it's important to have refuge pools for aquatic animals," Mr Casanelia said.

"Improved water quality will also help crayfish, shrimps, water bugs and native fish continue to recover after the blackwater event earlier this year.

"We're keen too to see if the higher flows in the Goulburn River at this time of the year attract native fish, particularly golden perch, to move here from the Murray."

In past years, environmental water delivered in spring has triggered golden perch spawning in the Goulburn River.

"While we've found lots of eggs in the Goulburn, only low numbers of young fish have been reported," Mr Casanelia said.

"The reason for this is unclear, although it seems highly likely that the eggs and juvenile fish move downstream into the Murray. We hope the higher flows in the Goulburn at this time of the year will attract more young perch back into the Goulburn."

As part of the monitoring program funded by the Commonwealth Environmental Water Office, fish ecologists from the Arthur Rylah Institute will use acoustic tracking to determine if fish move into the Goulburn from the Murray in response to the fresh.

■ **For more information, visit** www.gbcma.vic.gov.au

Refreshed . . . The Goulburn will get a fresh flush of water soon.

Helping hand . . . Golden perch could benefit from the extra flow planned.

Figure G-3. Story from Country News, February 2017

4 Country News week of Tuesday, May 16, 2017 www.countrynews.com.au

Fish numbers are on the rise

By **Alana Christensen**

Silver perch and Murray cod have returned to the Campaspe and Goulburn rivers in droves, with silver perch detected in the river systems in good numbers for the first time in a decade.

Murray cod numbers are also at a 10-year high in the Broken River system, according to monitoring data collected by the DELWP's Arthur Rylah Institute.

A number of other fish including golden perch and Murray River rainbowfish were monitored during environmental flow research, but Arthur Rylah Institute principal research scientist Jarod Lyon said the silver perch results were most exciting, with the fish rarely detected in the Campaspe River in past surveys.

"We want to use environmental flows to encourage silver perch to take up residence in the Victorian tributaries of the Murray River over the coming years, in line with the basin-wide aims for this important species, and this is a great start," he said.

According to research, Murray cod figures are at their highest numbers since monitoring started in 2017, with juvenile Murray cod recorded from a number of sites in the lower Campaspe River, with the number likely to be from recent stockings.

Follow-up monitoring in the Loddon River and Pyramid Creek will be completed this week, with environmental flows in the Campaspe, Loddon, Goulburn and Broken rivers continuing to be the subject of long-term monitoring.

Anglers enjoy the benefits

Avid fisherman Steve Threlfall has backed up the latest DELWP findings, saying there's been an increase in the number of fish flowing through the Goulburn and Campaspe rivers, much to the delight of those fishing in the region.

Mr Threlfall said the changes were down to a number of things, including the Victorian Government's work in restocking the rivers and environmental flows.

After a weekend fishing near Shepparton, Mr Threlfall said he'd started to see the beginning of the recovery from the blackwater event that hit the Goulburn Valley earlier this year, with the region beginning to bounce back.

"After a blackwater event there wasn't even a shrimp in the river, now some people are back catching cod some even up to a metre long, which is really good," he said.

"We're seeing good stocks above and below the weir. The area seems to be recovering pretty quick, which is good to see."

Oh my cod . . . Murray cod numbers are reaching a 10-year high in the Broken River system.

It's something fishermen in the region would like to see continue, and Mr Threlfall said he hoped a possible change in government in the future wouldn't see the current strategy change.

"The government have really been super active in fish in the last four or five years and it's been fantastic," he said.

"We just hope that if there's a change in government that they keep the same pattern or modelling as what they have now, it's been really good."

With continued research, Mr Threlfall said environmental flows could become more targetted and changed to suit events and migration.

"(Having that data) is really valuable and takes the emotion out of things and gives it a scientific basis."

Great news . . . Fisherman Steve Threlfall has been enjoying the increase in fish populations in the region.

Figure G-4. Story from Country News, May 2017

Co-ordinated flows a boost for native fish

The co-ordination of environmental flows in three rivers has been used to distribute Golden Perch (Macquaria ambigua), Silver Perch (Bidyanus bidyanus) and other native fish across river networks throughout parts of the southern Murray-Darling Basin.

Environmental flows have been used to distribute fish including Silver Perch across the southern Murray-Darling Basin.

Principal Research Scientist from the Department of Environment Land Water and Planning's (DELWP) Arthur Rylah Institute Jarod Lyon said Victoria co-ordinated flow releases in the Goulburn and Campaspe Rivers with an environmental flow in the Murray River to encourage fish movement and increase fish populations throughout the basin.

"During these co-ordinated flows we monitored tagged fish, such as Golden and Silver Perch, as part of a project supported by the Murray-Darling Basin Authority and Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) and found fish used the flows to move out of the Murray and into tributaries," Mr Lyon said.

"These results show that migration of native fish during flows into the tributaries of the Murray River could be a substantial driver of populations.

"Using this information our environmental watering programs can use these flows as a targeted management action to assist the recovery of native fish populations in the tributaries of the Murray."

According to Mr Lyon maintaining and increasing fish populations in the river systems was an important target of environmental flow releases under Victorian Government and Commonwealth Government programs such as Water for Victoria and the Murray Darling Basin Plan.

"By coordinating the delivery of environmental flows in northern Victoria we are making sure we maximise the shared benefits of water for productive, environmental, cultural and recreational users," he said.

"Fish don't respect state borders - our river systems are a network of corridors that fish use to complete their life cycle."

The development and implementation of environmental watering programs in Victoria occurs as a collaborative process between Victorian and Commonwealth government agencies, land managers and water authorities.

The agencies involved in this project include the Murray–Darling Basin Authority, Goulburn Broken Catchment Management Authority (CMA), North Central CMA, the Victorian Environmental Water Holder, the Commonwealth Environmental Water Holder and Goulburn Murray Water.

Understanding how to maximise the benefits of environmental watering requires ecological data to inform decision-making processes and management plans.

In view of this, the Victorian Government established VEFMAP to monitor and evaluate the ecological benefit of environmental water use in Victoria.

This project is part of a $222 million investment by the Victorian Government to improve the health of waterways and catchments.

For more information go to http://delwp.vic.gov.au/water/water-for-victoria

Figure G-5. Story from Shepparton News, April 2017.

River flow impact on native fish population

A DECADE of annual surveys in the Goulburn River has provided researchers with a clearer understanding of the impacts of flow events on native fish populations.

Fish ecologist Wayne Koster from the Arthur Rylah Institute for Environmental Research spent several weeks at a number of testing sights to gauge changes in fish population.

Mr Koster said the surveys were part of a long term program to restore aspects of the flow regime.

"The surveys are conducted annually. They involve a fish tagging program to help understand the movement behaviours of fish and how fish respond to flow events," he said.

Species researched as part of the program include golden perch, silver perch and Murray cod.

Mr Koster said species such as golden perch required increases in flows during spring to initiate breeding.

The research team used electrofishing technology to safely bring fish to the water surface.

Among the key findings was that some species undertook long distance migration in spring to facilitate breeding.

"We've found that golden perch are travelling up to 150 kilometres and those migrations are prompted by increases in flows-without those increases fish fail to breed," Mr Koster said.

The research also revealed that a Black Water event in the river earlier this year had devastated breeding patterns of native fish.

"The Black Water event has had a negative impact on native fish populations and that can take years and years to recover, which is why conservation measures such as restoring natural flow conditions will be important to giving the fish a kick along," he said.

"The main value of the work is to understand the flow conditions that native fish need to survive and using that information to inform how we manage our waterways to benefit fish populations using limited water resources."

The Commonwealth Environmental Water Holder's Long-Term Intervention Monitoring Project in the Goulburn River is a collaboration between the Goulburn Broken CMA, University of Melbourne, The Arthur Rylah Institute (Department of Environment, Land, Water and Planning), Monash University, Streamology, Goulburn Valley Water and Jacobs.

More information about monitoring in the Goulburn River is available at www.gbcma.vic.gov.au.

Figure G-6. Story from Cobram Courier, May 2017.

Figure G-7. Win News Facebook post, July 2017.

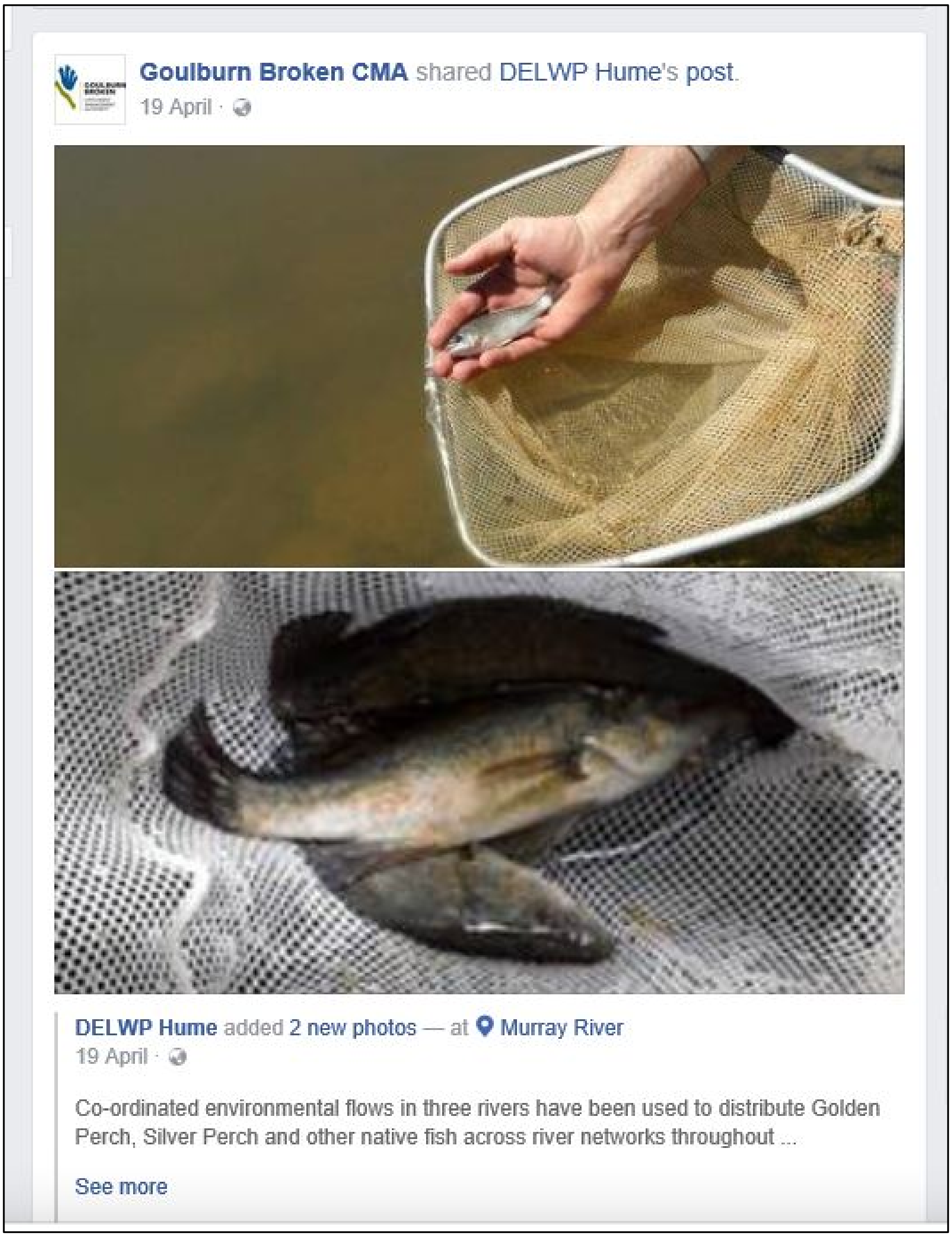


Figure G-8. GBCMA Facebook post, April 2017.

Goulburn Broken CMA
24 July at 23:41 ·

At the half-way point of #CEWO's 5-year Goulburn River Long Term Intervention Monitoring (LTIM) project it was great to share key findings &learnings with the local community and our partners of how native fish, waterbugs, veg, river and bank health are responding to #eflows. Find out more about LTIM here: http://bit.ly/2vV0XOo
The University of Melbourne
Monash University
DELWP Hume #ARI
#streamology... See more

244 Views

Like Comment Share

Fern Hames, Ellen Koster, DELWP Hume and 7 others like this.

3 shares

Figure G-9. GBCMA Facebook post at the Community Forum, July 2017.