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Commonwealth Environmental Water Office

Commonwealth Environmental Water Office

Long Term Intervention Monitoring Project

Goulburn River Selected Area evaluation report 2015-16

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Final Report

February 2017

Commercial Engagement Services

Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project – Goulburn River Selected Area evaluation report 2015-16

Project no:	UoMC 2014-235
Document title:	Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project – Goulburn River Selected Area evaluation report 2015-16
Revision:	Final Report
Date:	1 February 2017
Client name:	Commonwealth Department of the Environment and Energy
Project manager:	Angus Webb
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File name:	Lower Goulburn LTIM annual evaluation report 2015-16 FINAL.docx

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Document history and status

Revision	Date	Description	By	Review	Approved
First draft	28/10/16	Draft submitted to CEWO	Authors	co-authors	Angus Webb
Second draft	5/1/17	Revisions based on CEWO feedback	Angus Webb, Anna Lintern, Andrew Sharpe	CEWO	Kerry Webber
Third draft	21/01/17	Revisions based on CEWO feedback	Angus Webb, Anna Lintern	CEWO	Kerry Webber
Final	1/2/17	Final minor changes based on CEWO and VEWH feedback, plus minor text changes from authors	Angus Webb		

Acknowledgment: The Commonwealth Environmental Water Office acknowledges the efforts of all consortium partners in delivering the Goulburn Long-Term Intervention Monitoring project and preparing this report.

The authors of this report as well as the Commonwealth Environmental Water Office respectfully acknowledge the traditional owners, their Elders past and present, their Nations of the Murray-Darling Basin, and their cultural, social, environmental, spiritual and economic connection to their lands and waters; in particular the Taungurung Clans and Yorta Yorta Nation, traditional owners of the Goulburn River catchment

Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project – Goulburn River Selected Area evaluation report 2015-16

Citation: This report should be attributed as:

Title: 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

Date: October, 2016

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Publisher: Commonwealth of Australia

Funding: This monitoring project was commissioned and funded by Commonwealth Environmental Water Office, with additional investment from the Victorian Department of Environment, Land, Water and Planning, and the Victorian Environmental Water Holder.

Table of Contents

Table of Figures

Report main Body

Appendices

Table of Tables

Report main body

Appendices

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. It 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.

River flows in the Lower Goulburn River were lower in 2015–16 than in the first year of the Goulburn LTIM Project – 2014-15. A dry winter and spring led to low volumes of water in storage and reduced environmental allocations. Commonwealth environmental water in the lower Goulburn River over the 2015–16 period contributed to: baseflows, to ensure adequate habitat provision; one major spring fresh, delivered in October targeting continued recovery of riverbank vegetation; and a smaller autumn fresh delivered in March, to support new lower bank vegetation and improve macroinvertebrate and fish habitat and water quality.

Monitoring in the Goulburn River LTIM Project focuses on the stretch of river between the confluence of the Broken River near Shepparton to the Murray River Confluence near Echuca (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 these matters, with highlights and implications for adaptive and flow management in year 3 of the monitoring program is provided in the table below.

Matter	2015-16 highlight	Implications for Adaptive Management	Interim recommendations for environmental water delivery
Physical habitat	• Rates of bank erosion and deposition are related to inundation duration, but the effect of environmental flows on bank condition is very minor compared to changes that occur under the remainder of the regulated flow regime. • Managed recession of flow events allows the formation of sediment drapes, providing favourable conditions for vegetation establishment	• Environmental water delivery can proceed with confidence that it is not having major adverse effects on the banks of the Goulburn River. Future monitoring will concentrate on identifying the specific features of flow regimes that principally drive erosion, so these may be managed.	• Maintain current rates of flow recession to avoid bank surcharging and erosion, and allow mud drapes to develop. • 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. • Maintain variability in base flows and water levels to maintain bank wetting at varying levels on the bank; and to avoid bank 'notching'
Stream metabolism: production and respiration	• In-channel total volumes of Gross Primary Production (total amount of O_2 produced) and Ecosystem Respiration (total amount of O_2 consumed) are enhanced by environmental flows, but rates are suppressed by dilution of large volumes of water.	• Larger flow events may be required in the future to mobilise carbon and nutrients from backwaters and the floodplain. Future work will explore ways of reducing third party impacts to allow these larger flow events.	• Undertake flow events specifically aimed at improving stream primary productivity when water temperatures are warm (i.e. late spring or summer).

Matter	2015-16 highlight	Implications for Adaptive Management	Interim recommendations for environmental water delivery
Macro-invertebrate biomass and diversity	• Macroinvertebrate biomass in sweep samples from the river's edge increased following the spring environmental flows, matched by decreases from in-stream artificial substrate samples. • Large macroinvertebrates may be moving to edge habitats following flow events. • Responses of individual species have been consistent across the two years of sampling. • Environmental water may have reduced the impacts of low flows in the system caused by the very dry climate over 2015—16.The environmental flows, while not promoting an increase in macroinvertebrate abundance, may be preventing a decline in abundance.	• Increased primary productivity volumes may enhance river-edge habitats as areas for improved macroinvertebrate responses. Monitoring will attempt to test this hypothesis, possibly in conjunction with a student research project.	• Maintain an early spring fresh (as per 2015-16) to increase macroinvertebrate abundance and biomass for sustaining native fish, and to alleviate stress to macroinvertebrates.
Bankside vegetation abundance and diversity	• Areas of the bank inundated by the spring environmental flow improved vegetation abundance and diversity pre- to post-flow. This demonstrates the value of bank wetting as the climate grows drier over summer. • In particular, spring freshes likely contributed to maintaining the cover of water dependent vegetation low on the banks. • Terrestrial species, including woody recruits and grasses are more limited in their distribution to areas that experience shorter and shallower inundation, demonstrating the effectiveness of CEW.	• The earlier delivery of the spring fresh in 2015–16 compared to 2014–15 may have better buffered the bankside vegetation assemblage against the extreme dry and hot conditions that followed.	• Undertake winter environmental flow deliveries to facilitate reestablishment of bank vegetation. • Maintain variability in base flows and water levels to support young plants until they reach a more mature and robust life stages and/or develop soil seed banks.
Fish assemblage and the spawning and movement of golden and silver perch	• Little golden perch movement, and no spawning was seen in 2015–16, but this was expected because of the earlier timing (and therefore low temperature) of the spring fresh. • Movement data, however, demonstrate large-scale migrations for some fish, with one fish moving approximately 600 km among selected areas. • Larval surveys demonstrated spawning of 5 native species. • Adult surveys demonstrate recruitment of key species into adult populations, with the highlight being the capture of the endangered trout cod in locations (downstream of Shepparton) beyond where they had been detected in the last 15 years, indicating a more widespread distribution than previously thought and possibly a recent range expansion. • There are adult fish in the Golden Perch population in the Goulburn River that were spawned in years where there successful spawning events in the Goulburn River. However, it is currently unknown whether these fish were spawned in the Goulburn River, have migrated into the system from elsewhere, or were stocked.	• Future data collection will improve our understanding of the importance of antecedent flows on fish spawning, and whether spawning responses translate to recruitment. • Carp management principles for future water deliveries need to be explored to avoid further increase in the abundance of carp	• Undertake watering actions to promote golden perch movement and associated spawning when water temperature is 18° C or above. • Manage the timing of spring freshes such that they benefit native vegetation and fish, but have less benefit for carp.

All matters therefore reported at least some probable benefits of Commonwealth environmental water delivered to the lower Goulburn River in 2015–16, with some matters showing strong indications of ecological response. The monitoring program has also generated favourable media attention, with stories in local newspapers, and multiple posts to social media. The results provide confidence in the value of this investment in the environment.

A general recommendation to arise from the monitoring is to maintain an early spring fresh (as per 2015-16) as a priority for achieving multiple environmental outcomes: to encourage vegetation establishment on the bank; to improve bank wetting and vegetation abundance and diversity going into summer; to reduce the potential for drying and cracking of bank sediments; to increase macroinvertebrate abundance and biomass for sustaining native fish; and to alleviate stress to macroinvertebrates and mitigate potential declines in populations, particularly under hot and dry conditions. However, it is also noted that this recommendation is potentially contradictory to specific matter-level recommendations from the table above. Relative merits of different flow decisions over one another will remain a balancing act and part of the adaptive management process.

The Goulburn LTIM project team is currently implementing monitoring for year 3 of the monitoring program, building upon the data sets generated in 2014–15 and 2015–16 and through other monitoring programs (e.g. Victorian Environmental Flows Monitoring and Assessment Program, CEWO short-term intervention monitoring program), and taking on board the learnings that result from these.

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:

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 2015–16 and summarises the results and analysis outcomes of that monitoring. Where appropriate, it compares results to those obtained in 2014–15. 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), have based their sampling design around the existing environmental flow reaches. In order to complement this historical monitoring, promote consistency in the data sets, and potentially 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).

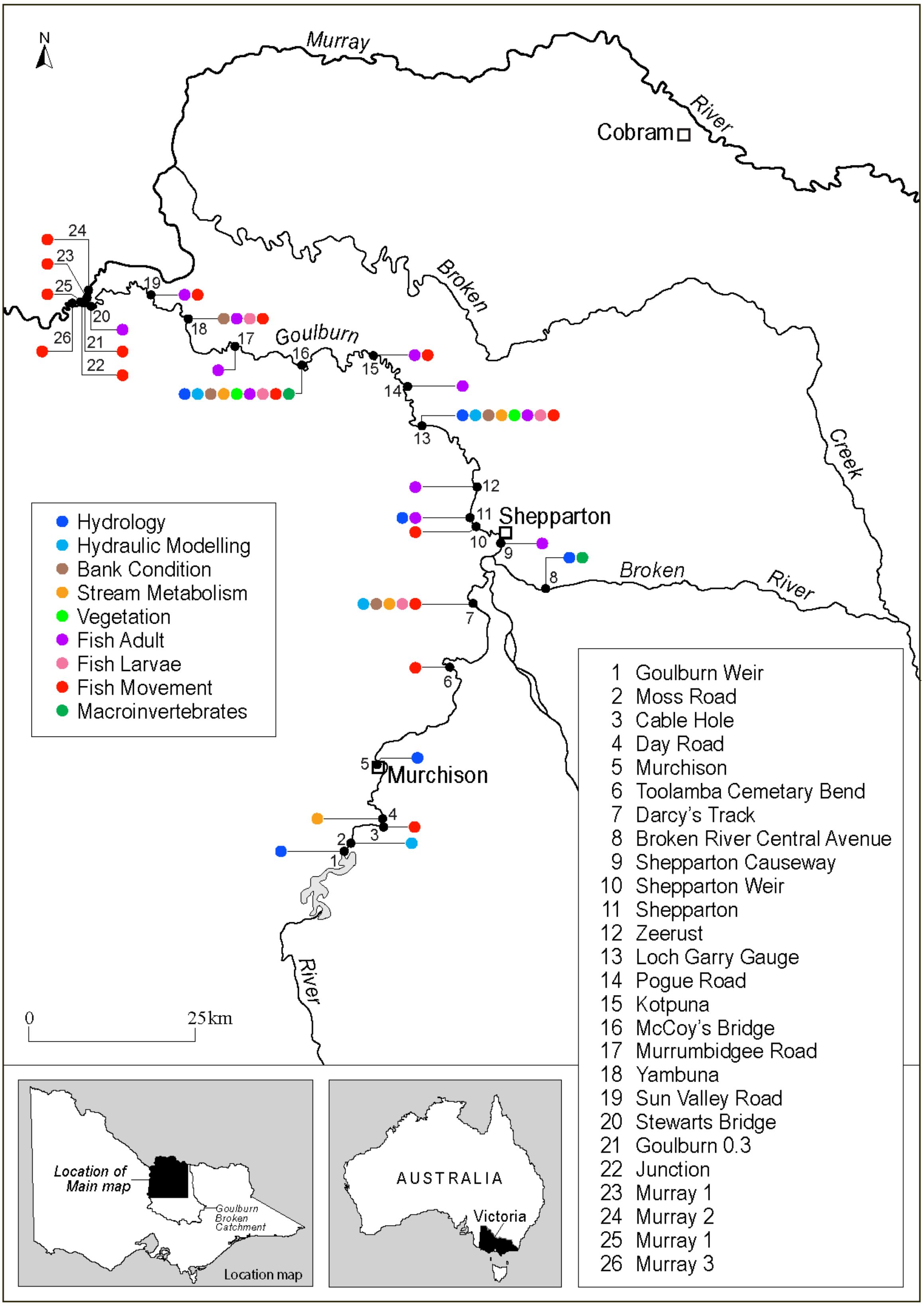


Figure 1-1. Map of the lower Goulburn River, with all monitoring sites marked, along with flow gauges used to generate flow data used in this report. Some sites extend into the Murray and Broken rivers. Colours denote different monitoring activities, with some sites being used for multiple activities.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

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 1 July 2015, the Commonwealth held 255.2 GL of high security and 18.4 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 2015-16 the Commonwealth environmental water entitlement provided most of the environmental water used to meet specific environmental flow objectives in the lower Goulburn River channel.

Table 1-2. Commonwealth environmental water entitlements as at 1 July 2015.

Entitlement type	Entitlement held (GL)	Entitlement held - Long term average annual yield (GL)
Goulburn (high reliability)	255.2	242.0
Goulburn (low reliability)	18.4	9.5

1.3.1 What type of watering was planned?

Potential watering actions for 2015-16 in Reaches 4 and 5 included continuous baseflows throughout the year for habitat, a spring fresh for bank vegetation, a spring/summer fresh for native fish, a summer/autumn fresh for continued recovery of bank-vegetation and a winter fresh to maintain habitat. 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.

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. To avoid flooding of private property or infrastructure, fresh actions are unlikely to exceed 9,500 ML/day at McCoy's Bridge and Commonwealth environmental water will not be used to contribute to flows greater than 18,000 ML/day at Shepparton. In the event of high natural flows, watering may commence at 15,000 ML/day at McCoy's Bridge to slow-down recession flow 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 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:

- Year-round minimum and high baseflows - to maintain water quality and provide suitable habitat and food resources to support native fish and macroinvertebrates condition and survival.
- Winter fresh (Jun-Aug) - to support the condition and survival of native vegetation and promote the transport of nutrients, carbon, sediment and biota.
- 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 promote the transport of nutrients, carbon, sediment and biota.

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 2015-16 and context

In 2015-16 a total of 228 GL of environmental water was delivered, with the major environmental water holders providing 190 GL (Commonwealth Environmental Water Holder), 10 GL (Victorian Environmental Water Holder), and 28 GL (The Living Murray). High priority base flows were delivered and the spring and autumn freshes were partially delivered. IVT delivered 49 GL, contributing to base flows (Table 1-3).

Table 1-3. Summary of planned and actual environmental flow for the Lower Goulburn River 2015–16. Information on planned delivery and expected outcomes from (CoA 2015). Information on actual delivery provided by CEWO (unpubl. data).

Dates (start/ end)	Flow component type and target/planned magnitude, duration, timing and/or inundation extent	Expected outcomes as at delivery)	Actual delivery details and any operational issues that may have affected expected outcomes
9 Jul – 2 Oct	Baseflow targeting 830 ML/d minimum flow at Murchison (940 ML/d at McCoy's) in winter/spring (July-Nov).	- maintain water quality - support native fish condition & macroinvertebrate abundance/diversity - longitudinal connectivity - fish passage - support ecosystem function (e.g. connectivity, dispersal, primary production)	Baseflow requirements were met throughout Jul-Nov with a combination of unregulated flows, e-water and IVT.
3 Oct to 29 Oct	Fresh Targeting a peak magnitude of 8,500 ML/d at Murchison, with 14 days above 5,600 ML/day at both Murchison and McCoy's in spring/early summer	– improved condition and cover of native in-channel vegetation (especially on banks) - discourage terrestrial vegetation encroachment on lower bank – support ecosystem function - breeding and movement of native fish	Action delivered as planned with respect to timing and duration, however peak magnitude was reduced. The peak flow target was revised down to 7,000 ML/d shortly before the commencement of the action due to high irrigation demand as a result of unusually hot and dry weather. Peak flow was 6,200 ML/d average and duration of flows above 5,600 ML/d was 11 days which is slightly shorter than the 14 day target.
30 Oct to 12 Mar	Baseflows Targeting 500-830 ML/day at Murchison (540-940 ML/d at McCoy's) in summer (Dec-Feb).	- maintain water quality - support native fish condition & macroinvertebrates - longitudinal connectivity - fish passage – support ecosystem function	Baseflows met using IVT. The target was not met for around 10 days at the end of November due to higher than expected river diversions or losses.
13 Mar to 5 Apr	Autumn fresh Targeting 4,500 ML/d at Murchison in Feb-Apr	– improved condition and cover of native in-channel vegetation - Support ecosystem function	A combination of Commonwealth and VEWH environmental water and IVT, reaching a peak of 4,072 ML/day at McCoy's, followed by a gradual recession.
6 Apr to 30 Jun	Autumn/winter baseflows Targeting a stepped/variable elevated baseflow (around 750 ML/day)	As above for summer and winter/spring baseflows	Target maintained. Rainfall increased flows in the last week of June.

Flows in the Goulburn River were much lower in 2015–16 compared to 2014–15 (Figure 1-2). The major use of environmental water in 2015-16 was to deliver a spring and autumn fresh (Figure 1-2b).

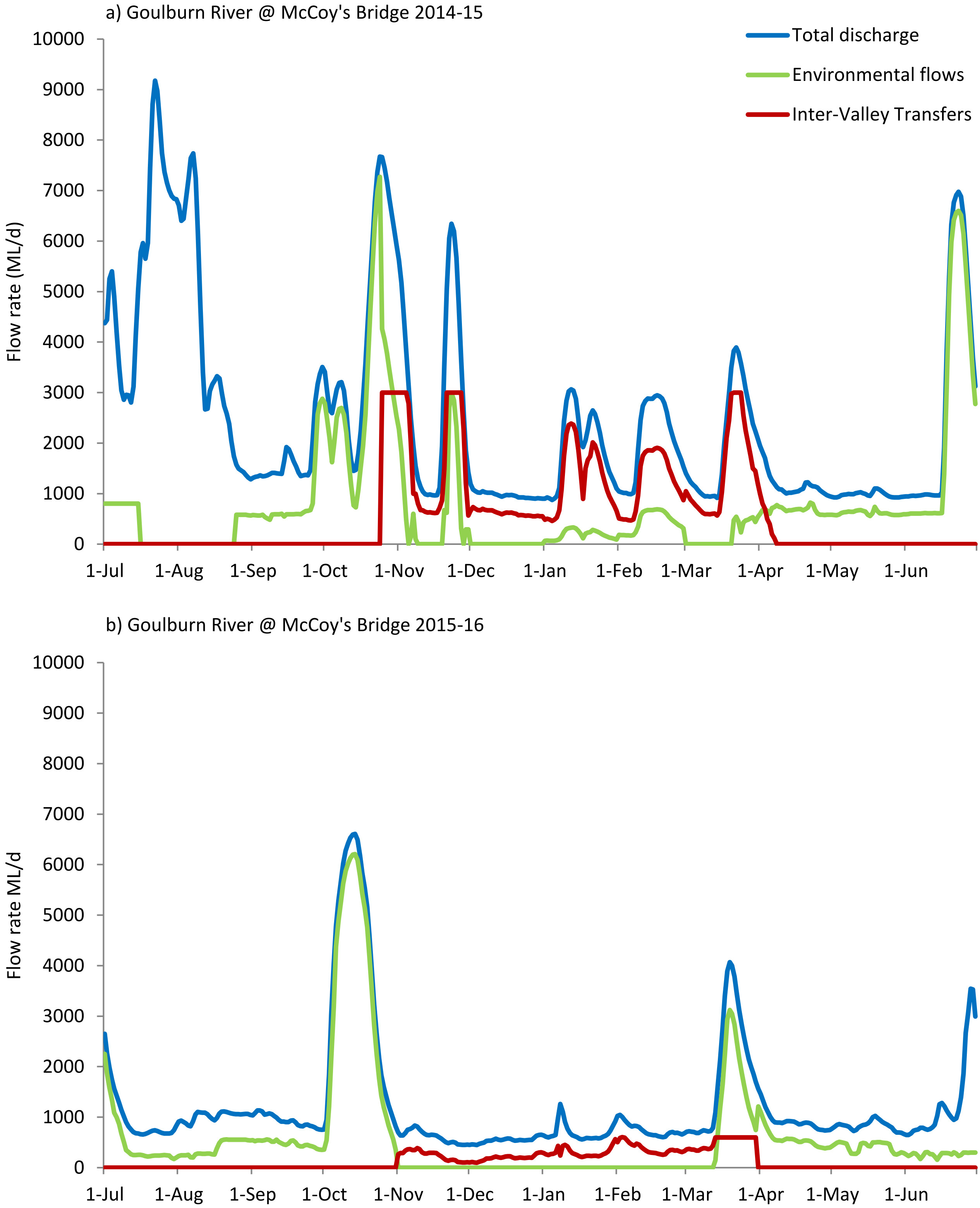


Figure 1-2. Summary of environmental flows delivery in the lower Goulburn River 2014–15 (a) and 2015–16 (b). Chart shows total flow rate (ML/d) at the McCoy's Bridge gauging station near the bottom of the system, along with managed environmental flows delivered at that point, and inter-valley transfer 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). 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 2016.

2. Overview of monitoring undertaken in 2015–16

All of the planned monitoring activities outlined in the Monitoring and Evaluation Plan (MEP; Webb et al. 2014) were implemented during 2015–16, although some activities were delayed by 1–2 months because of flow conditions (see Table 2-1). Bank condition monitoring, in particular, was dependent upon flow conditions and deliberately scheduled to take advantage of high and low flow events. Therefore, visits do not correspond to the initial 2-monthly estimated schedule (see Table 2-1). Bank condition monitoring was overall more intensive during 2015–16 than initially planned following a delay to the commencement of monitoring in 2014–15. For stream metabolism, in addition to the deployed monitoring periods shown below, the McCoy's bridge logger was left installed over winter 2015.

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). 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 2015–16. D indicates planned/actual timing for downloading data from fish movement loggers; I indicates planned/actual deployment of artificial substrates for macroinvertebrate sampling, O indicates planned/actual retrieval of artificial substrates for macroinvertebrate sampling. C indicates 2 trips done to obtain calibration data for the 2-dimensional hydraulic models

Monitoring activity	No of sites per Zone		Planned / Actual	Schedule of planned and actual activities in 2015-16											
	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	I	O						
Stream Metabolism	2	2	Planned												
			Actual												
Bank Condition	2	2	Planned												
			Actual												
2D Hydraulic Model	2	2	Planned												
			Actual	C											

3. Physical habitat and bank condition

Physical habitat monitoring aims to translate flow rates into the conditions experienced by biota, and the role this plays in ecosystem health. Physical habitat monitoring includes hydraulic modelling and bank condition monitoring.

Hydraulic modelling enables us to quantify habitat in terms of velocity, depth, and other hydraulic parameters. These relationships allow targeted flow delivery to maximise habitat (or prevent reduced habitat). Hydraulic modelling has been completed for four sites and a range of relationships have now been developed. A selection of these relationships is presented in Appendix B. These have been developed to specifically target physical habitat requirements of fish, macroinvertebrates and plants. The details of hydraulic model development are also provided in Appendix B.

River bank condition monitoring (erosion and deposition) was continued with environmental flows delivered in 2015–16. The period of monitoring to date has provided a range of hydrologic characteristics conducive to fieldwork and the assessment of physical habitat.

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 as well as improved opportunities for monitoring. This is an important story that is captured in Vietz et al. (in review).

3.1 Evaluation

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 2015–16 season contributed to changes in the hydraulic (i.e. flow velocity, depth, etc.) habitat known to be of value to fish.	Both baseflows and freshes increase wetted perimeter, pool area and mean depth. Slackwaters (slow and shallow) habitats are increased for baseflows, i.e. as the bed is inundated. For higher flows (~2,000–4,000 ML/d) slackwaters are reduced in area and patch size, but freshes above 5,000–6,000 ML/d increase slackwaters as benches are inundated. High velocities are considered to be important triggers for fish recruitment and migration and increases in flow increase the high velocity (99^{th} percentile), most dramatically for flow rates up to ~ 2,000 ML/d.	Habitat relationships developed from hydraulic habitat models for four sites. These relationships were used to undertake further hydrologic understanding of the influence of environmental flows.
What did CEW contribute to the provision of diverse and productive macroinvertebrate habitats?	Baseflows and freshes, such as those provided in the 2015–16 season, are known to provide 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.	
What did CEW contribute to inundating specific riparian vegetation zones and creating hydraulic habitats that favour the	Freshes and variable flow levels, such as achieved through flow management during the 2015–16 season, are known to increase opportunities for the	Variable flow rates and 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	Hydraulic models have demonstrated changes in velocities at banks where vegetation is sampled. Further coordination of hydraulic results and vegetation will confirm relationships.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
dispersal and deposition of plant seeds and propagules?	dispersal and deposition of plant seeds and propagules.	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 plants at higher flow rates. These outcomes require confirmation by coordinating hydraulic results with vegetation analyses.	
How does CEW affect bank erosion and deposition?	Yes. Magnitude, frequency and duration of flows were all appropriate to prevent excessive rates or riverbank erosion.	Environmental flows have little influence on bank erosion. The levels of erosion were higher than the levels of aggradation 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 re-measured pre/post environmental watering actions to assess bank change. 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?	Yes. Inundation frequency was appropriate to encourage lower bank vegetation, velocities at banks were not excessive, and mud drapes resulted from flow 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.	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.

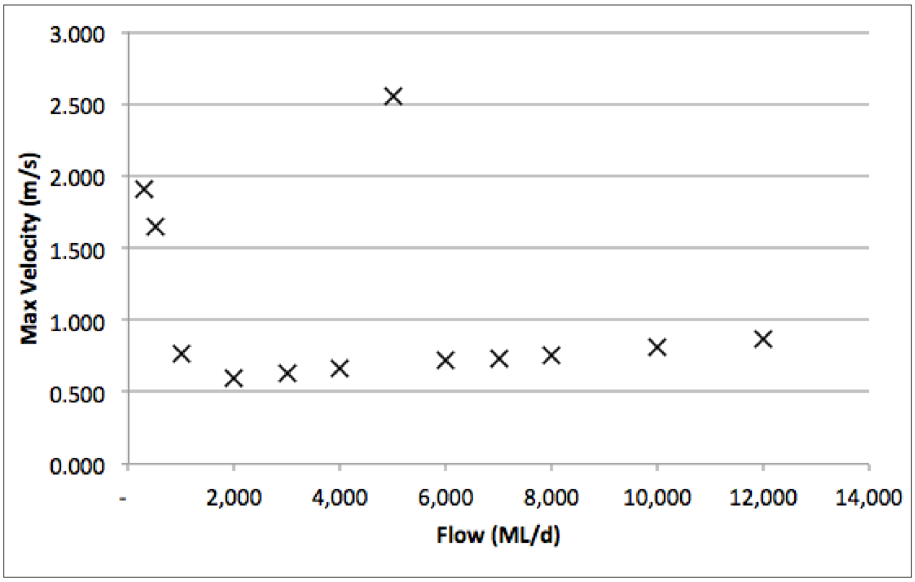
3.2 Main findings from physical habitat and bank condition monitoring program

Relationships between flow and physical habitat show that pool area and wetted area increase with flow, with a noticeably steeper increase for flow rates up to 2000 ML/d (for wetted area) or 5000 ML/d (pool area). Beyond these flows diminishing returns are seen for increases in flow rate. These relationships are similar for all sites.

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. However, for increasing flow rates between 3,000 and 6,000 ML/d, slackwaters decrease to a minimum for McCoy's Bridge, Loch Garry, and the Darcy's Track sites. Beyond these flow rates slackwater area increases. For the Moss Rd site, however, the area of slackwater habitat increased until a flow rate of ~2,000 ML/d, as large vegetated benches become inundated, then decreased and stabilised for flows of 4,000 ML/d and greater. Mean slackwater patch size follows a similar relationship for the sites.

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 2000 ML/d, then gradually increases for increasing flows, as shown for McCoy's Bridge (Figure 3-1a). Some extreme velocities (e.g. 2.5 m/s) may be a result of wood in the stream. Velocity relative to vegetation on the bank, however, is quite distinct from that experienced for the entire channel. Taking velocity at the point of monitoring for bank vegetation demonstrates the opposite, with a general increase in maximum velocities as flow rate increases, with peaks around 7,000–10,000 ML/d (Figure 3-1b). These maximum velocities at the bank, however, are considerably lower than those experienced in the channel (compare Figure 3-1a and b velocity magnitudes). Velocities greater than 0.3 m/s (pers. comm. Kay Morris) 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 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.

a)



b)

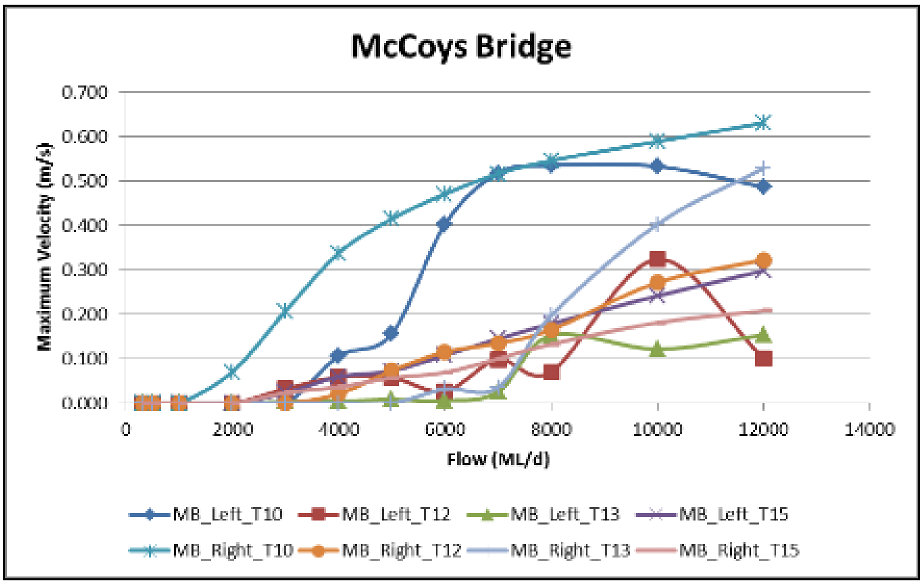


Figure 3-1. Maximum velocities for McCoy's Bridge by location: a) maximum velocity for the channel, and b) maximum velocity at the bank at the location of vegetation assessments. Note the differences in velocity depending on location.

Bank erosion monitoring evidence suggests that strategic environmental water management, including water provided as freshes, has not caused 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 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. These facts relative to visual observations may demonstrate the importance of community education on the dynamics of rivers and how appearance may differ from actual impacts.

3.3 Discussion, implications and recommendations for Commonwealth Environmental Water

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. Future research using data collected as part of the LTIM Project will concentrate on identifying the specific features of flow regimes that principally drive erosion, so these may be managed.

The results suggest that mud drapes (Figure 3-2), which encourage vegetation establishment, were more common during slow rates of recession of flow events. Re-establishment of bank vegetation has previously been assumed to be driven primarily by spring freshes. However, these observations also highlight the potential importance of winter environmental flow deliveries for this purpose.

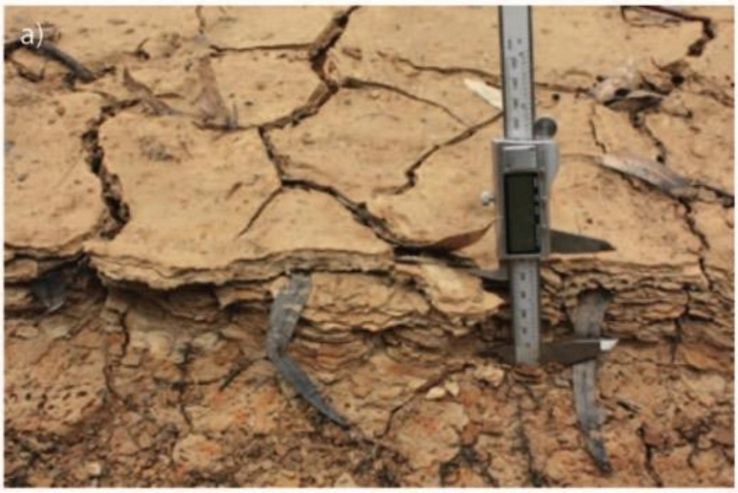


Figure 3-2. Sediment drapes (deposition) were more common during slow rates of recession and encourage vegetation establishment.

Interim recommendations for upcoming environmental flow deliveries support the current management approaches including:

- 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 current rates of flow recession to avoid bank surcharging and erosion, and allow mud drapes to develop (no major erosion events e.g. slumping have been observed from recent environmental flow management);
- 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. 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.

4. Stream metabolism

Whole stream metabolism (Figure 4-1) 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 and respiration (Odum 1956). Healthy aquatic ecosystems need both processes to generate new biomass (which becomes food for organisms higher up the food chain) and to break-down plant and animal detritus to recycle nutrients to enable growth to occur. Hence metabolism assesses the energy base underpinning aquatic food webs. 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).

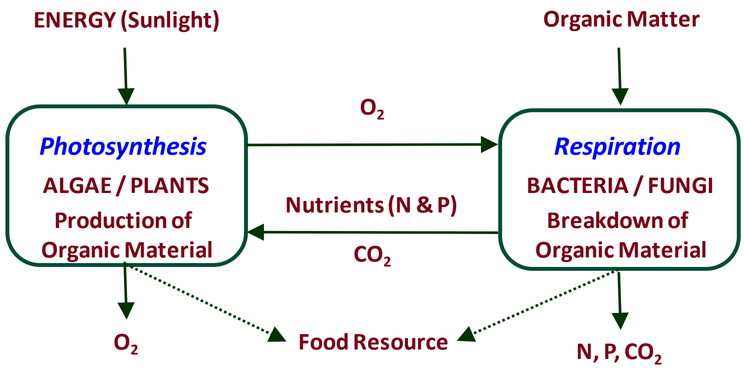


Figure 4-1. Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients.

Stream metabolism was monitored at four sites (Figure 1-1) over the period August 2015–April 2016. During this period there was one spring fresh, an inter-valley transfer (at a smaller level to 2014-–15), and an autumn fresh. No major changes were observed to rates of stream metabolism as a result of these flows, but there were effects upon the total amount of metabolism, as outlined below. The derivation of results, issues encountered, and more detailed analyses are included in Appendix C.

4.1 Evaluation

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 decomp-osition?	Yes	There was no consistent relationship between daily Ecosystem Respiration (ER) rates and flow across the four monitoring sites. It is expected that increases in ER will follow days after a flow event as it takes time for microbial populations to increase in response to the larger amounts of organic carbon. Total oxygen consumption in the river reach (based on ER) increased with flow and was best fitted to a model using a lag time of 2 days	Simple linear regression of rate of ER vs flow rate showed a weak positive relationship at two sites (Darcy's Track and McCoy's Bridge), a weak negative relationship at another (Loch Garry) and no significant relationship at Day Rd. A Bayesian model examining flow rate vs total oxygen consumption showed a consistent positive relationship. This is consistent with the time needed for microbial populations to increase after an influx of organic carbon.
What did CEW contribute to patterns and rates of primary	Yes	Similar to ER rates, there was no consistent relationship between daily rates of Gross Primary Production (GPP) and flow across the four monitoring sites. It is expected that if environmental watering actions introduce more nutrients, algal growth will take days to a few weeks to respond. This is based on the hypothesis that flow	Simple linear regression of GPP vs flow rate showed a weak positive relationship at two sites (as per ER, these sites were Darcy's Track and McCoy's Bridge), a weak negative relationship at another (Loch Garry) and no significant

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
productivit y?		events introduce nutrients which can then fuel algal and biofilm growth. Bayesian modelling showed a positive relationship between total oxygen production (Tonnes of O_2 per day) and flow rates, and that the best model involved a lag time of just one day. This is in contrast to the expectations just stated. The origin of this difference will be explored later in the LTIM Project.	relationship at Day Rd. A Bayesian model examining flow vs oxygen consumption showed a consistent positive relationship, and had a best fit with a lag time of one day between flow and oxygen consumption.

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, there was no consistent immediate effect of flow increases (including those from CEW delivery) across the 4 sites on rates of either GPP or ER. However, there was a positive effect of flow rate on total amounts of GPP and ER. It is expected that if flows introduce nutrients there will be a post-flow lag of perhaps 10-20 days for significant increases in GPP to occur (shorter response times are expected for ER as bacterial populations increase in size more quickly than algal populations). The key point is that rates of both GPP and ER were in the lower range of normal behaviour for river systems worldwide and all variability observed occurred within these low ranges.	Based on simple linear regression of rates of GPP and ER, and on Bayesian models relating daily estimates of GPP and ER to flow rate. Future models will increase the lag times considered compared to those presented here. In addition, we will be able to follow individual packets of water as each travels downstream from logger to logger. This requires excellent hydrological modelling and data regarding water velocities and transit times between each of the logger sites.
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	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. In neither system did flows get out of the river channel. 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 low 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 Main findings from stream metabolism monitoring program

The main findings from the second year of stream metabolism data (Aug 2015 –Apr 2016) included:

- Rates of Gross Primary Production (GPP) and Ecosystem Respiration (ER) showed no consistent relationship with flow rate (Figure 4-2). There were some indications of suppression of metabolism due to dilution effects of large flow events.
- In contrast, total amounts of oxygen produced (GPP) and consumed (ER) increased with flow rate, with a stronger effect on GPP. The relative importance of metabolic rates versus total amounts depends on

whether immediate benefits for the lower Goulburn River (rates) or for receiving waters downstream such as the lower Murray River (total amounts) are considered.

- 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 2014–15, these concentrations are marginally lower than median values measured over the last decade at McCoy's Bridge.

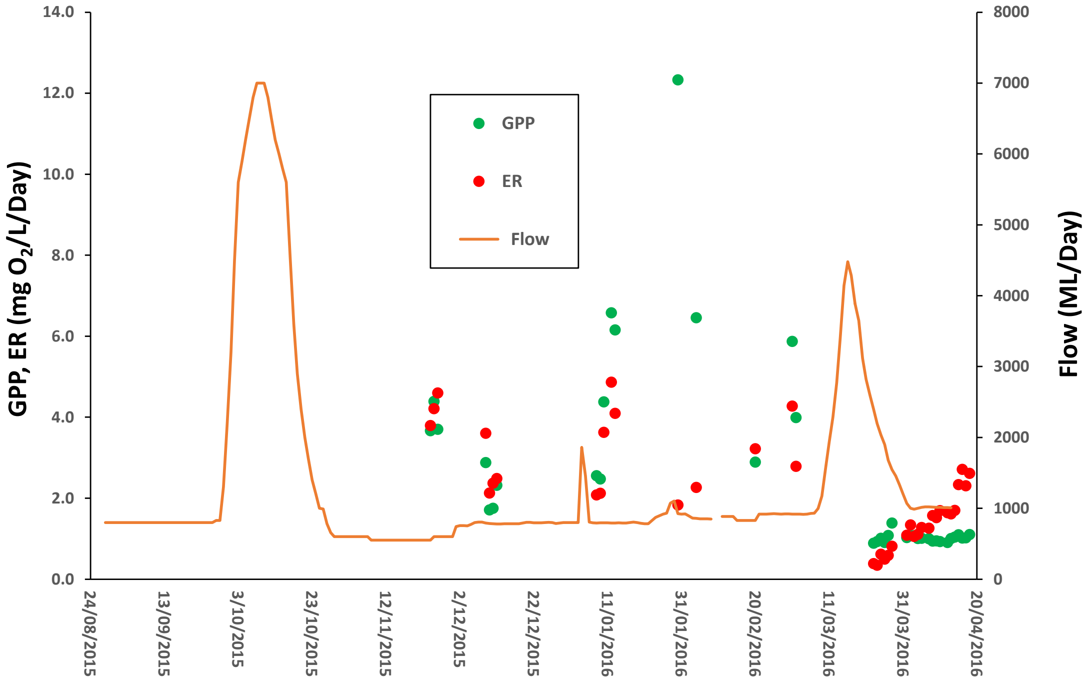


Figure 4-2. Stream Metabolism-Flow Relationships for Day Rd (Zone 1) from August 2015 to April 2016.

Rates of Gross Primary Production (GPP) and Ecosystem Respiration (ER) vary with flow but still sit within a small range at the lower end of rates observed in river systems around the world. Whether these rates are 'low' or are typical of Australian lowland river systems, will become more apparent as the LTIM Project progresses.

4.3 Discussion, Implications and Recommendations for Commonwealth Environmental Water

Flow rates experienced during the 2015–16 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.

The natural floods that occurred in September 2016 will provide an opportunity to test this hypothesis, although data from the McCoy's Bridge logger may not be able to be used because the extended inundation likely resulted in data being overwritten while the logger could not be retrieved. Flooding results will be looked at. In future however, it is likely that third party constraints will continue to restrict the amount of benefit stream metabolism that can be achieved using Commonwealth environmental water. Relaxation of constraints should remain a priority for further research.

In 2015-16 there were several instances of very low DO that raise some concerns about the immediate effects on aquatic biota. These poor water quality events were of short duration (typically 3-4 days). It is strongly suspected that the origin of the poor water quality lies within the Nagambie Lakes or originates even further upstream. Of highest relevance to this project, it is readily apparent that the reaeration rate and gross primary production rate are both insufficient (singly and in combination) to overcome this low DO further downstream. This is noted as matter for attention over summer, especially if these low DO events reoccur in 2016-17.

5. Macroinvertebrates

Macroinvertebrates are an important component of aquatic ecosystems, providing essential services for ecosystem functioning such as nutrient cycling. Macroinvertebrates form a key component of the diets of many native fish species and other vertebrates, so an important aspect of understanding how Commonwealth environmental water affects native fish is to determine how it affects their prey.

Macroinvertebrate objectives were measured in relation to Commonwealth environmental water delivered as a spring fresh in 2015. Sampling occurred before (1st August to 1st October), during (1st October to 9th October) and after (4th November to 9th December) the spring fresh. The spring fresh was delivered to promote bank vegetation and was expected to also increase macroinvertebrate diversity (number of taxa), abundance (the number of animals), biomass (their total weight) and adult emergence.

Three methods were employed to assess the effects of Commonwealth environmental water on macroinvertebrates in the Goulburn River: artificial substrates, which consist of a plastic mesh cylinder containing a substrate (onion bags) for macroinvertebrates to colonise; replicated edge sweep samples, which involve assessing the major edge habitat types present using a sweep net; and yellow sticky traps that were used to capture adult macroinvertebrates. The methods were used at two sites: the impact site (Goulburn River at McCoy's Bridge), which received environmental water, and the control site (Broken River at Shepparton East), which does not receive environmental water. The derivation of results, issues encountered, and more detailed analyses are included in Appendix D.

5.1 Evaluation

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?	Unknown.	Environmental flows did not appear to affect macroinvertebrate diversity in the lower Goulburn River. This is consistent with previous sampling (2014–15)	Qualitative analysis of monitored results from the 2015–16 survey period from the three survey methods, and comparison to the first year of monitoring (2014–15).
What did CEW contribute to macroinvertebrate abundance and biomass in the lower Goulburn River?	Yes.	Environmental flows were associated with an increase in macroinvertebrate biomass. The abundances of some macroinvertebrate taxa also increased in association with the environmental flows.	Qualitative analysis of monitored results from the 2015–16 survey period (for replicated edge sweep samples and yellow sticky traps), and comparison to the first year of monitoring (2014–15). Statistical analyses were conducted on biomass samples from edge habitats and abundance data from artificial substrates.
What did CEW contribute to macroinvertebrate emergence (and hence recruitment) in the lower Goulburn River?	Unknown.	Overall, environmental flows did not appear to stimulate macroinvertebrate emergence, although some taxa did increase in abundance during and after the environmental flow was delivered.	Qualitative analysis of monitored results from the 2015-16 survey, which were compared to the first year of monitoring (2014-15).

5.2 Main findings from the macroinvertebrate monitoring program

The following is a summary of results from 2014–15 and 2015–16 monitoring (unless otherwise specified), with more detailed results given in Appendix D

While diversity and abundance did not appear to be affected by the delivery of environmental water, there was evidence that an increase in macroinvertebrate biomass was associated with the spring fresh. The abundances of individual taxa also showed responses to environmental water.

Artificial substrates

- Diversity (number of taxa) did not show a response to Commonwealth environmental water, which is consistent with Year 1 (2014–15).
- Macroinvertebrate abundance decreased in both the Goulburn River and the control site (Broken River) post- Commonwealth environmental water (Figure 5-1a), but this decrease was less severe in the Goulburn River, suggesting a beneficial effect of the spring fresh.
- Macroinvertebrate biomass (for 2015–16 only) decreased in the Goulburn River post- Commonwealth environmental water, whereas it remained largely unchanged in the Broken River (Figure 5-1b). This was largely due to a decrease in crustacean, EPT (Ephemeroptera, Plecoptera and Trichoptera—mayflies, stoneflies and caddisflies) and Odonata (dragonflies and damselflies) biomass.
- Individual taxa that were common in both years differed in their responses to the spring fresh. For example, several taxa increased in abundance at both sites, but this increase was much greater in the Goulburn River in response to Commonwealth environmental water (e.g. the midges *Rheotanytarsus* sp. and *Cladotanytarsus* sp.). The mayfly *Atalophlebia* sp. AV6 (AV6 is the voucher code; the species name is not known) benefited from the spring fresh in the Goulburn River and increased in abundance post-Commonwealth environmental water, whereas it decreased in the Broken River. However, some taxa showed a negative response to environmental water. For example, the mayfly *Tasmanocoenis reiki* decreased in abundance at both sites, but this decrease was much more severe in the Goulburn River in response to environmental water.

Replicated edge sweep samples (2015–16 only)

- There appeared to be no effect of Commonwealth environmental water on the number of taxa in edge habitats, with species richness decreasing in both the Goulburn and Broken Rivers.
- Macroinvertebrate abundance decreased in both the Goulburn and Broken Rivers, but this decrease was much less in the Goulburn River, suggesting a beneficial effect of environmental flows (Figure 5-1c).
- Macroinvertebrate biomass increased in the Goulburn River after environmental water was delivered whereas it decreased slightly in the Broken River; there is a 92% probability that the positive change in the Goulburn River but not the Broken was associated with Commonwealth environmental water (Figure 5-1d).
- Individual taxa showed very different responses. Some showed a clear preference for one river over the other (e.g. the shrimp *Paratya australiensis* was only found in the Goulburn River whereas the mayfly *Offadens confluens* was only present in the Broken River). Other taxa displayed a preference for sampling time (e.g. the Orthocladiinae midges *Cricotopus hillmani* and *Parakiefferiella* sp. were only present at both sites before the spring fresh).
- The prawn *Macrobrachium australiense crassum* showed a positive response to Commonwealth environmental water, increasing in abundance post-Commonwealth environmental water in the Goulburn River but not in the Broken River (Figure 5-2).

Yellow sticky traps

- Far fewer adults of aquatic species were caught in sticky traps in 2015—16 (1% of total abundance) compared to 2014—15 (24%). This may be caused by the overall drier conditions over winter and spring in 2015—16.

- The midge family Chironomidae dominated the aquatic taxa (40%), which is similar to observations in 2014–15. Environmental water appeared to have a negative effect on adult aquatic chironomids, with a large decrease in their abundance post- Commonwealth environmental water in the Goulburn River (Figure 5-1e). This effect was not observed in 2014–15. Aquatic chironomid species richness increased during and after the Commonwealth environmental water, but this was observed at both sites, and to a greater extent in the Broken River, so it is probably influenced by increasing ambient temperatures rather than an effect of flows.

- Some aquatic taxa showed clear preferences for site (for example, bathroom flies Psychodidae were more abundant in the Broken River), while others varied primarily over time (e.g. adult midge *Microcricotopus parvulus* were not present at either site during pre-fresh sampling). The delivery of environmental water did appear to benefit some taxa, with the abundance of *M. parvulus* increasing post- Commonwealth environmental water at the Goulburn River (compared to a large decrease in Broken River) (Figure 5-1f).

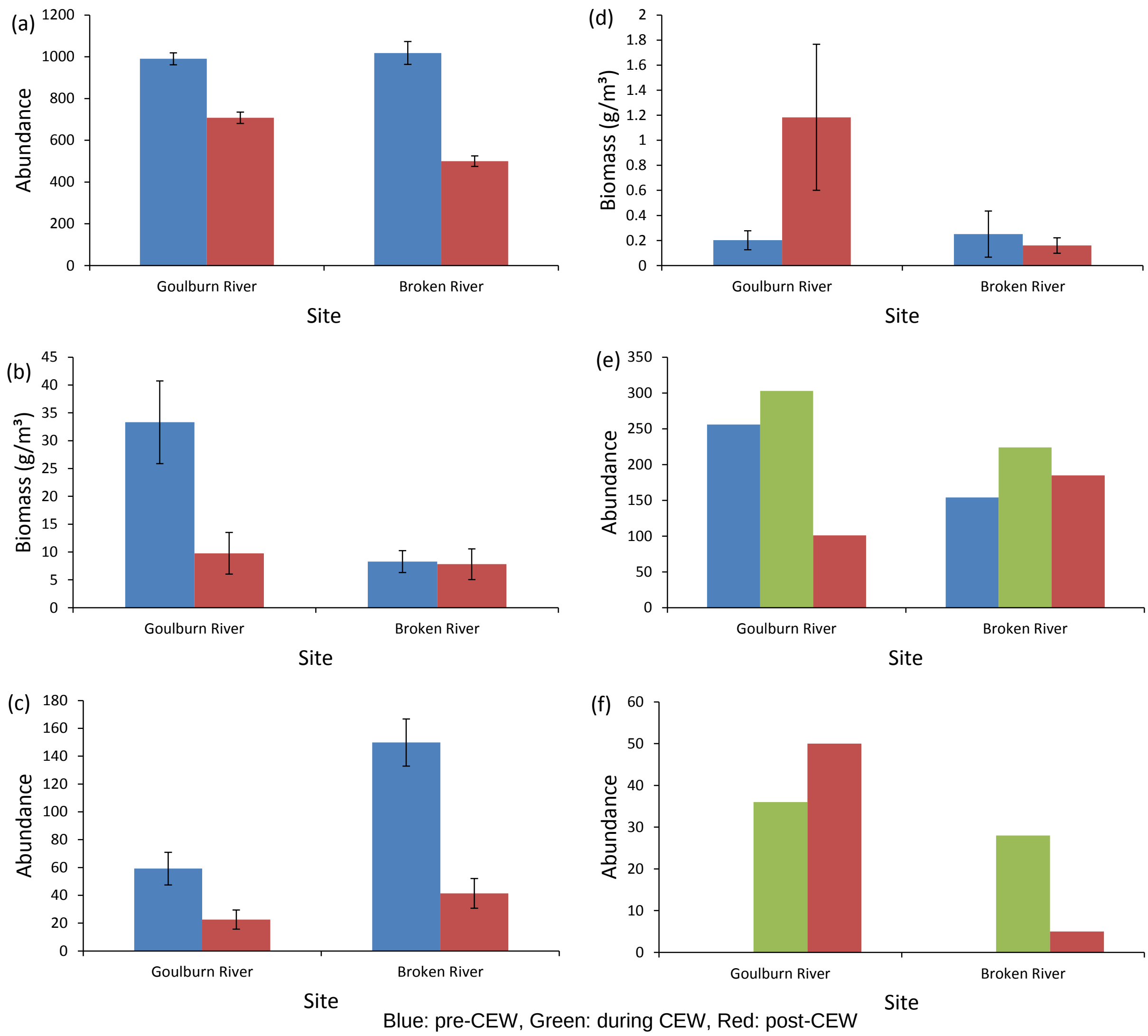


Figure 5-1. (a) Average abundance of macroinvertebrates in artificial substrates combined across 2014–15 and 2015–16 (± standard error of the mean), (b) average biomass of macroinvertebrates in artificial substrates in 2015–16 (± standard error of the mean), (c) average abundance of macroinvertebrates in replicated edge sweep samples in 2015-16 (± standard error of the mean), (d) average biomass of macroinvertebrates in replicated edge sweep samples in 2015-16 (± standard error of the mean), (e) abundance of adult aquatic midges (Chironomidae) on yellow sticky traps in 2015-16 and (f) abundance of midge *Microcricotopus parvulus* on yellow sticky traps in 2015-16.

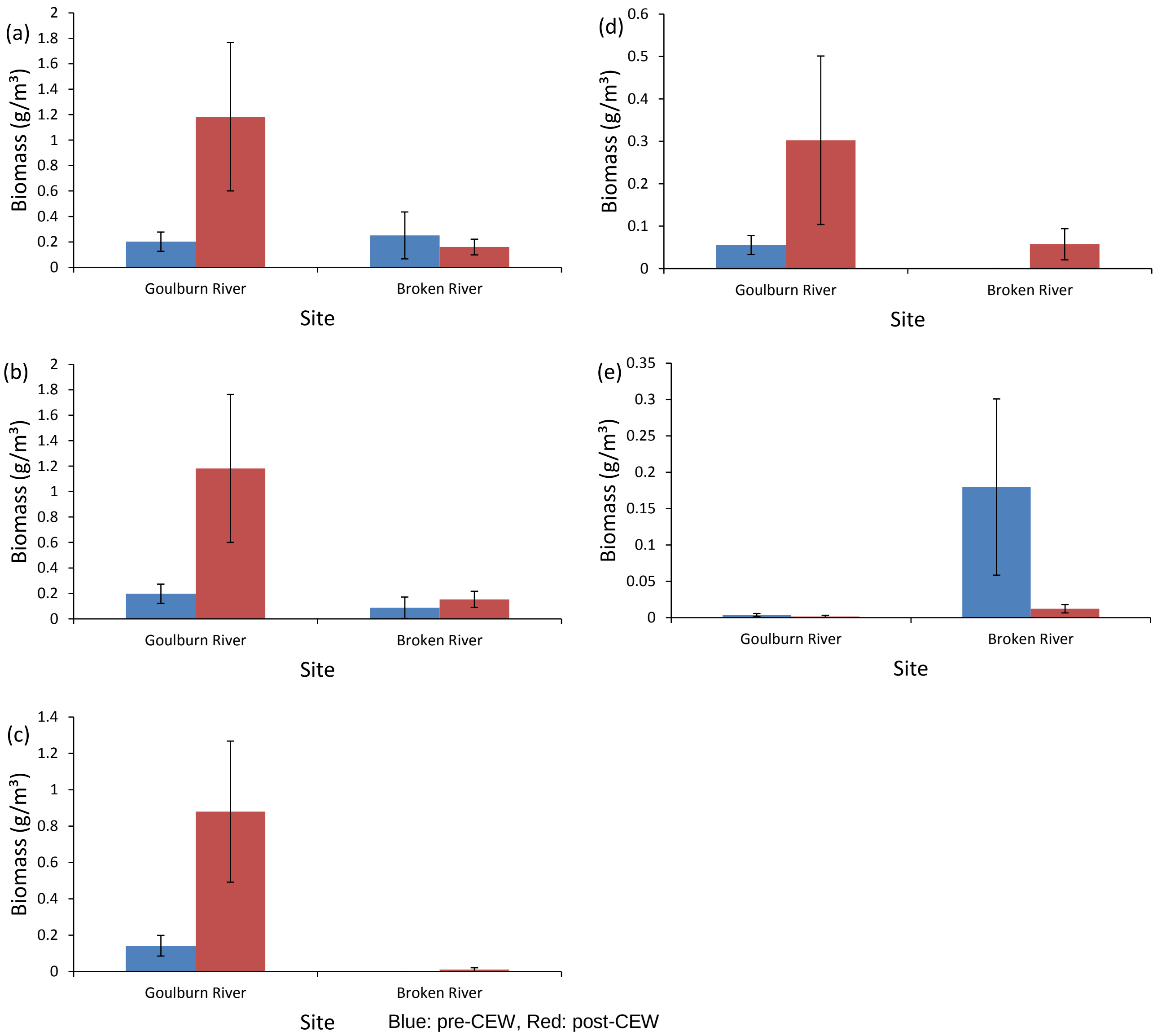


Figure 5-2. Large macroinvertebrate (>5mm) biomass of (a) all macroinvertebrates, (b) Crustacean, (c) prawn *Macrobrachium australiense crassum*, (d) shrimp *Paratya australiensis* and (e) Ephemeroptera, Plecoptera and Trichoptera (EPT) (average ± standard error of the mean) from replicated edge sweep samples in the Goulburn and Broken Rivers in spring 2015.

5.3 Discussion, Implications and Recommendations for Commonwealth Environmental Water

Macroinvertebrate responses to Commonwealth environmental water delivered as a spring fresh in 2015–16 are similar to those observed in 2014–15. Across all three sampling methods, macroinvertebrate diversity (richness) and abundance appeared unaffected by environmental water delivery. There was evidence, however, that environmental water was providing some benefit to macroinvertebrates—such as reducing the magnitude of abundance decreases in the Goulburn River compared to Broken River post-Commonwealth environmental water, and increasing the abundance or biomass of some taxa (e.g. prawns). Invertebrate biomass in the edge habitats also increased in response to Commonwealth environmental water delivery.

Macroinvertebrate biomass in sweep samples from the river's edge increased following the spring environmental flows, matched by decreases from artificial substrate samples. Large animals, such as the crustacean *Macrobrachium*, may be moving to edge habitats following flow events. Responses of individual species have been consistent across the two years of sampling.

Under the dry and warm conditions experienced in 2015—16, the delivery of spring freshes may have alleviated stress to the macroinvertebrate fauna, with declines in the macroinvertebrate fauna less severe in the Goulburn River than those observed in Broken River (which ceased to flow during post-Commonwealth environmental water sampling).

Increased primary productivity volumes may enhance river-edge habitats as areas for improved macroinvertebrate responses, stimulating the movement of large macroinvertebrates to this environment. Monitoring will attempt to test this hypothesis, possibly in conjunction with a student research project.

Monitoring methods being used in the LTIM Project are somewhat experimental, as there is little history of being able to link macroinvertebrate responses to flow events in lowland systems. An 'adaptive monitoring' approach may be necessary to continue to improve monitoring in this area. Ideas generated during 2015–16 include delaying post-fresh sampling by longer to allow a greater response from the disturbance created by the flow event, and the examination of biofilm formation (as a food source for macroinvertebrates) in different portions of the river channel.

Interim recommendations:

- Continue the delivery of spring freshes for increasing macroinvertebrate abundance and biomass for sustaining native fish.
- Investigate the role of variable summer baseflows for stimulating macroinvertebrate food sources (biofilms).
- Use an 'adaptive monitoring' approach to improve monitoring. For example, delay post-fresh sampling to allow a greater response from the disturbance created by the flow event.

6. Vegetation diversity

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.

Bankside vegetation was measured at two sites (Loch Garry and McCoy's Bridge) before and after spring freshes were delivered in 2014 and 2015. These freshes were delivered to improve vegetation outcomes by wetting banks to provide opportunities for germination and growth of inundation-adapted native species. In 2014 a second fresh was also delivered in early summer, primarily to meet fish objectives and with a secondary objective of maintaining bank soil moisture stores.

In 2015 the delivery of the spring fresh differed in two ways compared to 2014. First, in 2015 the spring fresh was delivered two weeks earlier than in 2014. This was done to provide a longer growth window after the recession of the fresh and before the onset of hot dry conditions over summer. Second, a second fresh was not delivered due to limited water availability and because these flow events are not required annually to support fish populations.

Determining the effects of environmental flows is made difficult as flows and climatic conditions in the year prior to the fresh, as well as climatic condition after flow recession, also influence vegetation. Nevertheless, the gradient of inundation duration up the bank allows some inference as to the likely benefit of environmental flows.

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

6.1 Evaluation

6.1.1 Basin-scale evaluation questions

<table>
<tr><th>Question</th><th>Were appropriate flows provided?</th><th>Effect of environmental flows</th><th>What information was the evaluation based on?</th></tr>
<tr><td>What did Commonwealth environmental water contribute to vegetation species diversity?</td><td>The spring fresh flows delivered are of the type expected to be of benefit to species diversity.</td><td rowspan="2">Spring freshes did not increase total species number at either Loch Garry or McCoy's Bridge in 2015–16.
Spring freshes increased the cover of several water dependent species in 2014–15. Responses to the spring fresh in 2015–16 were minimal, possibly due to the drier conditions in the year prior. However, it is likely that spring freshes contributed to maintaining the cover of water dependent vegetation on the banks.
Although highly variable, data from both years showed that freshes tended to increase the probability of occurrence of aquatic vegetation as a group, and decrease the probability of occurrence of grasses as a group.
Change in the cover and probability of occurrence of vegetation along the elevation gradient reflects the longer term influence of spring freshes. The cover and probability of occurrence of aquatic vegetation as a group tended to be higher in regions of the bank inundated by spring freshes and declined at elevations above this.</td><td rowspan="2">Count of species at each site and sampling time in 2015
Qualitative examination of species cover plots versus elevation and inundation profiles.
Statistical analyses of probability of occurrence across the elevation gradient.</td></tr>
<tr><td>What did Commonwealth environmental water contribute to vegetation community diversity?</td><td>The spring fresh flows delivered are of the type expected to be of benefit to community diversity.</td></tr>
</table>

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 flows delivered are of the type expected to be of benefit to species diversity. However it is not known how the duration and height of freshes influence bank soil moisture or how antecedent flows and climate conditions modify these relationships (see Appendix E for further discussion of flow management)	Over the two years of the monitoring program, CEW appears to have promoted the re-establishment of water-sensitive vegetation on the banks of the Goulburn River and reduced encroachment of terrestrial vegetation. Spring freshes in 2014–15 increased the cover of water-sensitive taxa such as Lesser Joyweed (*Alternanthera denticulata*) and Cyperaceae. However, spring freshes in 2015–16 had little effect on the cover of bank vegetation possibly due to the dry conditions leading up to the 2015–16 survey. Although highly variable, spring freshes tended to increase the probability of occurrence of Lesser Joyweed and aquatic vegetation as a group, and decrease the probability of occurrence of grasses as a group. The probability of occurrence of Cyperaceae and Creeping Knotweed (*Persicaria prostrata*) were not altered by spring freshes. Although short term responses of vegetation to freshes were limited, the cover of vegetation along the elevation gradient reflects the longer term influence of spring freshes. The cover and probability of occurrence of vegetation associated with wet habitats as a group tended to be higher in regions of the bank inundated by spring freshes and declined at elevations above this. In contrast, the cover and probability of occurrence of grasses as a group tended to be higher along parts of the bank not inundated by freshes. The data suggest that freshes are likely to have contributed to maintaining species with an affinity for wet habitats. In line with expectations, the recruitment of woody species (*Acacia dealbata* and *Eucalyptus camaldulensis*) was limited and restricted to higher areas of the bank which experience shallow and less frequent inundation.	Qualitative examination of species cover plots versus elevation and inundation profiles. Statistical analyses of probability of occurrence across the elevation gradient.
How do vegetation responses to CEW delivery vary between sites with different channel features and different bank conditions?		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. In 2014–15 differences among sites were apparent with vegetation responses to the spring fresh more evident at Loch Garry than McCoy's Bridge. In 2015–16 differences between sites were not evident.	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?		Spring freshes increased the total cover of species associated with wet habitats in 2014–15. Increased cover was due mostly to increases in the cover of Cyperaceae (mostly *Cyperus eragrostis*) and Lesser Joyweed (*Alternanthera denticulata*). Similar responses were not observed in 2015, possibly due to the dry conditions leading up to the survey. Although short term responses of vegetation to freshes were limited, the cover of vegetation along the elevation gradient reflects the longer term influence of spring freshes. Although highly variable, the cover and probability of occurrence of vegetation associated with wet habitats as a group tended to be higher in regions of the bank inundated by spring freshes and declined at elevations above this. In contrast, the cover and probability of occurrence of grasses as a group tended to be higher along parts of the bank not inundated by freshes.	Visual observation

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
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?		Conditions at other times of the year exerted a strong influence on vegetation. Between the post-fresh survey in Dec 2014 and the pre-fresh survey in Sept 2015 several water dependant species had colonised the river margin at low flows and vegetation cover tended to shift toward lower elevations. This was most evident for Lesser Joyweed which was almost eliminated from the high elevation it has occupied previously.	Visual observations

6.2 Main findings from vegetation surveys in 2014–15 and 2015–16

The main findings from the first two years of vegetation data can be summarised as:

Responses to spring freshes

- Species richness did not change in response to the spring fresh at either Loch Garry or McCoy's Bridge. Seasonal patterns of plant growth, particularly annual species, made it difficult to compare total species number pre- and post-fresh. Longer-term changes in species number in similar seasons are more appropriate but cannot be attributed to particular flow events.

- The spring fresh delivered in 2014 increased the cover of several water dependant species in 2014–15. Similar increases in cover were not evident in 2015–16, possibly due to the dry condition over the prior year.

- Although increases in cover following the spring fresh were limited, it is likely that they contributed to maintaining water dependent vegetation particularly at higher elevations given the dry conditions leading up to the 2015–16 spring fresh.

- Changes in the probability of occurrence, although highly variable, indicate that the probability of water dependent species as a group tended to increase after spring freshes while the probability of occurrence of grasses as a group tended to decrease.

- Although short-term responses of vegetation to freshes were limited, the cover of vegetation along the elevation gradient reflects the longer-term influence of spring freshes. The cover and probability of occurrence of aquatic vegetation as a group tended to be higher in regions of the bank inundated by spring freshes and declined at elevation above this. In contrast, the cover and probability of occurrence of grasses as a group tended to be higher along parts of the bank not inundated by freshes.

- Woody recruits represented by *Acacia dealbata* and *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.

Responses of vegetation to flows at other times of the year

- Conditions at other times of the year exert a strong influence on vegetation. In the period between the post-fresh survey in Dec 2014 and the pre-fresh survey in Sept 2015 several water dependant species had colonised the river margin exposed at low flows and vegetation cover on the banks tended to shift toward lower elevations. This was most evident for Lesser Joyweed, which was almost eliminated from the higher elevations it had occupied previously. The drier conditions over the year prior to the spring fresh 2015 are likely to have contributed to these vegetation changes.

6.3 Discussion, implications and recommendations for Commonwealth Environmental Water

Spring freshes appear to contribute to maintaining water dependant species on the bank face and limit the occurrence and cover of grasses and woody species at lower elevations along the bank. The earlier delivery of the spring fresh in 2015–16 compared to 2014–15 may have better buffered the bankside vegetation assemblage against the extreme dry and hot conditions that followed.

Flow and climatic conditions the year prior to spring freshes exert a strong influence on vegetation. The dry conditions prior to the spring fresh in 2015 was associated with a shift in bank vegetation toward lower (presumably wetter) elevations, the colonisation of some water dependent species along the river margin exposed at low flows and the near elimination of Lesser Joyweed from higher elevation.

Providing rigorous evidence of vegetation responses to spring freshes remains challenging, as vegetation communities reflect cumulative responses to flow and climate over short and long time frames. As the dataset builds and a larger range of flow and environmental conditions are sampled, the influence of these factors can be better elucidated in quantitative models. In particular, it is necessary to further explore how the duration of the spring freshes affects vegetation cover and establishment. This may be possible with ongoing data collection.

Seasonal patterns of plant growth, particularly annuals make it difficult to assess the influence of freshes on species diversity. Changes over annual cycles in similar seasons are more appropriate but cannot be attributed to particular flow events.

Maintaining these young plants until they reach more mature and robust life stages and/or develop soil seed banks that will promote recovery from unfavourable conditions is a key objective of flow management in 2016-17. Due to natural high flows occurring in the lower Goulburn in spring 2016, and the likely persistence of high water levels, both planned spring freshes for 2016-17 were cancelled. This will reduce the impact of prolonged inundation on young plants that have colonised the river margin.

Studies are needed to establish the influence of freshes in replenishing bank soil moisture stores as this is a key assumption underlying flow management for vegetation but remains untested.

Interim recommendations:

- Continue spring environmental flows to improve bank wetting and vegetation abundance and diversity going into summer. In particular, consider an early first spring fresh as undertaken in 2015-16 to better buffer bankside vegetation against potential dry and hot conditions.
- When possible maintain a flow regime to support young plants until they reach a more mature and robust life stages and/or develop soil seed banks that will promote recovery in the event of unfavourable conditions. This may be difficult to achieve when substantial inter-valley transfers are being delivered down the river.
- Continue data collection to further explore how the duration of the spring freshes affects vegetation cover and establishment.
- Undertake studies to establish the influence of freshes in replenishing bank soil moisture stores.

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, silver perch, and Murray River rainbow fish. Three fish monitoring methods are employed in the Goulburn River LTIM Project: annual adult fish surveys, larval surveys, and fish movement.

- 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.

- 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.

- 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.

Environmental water was not delivered to the Goulburn River specifically for golden perch or silver perch spawning in spring 2015 due to limited water resource availability. Environmental water was delivered in October 2015 for vegetation objectives but the timing of this flow pulse was too early (with lower water temperatures) to induce golden or silver perch spawning.

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

7.1 Evaluation

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.	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.	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?	No provision of fresh flows for reproduction.		
Short-term evaluation questions			
What did CEW contribute to fish community resilience?	Unknown at this stage		
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 for spawning of golden perch or silver perch in 2015–16 because of limited water availability.	Environmental water was delivered in October 2015 to provide a within-channel pulse for vegetation objectives. No golden perch or silver perch eggs or larvae were collected. Spawning of other native species was observed (Murray cod, flathead	Qualitative observations based on drift netting data.

Question	Were appropriate flows provided?	Effect of environmental flows	What information was the evaluation based on?
		gudgeon, carp gudgeon, Murray River rainbow fish, Australian smelt) and is expected regardless of environmental flow delivery, as they are not flow-cued spawners	
What did CEW contribute to native fish dispersal?	Partly (for golden perch)	Long-distance movements coincided with environmental flow freshes. However, in the 2015 spawning season there was only limited movement compared to the 2014 spawning season.	Qualitative observations and statistical analysis of telemetry data.

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?	Unknown	Golden perch spawned in 2014–15 during an environmental flow release in November, but no 0+ (i.e. young-of-year) or 1+ fish were collected in surveys in autumn 2015 or 2016, respectively. This result suggests that spawning may not necessarily translate into immediate recruitment of juveniles into the local population.	Qualitative observations based on comparisons between electrofishing and drift netting data
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?	No. Environmental water was not delivered specifically for spawning of golden perch or silver perch in 2015–16.	No golden perch eggs or larvae were collected in 2015–16. These data have been used to update the predictive statistical model developed with 2014–15 data.	Qualitative observations based on drift netting data. No golden perch eggs or larvae were collected in 2015.
What did CEW contribute to the survival of golden perch larvae in the lower Goulburn River?	Unknown	No golden perch eggs or larvae were collected in 2015–16. Golden perch did spawn in 2014–15 during an environmental flow release in November, but did not show evidence of local recruitment (i.e. there were no 0+ (i.e. young-of-year) fish in 2015 electrofishing surveys, or 1+ fish in 2016 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?	Yes	Long-distance movements (mostly downstream) coincided with environmental flow releases. These movements are believed to be a pre-cursor to fish spawning, with eggs/larvae found mostly at the downstream sites.	Qualitative observations based on telemetry data.

7.2 Main findings from fish monitoring program

Annual surveys (electrofishing and netting)

- In total, 1442 individuals were caught in 2016, compared to the 876 in 2015, with a larger number of individuals of each species caught in 2016 compared to 2015.

- Annual electrofishing and netting survey results suggest that adult native fish populations may be increasing, regardless of whether or not they spawn according to flow cues. These increases could potentially be attributed (at least partly) to flow changes that have increased the quality and quantity of in-stream habitat and food, which increases the health, survival and reproductive success of adult fish.

- Significant populations of native fish occur in the lower Goulburn River, including several species of conservation significance, namely trout cod, Murray, silver perch and Murray River rainbowfish. In the last two years (2015 and 2016) trout cod (Figure 7-1) of a range of sizes (110 – 354 mm) have been recorded downstream of Shepparton, indicating a more widespread distribution than previously thought, and probable localized breeding and recruitment.

Figure 7-1. Trout cod collected during 2015 adult fish surveys.

- Several young-of-year golden perch were collected in the Goulburn River in 2016 at Shepparton (Figure 7-2). Golden perch fingerlings were stocked by Fisheries Victoria at this site in April 2016 immediately prior to the autumn survey, which may explain this result. Otolith (the ear bones of fish) microchemistry will be used to determine whether these young-of-year golden perch were spawned in the Goulburn River, were stocked, or have migrated into the system from elsewhere.

- Golden perch have spawned in the Goulburn River each year between 2010 and 2014, and silver perch spawned each year between 2010 and 2014 except in 2012, yet no young-of-year fish (i.e. age 0+) have been collected in surveys in each of the following autumns (Figure 7-2).

- Otoliths collected from golden perch and silver perch show fish that were spawned between 2010 and 2013 are present in the population, but is unknown whether these fish were spawned in the Goulburn River, have migrated into the system from elsewhere, or—in the case of golden perch—were stocked.

- 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 and also potentially by fish from other river systems.

- A range of introduced fish species, namely carp, goldfish, eastern gambusia and oriental weatherloach, were collected. The abundance of young-of-year carp was considerably higher than in previous years, indicating recent successful spawning and recruitment, possibly associated with increases in flow rates in October 2015 during the carp breeding season.

- Oriental weatherloach were collected in low numbers at Stewarts Bridge in the lower part of zone 2. This introduced species has been recorded occasionally, but only in low numbers in surveys since 2003. It appears to be restricted to the lower reaches of the Goulburn River, but can be difficult to capture in turbid waters using electrofishing. Therefore, its relative abundance and distribution may be underestimated.

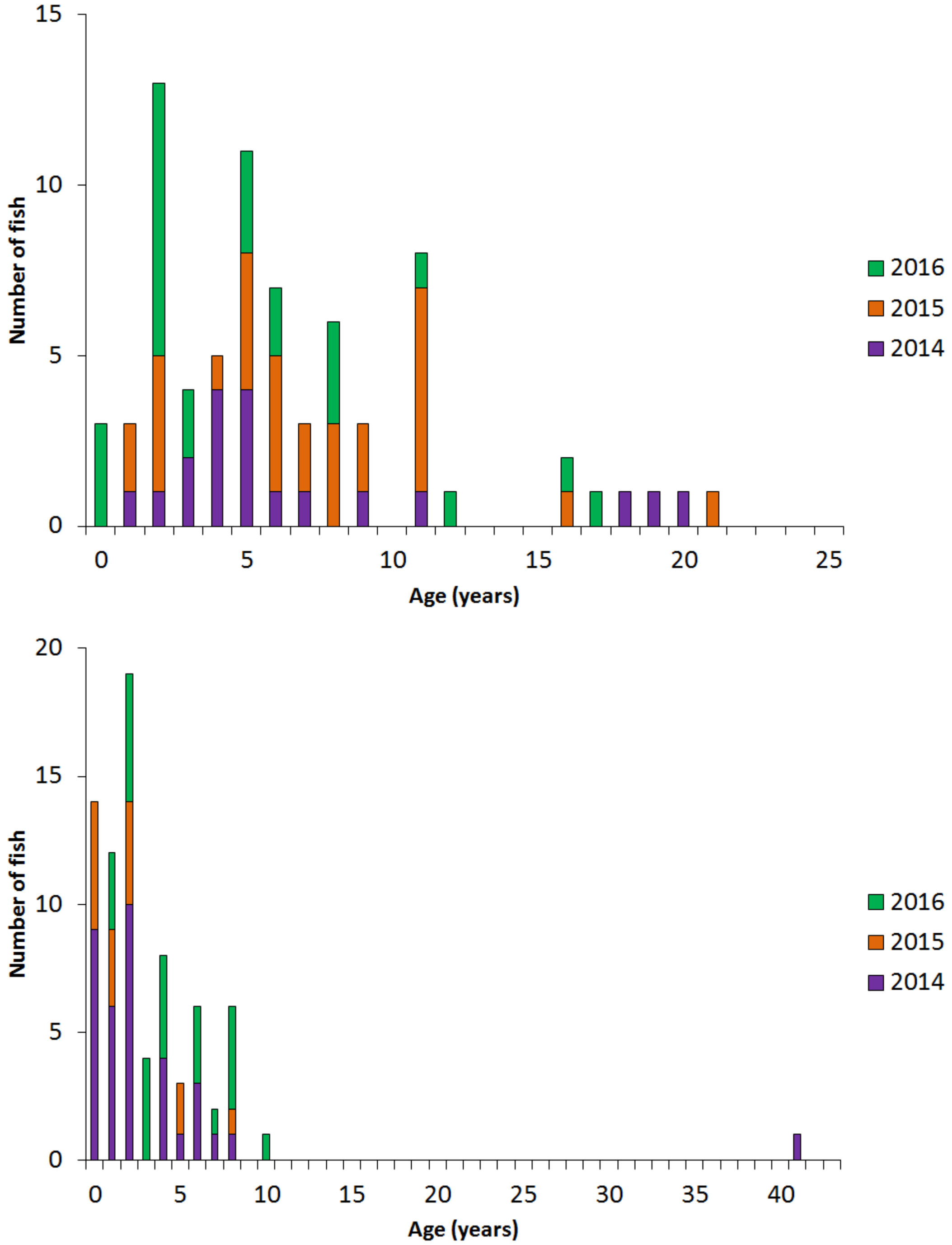


Figure 7-2. Age structure of golden perch (upper panel) and Murray cod (lower panel) from fish collected in the Goulburn River in 2014, 2015 and 2016. Bar colour denotes year of collection.

Surveys of eggs and larvae (drift nets and light traps)

- No golden perch or silver perch eggs or larvae were collected in spring 2015. Environmental water was not delivered to the Goulburn River specifically for spawning of golden perch in 2015 due to limited water resource availability, although environmental water was delivered in mid-October 2015 to provide a within-channel pulse for vegetation objectives.

- The mid-October environmental flow action likely occurred too early to induce golden perch or silver perch spawning. Water temperature around the time of the flow peak in October 2015 was only about 17–18° C. Golden perch and silver perch typically spawn in spring during increases in flow rates, with the greatest spawning outcomes at water temperatures around18–20° C. Indeed, in 2014 golden perch exhibited a strong spawning response during an environmental flow fresh in the Goulburn River in November when water temperature was about 20° C.

- Spawning of Murray cod and Murray River rainbow fish were detected in the 2015-16 period.

- Carp larvae were collected coinciding with the fresh delivered for vegetation objectives in mid-October 2015. Carp spawn in spring-summer amongst submerged vegetation and flows that provide access to bank vegetation can enhance spawning opportunities.

Movement of golden perch

- Movement of golden perch was strongly seasonal, being most prevalent during the spawning season (i.e. October–November).

- Some golden perch movement occurred outside of the spawning season (e.g., in March). This could be due to the fact that golden perch spawning can occur between September to March or this movement could be due to occasional exploratory behaviour.

- Movement occurred primarily downstream into the lower river reaches during elevated flows, including environmental flow freshes, and corresponded to the timing of spawning. Most long-distance movements were between 50 and 150 km. Several golden perch moved downstream into the Murray River, with one of these fish also being detected in another LTIM Project Selected Area (Wakool River), having travelled approximately 600 km over a two month period.

- Movement varied substantially among spawning seasons, with greater prevalence of movement in the 2014 spawning season compared to 2015. This result might relate to differences in the timing of freshes and associated water temperature.

- In 2014, water temperature was about 20° C during the environmental flow fresh in November, whereas in 2015 water temperature was only about 17–18° C during the fresh in October.

7.3 Discussion, Implications and Recommendations for Commonwealth Environmental Water

The 2016 findings regarding golden perch movement and spawning are an important consideration for Commonwealth environmental water management. The findings suggest that to promote golden perch movement and spawning, water releases should be coupled with preferred water temperatures (≥18° C).

The findings, particularly the long-distance migration – from the Goulburn River to the Murray River to near the junction of the – Wakool River also highlight the importance of hydrological and biological connectivity and the need for a river-scale perspective for the management of flows and habitat for golden perch.

Natural recruitment of young-of-year golden perch and silver perch in the Goulburn River appears to be limited. It is possible that recruitment sources outside of the Goulburn River, such as the Murray River, act as a key source of recruits for these species in the Goulburn River.

While good spawning outcomes for golden perch are achievable, adjusting the timing of the second spring fresh to times of different water temperatures will be important for determining how closely spawning is tied to temperature. Future data collection will improve our understanding of the importance of antecedent flows on fish spawning, and whether spawning responses translate to recruitment.

One negative to come out of the fish monitoring in 2015–16 was the widespread spawning and recruitment of carp, an event that is rare for the Goulburn River. We very tentatively hypothesise that carp recruitment may have benefited from the improved littoral habitat caused by the desired recruitment of semi-aquatic vegetation species low down on the banks of the river. One focus for adaptive learning for the future will be to try to fine-tune timing of spring freshes such that they benefit native vegetation and fish, but have less benefit for carp. Consideration could also be given to carp management principles such as drawing down water levels immediately after carp spawning events to desiccate carp eggs to minimise the potential for carp spawning associated with environmental flows in the Goulburn River.

Interim recommendations:

- Future environmental water releases to promote golden perch movement and associated spawning are to be coupled with preferred water temperature (≥18° C).
- Ongoing monitoring and possibly new research should be undertaken to determine how closely spawning is tied to temperature and improve our understanding of the importance of antecedent flows on fish spawning and whether spawning responses translate to recruitment
- Manage the timing of spring freshes such that they benefit native vegetation and fish, but have less benefit for carp.
- Explore carp management principles for future water deliveries to avoid further increase in the abundance of carp
- Apply a river-scale perspective for the management of flows and habitat for golden perch including the importance of hydrological and biological connectivity
- As part of this, future monitoring should explore whether golden perch and silver perch were spawned locally or have migrated into the system from elsewhere and relating this to patterns of flow.

8. Integration of monitoring results

The monitoring and evaluation plan for (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. After two years of monitoring, it is appropriate to assess whether evidence has emerged to support that original conceptual model, what linkages remain to be supported or disproved, and what new evidence has emerged to update our understanding of linkages (Figure 8-1).

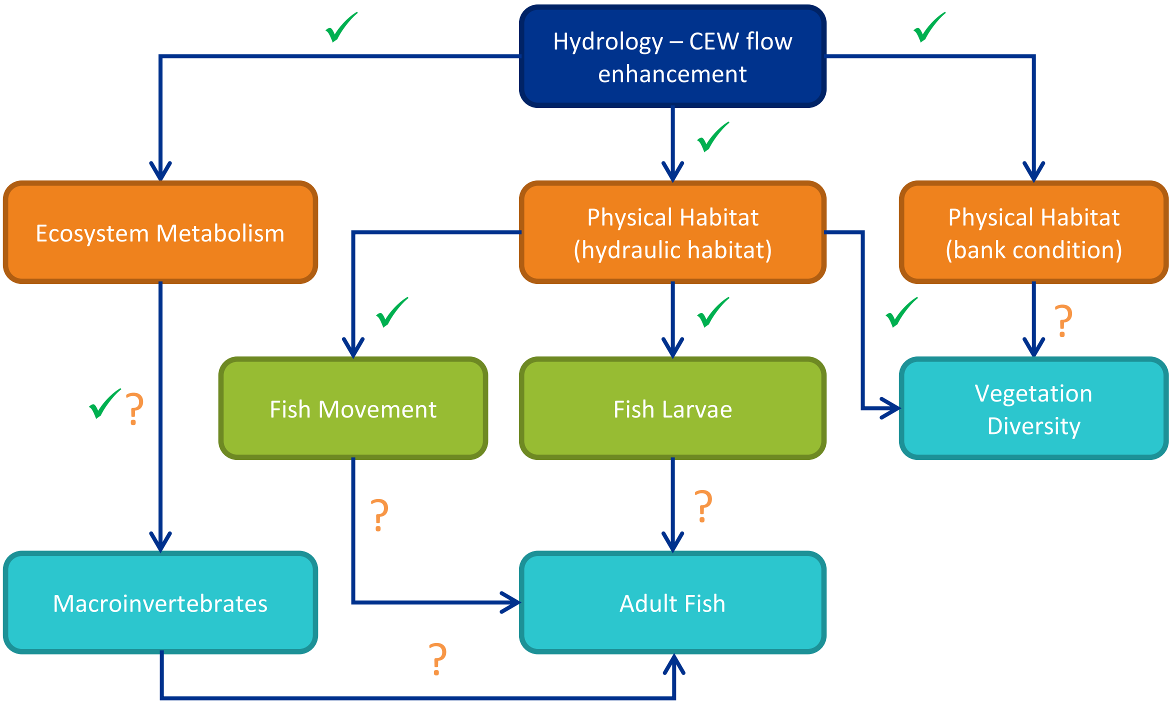


Figure 8-1. Conceptual model of the linkages among monitoring matters in the Goulburn LTIM Project (modified from Webb et al. 2014). Ticks represent linkages supported by data to date, with question marks yet to be confirmed or disproved.

8.1 Hydrologic or hydraulic predictors of ecosystem response to changing flows?

One of the original hypotheses was that understanding of the hydraulic responses to flow variation was necessary to understand ecological responses. The 2-dimensional hydraulic habitat models translate river flow rate data into hydraulic parameters that more closely approximate the conditions actually experienced by the riverine biota. For example, there is now a statistical link between the probability of golden perch spawning and movement and the velocity of river flows. Linking these behavioural responses to velocity rather than flow rates volume means the relationship can be more readily transferred to other river systems, which is very useful for river managers. Similarly, the hydraulic models have allowed us to model changes in ecosystem metabolism as a function of the cross sectional area of river inundated. It is acknowledged that both of these metrics are correlated with flow rate, and this is explored further in Section 9.

Some monitoring matters – bank condition and vegetation – are well explained by simpler hydraulic metrics, namely, the number of days of inundation experienced at different elevations on the river bank. This information can be taken directly from the hydrologic record for model fitting (i.e. developing the relationship), but hydraulic models are used to predict how inundation regimes would differ under 'no environmental flows' scenarios.

The scale of the data being collected for macroinvertebrate and adult fish monitoring makes it more difficult to link the observed responses to detailed descriptions of the flow regime (or its hydraulics), although as more data accumulate over the term of the project, we should be able to make progress in this area. Changes in macroinvertebrate species, abundance and biomass have been related to the occurrence (but not specific hydrologic or hydraulic descriptions) of the spring freshes in 2014 and 2015. The slow changes in adult fish populations make linking results to changes in flows harder again. However, in 2016–17, changes in populations will be assessed over a longer term (i.e. three years of data from the current project plus data collected from studies conducted prior to the LTIM Project) to determine whether changes in fish populations can be related to the availability of deep water pools, as predicted by the 2-dimensional hydraulic models.

8.2 Linkages among biological monitoring results

Ecosystem metabolism results in 2015–16 demonstrate that the total amount of gross primary productivity increases with environmental flow actions, but not the specific volumetric rate of production. In general, rates of primary production 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, in the edge habitats following the spring fresh, matched by a concomitant decrease in biomass from the artificial substrates further out in the channel. Large grazers may be shifting habitats to take advantage of increased primary production in the edges following environmental flows. A student may be recruited to investigate whether biofilm production in edge habitats is improved by environmental flow delivery, 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.

The comparative result among the edge samples and artificial substrates highlighted the importance of using multiple approaches for sampling macroinvertebrates. Had the artificial substrates only been used, a different picture would have emerged. Related to this, the yellow sticky traps did not provide any strong evidence of responses to environmental flow actions in 2015–16, but did capture far fewer aquatic insects compared to the first year of data collection in 2014–15. It is hypothesised that this might have been a result of the much lower flows experienced in year two of the monitoring program (Figure 8-1), and further years’ data will resolve this question, especially with the extremely high flows experienced over winter and spring 2016.

Vegetation, while displaying overall similar responses to inundation as in 2014–15, also seemed to be reduced, possibly in response to the lower flows experienced in 2015–16. The original conceptual model of the program also proposed closer linkages of bankside vegetation to hydraulic parameters such as sheer stress, and to changes in the bank caused by erosion and deposition. Modelling vegetation responses in terms of these variables is yet to occur, but that will be a focus for year 3 analyses.

The adult fish surveys demonstrate improving populations of some important native fish species like golden perch and Murray cod. Trout cod were also found in greater numbers and at a greater range of locations than previously seen for the Goulburn River. The spring fresh provided in October 2015 for riparian vegetation probably occurred when the water was too cold to trigger golden perch or silver perch to spawn, but larval surveys confirmed that some non-flow dependent spawning native species including Murray cod, flathead gudgeon, Murry River rainbow fish, carp gudgeon and Australian smelt did spawn later in spring 2015. These results collectively paint a favourable picture of long-term river conditions in the lower Goulburn River, with flow enhancement through various water holders, including the CEWO, being part of an integrated approach to managing the system.

It is yet to be demonstrated that golden perch spawned in the Goulburn River prior to 2015–16 are recruiting back to the river. The younger fish in the adult fish surveys are too old to be recruits from the successful spawning event recorded in 2014–15, and no young-of-year were found. It is noted, however, that there are fish in the population that were spawned during years when there were successful spawning events in the Goulburn River. It is possible that fish larvae from spawning events in the Goulburn River are washed downstream, successfully recruit in the Murray River and then some of those individuals return to the Goulburn River in later years.

Indeed, fish telemetry data are improving our understanding of the large spatial scales over which golden perch move, with one fish in particular moving from the Goulburn to the Edward-Wakool system - a distance of approximately 600 km over the course of ~2 months. Changes to the fish monitoring program have freed up some funding to do microchemical analyses of otoliths. These can identify the river in which adult fish were born, as well as where they have spent periods of their life. This information will help us to better understand the causes of improvements in the adult fish populations.

8.3 Conclusion

Overall, there is confirmation (sometimes tentative) for many of the linkages proposed in the MEP (Figure 8-1). 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). Analyses in future years of the LTIM Program 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 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).

Table 9-1. Specific examples of adaptive management undertaken through the Goulburn River LTIM Project and/or implications of 2015–16 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	What is the advantage of the extra time and expense required to develop hydraulic models that correlate parameters such as water velocity, depth and shear stress with flow rate (see Section 8)? The answer lies in the transferability of learnings from the Goulburn system to other systems in the LTIM project and to systems for which monitoring is not being done. For example, the flow rate required to initiate spawning in golden perch will be much greater in the Goulburn River than in the Edward-Wakool, but this is because of a difference in channel size. 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, providing confidence for continued operations.
	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; however, these observations suggest winter environmental flow deliveries may be more important for this purpose.
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 results highlight the need for larger flow events in the future to mobilise carbon and nutrients from major backwaters and the floodplain. The constraints project currently being undertaken by the Goulburn-Broken Catchment Management Authority may allow the release of higher flows in future.

Matter	Examples of adaptive management and implications for future monitoring and management
Macro-invertebrates	Monitoring methods being used in the LTIM Project are somewhat experimental, as there is little history of being able to link macroinvertebrate responses to flow events in lowland systems. An 'adaptive monitoring' approach may be necessary to continue to improve monitoring in this area. Ideas generated during 2015–16 include delaying post-fresh sampling by longer to allow a greater response from the disturbance created by the flow event, and the examination of biofilm formation (as a food source for macroinvertebrates) in different portions of the river channel.
Vegetation	A number of water dependant species were recruited along the river margin exposed at low flows in 2015–16. A key objective for environmental water management in 2016–17 is to maintain these young plants until they reach more mature and robust life stages and/or develop soil seed banks that will promote recovery from unfavourable conditions including long periods of inundation. High flows over winter/spring 2016 submerged young emergent plants along the lower bank for extended periods; 2016-17 monitoring will determine how much of that vegetation has survived.
Fish	The absence of spawning by golden perch following the 2015 spring fresh was expected, and further improves knowledge regarding the spawning requirements of this species. In particular, it appears that spawning outcomes for golden perch are improved at water temperatures ≥ 18°C under appropriate flow conditions. Movement in response to high flows was also reduced compared to 2014–15, and this is attributed to lower water temperatures.
	Several adult golden perch moved downstream into the Murray River in response to elevated flows, with one of these fish also being detected nearby to another LTIM Project Selected Area (Wakool River). These findings highlight the importance of hydrological and biological connectivity and the need for a river-scale perspective for the management of flow and habitat for golden perch.
	The lack of golden perch young-of-year in the annual electrofishing surveys may indicate that eggs or larvae spawned in the Goulburn River are exported from the system, potentially only recruiting back into the Goulburn River in later years. Environmental flows to promote recruitment into the Goulburn River may represent a targeted management action to support golden perch populations.
	One negative to come out of the fish monitoring in 2015–16 was the widespread spawning and recruitment of carp, an event that is rare for the Goulburn River. It is very tentatively hypothesised that the recent increase in semi-aquatic vegetation on the lower parts of the river bank (a desirable effect of recent flows) may have provided conditions in littoral habitat that facilitated successful carp recruitment. One focus for adaptive learning for the future will be to try to adjust the timing of spring freshes so they benefit native vegetation and fish, but have less benefit for carp.

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 for 2016–17 and beyond. 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.

10. Stakeholder communications

The following planned communication and engagement actives were undertaken over the 2015–16 period to inform stakeholders and the broader community about the aims and results of the Goulburn River LTIM Project and the role of the CEWO in environmental water management. Selected examples of communications are included in Appendix G.

10.1 Media Releases and Articles

Five media releases were prepared and distributed between May 2015 and April 2016. These promoted the Goulburn River LTIM 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. The media releases resulted in corresponding articles in the *Country News* and *Shepparton News*. Articles were also included in the Goulburn Broken Catchment Management Authority (GB CMA) electronic newsletter 'Connecting Community and Catchment', which has over 900 subscribers.

In addition, Dr Angus Webb wrote an article in *The Conversation* about the use of macroinvertebrates in stream condition monitoring. The Goulburn River LTIM Project macroinvertebrate monitoring was held up as an example of this type of monitoring. This article has been read 3400 times and been tweeted 31 times as of October 2016.

- http://theconversation.com/how-healthy-is-your-river-ask-a-waterbug-43842

10.2 Technical publications

Dr Geoff Vietz, along with Drs Angus Webb and Anna Lintern from The University of Melbourne and David Straccione from the CEWO submitted a journal paper to a special issue of the international journal *Environmental Management* on the bank condition monitoring results. This article is currently undergoing peer review, and is expected to be published in 2017.

10.3 Social Media

A total of 10 posts to the GB CMA iSpy Facebook page and the GB CMA Facebook page promoted the Goulburn River LTIM project, Commonwealth environmental water use in the Goulburn River and fish monitoring results. These posts were viewed over 20,000 times, and associated tweets reached over 10,000 people.

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

10.4 Fact sheets

Goulburn River LTIM Project fact sheets were developed incorporating feedback from all environmental water holders, waterway managers and delivery partners. One of these outlined the overall project with additional fact sheets for each of the key monitoring activities (fish, vegetation, macroinvertebrates, stream metabolism and riverbank condition). The fact sheets have been distributed to partners, government agencies and the broader community at meetings, workshops and field days. The fact sheets are available for viewing and downloading on the GB CMA website along with the associated web videos (see 10.5).

- http://www.gbcma.vic.gov.au/projects/environmental-water/monitoring

10.5 Videos

Short web videos (3–5 minutes) have been developed on each of the key monitoring activities (fish, vegetation, macroinvertebrates, stream metabolism and riverbank condition) and are available for viewing on the GB CMA website. The videos have been viewed a total of 560 times.

- Physical habitat: https://www.youtube.com/watch?v=l8KN2b9sEbw
- Ecosystem metabolism: https://www.youtube.com/watch?v=eiOk0BcstJU
- Macroinvertebrates: https://www.youtube.com/watch?v=o0cqN0FoxoI
- Vegetation: https://www.youtube.com/watch?v=vKdFxu9_mfc
- Fish: https://www.youtube.com/watch?v=dvnPb6plTQc

10.6 Presentations

Dr Geoff Vietz presented to the Goulburn River Environmental Water Advisory Group on the findings of the riverbank condition monitoring. The Goulburn River Environmental Water Advisory Group is run by the GBCMA and is comprised of community members and representatives from key agency partners. Presentations to this group on other monitoring findings are planned for 2016–17.

In February 2016 Dr Geoff Vietz spoke at the 11th International Symposium on Ecohydraulics held in Melbourne. The talk discussed the findings of the riverbank condition monitoring and was titled ‘Knowing then doing, or is it doing then knowing? Environmental flows and bank condition monitoring in the Goulburn River, Australia’. Geoff’s presentation was accompanied by a peer-reviewed proceedings paper

- http://proceedings.ise2016.org/tracks/1018/abstract/26972.html

At the same conference, the plenary presentation by the Commonwealth Environmental Water Holder, David Papps, used golden perch monitoring in the Goulburn River as an example of how the Commonwealth Environmental Water Office is undertaking adaptive management as part of the LTIM Project.

In May 2016, Dr Angus Webb was a plenary speaker at the international Society for Freshwater Science meeting, held in Sacramento, California. Speaking on the general topic of water reform and responses to water scarcity in south-eastern Australia, Angus also mentioned the LTIM Project and the golden perch spawning results from the Goulburn River.

- https://vimeo.com/168858392

GB CMA staff presented/provided updates to a number of community and agency groups throughout the year on the Goulburn River LTIM Project, the role of the Commonwealth Environmental Water Office and Goulburn River environmental water management. These groups included:

- GB CMA Indigenous Consultation Group;
- Yorta Yorta Nation Aboriginal Corporation;
- Goulburn-Murray Water;
- Parks Victoria;
- GB CMA partnership group;
- Shepparton Irrigation Region People and Planning Integration Committee;
- Farm and Environment Working Group;
- Goulburn Broken Water Quality Coordination Group;
- recreational fishing groups and fish management agencies at the Talking Wild Trout Conference;
- Broken Environmental Water Advisory Group; and
- Fairley Leadership Group.

In addition, the GB CMA consulted with over 250 landholders along the mid and lower Goulburn River and eight State and Federal Members of Parliament concerning the development of the Goulburn Constraints Management Strategy Business Case. As part of this consultation Goulburn River environmental water management was discussed.

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Appendix A. Hydrology and Hydraulics Methods

A.1 Introduction

There are five established flow gauges in the lower Goulburn River that provide high-quality data over a long period and have good rating curves (Table A-1). The gauges at Goulburn Weir and Murchison provide good information about flow rates in Zone 1, and the gauges at Loch Garry and McCoy's Bridge provide good 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 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

Loch Garry discharge data were unavailable for several lengthy periods of the record, including all periods covered by monitoring in this report. Therefore a regression was developed to infill flows with the McCoy's Bridge flows. The regression equation used was:

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. Discussions have occurred with the Victorian Department of Environment, Land, Water and Planning (DELWP) about re-instatement of the gauge at Loch Garry, but to this point have not been successful.

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 will be superseded in future years by the 2-dimensional hydraulic models being 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 Erosion

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.

B.2 Monitoring sites and 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 are described in the *Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Goulburn River Selected Area evaluation report 2014-15* (Webb et al. 2016). That report further describes hydraulic model development and verification. Methods for bank condition monitoring were described in detail in the 2014-15 report and are therefore only briefly summarised here. Additional statistical analyses have been performed on data collected during 2015-16 and more details about those analyses are provided in the following pages.

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.3 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) and requires bed topography as an input. This is obtained from LiDAR (provided by the GBCMA) and bathymetry 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-4). 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). The hydraulic models will be run to quantify changes in hydraulic habitat once metrics are selected in consultation with ecologists.

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.3.1 Elevation data verification

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

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.3.2 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.

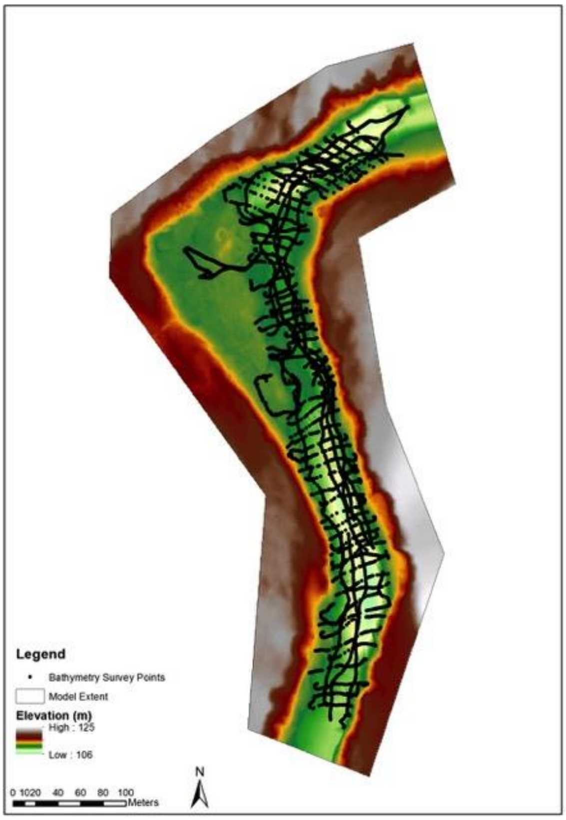


Figure B-2. Topography used to develop the hydraulic model for Moss Rd based on LiDAR and bathymetric survey. The main channel (represented here in green) has path of the bathymetric survey overlain in black to demonstrate coverage. This includes some verification runs of the boat into the backwater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

B.3.3 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.

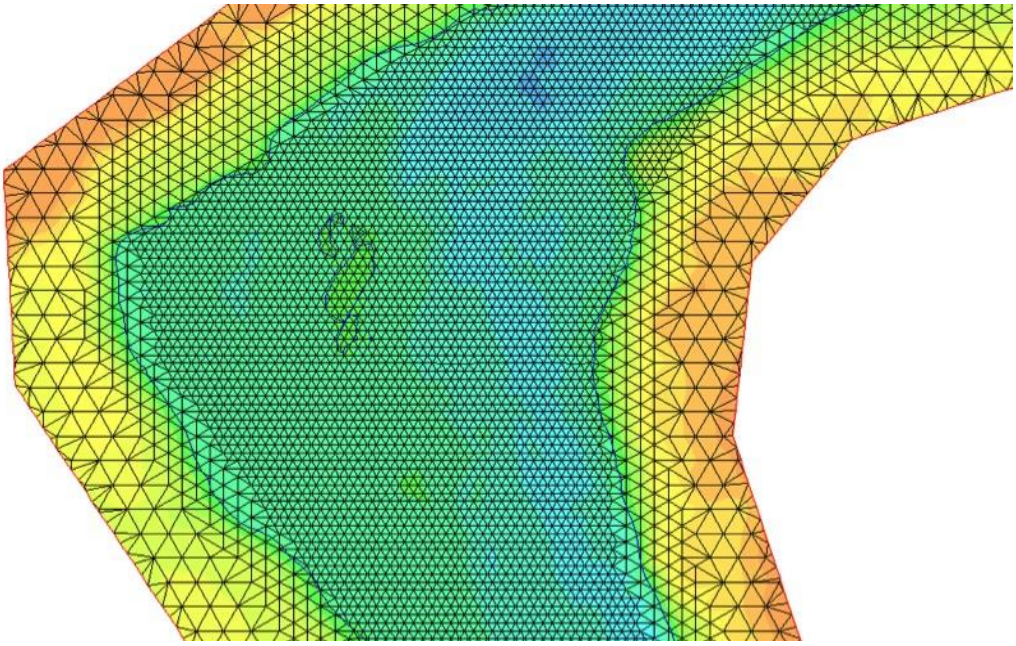


Figure B-3. Example of computational mesh resolution and setup for Moss Road. Greater detail (higher resolution) is provided within the channel to capture small-scale hydraulic variation on the bed of the channel and for lower velocities.

B.3.4 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.3.5 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.

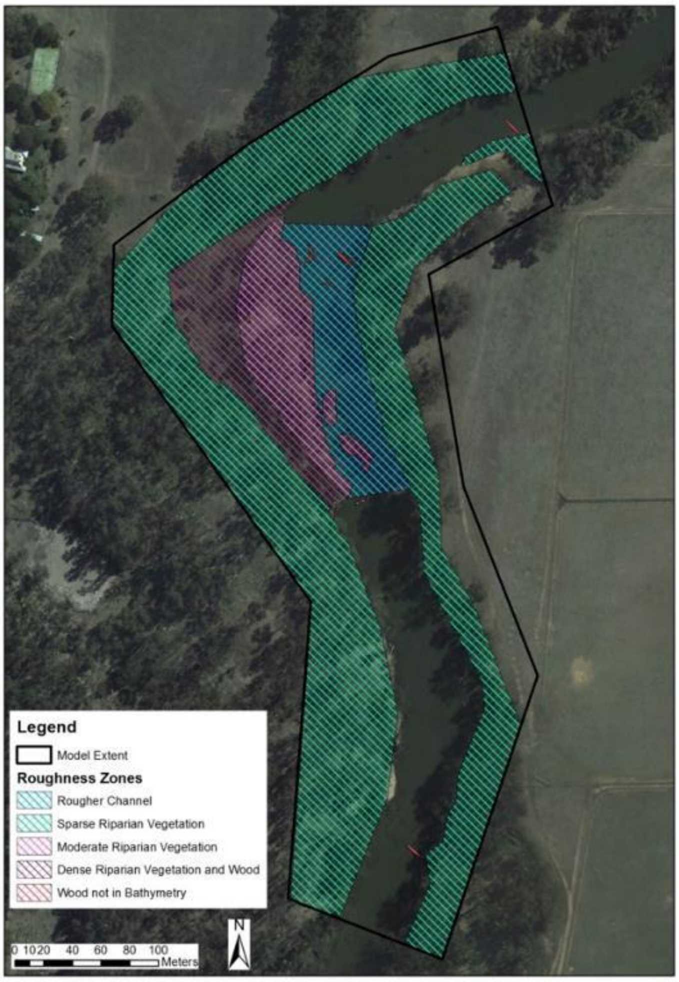


Figure B-4. Roughness zones for Moss Road

B.3.6 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. For the low flow event, Section 8 had the worst match, with some observed velocities near the channel margins being underestimated by up to 0.32 m/s by the model. The observed velocity profile had higher velocity at the channel margins (around 10 m on each side of the channel) and lower velocity in the middle, whereas the modelled profile had higher velocity in the middle. There is no blockage evident in the survey data which would cause this split of the current, and the density of survey data is good through this section. The observed velocity profile may have been produced by a local but temporary blockage. Rather than make arbitrary changes to the topography, the calibration was accepted as is, noting that results in this region 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.

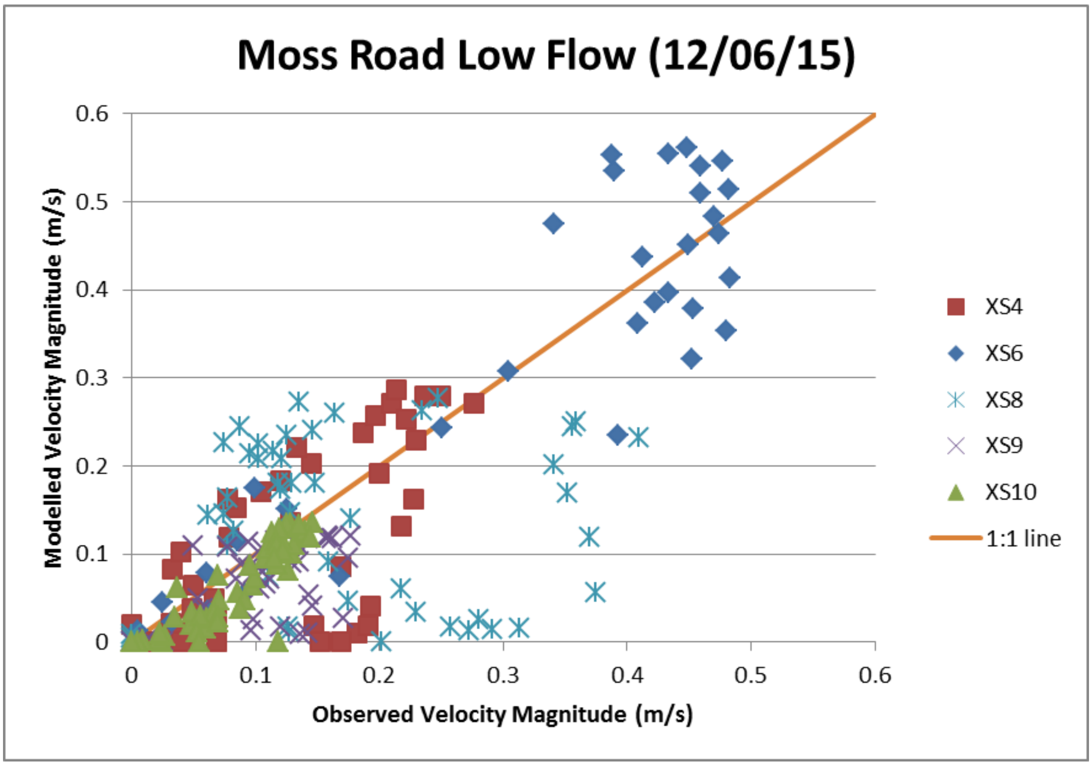


Figure B-5. Calibration results (velocity comparison) for Moss Road low flow event (12/06/15)

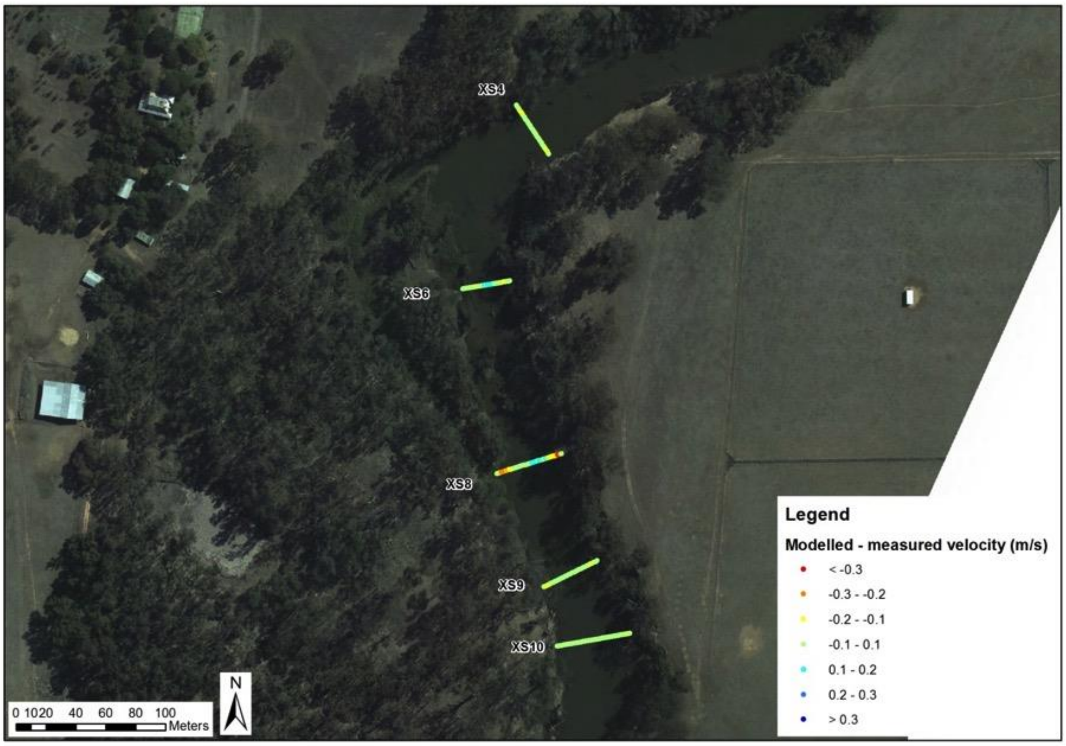


Figure B-6. Calibration results (velocity difference) for Moss Road low flow event (12/06/15)

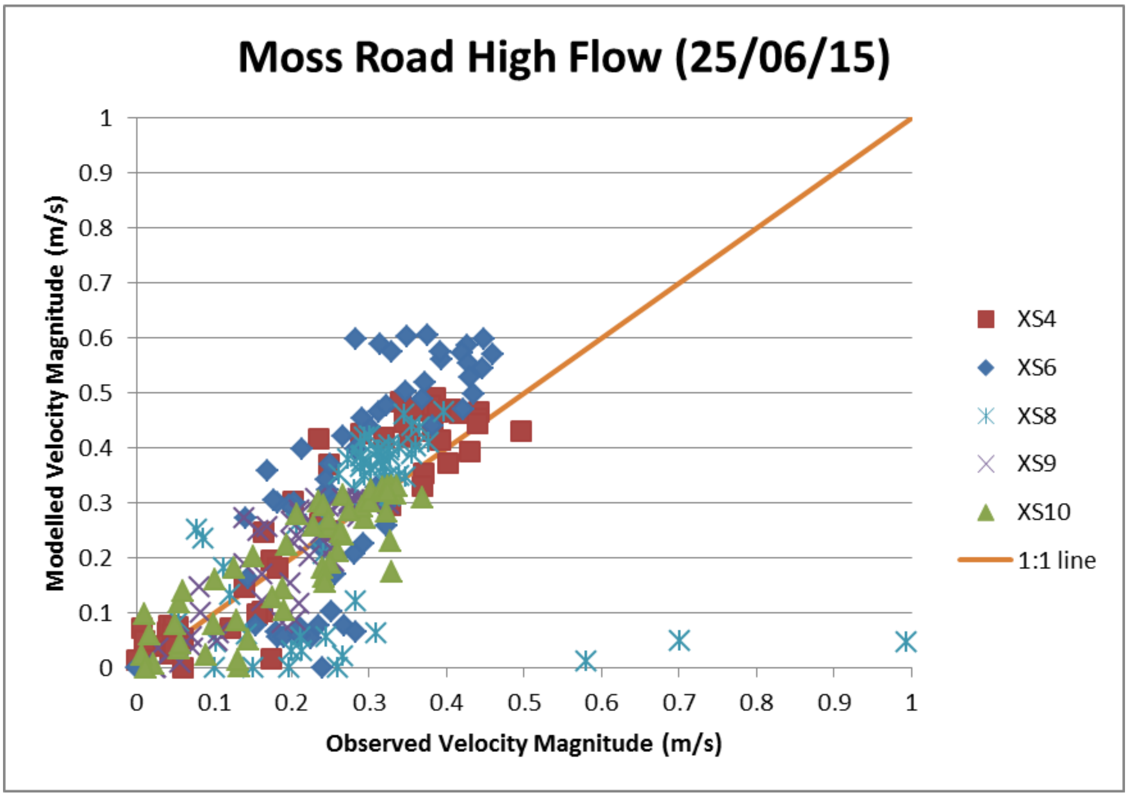


Figure B-7. Calibration results (velocity comparison) for Moss Road high flow event (25/06/15)

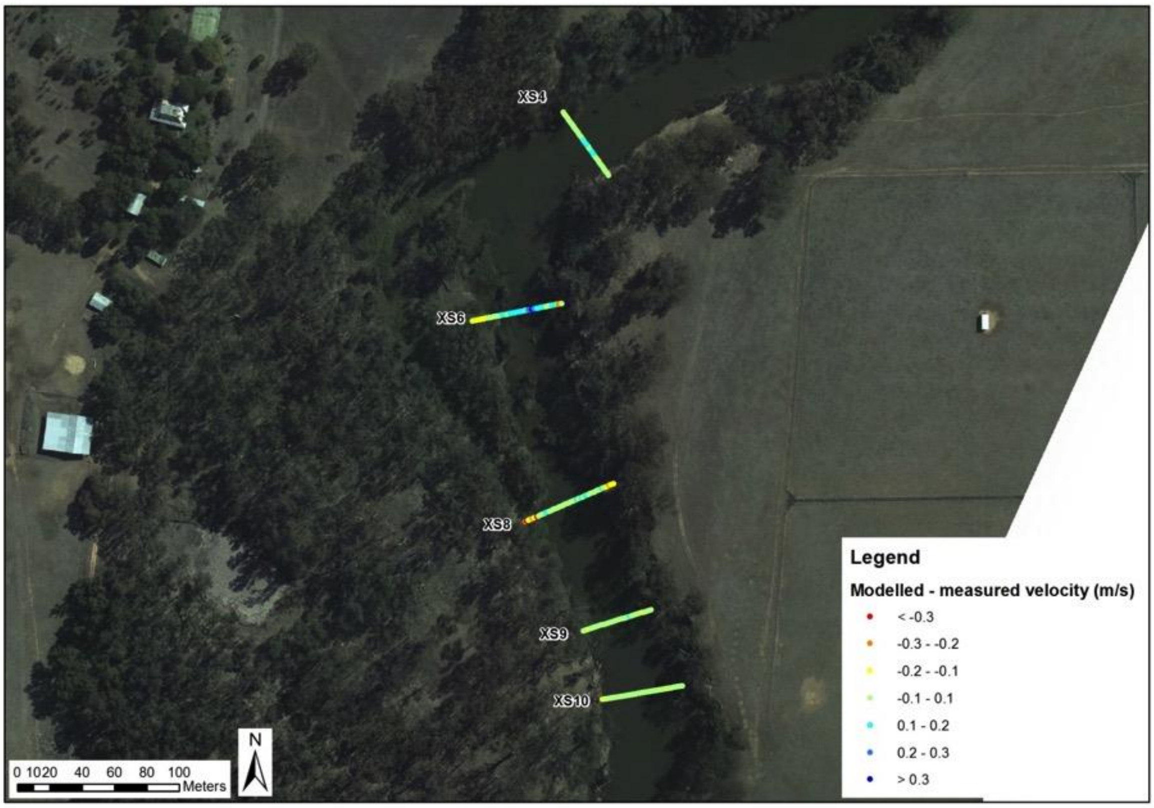


Figure B-8. Calibration results (velocity difference) for Moss Road high flow event (25/06/15)

B.3.7 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).

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 then decreases and stabilises at around 2,000 m^2 when discharge exceeds 4,000 Ml/d. Mean slackwater patch size is high for discharges less than 2000 ML/d, is at a maximum for 2000 ML/d, and is very low for discharges of 3000 ML/d or greater (Figure B-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 2000 ML/d, is at a maximum for 2000 ML/d, and is very low for discharges of 3000 ML/d or greater (Figure B-11).

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. Maximum velocity at vegetation transects was developed by extracting velocity at the specific locations vegetation samples were undertaken. The nearest velocity node was used to develop a relationship to (Figure B-14)

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

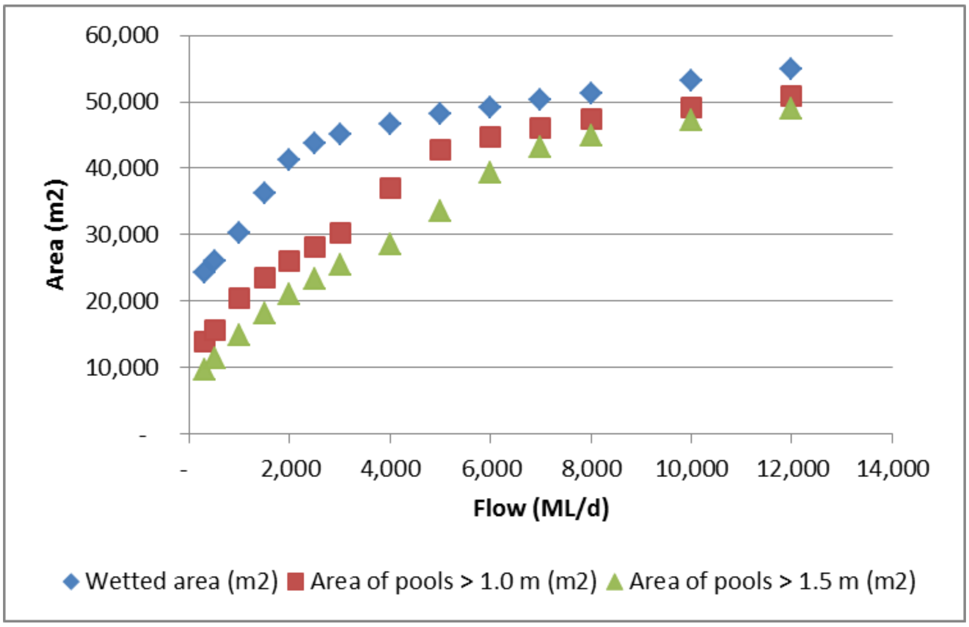


Figure B-9. Results (wetted area and area of pools) for Moss Road

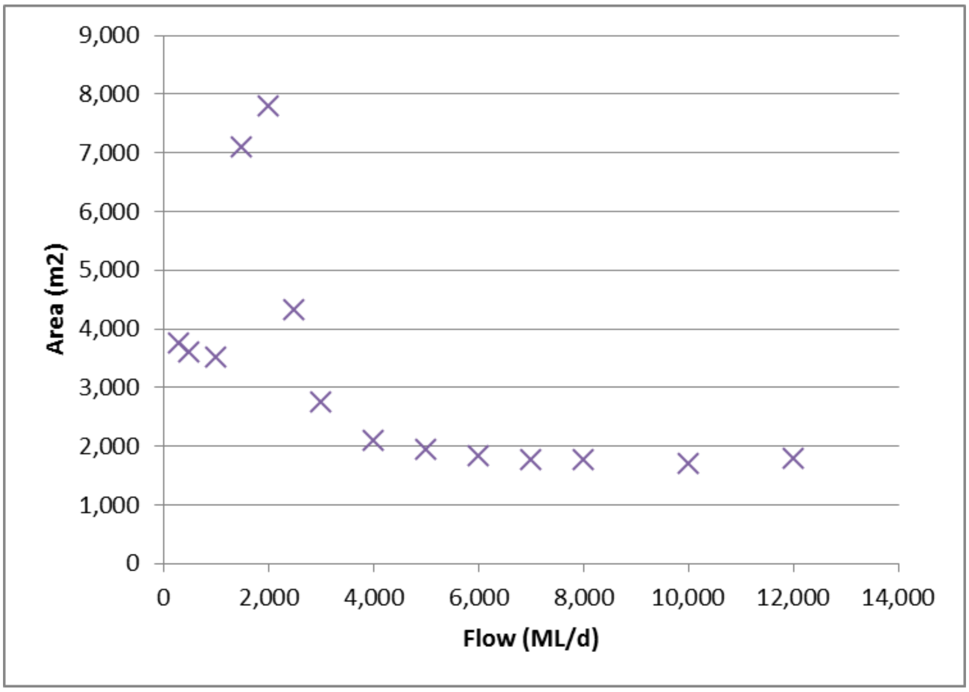


Figure B-10. Results (area of slackwater habitat) for Moss Road

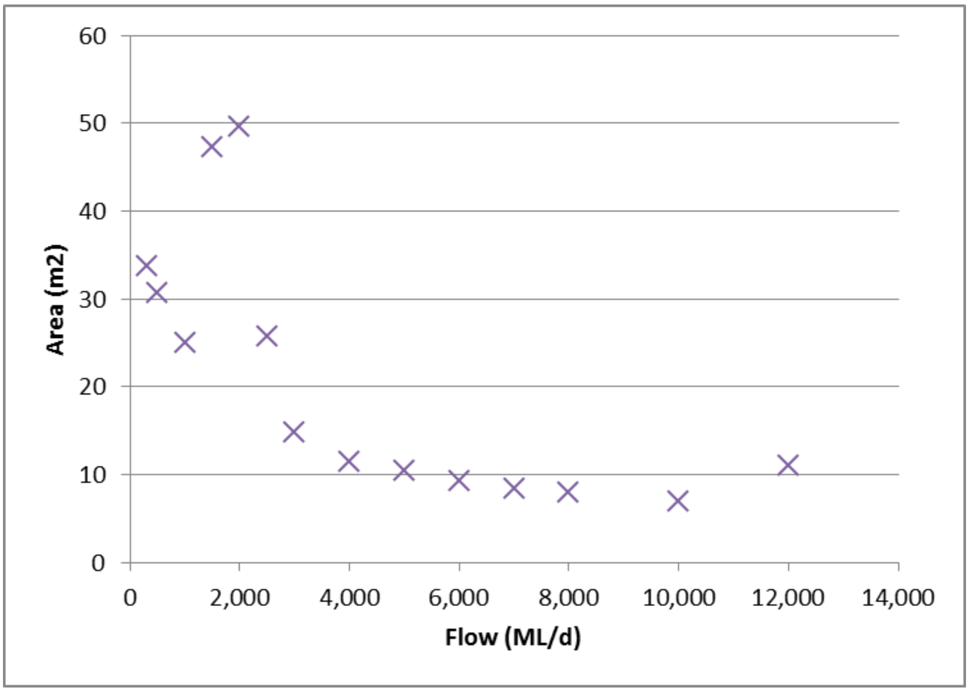


Figure B-11. Results (mean patch size of slackwater habitat) for Moss Road

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.*

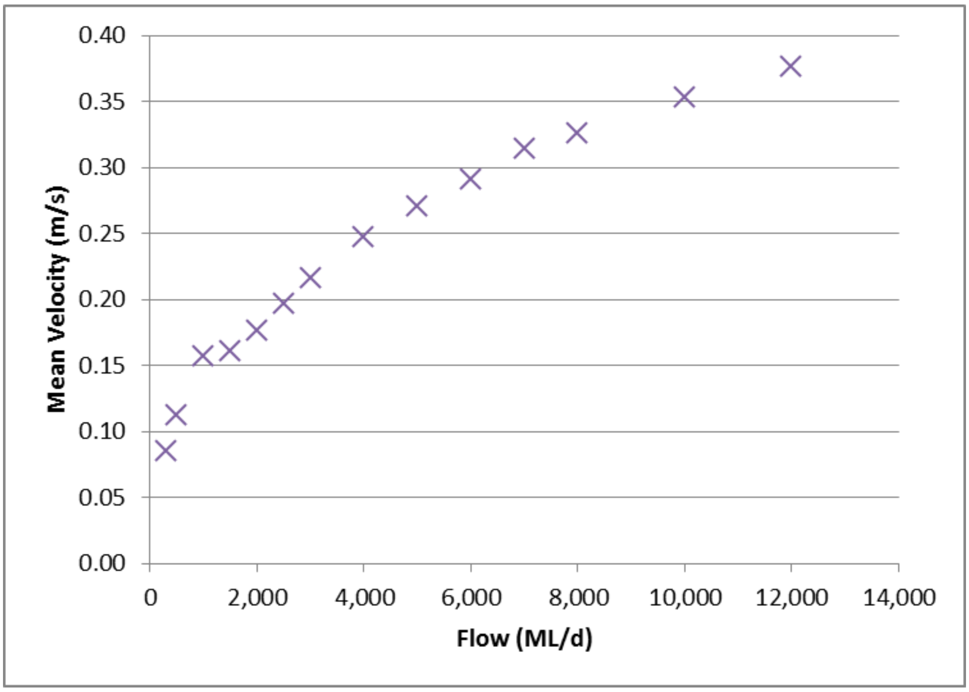


Figure B-12. Results (mean velocity) for Moss Road

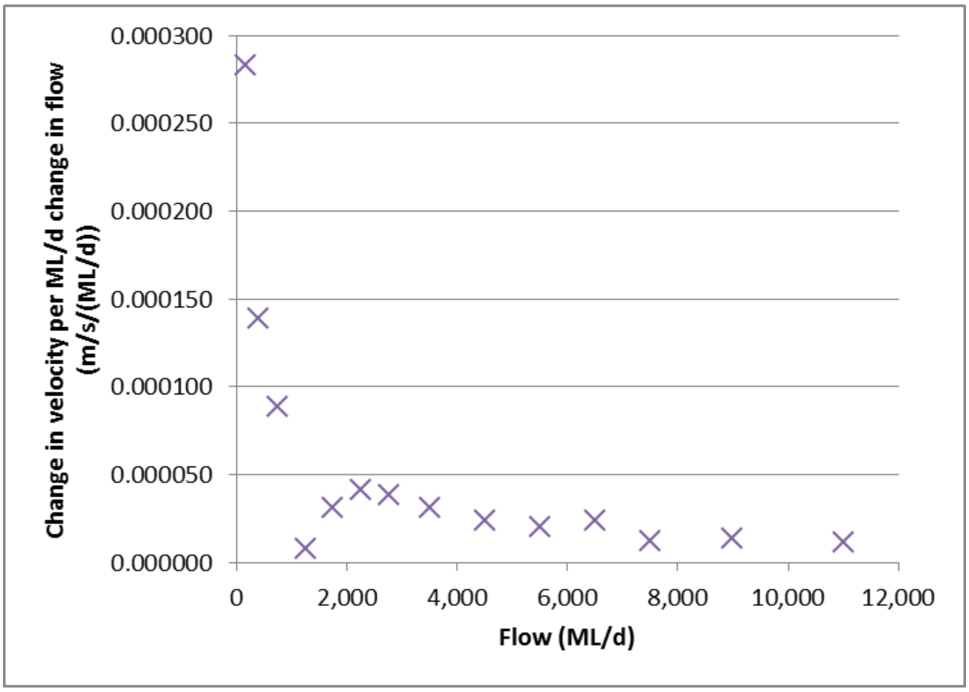


Figure B-13. Results (velocity rate of change with flow) for Moss Road

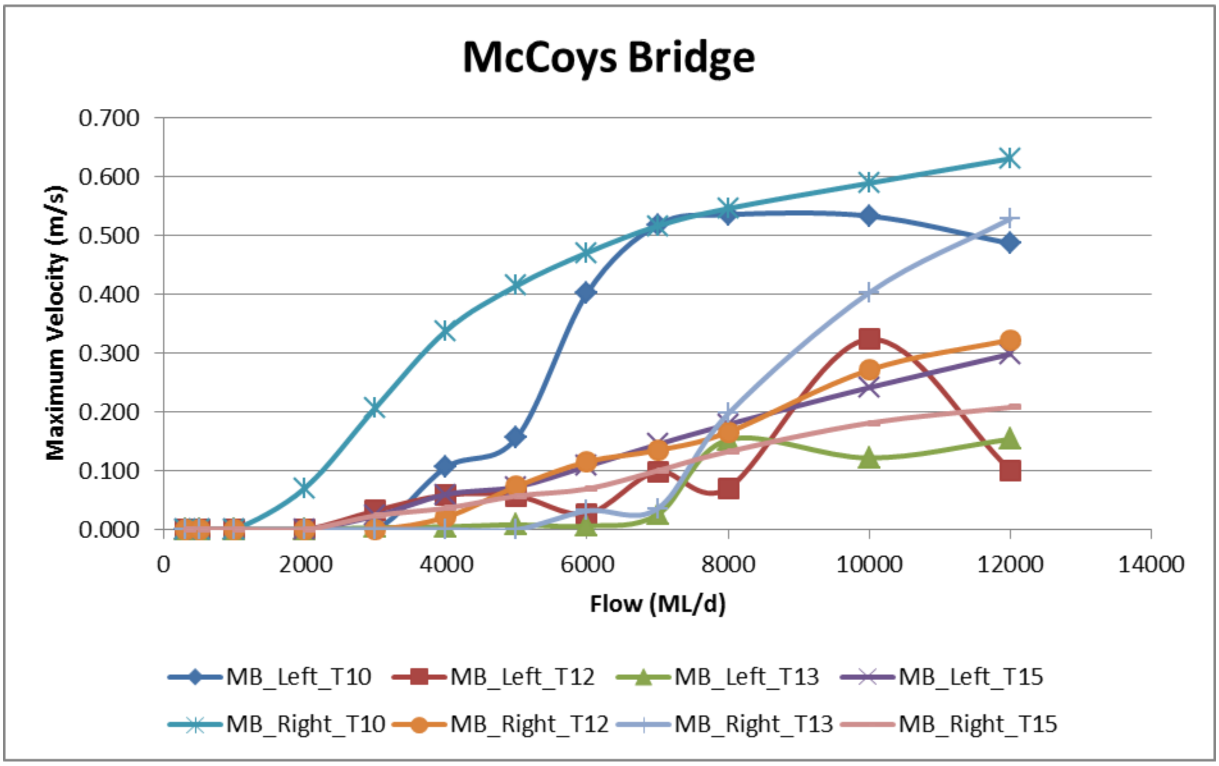


Figure B-14. Maximum velocity at vegetation transects for McCoy's Bridge

B.4 Bank condition

B.4.1 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-15, 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-15, 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).

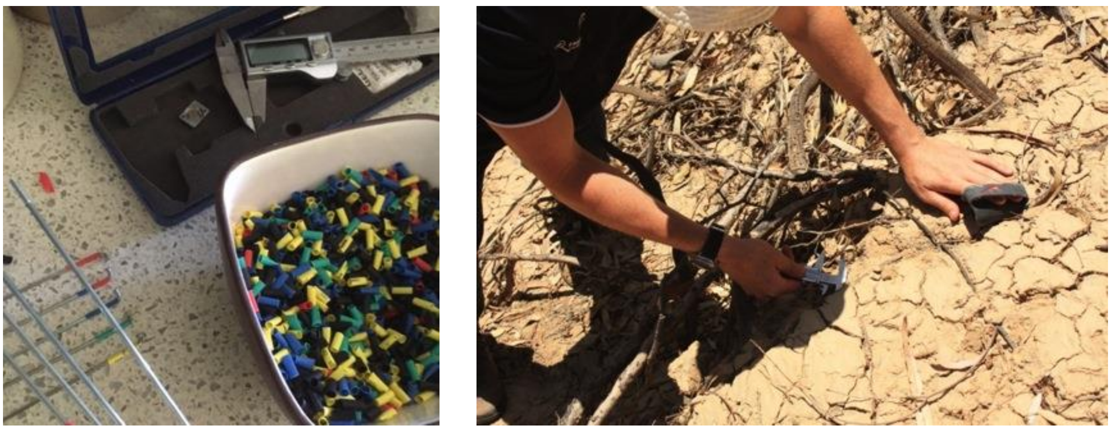


Figure B-15. (left) Colour coded erosion pins inserted at each transect to indicate location/elevation on the river bank and measured by digital callipers, and (right) field placement.

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 the end of March 2016. Further details on the erosion assessment protocol can be found in Vietz *et al*. (in-review).

B.4.2 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.

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 during each of the nine survey periods. Other flow characteristics, such as the rate of drawdown, are sometimes considered with respect to bank condition, but have not been statistically assessed for the results presented here. Details of the statistical analysis can be found in Vietz et al. (in review).

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.4.3 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-16).

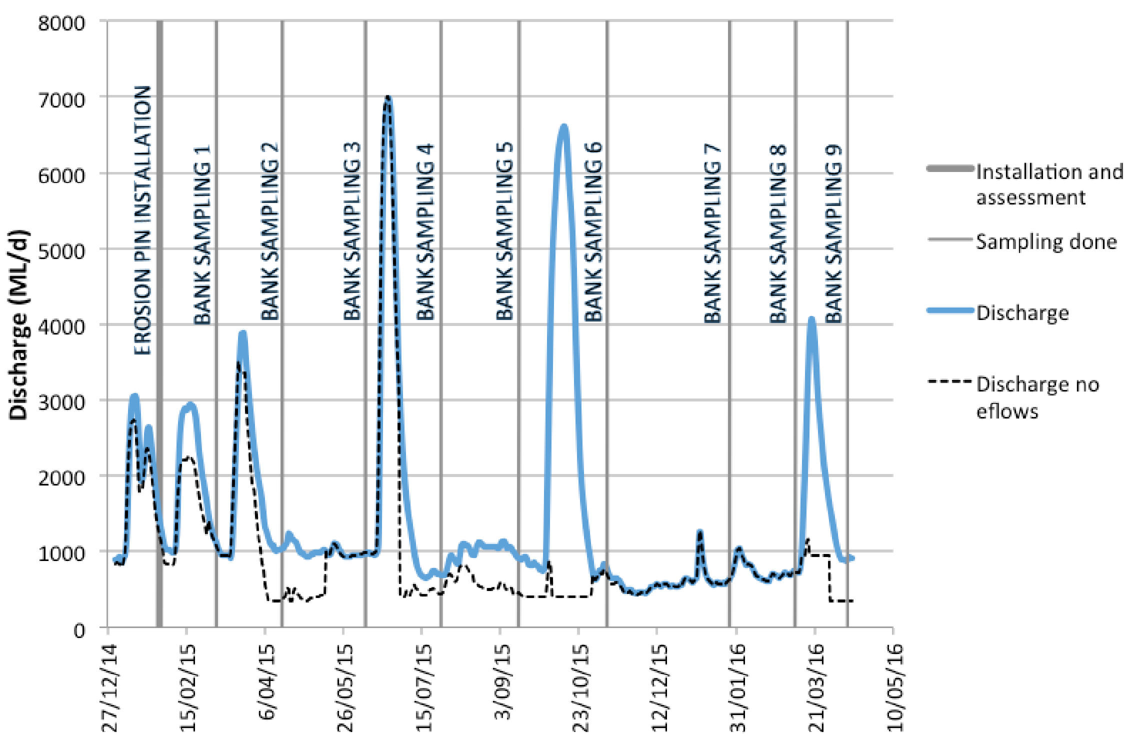


Figure B-16. Bank erosion sampling visits relative to discharge with eflows (blue) and without (purple). Data for McCoy's stream gauge.

B.4.4 Overall bank condition results

Bank erosion and deposition is highly variable both in time and space in the regulated lower Goulburn River. Measurements from a single erosion pin can often oscillate from erosion following one event to deposition following another.

Significant erosion (>30 mm) was not common, observed in less than 6 percent 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. For the three most downstream sites bank activity was more common and results were surprisingly consistent. For these sites deposition occurred approximately 25% of the time and erosion approximately 30% of the time (Table B-8).

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.

Proportion of measurements	Darcy's Track	Loch Garry	McCoy's Bridge	Yambuna
n	435	441	401	448
<0 mm (deposition)	21%	25%	29%	27%
No change	60%	43%	40%	40%
>0 mm (erosion)	19%	32%	31%	33%
>30 mm (significant erosion)	2%	6%	4%	5%

B.4.5 Changes in probability of erosion and deposition with changing flow metrics

There were positive relationships between the probability of erosion (both >0 mm and >30 mm) and the duration of inundation, although erosion also occurs in the absence of inundation, i.e. note the graph intercepts (Figure B-17). The probability of deposition was negatively related to the duration of inundation (Figure B-18).

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 (Figure B-19).

Probability of erosion >30 mm was substantially lower than probability of any erosion, and the probability rose more slowly with increasing duration of inundation (Figure B-17). Compared to the effect of inundation duration, there was no evidence of any relationship between erosion/deposition and either the peak flow during a survey period or the total volume of flow above a pin (Figure B-20).

There were weak negative relationships between the probability of erosion and maximum dry weather period, indicating that erosion is less likely the longer a bank is allowed to dry between inundation events. The probability of deposition also decreased slightly with increasing maximum dry weather period (Figure B-21). Summary statistics for all regressions are provided in Table B-9.

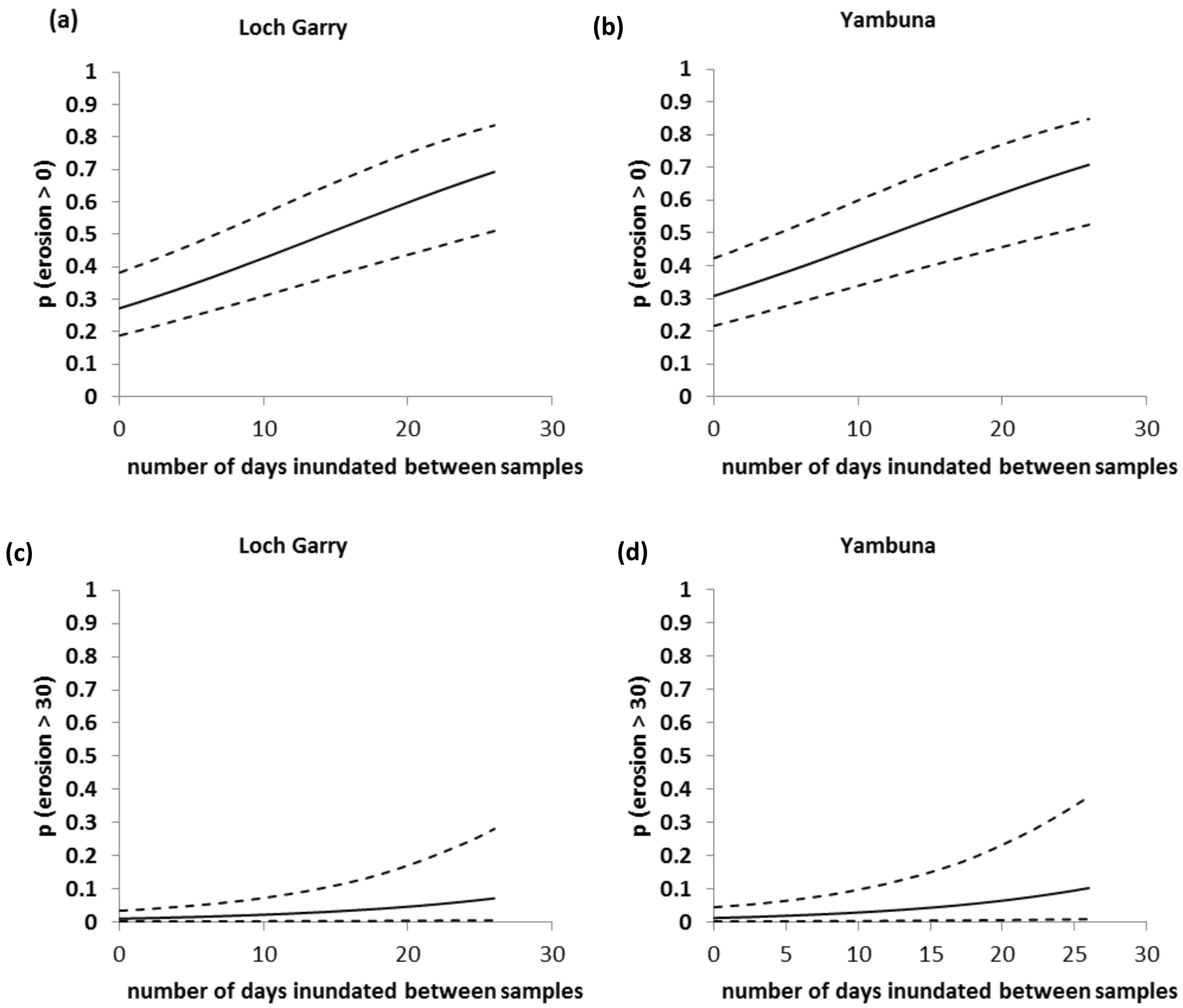


Figure B-17. Probability of erosion of > 0 mm (a, b) and > 30 mm (c, d) with increases in the duration of inundation. Results are shown for two sites, Darcy's Track (a, c) and Yambuna (b, d). The solid line is the median probability of erosion with the dotted lines encompassing the 95% credible interval for the estimate.

B.4.1 Effects of environmental flows upon probability of erosion and deposition

Positive relations between the duration of inundation and probability of erosion translate to increased probabilities of erosion under the environmental flow regime, because environmental flows lead to increased bank inundation. However, the effect is relatively small, and is restricted to those erosion pins relatively low on the bank. For pins more than approximately 2 m up the bank, there is no difference in erosion attributable to environmental flows (Figure B-22a-d). It should be noted that the increase in inundation duration due to environmental flows also increases the probability of deposition at lower elevations (Figure B-22e,f). Given the lack of relation between erosion and either peak flow or total volume, no results are presented of the effects of environmental flows on erosion/deposition based upon these variables. The removal of environmental flows from the hydrograph did less to change the maximum dry weather period experienced by pins compared to changes in the duration of inundation. Consequently changes in erosion and deposition as a function of MDWP are smaller when the environmental flows are removed from the hydrograph (Figure B-23).

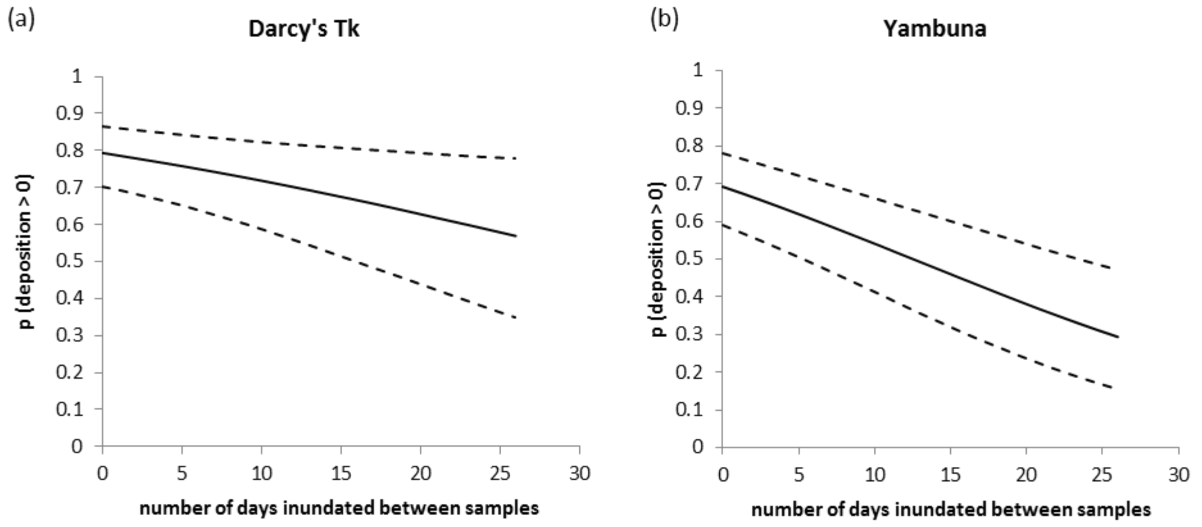


Figure B-18. Probability of deposition of > 0 mm (i.e. negative erosion) for Darcy's Track (a) and Yambuna (b) with increases in duration of inundation.

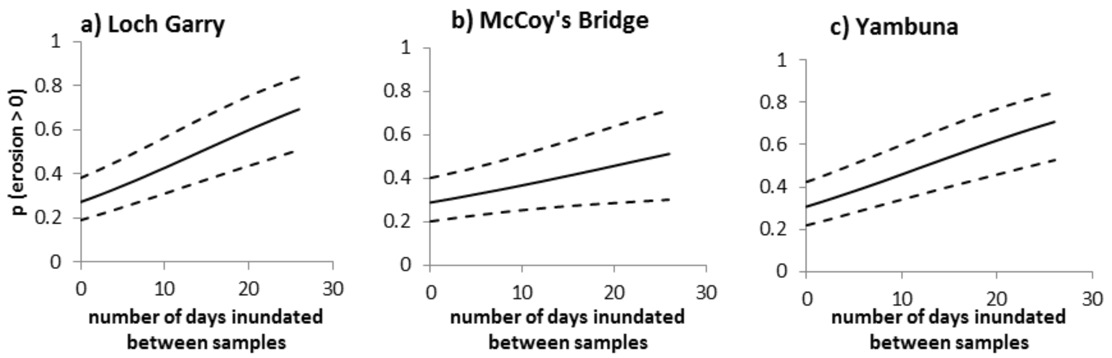


Figure B-19. Probability of erosion > 0 mm at Loch Garry (a), McCoy's Bridge (b) and Yambuna (c) with increasing duration of inundation. Results for erosion > 30 mm and deposition > 0 mm were also similar among the three sites.

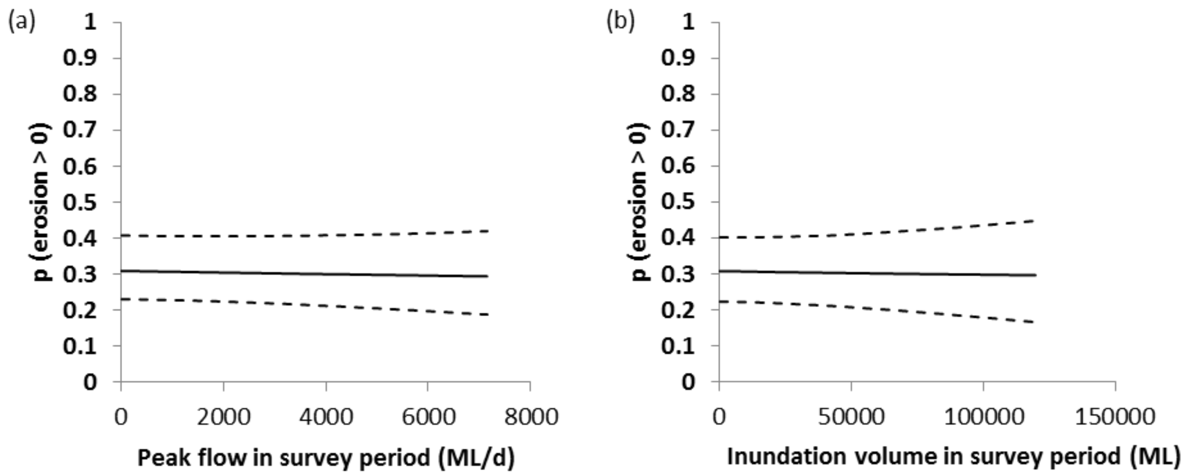


Figure B-20. Probability of erosion > 0 mm at Yambuna (the most responsive site in the study) with increasing peak flow (a) and the volume of discharge above a pin (b). Relationships were similarly lacking for erosion > 30 mm, deposition > 0 mm, and at all other sites.

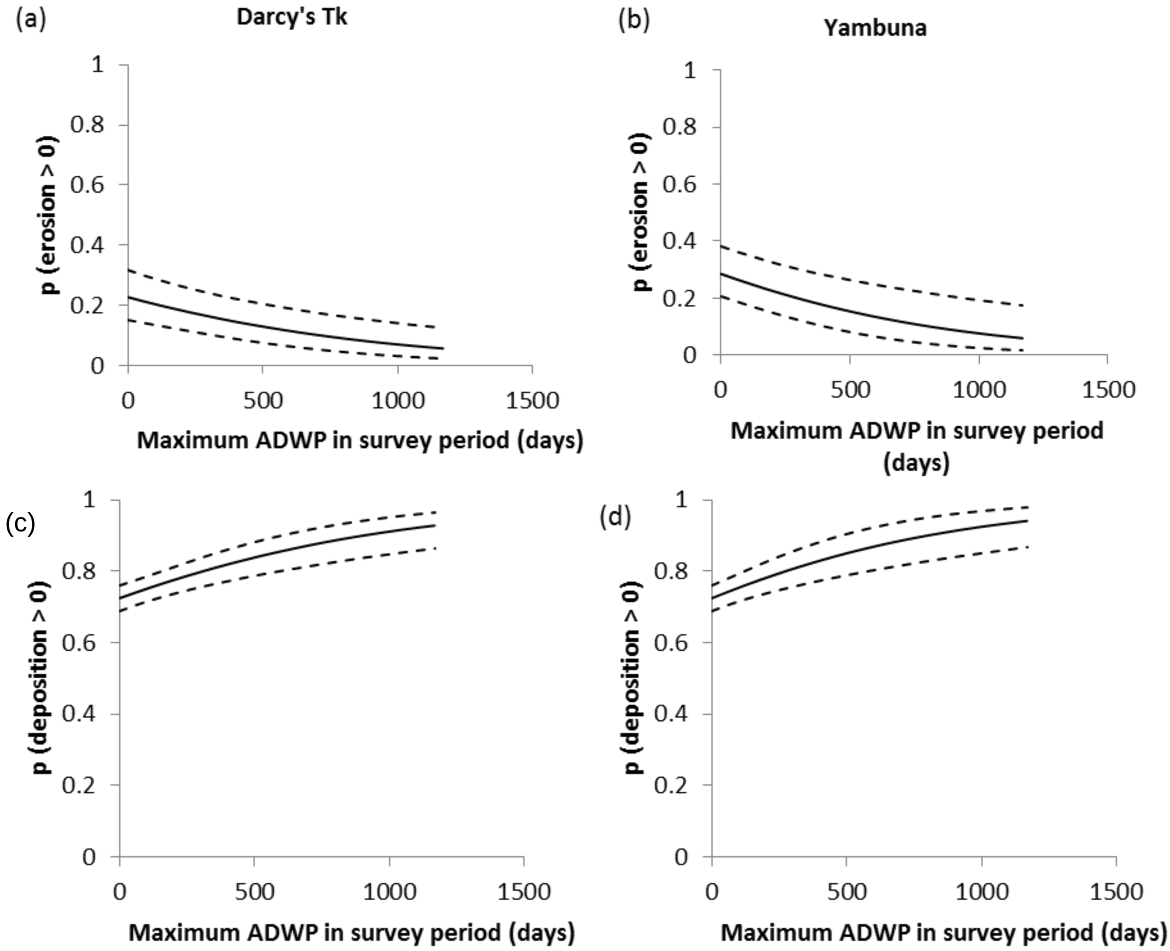


Figure B-21. Probability of erosion > 0 mm (a, b) and deposition > 0 mm (b, c) at Darcy's Track (a, c) and Yambuna (b, d) with increasing duration of maximum dry weather period (MDWP).

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)	**0.08**	**0.63**	**0.39**	**0.87**	**0.06**	**0.58**	**0.36**	**0.84**	-0.05	0.98
	Peak Flow (ML/d)	-0.27	0.19	-0.1	0.28	-0.14	0.25	-0.24	0.13	-0.27	0.30
	Inundation Volume (ML)	-0.34	0.16	-0.13	0.26	-0.11	0.27	-0.22	0.14	-0.28	0.28
	Maximum dry weather period (days)	**-0.71**	**-0.23**	**-1.89**	**-0.39**	**-0.76**	**-0.2**	**-0.89**	**-0.23**	-0.13	1.54
>30 mm	Inundation Duration (days)	-0.3	1.04	**0.26**	**1.19**	**0.4**	**1.4**	**0.34**	**1.25**	-0.02	1.40
	Peak Flow (ML/d)	-0.3	0.89	-0.42	0.49	-0.19	0.72	-0.38	0.44	-0.47	0.79
	Inundation Volume (ML)	-0.5	0.71	-0.52	0.45	-0.14	0.70	-0.29	0.48	-0.51	0.74
	Maximum dry weather period (days)	**-5.58**	**-0.83**	**-7.15**	**-1.96**	**-5.82**	**-1.58**	**-5.54**	**-1.45**	-0.15	1.55
< 0 mm	Inundation Duration (days)	**0.22**	**0.74**	-0.07	0.44	**0.4**	**0.93**	**0.18**	**0.64**	-0.17	1.03
	Peak Flow (ML/d)	-0.37	0.16	**-0.49**	**0.00**	**-0.49**	**0.01**	-0.12	0.33	-0.65	0.42
	Inundation Volume (ML)	**-1.86**	**-0.41**	-0.38	0.18	**-0.52**	**-0.01**	**-0.51**	**-0.01**	-0.64	0.40
	Maximum dry weather period (days)	**-0.55**	**-0.41**	-0.54	0.16	**-0.73**	**-0.19**	**-0.96**	**-0.26**	-0.94	0.17

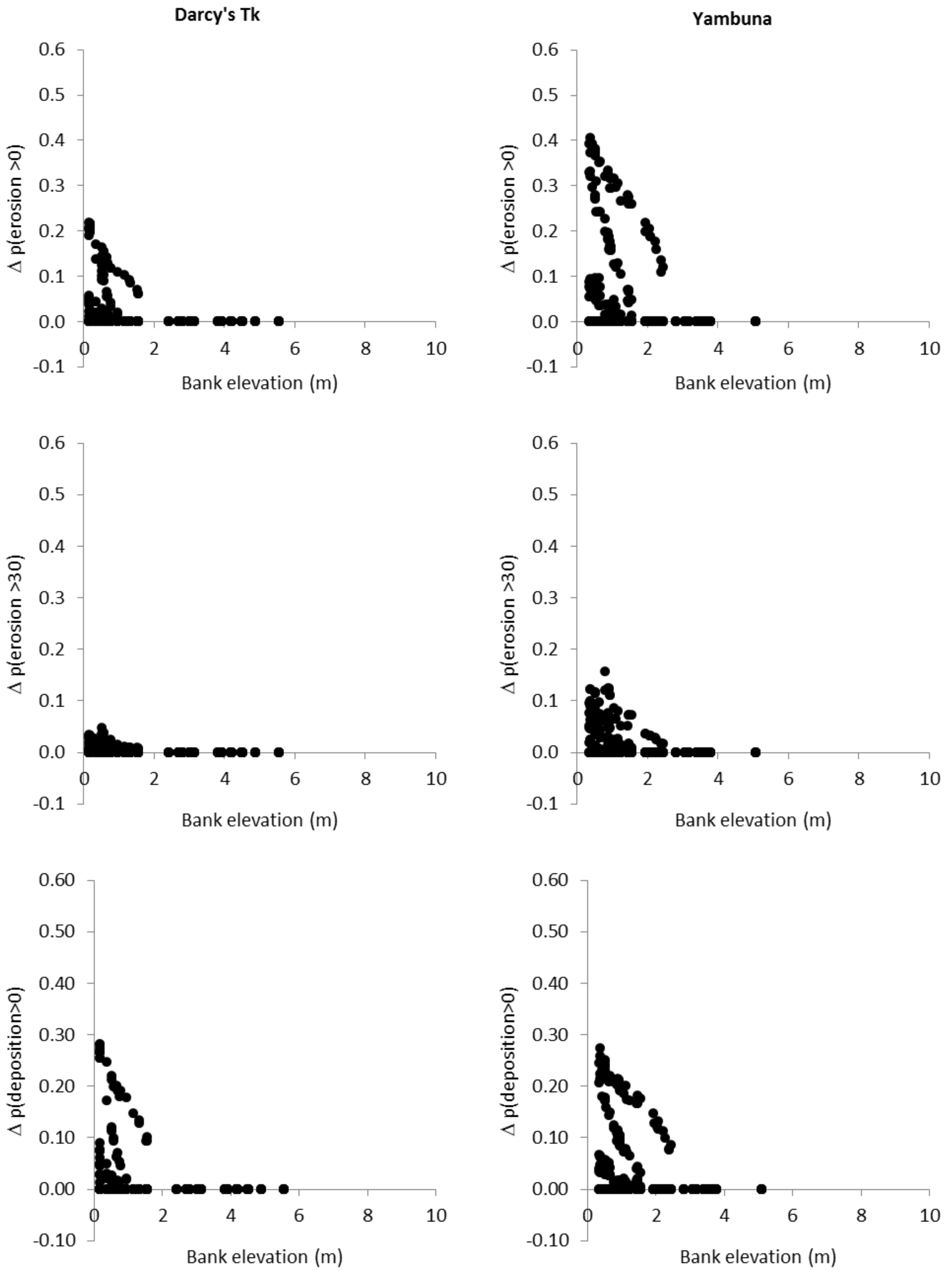


Figure B-22. Effect of the environmental flow component on the probability of erosion (erosion > 0 mm), significant erosion (erosion > 30 mm) and deposition (erosion < 0 mm), at each erosion pin, relative to bank elevation (m) for Darcy's Track and Yambuna (when bank erosion/deposition is modelled as a function of inundation duration).

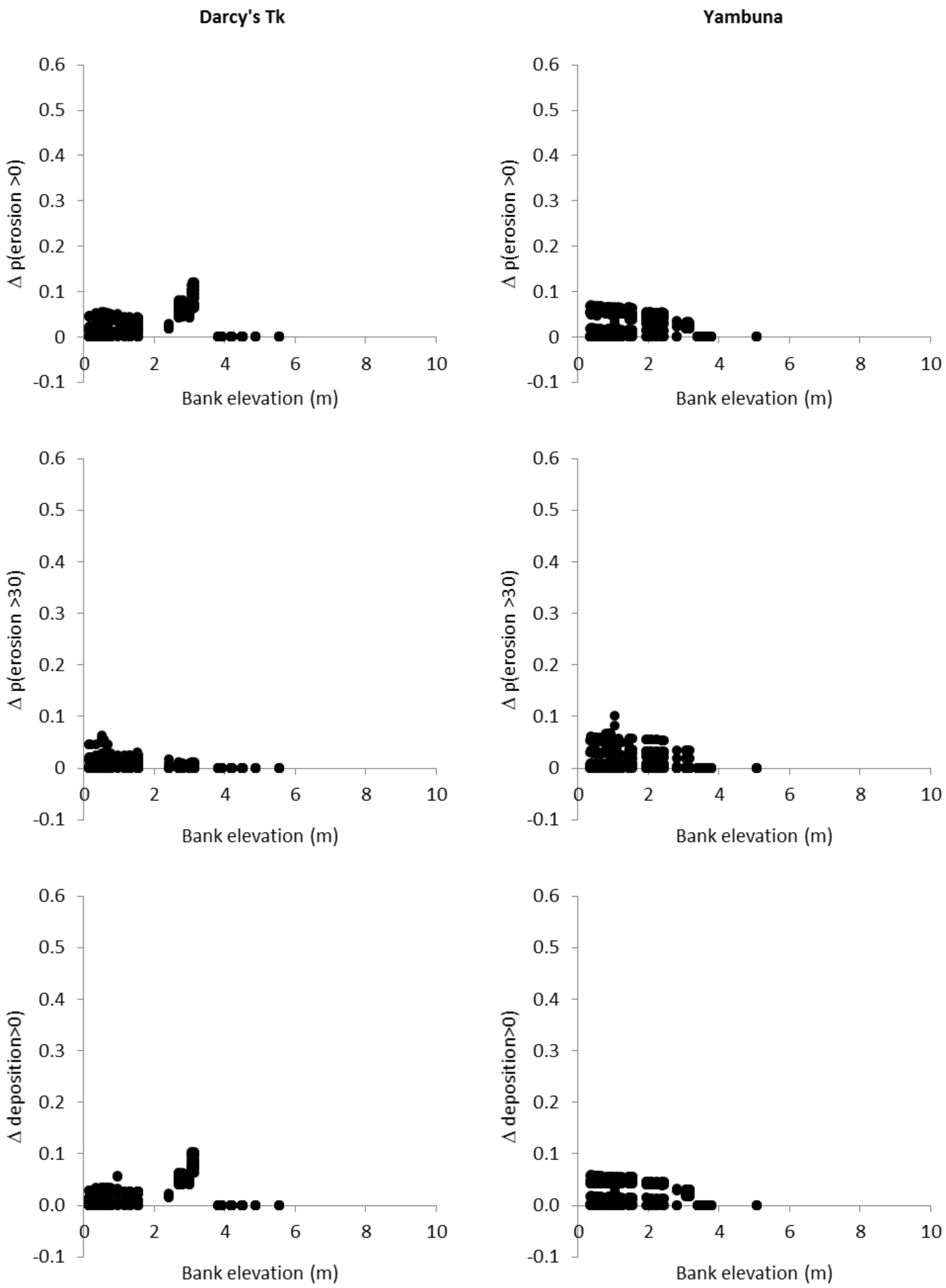


Figure B-23. Effect of the environmental flow component on the probability of erosion (erosion > 0 mm), significant erosion (erosion > 30 mm) and deposition (erosion < 0 mm), at each erosion pin, relative to bank elevation (m) for Darcy's Track and Yambuna (when bank erosion/deposition is modelled as a function of maximum dry weather period).

B.5 Discussion of bank condition results

B.5.1 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-24a-b). 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).

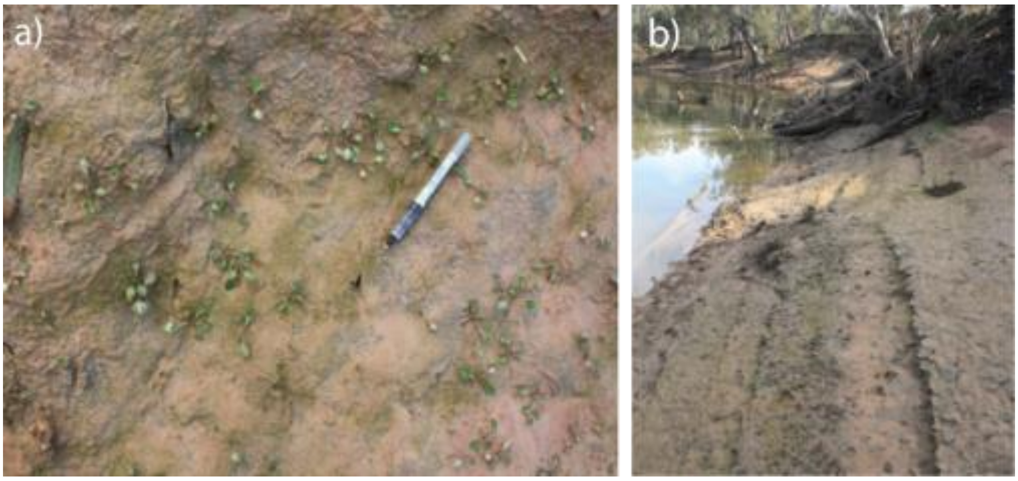


Figure B-24. a) Bank vegetation (*Aster subulatus*) regenerating following mud drapes, and b) the perception of erosion of a bank that has instead experienced deposition (mud drapes during flow recession).

B.5.2 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 could be assessed. Of the four 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 (see example for Yambuna Bridge, Figure B-25). 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 extremely 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.

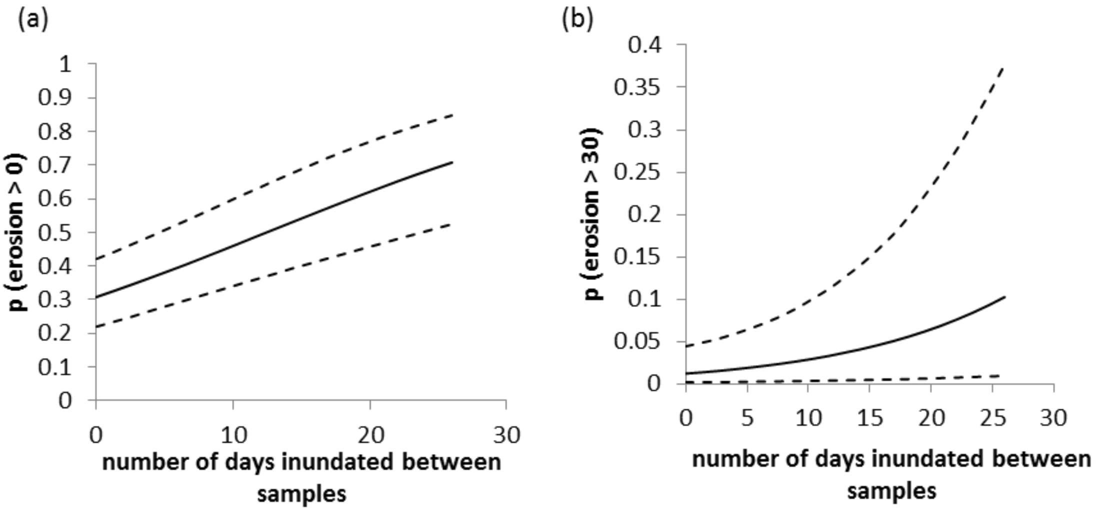


Figure B-25. Erosion relative to inundation for Yambuna Bridge, for a) erosion > 0 mm, and b) significant erosion > 30 mm.

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-26).

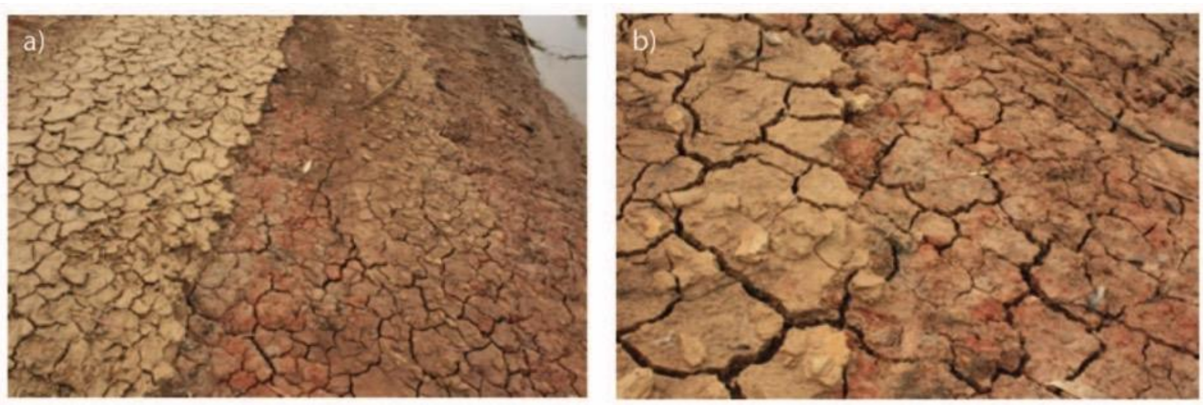


Figure B-26. a) Drying of clay-rich sediments prepares bank materials for removal during subsequent inundation, and b) note erosion pin exposed (centre picture) at the Yambuna site with 54 mm of erosion measured following the first fresh of 3000 ML/d as desiccated sediment was removed.

Considering the suspected role of bank drying and desiccation in sub-aerial preparation, it was expected that the greater the number of dry days prior to an event the greater the erosion at the next event would be. This was not the case, and the opposite relationship was found with a negative relationship between riverbank erosion and MDWP. This relationship, however, may be confounded. Firstly, MDWP is negatively correlated with inundation duration of the subsequent flow event, with a greater inundation duration corresponding to a lower value in MDWP ($\rho=0.5$, $p<0.05$). Furthermore, desiccation of bank sediments is most likely to occur during the dry weather summer period, when temperatures are highest. However, winter periods (during dam storage filling) now often experience low flow for longer periods than prior to regulation. The dry periods during winter when temperatures are low are unlikely to have a significant influence on desiccation of riverbanks.

Significant erosion (>30 mm) was most influenced by inundation duration. 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 at least 20 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.5.3 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 6 percent of measurements (a maximum at Loch Garry). Observations and photo points reveal that no mass failure erosion occurred 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-27a) 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-27b), appeared to be eroding, but experienced almost no measurable change during our survey period.

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.

There are no major issues associated with the development of the physical habitat or bank condition monitoring program. Finalising the final two visits for the bank condition monitoring was to occur in July but rain and high water levels hampered field campaigns. These will be undertaken as soon as the water levels recede and will be used to capture late winter flows. They will be finalised prior to the 2016/17 irrigation season.

Further hydrologic analysis will investigate a range of flow characteristics, including the rate of recession. These will also be related to bank condition and erosion and deposition mechanisms.

Figure B-27. (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.

B.5.4 Adaptive management of river bank erosion

Flow management has been modified through collaboration with researchers during the two 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 2014-15 and 2015-16, water delivery officers regularly sought advice from the Goulburn River LTIM geomorphologist regarding the design of elevated flows aimed at re-establishing native vegetation on the river banks. As a direct result of these consultations, the rates of recession were decreased based on hydrologic data for natural flows in an informed effort to minimise the contribution to any potential degradation on riverbanks. Further monitoring of altered flow events suggested low rates of erosion, providing confidence for continued operations. 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. These observations instead supported winter environmental flow deliveries for this purpose. Furthermore, observations of bank notching, associated with the water surface level of delivered freshes, suggested 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 2014-16 indicated that environmental flow deliveries can proceed with confidence on the Goulburn River, as to date results suggest 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.6 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 results will be developed further to specifically target fish, 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 four inundation metrics assessed here, there is a range of flow characteristics that could be included in assessments, such as quantifying the rate of drawdown and 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. 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.

There are no recommendations for changes to current management. Interim recommendations for upcoming environmental flow management supports the current management approaches including:

- Maintain variability in discharges and water levels to increase opportunities for recruitment, transport and deposition of seeds and plant propagules, maintain bank wetting at varying levels on the bank, and avoid bank ‘notching’ (these are hypotheses still to be tested);

- Maintain high discharges (flow freshes) to encourage vegetation establishment on the bank to reduce the potential for desiccation (drying and cracking) of bank sediments;

- Maintain current rates of flow recession to avoid bank surcharging and erosion, and allow mud drapes to develop (no major erosion events e.g. slumping have been observed from recent environmental flow management); and

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.

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 food webs. The relationships between these processes are shown in Figure C-1.

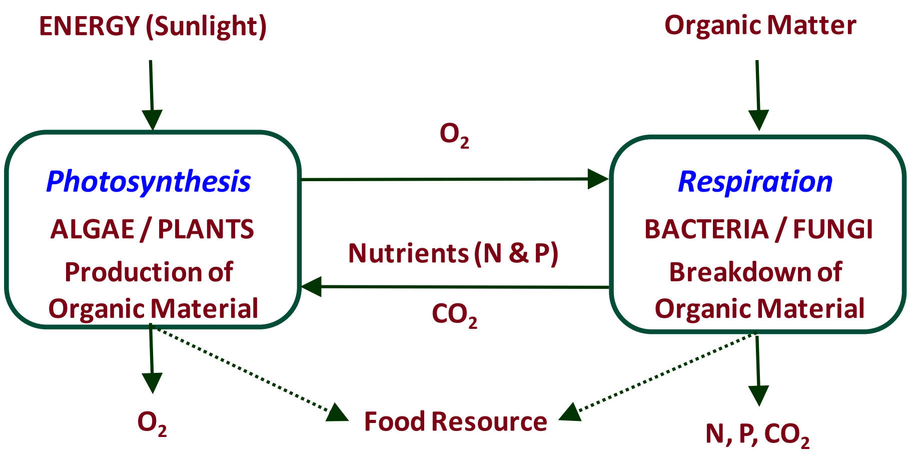


Figure C-1. Relationships between photosynthesis, respiration, organic matter, dissolved gases and nutrients.

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 0.2-20 mg O_2/L/Day with most measurements falling between 0.5-10 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 DO swings from day to night. 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 nutrient concentrations. Habitat availability, climate and many other factors also influence food web structure and function. Uehlinger (2000) demonstrated that freshes with sufficient stream power to cause scouring can 'reset' primary production to very low rates which are then maintained until biomass of primary producers is re-established.

C.2 Methods

The stream metabolism and water quality measurements were performed in accordance with the LTIM Project Standard Operating Procedure (SOP) (Webb et al. 2014).

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). Light (PAR) loggers were also deployed in open fields at Shepparton and Nagambie (Tahbilk); these data were downloaded approximately every three months. The data collected by the DO loggers was also used to calculate daily average temperature (Figure C-2 upper) and dissolved oxygen concentrations (Figure C-2 lower) for each of the sites from August 2015 to mid-April 2016.

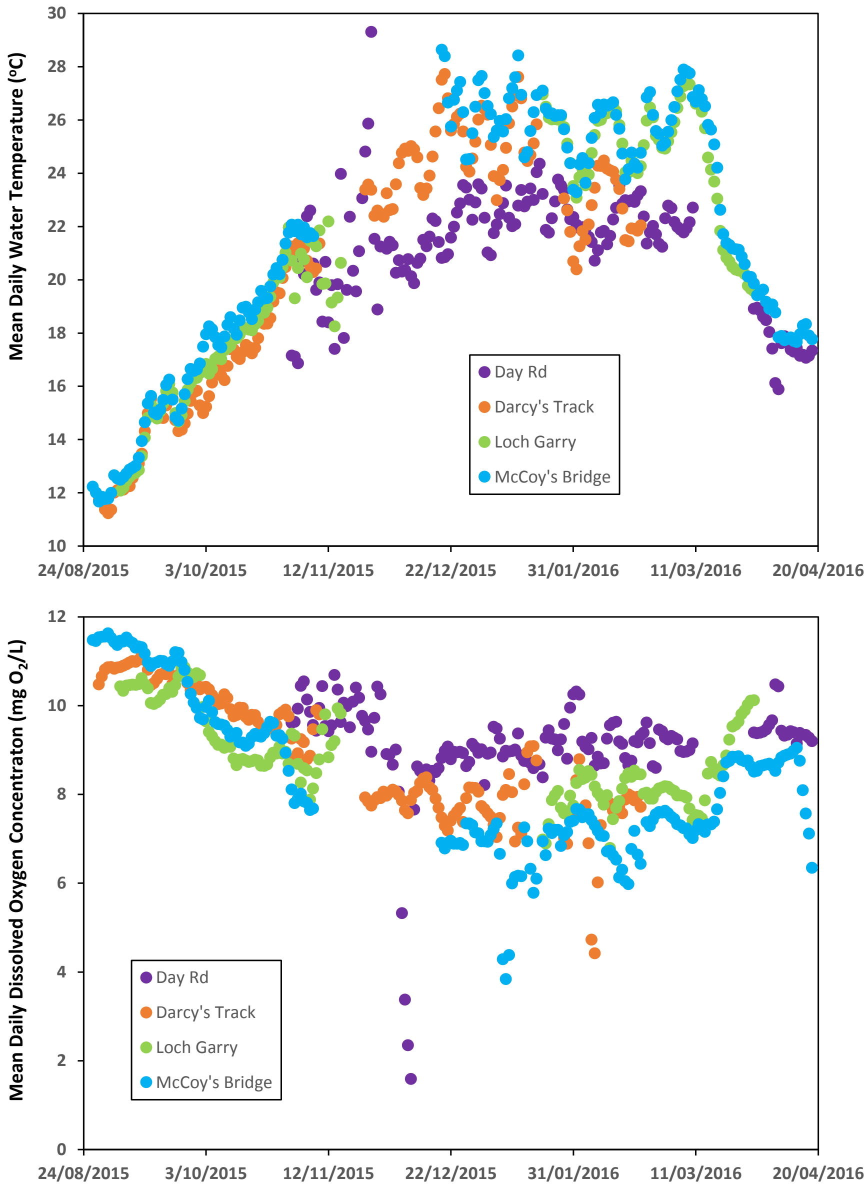


Figure C-2. Mean Daily Water Temperature (upper) and Dissolved Oxygen Concentration (lower) for the four study sites from August 2015 to April 2016.

1 The site at Day's Rd was chosen 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 (meeting acceptance criteria) was obtained.

In accord with the LTIM Project Standard Protocol (Webb et al. 2014), 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))

Acceptance criteria for inclusion of daily results from the BASEv2 model (Song et al. 2016) in the data analysis presented here were established at the July 2015 LTIM Workshop in Sydney. These criteria were that the fitted model for a day must have both an r^2 value of at least 0.90 *and* a coefficient of variation for the GPP parameter of < 50%.These criteria might be modified in the future due to the relatively small acceptance rate in 2015-16 for this selected area, but also based on even lower acceptance rates in other selected areas. Nevertheless, these criteria are still in place for this Year 2 data. It was however noted that for a few specific days, an additional criterion of CV for ER and for K of < 50% also needed to be implemented otherwise some very strange (and physically nonsensical) values were obtained. This matter will be raised with all other LTIM Stream Metabolism teams and be a matter for discussion in 2017.

C.2.1 Statistical Modelling

Relationships between discharge and gross primary production (GPP), ecosystem respiration (ER) and net primary production (GPP – ER = NPP) 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.

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

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

Metabolism (Gross Primary Productivity, Ecosystem Respiration or Net Primary Productivity, represented by *y*) on day *i* and at site *j* is 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 because of poor fit to the expected value from the BASEv2 model. 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 discharge 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 10 days. The optimal lag was determined as the lag at which the minimum Deviance Information Criterion value occurs. Future work will extend this lag time out to 20 days.

Also assessed was the effect of mean velocity (m/s), and inundated cross sectional area (m^2) on stream metabolism by modelling stream metabolism as a linear function of the log of mean velocity (or inundated cross sectional area) and temperature.

C.3 Results

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 LTIM Project annual forum in Sydney in July 2016, it was decided that an updated version of the BASE model (BASEv2) would be used for analysing the 2015-16 metabolism data. This change was a result of the paper published by Song et al. (2016) which showed that our BASE model could be improved by changing from stepwise progression and fitting using each data point to integrated (whole data set) fitting and progression using modelled data. The periods of data logger deployments are listed in Table C-1 along with the number of days' data that meet the extended acceptance criteria ($r^2 > 0.90$, coefficient of variation for all of GPP, ER and K < 50%) using both the original BASE model and with BASEv2.

There are two key features demonstrated in Table C-1. The first is that the number of compliant days using BASEv2 in 2015-16 was generally much lower than the percentage of compliant days in 2014-15. For the three sites used in both years, the compliance rates for Darcy's Track dropped from 72% to 28%, Loch Garry declined to 33% from 38% in 2014-15 and McCoy's Bridge fell from 66% to 48%. It might be concluded that this is due to the change in model from BASE in 2014-15 to BASEv2 in 2015-16. However, the second key point is that the same data for all four sites in 2015-16 was rerun with the original BASE model and the rejection rates were extremely high. The number of compliant days ranged from a low of 3% at Loch Garry to a still extremely low value of 9% for McCoy's Bridge. Hence it is *not* the change in model that caused the fall in model acceptance rates in 2015-16. The origin of the extremely low acceptance rates using BASE in 2015-16 was the extremely large uncertainties (often well in excess of 50% coefficient of variation) for the correlated variables ER and K. BASEv2 was far superior in reducing the uncertainty surrounding these parameter estimates and hence produced a far higher number of days that met the acceptance criteria.

Table C-1. DO Logger Deployment and Data Acceptance Information, 2015-16.

Site	First Date	Last Date	Number of Days with data	Compliant Days using BASEv2	% of total days in compliance	Compliant Days using BASE	% of total days in compliance	% of total days in compliance, 2014-15 (BASE)
Day Rd	24/10/15	18/4/16	143	39	27	8	5	n/a
Darcy's Track	29/8/15	22/2/16	155	43	28	10	6	72
Loch Garry	5/9/15	30/3/16	141	47	33	4	3	38
McCoy's Bridge	27/8/15	18/4/16	193	92	48	18	9	66

An important question arising from Table C-1 is 'Why was the acceptance rate much lower in 2015-16 than for the previous year at McCoy's Bridge and especially Darcy's Track?' To investigate this matter, all of the 2014-15 data were rerun using BASEv2. Compliance rates were even higher than when using BASE (BASEv2 yielded acceptance % values of 77% for Darcy's Track, 39% for Loch Garry and 73% for McCoy's Bridge). These facts clearly rule out the change in model as the cause of the decreased acceptance rates in 2015-16. BASEv2 clearly is a superior model on the basis of generating parameter estimates that meet the existing acceptance criteria. This leaves the most likely scenario being that the diel curves were simply less amenable to precise modelling (using BASEv2 or BASE) in 2015-16. Many more days' data had r^2 values < 0.90. The origins of this less satisfactory fitting to the fundamental stream metabolism model will remain a matter for ongoing investigation into 2017.

In addition to missing data days due to regular maintenance, some severe problems were experienced with some of the loggers. Most notably, the logger at Darcy's Track had to be returned to ZebraTech in New Zealand for a major service and repair. Another logger had to be replaced around the same time and there was only one spare logger. Hence no data were recorded at Darcy's Track from late February 2016 onwards. This matter clearly warrants close attention over future years. Data were also lost when loggers could not be retrieved due to high water levels. Logger memory is overwritten when capacity is exceeded.

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 DO 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. It is also pertinent to note that these higher temperatures persisted through to mid-March (and have been identified as a probable cause of the major blue-green algal bloom that occurred in the Edward-Wakool system in autumn 2016). 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 an underflow weir hence bottom water is released from the Nagambie Lakes which will be cooler than the surface water, especially during daytime in summer when solar irradiance (and hence epilimnetic heating) is at a maximum. This temperature difference between Day Rd and the sites further downstream can be several degrees. This temperature differential is partially restored by Darcy's Track but does emphasise 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.

Of much greater significance are the periods of low to very low average dissolved oxygen concentrations at several sites. Most notably, the mean daily DO was as low as 1.6 mg O_2/L on December 2nd 2015 at the Day Rd site (and was just 2.35 mg O_2/L the preceding day). It recovered to over 7.6 mg O_2/L the following day. The origin of this very low DO event remains unclear as unfortunately the Victorian Surface Water Monitoring Partnership DO logger at the Goulburn Weir outlet was out of commission over this period. It is highly likely the low DO originated in either the Weir or further upstream. Dissolved oxygen concentrations of less than 4 mg O_2/L can be deleterious to aquatic ecosystem health, hence the origin needs to be identified. There was no significant flow event in the weeks leading up to this short (3 day) period of very low DO. Other short periods of DO drops were seen at McCoy's Bridge (twice) and once at Darcy's Track.

It is possible that the decline in DO at McCoy's Bridge from the 7th to the 10th of January (minimum mean daily DO was 3.84 mg O_2/L on the 9th January) was associated with the concurrent small flow event passing through that site at this time (these flows are shown in the following sub-section).

Reasonable estimation of water travel times between the sites (to be done during 2016-17) will allow determination of whether some of these events are independent or simply the same parcel of low DO water travelling downstream.

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.

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 caused by a relatively few much higher values. The median GPP values from all four sites fall within a very narrow range of 1.10 (Day Rd) to 2.10 (Loch Garry) mg O_2/L/Day. The range of median ER values is equally small, varying from 1.76 mg O_2/L/Day at McCoy's Bridge up to 2.76 mg O_2/L/Day at Darcy's Track. 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 different sites. For example, missing a month of data during February would most likely cause a decrease in median GPP.

Table C-2. Summary of primary production (GPP) and ecosystem respiration (ER) rates, P/R ratios and reaeration coefficients for the four study sites, August 2015 – April 2016.

Parameter	Day Rd (n = 39)			Darcy's Track (n = 43)		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	1.10	0.89	12.3	1.41	0.26	6.40
ER (mg O_2/L/Day)	2.08	0.34	4.86	2.76	0.03	9.46
P / R	0.93	0.37	6.74	0.70	0.40	8.97
K (/Day)	3.38	1.14	24.2	2.08	0.22	7.24
Parameter	**Loch Garry (n = 47)**			**McCoy's Bridge (n = 92)**		
	Median	Min	Max	Median	Min	Max
GPP (mg O_2/L/Day)	2.10	0.67	5.32	1.67	0.56	5.97
ER (mg O_2/L/Day)	2.38	0.23	6.83	1.76	0.12	17.6
P / R	0.90	0.33	8.56	0.68	0.33	12.6
K (/Day)	1.87	0.09	9.09	1.97	0.27	10.8

Figure C-3 to Figure C-6 display the daily rates of GPP, ER and then P/R ratio at all 4 sites. The daily discharge 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. A ratio of > 1, indicates that more oxygen (and hence organic carbon) is being produced than is being consumed. As GPP can vary significantly depending on the daily weather conditions, looking at this ratio over only a short period can give misleading results.

The P/R ratios (medians 0.68 to 0.93) indicate that there is a relatively close balance between gross primary production and ecosystem respiration. Such a relationship occurs in the absence of both large sources of allochthonous organic matter (which can drive very high respiration rates) and of significant nutrient limitation which may constrain primary production (as discussed below). 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. It appears from these figures that flow events can dramatically change P/R ratios. The highest values at the Darcy's Track site are associated with the large flow event in October 2015 although these affects are actually misleading. The flow event suppressed ER rates to extremely low levels (dilution effects) hence even the low GPP at the time resulted in a high P/R ratio.

The onset of a large flow event does seem to depress metabolic rates, presumably due simply to dilution with large amounts of incoming water. This is exemplified in the March 2016 flow event at Loch Garry (Figure C-4a), where ER in particular is reduced as stream discharge increases substantially. The relationship between discharge and metabolic parameters is picked up several times later in this section of the report.

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.

It is interesting to compare the metabolic data for 2015-16 with data from the previous year. Note that all data presented in Table C-3 below has been calculated using the BASEv2 model, and with the 2015-16 acceptance criteria, and hence comparison is not confounded by use of different models.

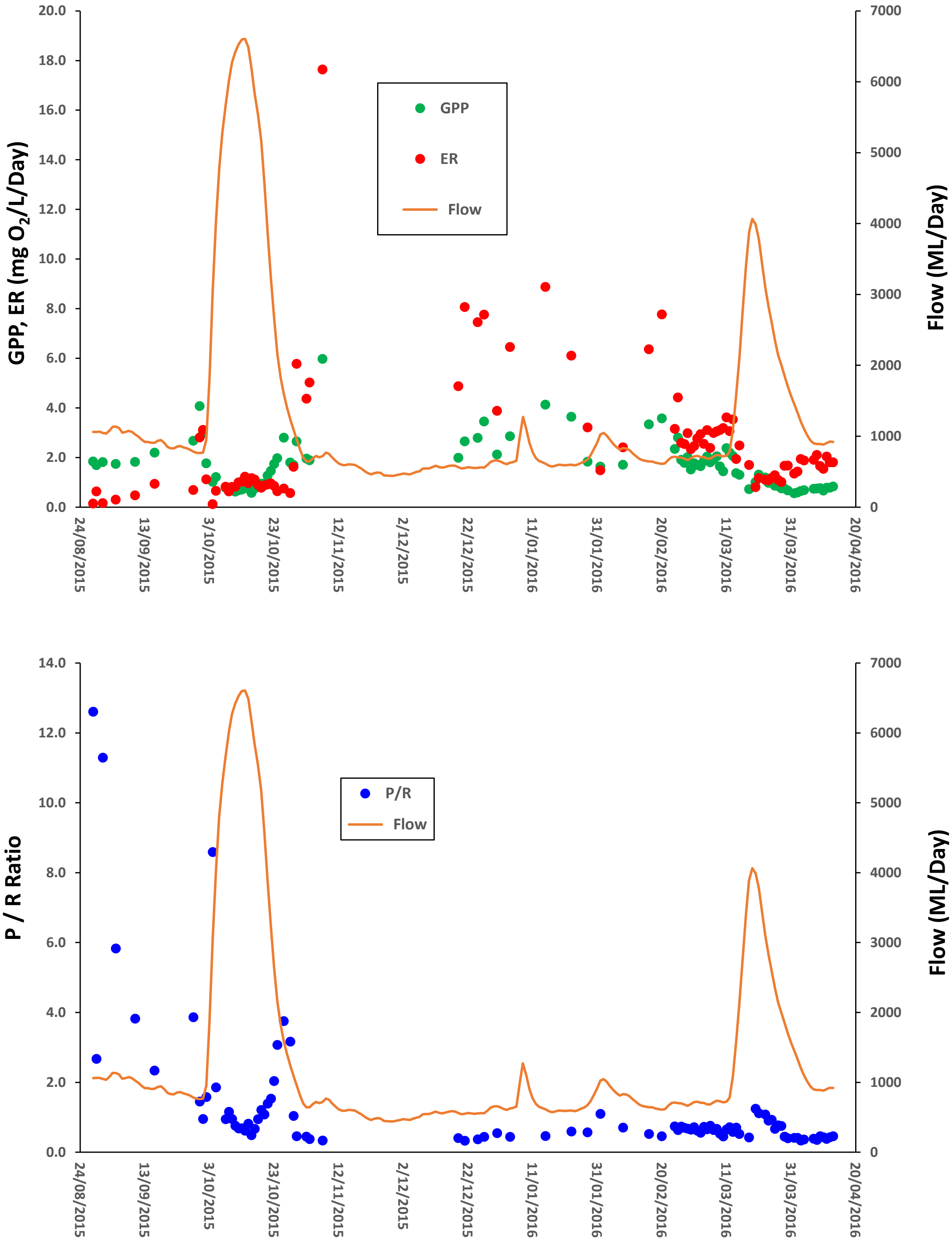
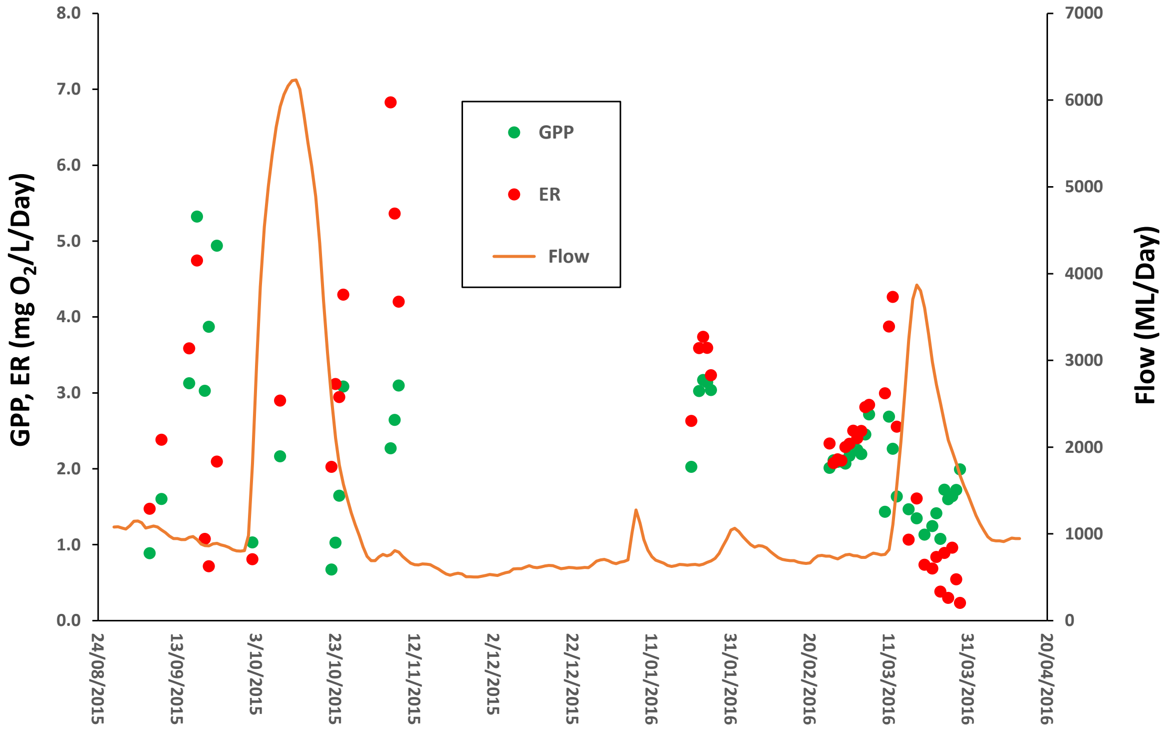


Figure C-3. Stream Metabolism-Flow Relationships for McCoy's Bridge (Zone 2) from August 2015 to April 2016: a) Gross Primary Production and Ecosystem Respiration; b) P / R ratio.



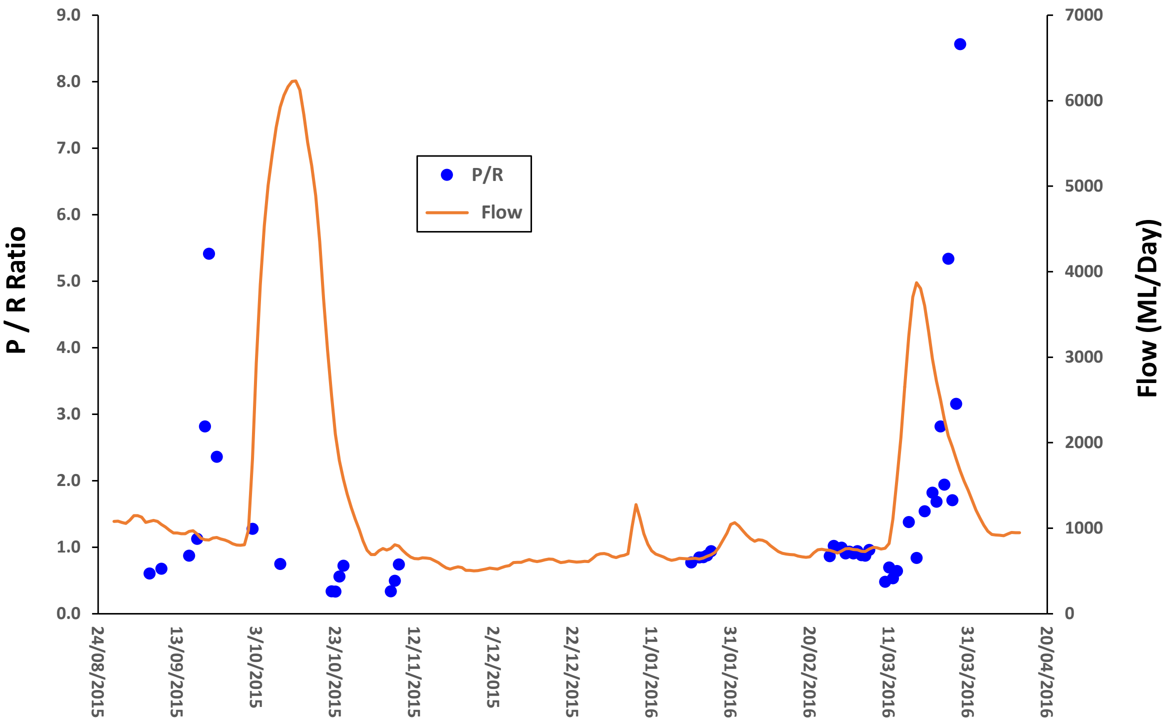


Figure C-4. Stream Metabolism-Flow Relationships for Loch Garry (Zone 2) from August 2015 to April 2016: a) Gross Primary Production and Ecosystem Respiration; b) P / R ratio.

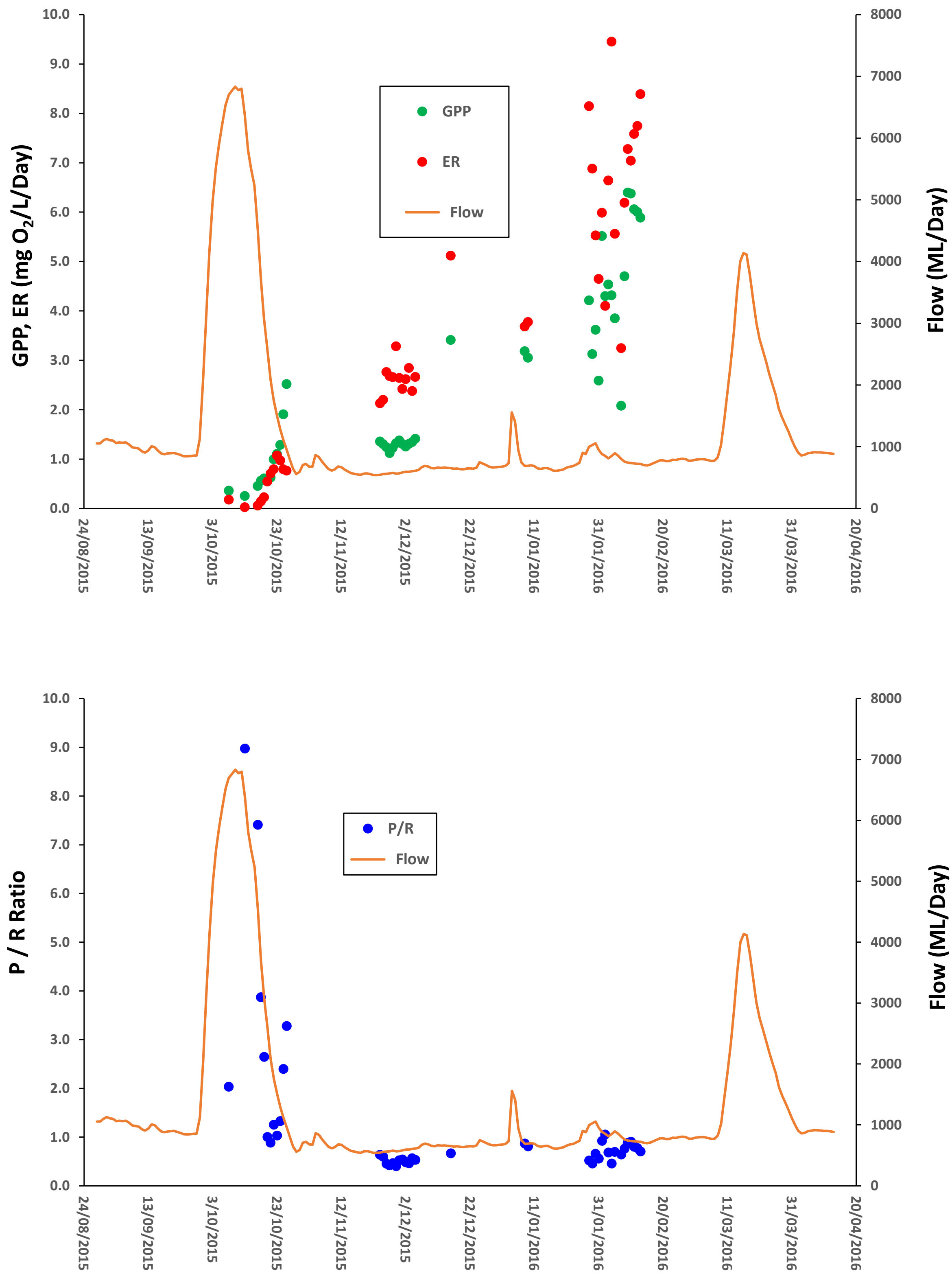
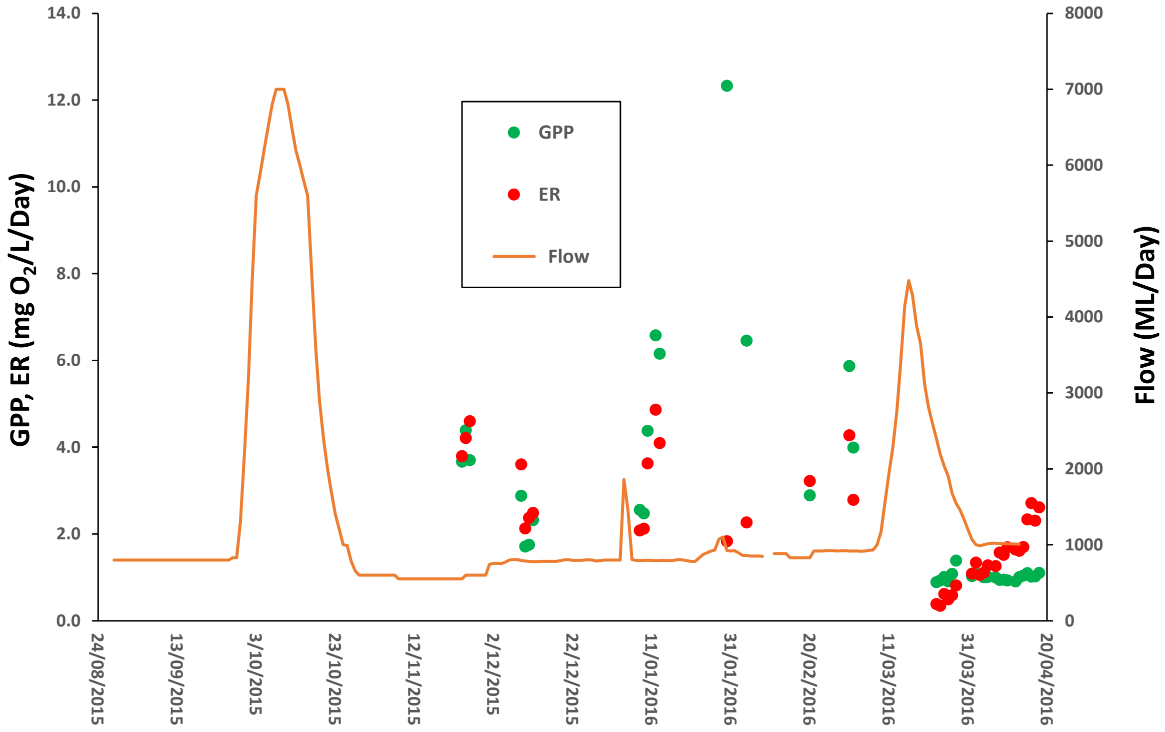


Figure C-5. Stream Metabolism-Flow Relationships for Darcy's Track (Zone 1) from August 2015 to April 2016: a) Gross Primary Production and Ecosystem Respiration; b) P / R ratio.



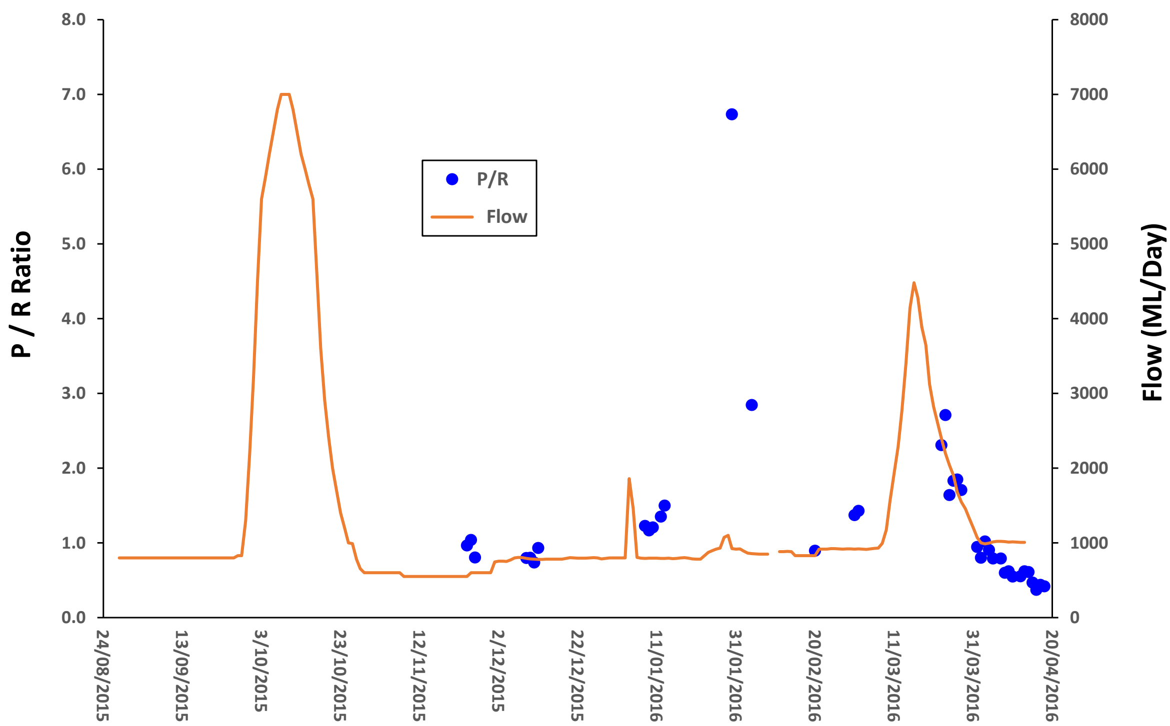


Figure C-6. Stream Metabolism-Flow Relationships for Day Rd (Zone 1) from August 2015 to April 2016: a) Gross Primary Production and Ecosystem Respiration; b) P / R ratio.

Table C-3. Comparison across the two years of 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	
Year	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
n	109	43	52	47	193	92
GPP (mg O_2/L/Day)	1.53	1.41	1.36	2.10	1.39	1.67
ER (mg O_2/L/Day)	1.34	2.76	1.24	2.78	1.03	1.76
P/R	1.00	0.70	1.07	0.90	1.15	0.68
K (/Day)	1.45	2.08	2.11	1.87	3.02	1.97

Apart from noting again the very large decrease in amount of data available for analysis in 2015-16, the most salient feature of this table is that in most, but not all, cases, rates are slightly lower in 2015-16. However, given that these differences in median rates are typically less than 2 mg O_2/L/Day, and are all again at the low end of the 'world' range, no major ecological significance is attached to these differences. More confidence could be given to the changes between years if there were more data available for the 2015-16 data set. Missing blocks of a month or more, especially during warmer months, will almost certainly lead to lower median rates for the rest of the deployment period. Further insights should be obtained when a third year's data become available later in 2017 although at the time of writing much data has already been missed due to the extended period of extremely high water levels in the Goulburn River that preclude access to, or installation of, the data loggers.

Linear regression was preformed to examine whether there was any significant relationships between stream flow and the rates of Gross Primary Production or Ecosystem Respiration. The results of this regression are presented in Table C-4.

Table C-4. Exploration of Linear Relationships between the metabolic parameters (GPP and ER) and Stream Flow for the four study sites, Aug 2015 - Apr 2016. Statistical significance was inferred at $p < 0.05$.

Site		GPP vs Flow	ER vs Flow
Loch Garry	r^2	0.15	0.43
	p	0.007	< 0.001
	slope	- 0.00019	- 0.00049
McCoy's Bridge	r^2	0.30	0.19
	p	< 0.001	< 0.001
	slope	0.00025	0.00058
Darcy's Track	r^2	0.53	0.38
	p	< 0.001	< 0.001
	slope	0.00071	0.00017
Day Rd	r^2	0.06	0.003
	p	0.13	0.72
	slope	-	-

The regression results presented in Table C-4, demonstrate no clear and consistent relationship between discharge and either GPP or ER. Two sites, Darcy's Track and McCoy's Bridge' showed positive relationships whilst the river site between these two at Loch Garry, demonstrated a negative relationship. There was no significant relationship found at Day Rd. In all cases, the slopes of any relationships were very small. In all cases, the relationships found were driven by a handful of points at higher flows. There was insufficient data at flows much above base flow level to draw any ecological significance to these findings. These regressions are highly exploratory. The p-values created would not be valid because of the lack of independence among daily data points. Nevertheless, they provide a starting point for more detailed modelling of flow-metabolism relationships presented below.

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 product of the metabolic rate in mg O_2/L/Day multiplied by the discharge 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-5 summarises the GPP and ER loads for each of the sites. The table shows that although the rates of oxygen consumption were higher in Zone 2 (Loch Garry and McCoy's Bridge) than at the two more upstream sites, these differences were 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 at this stage.

Table C-5. Mean Daily Oxygen Production and Consumption Data for the 4 sites within the Goulburn River from August 2015 until April 2016.

Zone & Site	n	O_2 Production (Tonnes)	sd	O_2 Consumption (Tonnes)	sd
McCoy's Bridge, Zone 2	92	2.3 (1.9)	1.4	3.0 (2.4)	2.0
Loch Garry, Zone 2	47	2.8 (2.1)	1.9	3.0 (2.1)	2.6
Darcy's Track, Zone 1	43	2.3 (2.1)	1.4	2.9 (1.6)	2.2
Day Rd, Zone 1	39	2.2 (1.7)	2.0	1.9 (1.7)	0.8

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-7. This site was chosen as it has the most data available.

Figure C-7 illustrates that the highest amounts of oxygen production and consumption occur when discharge is just above base flow levels (around 1000 ML/Day). The majority of these high oxygen production rates occurred during September 2015 on the falling hydrograph after the peak flow at the start of that month. This result is quite unusual given that the highest rates of primary production are expected during summer time (as shown in Figure C-3 to Figure C-6). The load-flow patterns at the other sites are not as clear and typically do not appear to show a strong relationship between these parameters. The relationships between discharge and metabolism loads are explored formally in the statistical analysis below.

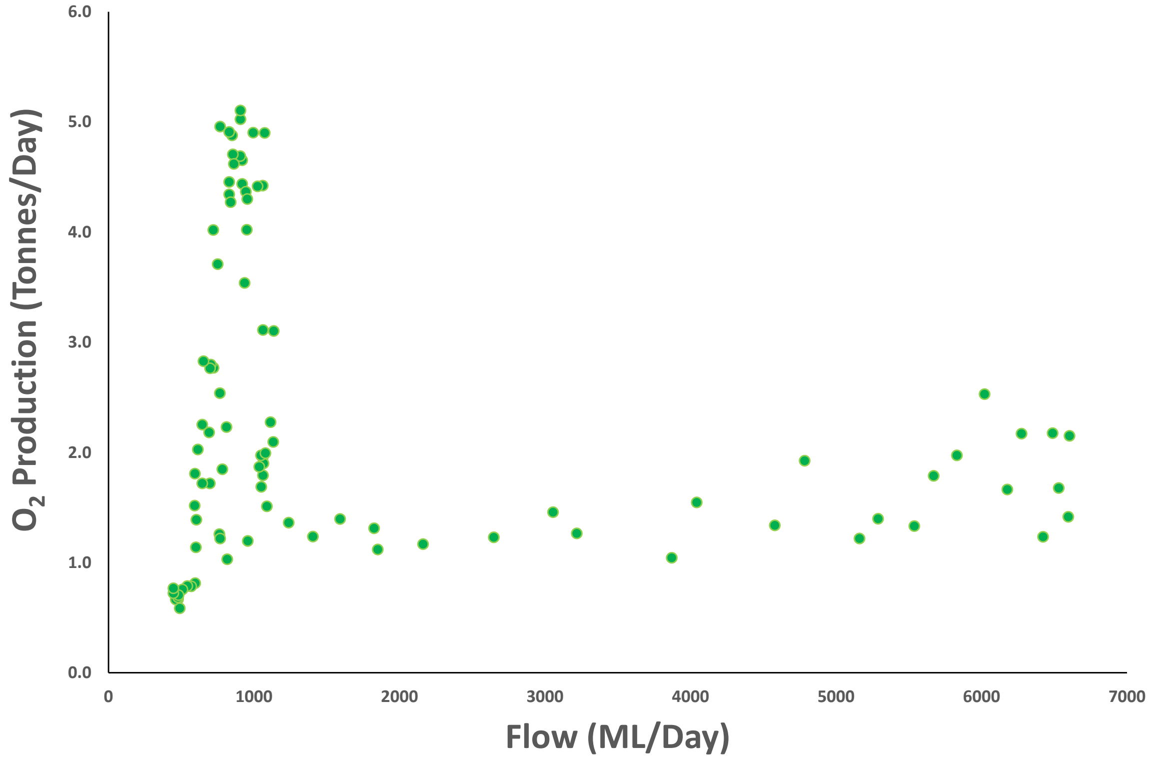
This raises the issue of concentration versus load. A concentration is important to biota in the immediate vicinity (utilising that oxygen). Two loads that are the same but one with a 10 mg O_2/L concentration and a discharge of 1000 ML/Day will provide a healthy environment for a fish (ignoring other factors affecting fish health) yet the same load constituted of 1 mg O_2/L DO and 10,000 ML/ Day discharge 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.

Close attention will be given to results from following years to see whether the results shown in Figure C-7 were a 'one-off' largely driven by the September 2015 event or are a common occurrence whose origin requires much further investigation.

C.3.4 Investigating the Basal Drivers for Metabolism

As noted in the 2014-15 Goulburn River LTIM Project evaluation report (Webb et al. 2016), 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-6.

As expected, both GPP and ER daily rates were positively correlated with mean daily water temperature (Table C-6), with the exception of GPP and ER at Loch Garry where no statistically significant relationship was found (this was also the case in 2014-15). There was a large degree of variability (scatter) in these regression plots (an example is shown below for Darcy's Track GPP vs Average Daily Water Temperature as Figure C-8), partially due to the effects of discharge and light (for GPP). GPP was positively correlated with light at each site, although only two of these relationships (Day Rd and McCoy's Bridge) were statistically significant as the plots again showed a very large scatter. 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.



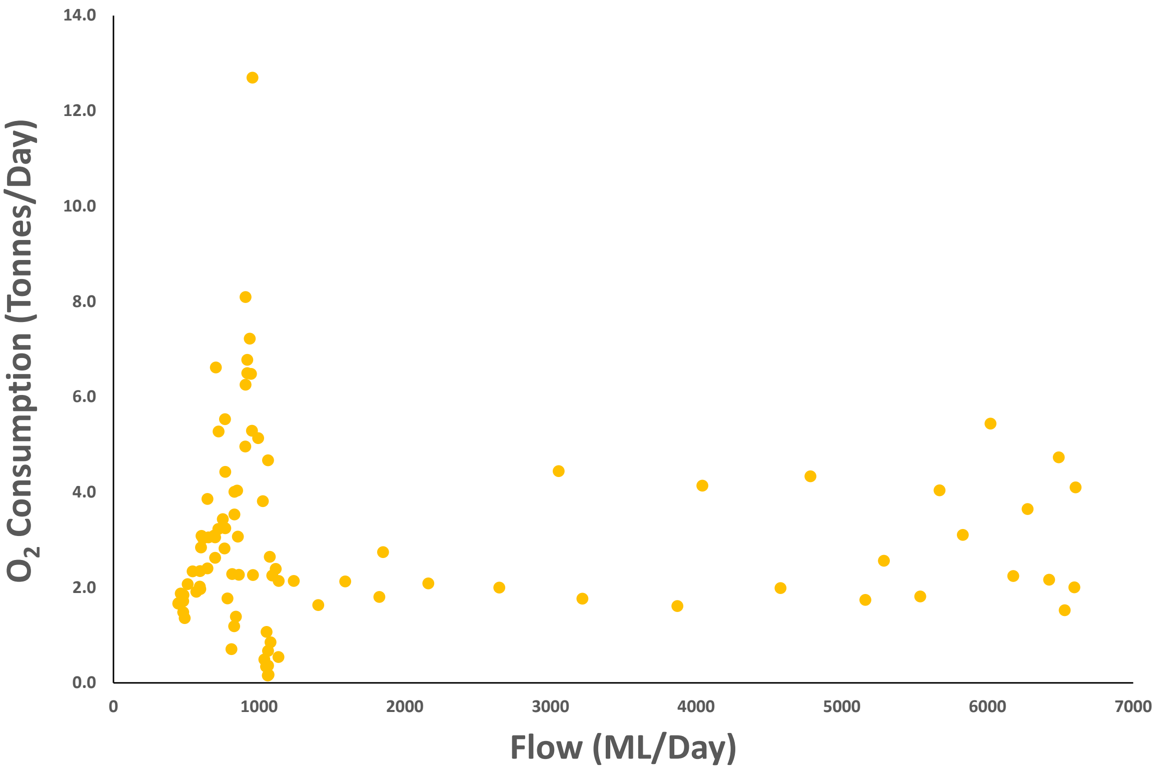


Figure C-7. Mean daily oxygen production - created by photosynthesis (GPP) - and consumption – through aerobic respiration (ER) over the period August 2015 to April 2016.

Table C-6. Exploration of Linear Relationships between the metabolic parameters (GPP and ER) and, Light and Temperature for the four study sites, Aug 2015 - Apr 2016. 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	< 0.01	0.016	0.05	0.15
	p	0.67	0.40	0.14	0.008
	slope	-	-	-	0.16
McCoy's Bridge	r^2	0.10	0.17	0.229	0.128
	p	0.002	< 0.001	< 0.001	< 0.001
	slope	0.067	0.21	0.26	0.86
Darcy's Track	r^2	0.31	< 0.01	0.43	0.17
	p	< 0.001	0.885	< 0.001	0.006
	slope	0.41	-	0.69	0.50
Day Rd	r^2	0.46	0.22	0.43	0.77
	p	< 0.001	0.003	< 0.001	< 0.001
	slope	0.67	0.46	0.34	0.89

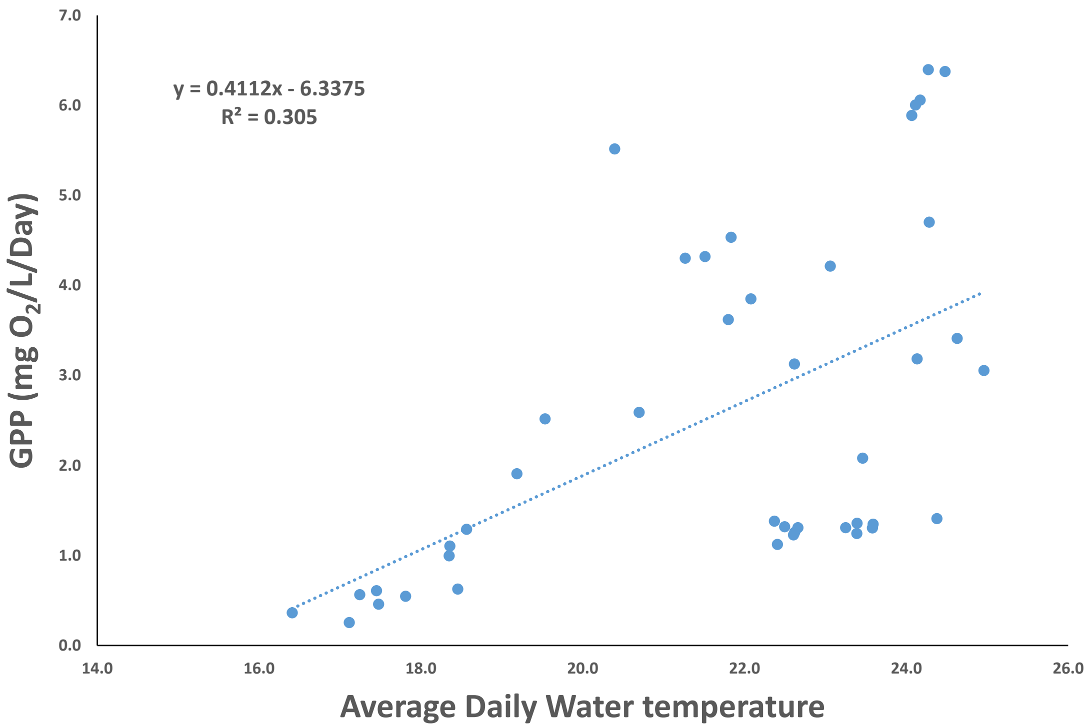


Figure C-8. The Relationship between Daily Gross Primary Production and Average Daily Water Temperature at the Darcy's Track site (n = 43).

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 and into April. This is best exemplified by the decline in GPP and ER rates at McCoy's Bridge (Figure C-3) from summer and into early March prior to the further decreases associated with the mid-March flow event. 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 from the samples that were collected approximately monthly during the DO probe deployment, downloading and maintenance. These data are presented in Table C-7. Also included in the table are data from the long term monitoring program at McCoy's Bridge (DELWP 2015). Dating back to 1990, data were collected weekly up until December 2013, when monthly sampling was instituted.

Table C-7. Nutrient (N, P & C) concentrations of water samples collected from the four study sites over the period August 2015 to April 2016. Long term data from McCoy's Bridge are also included.

		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	28/08/2015	0.03	0.56	4.6	0.003	0.001	0.27	
	23/11/2015	0.03	0.24	3.1	0.001	0.002	<0.001	< 7
	7/01/2016	0.04	0.39	5.6	0.007	0.003	0.033	11
	20/01/2016	0.04	0.36	4.3	0.001	0.002	<0.001	7
	23/02/2016	0.03	0.29	3.0	0.003	0.002	<0.001	8
	19/04/2016	0.03	0.34	5.1	0.005	0.004	0.008	10
Day Rd	23/10/2015	0.02	0.28	2.5	0.002	0.003	0.054	4
	26/11/2015	0.03	0.30	2.8	<0.001	0.003	0.019	8
	7/01/2016	0.02	0.28	3.5	0.002	0.002	0.036	< 5
	23/02/2016	0.02	0.29	3.1	0.002	0.002	0.072	< 5
	19/04/2016	0.02	0.23	2.5	0.006	0.001	0.016	< 5
Loch Garry	4/09/2015	0.03	0.53	6.0	0.006	0.003	0.16	
	26/11/2015	0.05	0.30	4.4	0.001	0.003	<0.001	9
	20/01/2016	0.04	0.36	5.5	0.001	0.003	0.002	15
	23/02/2016	0.04	0.33	3.4	0.003	0.003	<0.001	9
	19/04/2016	0.03	0.20	2.7	0.002	0.002	<0.001	6
McCoy's Bridge	26/08/2015	0.05	0.63	6.9	0.006	0.013	0.15	
	23/11/2015	0.06	0.38	3.8	<0.001	0.003	<0.001	< 13
	18/12/2015	0.04	0.31	5.1	0.011	0.027	0.003	< 11
	20/01/2015	0.05	0.37	3.6	<0.001	0.003	<0.001	12
	23/02/2016	0.05	0.49	4.3	0.004	0.003	<0.001	12
	19/04/2016	0.02	0.20	2.8	0.003	0.002	<0.001	6
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	

The key finding from Table C-7, is that, consistent with 2014-15, the concentrations of bioavailable nutrients in the Goulburn River at all 4 sites were very low. In particular, the bioavailable phosphorus concentration FRP, with rare exceptions at McCoy's Bridge, was consistently below 0.01 mg P/L. 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.

It is interesting to note that the nitrate concentrations at Day 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 is mostly lost by the time water reaches Darcy's Track and beyond. It is likely this nitrate loss is due to both denitrification by sediment bacteria and assimilation of the nitrate into plant material (algae, macrophytes).

C.4 Statistical modelling

C.4.1 Temporal lag between flow and stream metabolism

Temporal lag between flow and stream metabolism does not appear to have a significant influence on predictive ability of the model. Most optimal models (lowest DIC value) appear to occur for GPP for a lag of 1 day, for ER 2 days and for NPP, 6 days (Table C-8). Further work focused on the model that provided the optimal predictive ability for GPP (i.e., lag of 1 day), for ER (lag of 2 days) and for NPP (lag of 6 days).

C.4.2 Effect of hydrology on stream metabolism

Based on the best models (lowest DIC) for GPP, ER and NPP, Figure C-9 to Figure C-11 indicate that stream metabolism (gross primary production, ecosystem respiration, net primary production) as measured by the load of oxygen production or consumption (rather than the volumetric rates in mg O_2/L/Day) responds positively to discharge, and whilst there are slightly different trends observed at the different sites (e.g., Loch Garry for Net Primary Production – Figure C-11), generally relationships were similar across all four sites. The wide 95% credible intervals at Day Rd are probably due to the fact that only the data from year 2 was included in the statistical model, whereas data from both years 1 and 2 of the monitoring were included in the models for Darcy's Track, Loch Garry and McCoy's Bridge. Similarly, both mean velocity and inundated cross sectional area also appeared to have a positive relationship with stream metabolism (Figure C-12). This is to be expected because of the positive correlation between discharge and mean velocity and cross sectional area.

Table C-8. DIC values for stream metabolism models using different response lags. Lowest values are printed in bold typeface and indicate the strongest fit of model to data.

Lag (Days)	GPP	ER	NPP
0	1446	2035	1973
1	**1437**	2027	1977
2	1446	**2023**	1978
3	1466	2028	1974
4	1491	2037	1974
5	NA	2045	1974
6	1537	2053	**1972**
7	1557	2061	1977
8	1559	2061	1979
9	1557	2064	1978
10	1555	2062	1977

C.4.1 Summed effect of environmental flows

Figure C-13 indicates the effect of environmental flows in terms of the tonnes DO produced and consumed when comparing conditions with and without environmental flows. This metric was calculated as the difference between DO loads over the two monitoring years (1) under the real situation, and (2) under a counterfactual situation where there are no environmental flows. Figure C-13 suggests that particularly for Gross Primary Productivity, environmental flows have a positive effect on stream metabolism at the three most downstream sites: Darcy's Track, Loch Garry and McCoy's Bridge. At the Day Rd site, the 95% credible intervals include zero, which suggests that there is no clear positive or negative effect of environmental flows on stream metabolism at this site. This lack of conclusive evidence is likely due to the fact that only one year's worth of data were included in the analysis compared with the other three sites where monitoring data from both years were included in the statistical model.

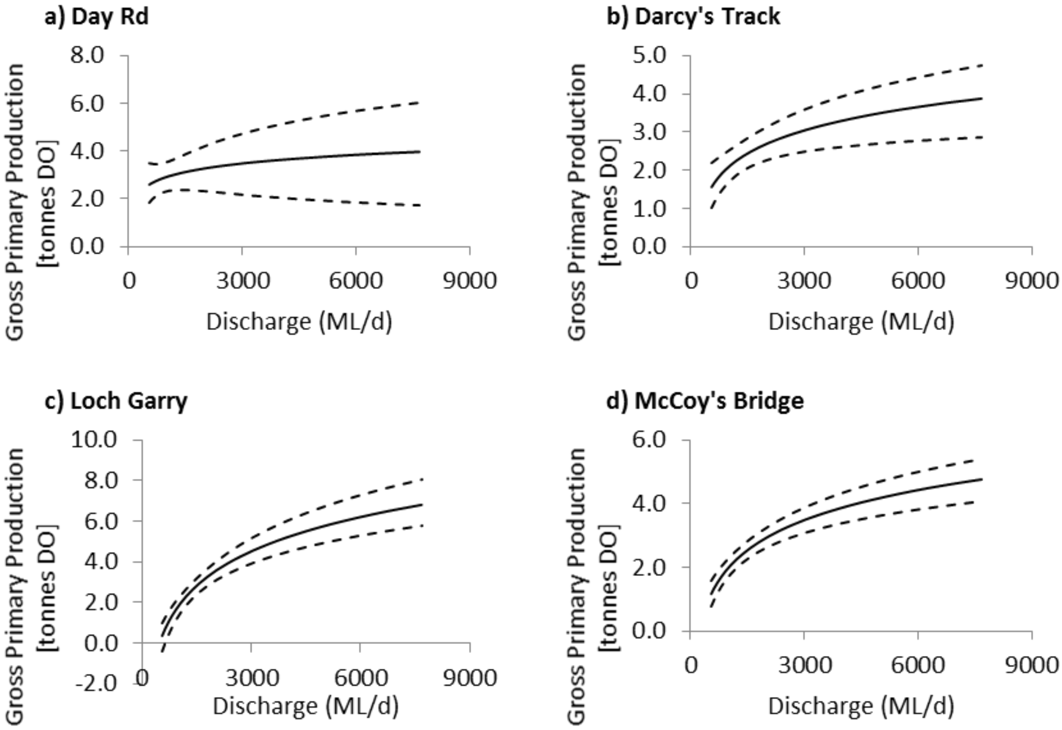


Figure C-9. Effect of discharge on Gross Primary Production with a temporal lag of one day. Solid line is the median predicted GPP at different discharge levels, with the dotted lines encompassing the 95% credible interval for the estimate.

For Ecosystem Respiration and Net Primary Productivity, the 95% credible intervals encompass the zero line at all four sites. As such, it appears that the relationships between environmental flows and Ecosystem Respiration and Net Primary Productivity are weaker than those with Gross Primary Productivity. It is possible that with the collection of more monitoring data, the 95% credible intervals may narrow and a positive effect of environmental flows on these two measures of stream metabolism may be seen.

C.5 Discussion

Unlike 2014-15 when the mean daily DO data ranged between ~6.5–10.5 mg/L, in 2015-16 there were several instances of very low DO that raise some concerns about the immediate effects on aquatic biota. These poor water quality events were of short duration (typically 3-4 days). It is strongly suspected that the origin of the poor water quality lies within the Nagambie Lakes or originates even further upstream. It was unfortunate that the DO logger at Goulburn Weir was out of commission for several months. Nevertheless, data from further upstream will be interrogated to identify the possible causes of this problem. Of highest relevance to this project, it is readily apparent that the reaeration rate and gross primary production rate are both insufficient (singly and in combination) to overcome this low DO further downstream. This is noted as matter for attention over the upcoming summer time, especially if these low DO events reoccur in 2016-17.

The data presented in Figure C-3 to Figure C-6 did not indicate a strong relationship between GPP and discharge events, although Figure C-9 showed a positive response when the overall amount of oxygen produced was considered. It is clear however that the immediate effect of flow is to lower the extant GPP (and ER) rates, almost certainly by simple dilution with large amounts of water.

Primary production is expected to respond 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 discharge will introduce nutrients into the river channel which will then stimulate biomass growth and hence higher rates of GPP. It is extremely likely that the absence of significant growth 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.

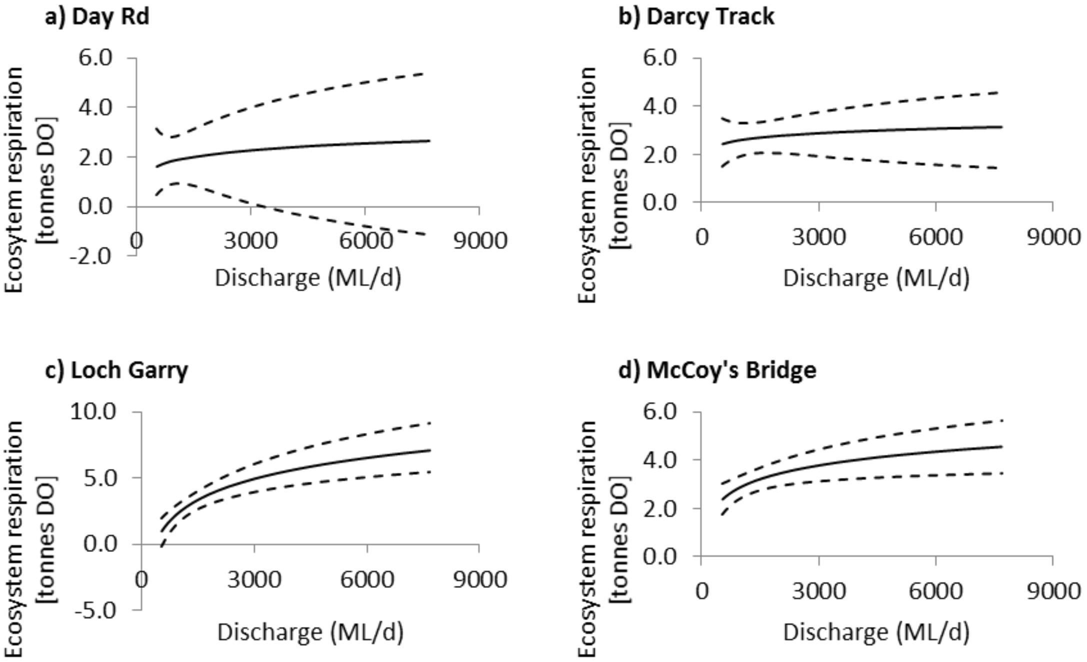


Figure C-10. Effect of discharge on Ecosystem Respiration with a temporal lag of two days. Solid line is the median predicted ER at different discharge levels, with the dotted lines encompassing the 95% credible interval for the estimate.

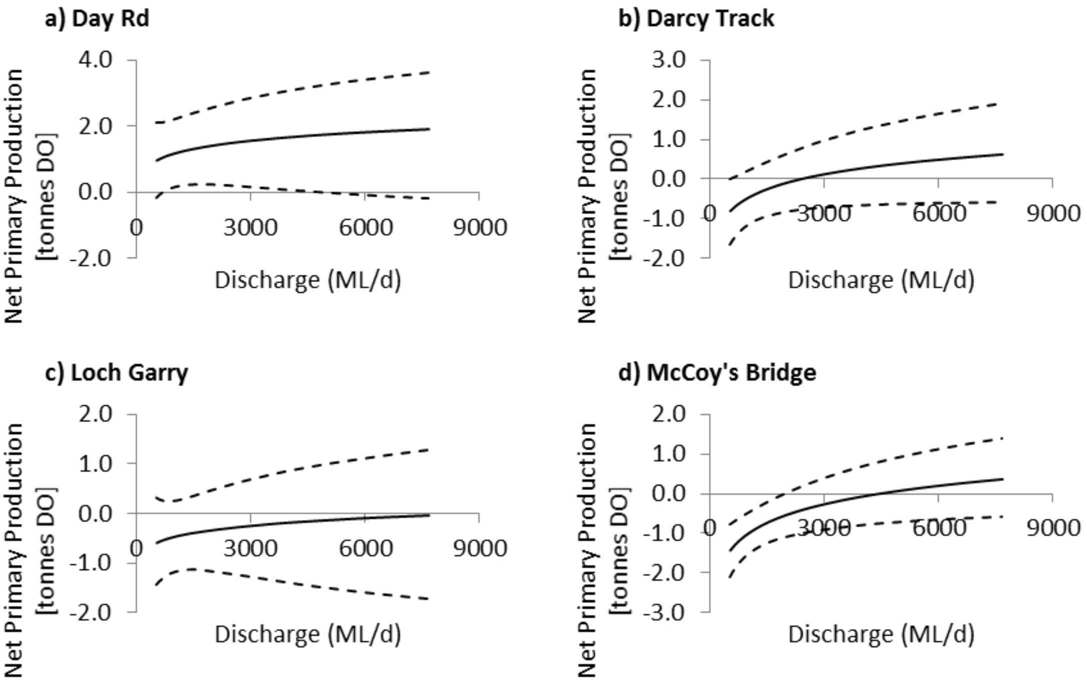


Figure C-11. Effect of discharge on Net Primary Production with a temporal lag of six days. Solid line is the median predicted GPP at different discharge levels, with the dotted lines encompassing the 95% credible interval for the estimate.

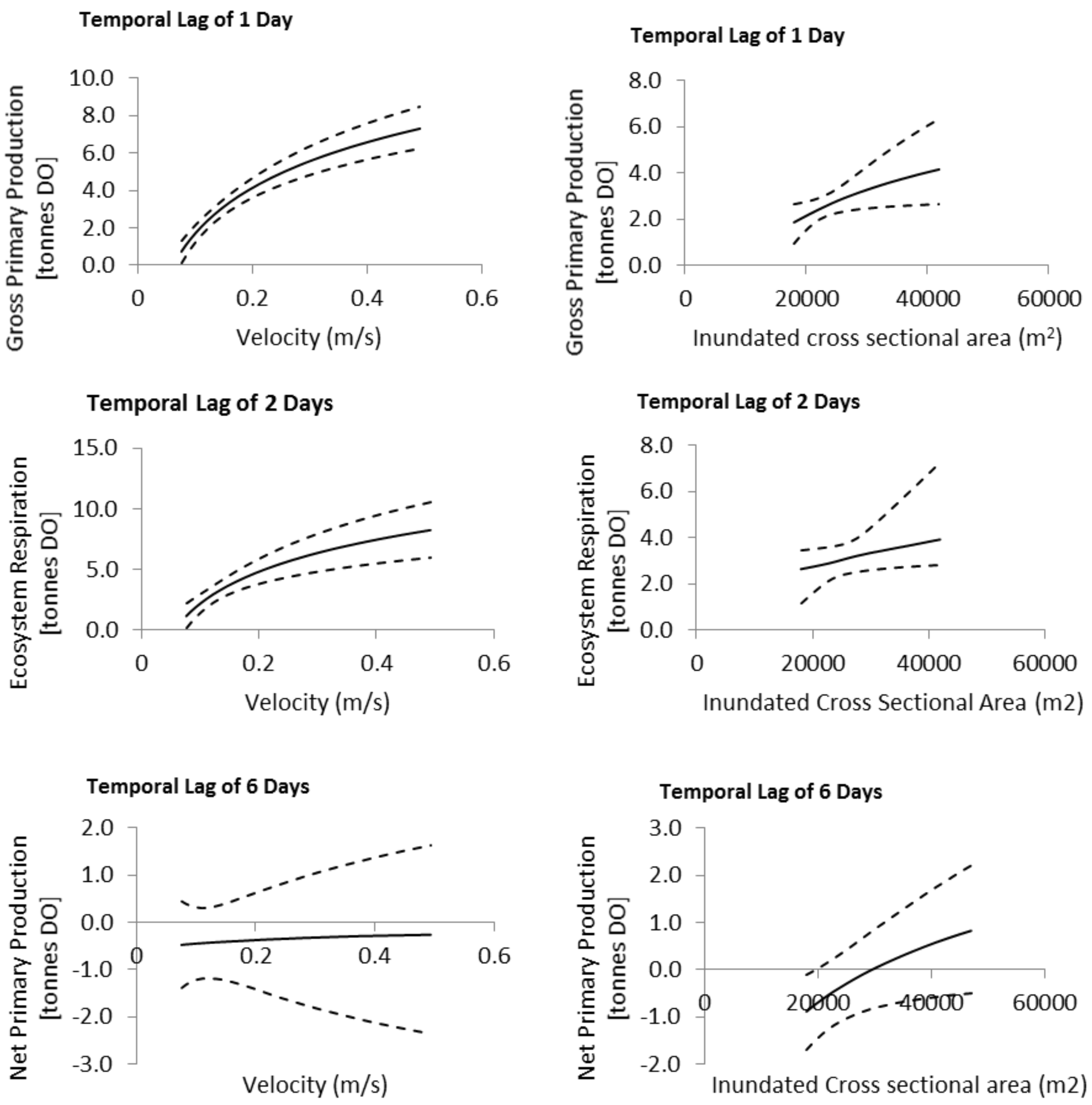


Figure C-12. Effect of mean velocity and inundated cross sectional area on stream metabolism at Loch Garry when there is a temporal lag of one day (for GPP), two days (for ER) and six days (for NPP). Solid line is the median predicted GPP/ER/NPP at different discharge levels, with the dotted lines encompassing the 95% credible interval for the estimate.

The Bayesian modelling indicated that discharge with a temporal lag of one day best explained the gross primary production. The Bayesian modelling also indicated a positive relationship between discharge, velocity and cross sectional area and GPP, ER and NPP at most sites (Figure C-9 to Figure C-11). As such, a positive effect of environmental flows on stream metabolism when determined as the overall total amount of oxygen produced or consumed was identified.

As noted in 2014-15, it is expected that higher flows that remain within the river channel are unlikely to introduce significant amounts of nutrients which in turn will constrain primary production.

Comparison with the long term data set from McCoy’s Bridge shows that the 5 or 6 sample sets collected at the 4 sites during DO logger deployment displayed nutrient concentrations slightly lower than the corresponding long term median results (ammonia and total nitrogen were not measured in the long term monitoring).

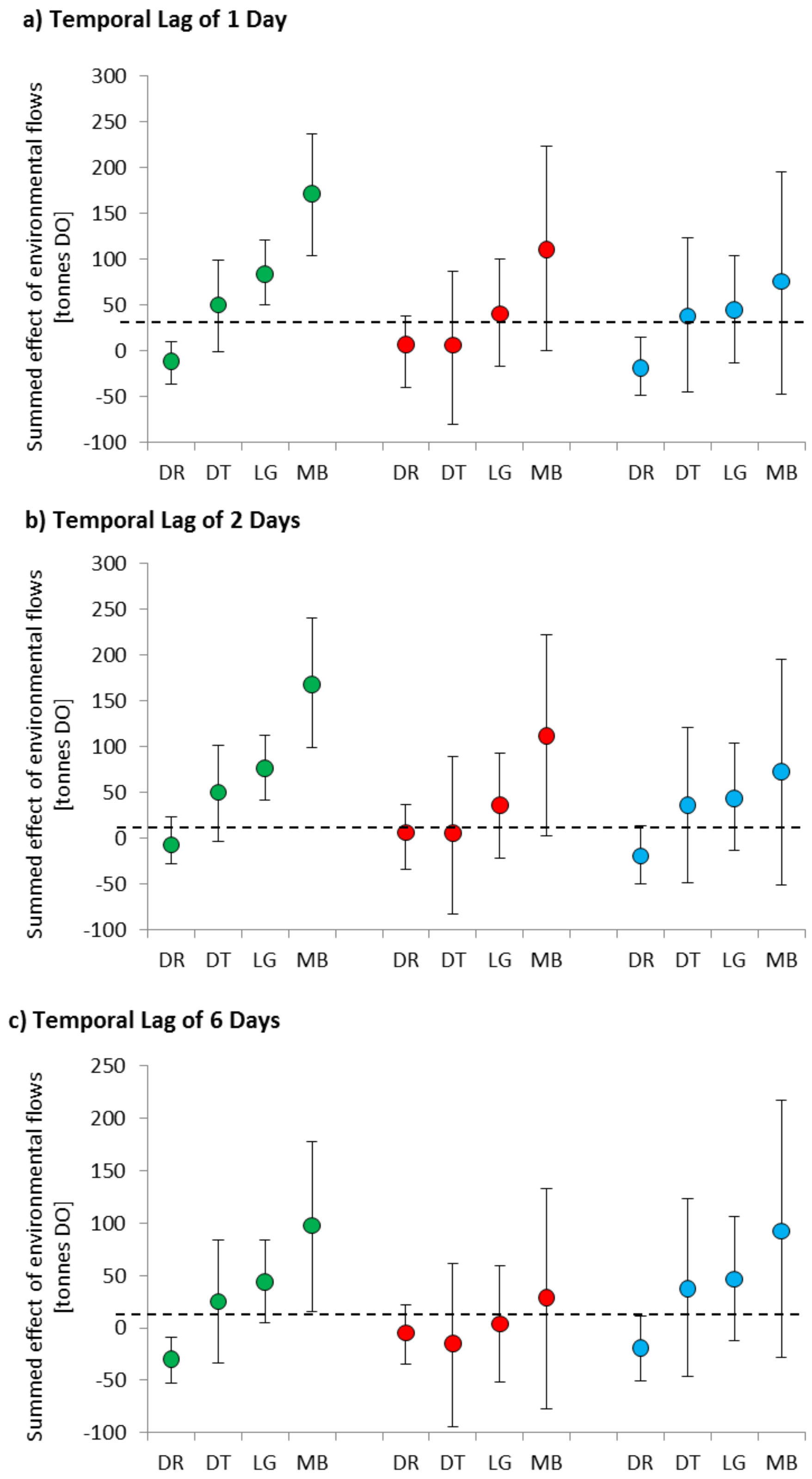


Figure C-13. Summed effect of environmental flows upon ecosystem metabolism measures. Dots are the median summed effect of environmental flows delivered over the monitoring period (2014-2016) on GPP (green), ER (red) and NPP (blue) for each site. Error bars encompass the 95% credible interval for the estimate. Abbreviations: DR – Day Rd, DT – Darcy's Track, LG – Loch Garry, MB – McCoy's Bridge.

C.6 Conclusions and recommendations

During the 2015–16 monitoring period, water was always retained within the river channel. As a result, nutrients and organic matter from major backwaters and other floodplain habitats were not carried to the river. Discharges greater than 18,000 to 19,000 ML/d are required to connect the main channel of the lower Goulburn River to flood-runners (GBCMA, unpubl.). Such flows are critical for moving carbon and nutrients from the floodplain to the river and should be considered when designing future environmental flows. Lowland river food webs rely on periodic pulses of carbon and nutrients and therefore providing flows that connect the river to floodplain habitats should be considered a priority to maximise the beneficial effect of Commonwealth environmental water on stream metabolism.

Several instances of very low dissolved oxygen concentration were recorded during low flow periods in the 2015-16 monitoring period. Whilst these poor water quality events were of short duration (typically 3-4 days), they have the potential to adversely affect riverine biota. These poor water quality events are likely due to poor water quality management in the Nagambie Lakes, or upstream of these lakes. The reaeration rate and gross primary production rates under prolonged low flow conditions are insufficient to increase dissolved oxygen concentrations and periodic higher flows are needed to improve water quality. Bayesian modelling undertaken for this project indicated that environmental flows have a positive influence on gross primary productivity and oxygen masses in the water column. Further monitoring should aim to identify critical flow thresholds to aerate the water column and minimum flows required to deliver significant pulses of carbon and nutrients to stimulate primary production.

Appendix D. Detailed results for Macroinvertebrates

D.1 Introduction

Macroinvertebrates are an important component of aquatic ecosystems, providing essential services for ecosystem functioning such as nutrient cycling. Macroinvertebrates form a key component of the diets of many native fish species and other vertebrates, so an important aspect of understanding how Commonwealth environmental water affects native fishes is to determine how it affects their prey. However, many of the methods used to assess macroinvertebrates rely on rapid bioassessment methods and biotic indices that focus on measures of diversity and richness. These methods are often only sensitive to larger impacts on macroinvertebrate communities (Krantzberg 1992, Boulton 1999, Smith et al. 1999). In addition, macroinvertebrate diversity may not be important for sustaining native fish populations. Instead, measures of macroinvertebrate abundance and biomass are likely to be more sensitive to flow events, such as environmental water delivery, and are more important for sustaining native fish.

Three methods have been employed in lower Goulburn LTIM Project to assess the macroinvertebrate fauna, using measures that are potentially more sensitive and relevant for sustaining native fish. These methods are being deployed at two sites in the region: the Goulburn River at McCoy's Bridge (a site that receives Commonwealth environmental water) and Broken River at Shepparton East (a site that does not receive Commonwealth environmental water). Monitoring was conducted before, during and after a Commonwealth environmental water event delivered as a spring fresh in 2015. In the previous year, monitoring was also conducted around Commonwealth environmental water events delivered as spring freshes, and in investigating the data from this year, comparisons were also made to last year. The monitoring program aimed to answer the following questions for the lower Goulburn River:

- 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?

D.2 Methods

The methods used for monitoring macroinvertebrates are given in (Webb et al. 2014) with some modifications. These methods are briefly outlined here and any modifications described. Three methods were employed at two sites in the region: the impacted site (Goulburn River at McCoy's Bridge) and the control site (Broken River at Shepparton East). In spring, 2015, environmental water was delivered as a spring fresh to promote bank vegetation. Monitoring was conducted before, during and after the spring fresh at both sites (Table D-1).

The first method used artificial substrates (adapted from Cook et al. 2011), which consist of a plastic mesh cylinder containing an artificial substrate (onion bags) for macroinvertebrates to colonise. Fifteen of these were deployed at each site for a period of four to six weeks. Upon retrieval, five of these were randomly selected and the entire contents were preserved in 100% ethanol for processing and macroinvertebrate identification in the laboratory. Large macroinvertebrates (>5mm) were live-picked from the remaining artificial substrates and preserved in ethanol. These were identified to genus, air-dried, oven dried (at 60°C for 24 hours) and weighed to calculate macroinvertebrate biomass.

The second method was Replicated Edge Sweep Sampling (RESS), modified from the method developed by (Gigney et al. 2007a, b).This involved assessing the major edge habitat types present at a site and sampling these in proportion to the availability of those habitats using a sweep net. Five replicate samples are taken from each site. In the previous year the whole sample was stored in ethanol and processed in the laboratory. To increase efficiency, the current survey samples had macroinvertebrates live-picked from them in the field for a total of 30 minutes with the intention of getting a good representation of the diversity and abundance of macroinvertebrates in each sample. An additional five replicate samples were taken for biomass analyses, although with these the area sampled in each river was measured (for biomass calculations), and only large macroinvertebrates (>5mm) were picked from the samples. These were also identified to genus, dried and weighed as outlined above.

The final method was an assessment of adult macroinvertebrates (and other invertebrates) inhabiting the riparian zone. Yellow sticky traps were used to capture these invertebrates (described in Townsend 2013). At each site 15 of these were deployed by hanging them from star pickets or vegetation for a week. Once retrieved, invertebrates stuck on the traps were identified and counted in the laboratory.

Table D-1. Macroinvertebrate sampling times in the Goulburn River and Broken River during 2015-16. CEW= Commonwealth environmental water event delivered as a spring fresh.

		Pre-CEW		CEW		Post-CEW	
Method	Site	Deployed/Conducted	Retrieved	Deployed	Retrieved	Deployed/Conducted	Retrieved
Artificial substrates	Goulburn River	1/9/2015	1/10/2015	-	-	4/11/2015	9/12/2015
	Broken River	1/9/2015	30/9/2015	-	-	4/11/2015	9/12/2015
Replicated edge samples	Goulburn River	1/9/2015	-	-	-	4/11/2015	-
	Broken River	31/8/2015	-	-	-	5/11/2015	-
Yellow sticky traps	Goulburn River	1/9/2015	8/9/2015	1/10/2015	9/10/2015	4/11/2015	10/11/2015
	Broken River	1/9/2015	8/9/2015	30/9/2015	9/10/2015	4/11/2015	10/11/2015

D.2.1 Statistical modelling

Abundance of macroinvertebrates.

Before-After-Control-Impact Analysis of Variance tests (BACI ANOVAs) within a Bayesian framework were used to assess the impact of the spring fresh on abundance of macroinvertebrate species (as measured using artificial substrates). The model is structured as follows:

$$y_i \sim Pois(mu_i)$$

$$log(mu_i) = eff.Year_m + g.mu_{b,r}$$

The abundance of macroinvertebrates (*y*) for artificial substrate *i* has a Poisson distribution with an expected value of mu_i. mu_i is modelled using a log-link function and is driven by the global abundance at river *r* (Broken River or Goulburn River) and at time *b* (before or after the spring fresh) (*g.mu*), and the random effect of year (*eff.Year)*.

The global abundance (*g.mu*) is drawn from a truncated normal distribution with a mean of 0, standard deviation of *s.g.mu* and a minimum of 0. Likewise, the random effect of year (*eff.Year)* is drawn from a normal distribution with a mean of 0 and standard deviation of *s.year. s.g.mu* and *s.year* are drawn from a minimally informative uniform distribution with limits of 0 and 10.

$$g.mu_{r,b} \sim N(0, s.g.mu^2)I(0,)$$

$$eff.year_m \sim N(0, s.year^2)$$

Macroinvertebrate biomass

BACI ANOVAs within a Bayesian framework were also used to assess the effect of the spring fresh on macroinvertebrate biomass (as measured using artificial substrates and replicated edge sampling). The model is structured as follows:

$$y_i \sim N\left(mu_{i,}s^2\right)$$

$$mu_i = g.mu_{b,r}$$

The natural logarithm of macroinvertebrate biomass (*y*) in sample *i* is normally distributed, with a mean of mu_i and standard deviation of *s*. mu_i is driven by the global abundance at river *r* (Broken River or Goulburn River) and at time *b* (before or after the spring fresh) (*g.mu*). The random effect of year (*eff.Year)* was not included in the biomass statistical model because the data from only one year (2015-16) was analysed. The global abundance (*g.mu*) is drawn from a truncated normal distribution with a mean of 0, variance of 10 and a minimum of 0. *s* is drawn from a uniform distribution with limits of 0 and 10.

A 'step' function in OpenBUGS was used to assess the probability that the increase in macroinvertebrate abundance/biomass is greater in the Goulburn River (which experiences the spring fresh due to the environmental flows) compared to the Broken River (which does not receive environmental flows).

$$p.difference = step(change.goulburn - change.broken)$$

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.

D.3 Results

D.3.1 Relevant flow components delivered to the lower Goulburn River in 2015-16

Bankfull flows and freshes were predicted to be the flow components with the greatest effect on macroinvertebrates. In the 2015-16 survey period, the effects of a spring fresh on macroinvertebrates was monitored, giving results that are comparable to the previous year (which also involved the monitoring of a spring fresh). Macroinvertebrate monitoring was conducted before and after the spring fresh (as well as during the spring fresh for yellow sticky traps).

During the survey period conditions were warm and dry across the region. Temperatures were very much above average while rainfall was below average (Bureau of Meteorology 2016). In September, maximum temperatures were slightly above average, but this increased to >8°C above average and 2-3°C above average in October and November respectively. Rainfall in September and October was below average, while it was average or above average in November (Bureau of Meteorology 2016). Under these dry and warm conditions, the delivery of spring freshes may have alleviated stress to the macroinvertebrate fauna, and this did appear to be the case, with declines in the macroinvertebrate fauna less severe in the Goulburn River than those observed in Broken River (which ceased to flow during post-Commonwealth environmental water sampling).

D.3.2 Artificial substrates

D.3.2.1 Observations

A total of 15,794 macroinvertebrates belonging to 111 taxonomic groups were captured in the artificial substrates, which is lower than the previous year (16,368 macroinvertebrates belonging to 155 taxa). The effect of the spring fresh on macroinvertebrate abundance was determined by using the data from both years and comparing the change before and after the fresh in the Goulburn River and Broken River. Total macroinvertebrate abundance decreased at both sites post-Commonwealth environmental water (Figure D-1a). An examination of the data from 2015-16 alone showed that there was only a slight decrease in abundance in the Goulburn River compared to a much larger decrease in the Broken River (Figure D-1). In comparison, both sites experienced a similar large decrease in abundance in 2014-15 (Figure D-1a in Webb et al. 2016).

The number of taxa in the artificial substrates was greater in the Broken River than the Goulburn River when combined across both years, and remained relatively unchanged pre- and post- Commonwealth environmental water (Figure D-1c). This was also true when each year was considered separately, although in 2015-16 taxonomic richness decreased slightly at each site post- Commonwealth environmental water (Figure D-1d) whereas it increased slightly in 2014-15 (Figure D-1b in Webb et al. 2016).

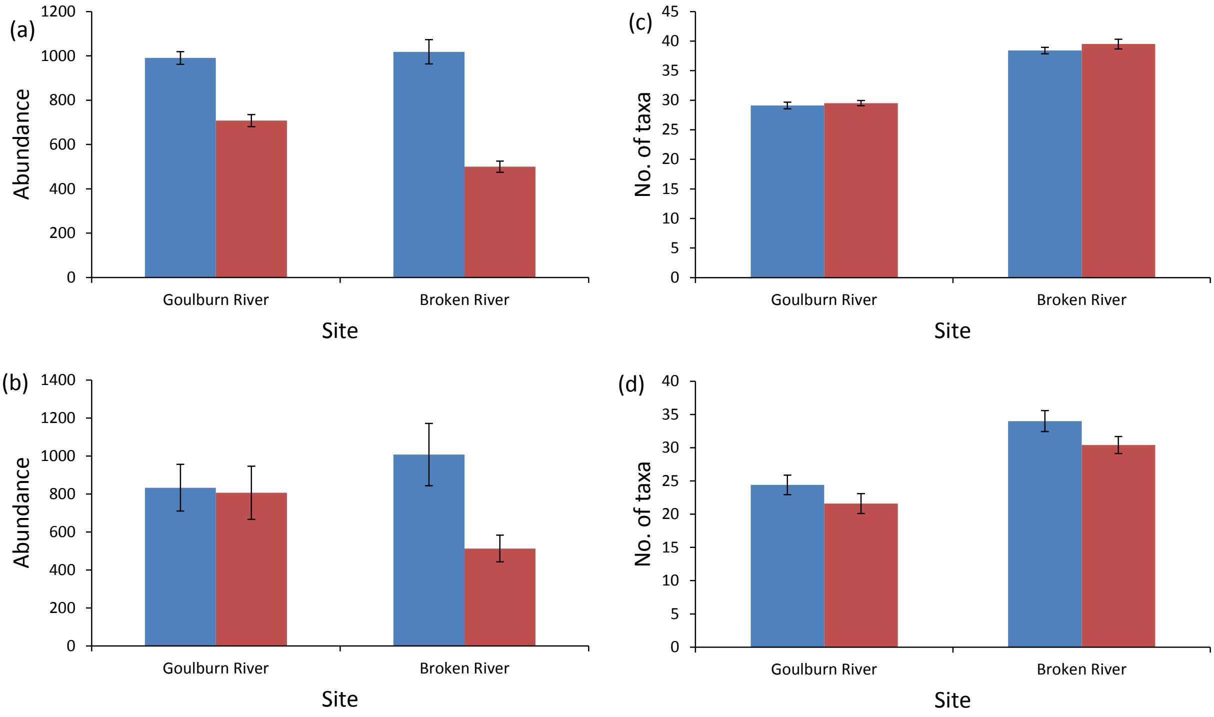


Figure D-1. Abundance (a) combined across 2014-15 and 2015-16, (b) 2015-16 alone and taxonomic richness (a) combined across 2014-15 and 2015-16 and (b) in 2015-16 alone in artificial substrates deployed in the Goulburn and Broken Rivers before and after Commonwealth environmental flows (average ± standard error of the mean). Blue = before a Commonwealth environmental flow event; red = after a Commonwealth environmental flow event.

Macroinvertebrate biomass in the artificial substrates was only examined for 2015-16. Total macroinvertebrate biomass was greatly reduced in the Goulburn River following the spring fresh, whereas it remained relatively unchanged in the Broken River (Figure D-2a). This same decline was observed in all of the common macroinvertebrate taxa that contributed most to biomass, although Crustacea and EPT (Ephemeroptera, Plecoptera and Trichoptera) biomass also declined in the Broken River post- Commonwealth environmental water (Figure D-2b,c). In contrast, Odonata biomass increased in the Broken River (Figure D-2d).

Taxa that commonly occurred at both sites, in both seasons and across both years (2014-15 and 2015-16) were investigated further. Eight of these belonged to the midge fly family Chironomidae. Analyses were conducted on combined data from 2014-15 and 2015-16, but only the 2015-16 results are presented graphically. There was evidence that the environmental flow was benefitting some taxa in the Goulburn River. For example, the abundance of *Procladius* sp. increased in both rivers post- Commonwealth environmental water (Figure D-3a), but this increase was much greater in the Goulburn River (Figure D-2b). Interestingly, this response was also observed in 2014-15 (Figure D3b in Webb et al. 2016). *Cryptochironomus* sp. also showed a positive response to environmental flows in the Goulburn River in both 2014-15 and 2015-16. In 2014-15, the abundance of this species increased post-Commonwealth environmental water at both sites, but the increase was much greater in the Goulburn River (Figure D3n in Webb et al. 2016). In 2015-16, abundance increased post-Commonwealth environmental water in the Goulburn River but decreased in the Broken River (Figure D-3b). Similarly, *Cladotanytarsus* sp. increased in abundance post-Commonwealth environmental water at both sites in both years, and this increase was much greater in the Goulburn River than the Broken River (Figure D3c; Figure D3l in Webb et al. 2016). The larger increase in abundance in the Goulburn River was associated with the spring fresh. (Figure D-2e).In 2015-16 there was a slight increase in abundance post-Commonwealth environmental water in the Goulburn River, while a large decrease in abundance was observed in the Broken River (Figure D-3d). However, this response was not consistent across years, with abundance increasing at both sites post-

Commonwealth environmental water in 2014-15, and to a greater extent in the Broken River (Figure D3e in Webb et al. 2016).

Some taxa showed a negative response to environmental water. *Parakiefferiella* sp. declined in abundance at both sites post-Commonwealth environmental water in 2015-16, but this decrease was much greater in the Goulburn River (Figure D-3e). The same response was also observed in 2014-15 (Figure D3k in Webb et al. 2016), and analysis showed there was a high probability the environmental flow made things worse for this species in the Goulburn River. *Tanytarsus manleyensis* abundances also decreased more severely post-Commonwealth environmental water in the Goulburn River than the Broken River, with the decrease in abundance in the Goulburn River post-Commonwealth environmental water observed in both years (Figure D-3f (Figure D3c in Webb et al. 2016), while responses in the Broken River differed between years (abundance increased post-Commonwealth environmental water in 2014-15 but decreased in 2015-16). Some taxa did not show consistent responses across years, and there was no obvious effect of environmental water on these animals. *Nanocladius* sp., for example, appeared to have a negative response to environmental water in 2014-15 (Figure D3a in Webb et al. 2016) but the opposite was observed in 2015-16, with an increase post-Commonwealth environmental water in the Goulburn River that did not occur in the Broken River (Figure D-3g). *Djalmabatista* sp. increased at both sites post-Commonwealth environmental water in 2014-15, with a larger positive change in the Goulburn River (Figure D3m in Webb et al. 2016), whereas it became absent from the Goulburn River post-Commonwealth environmental water in 2015-16 (Figure D-3h).

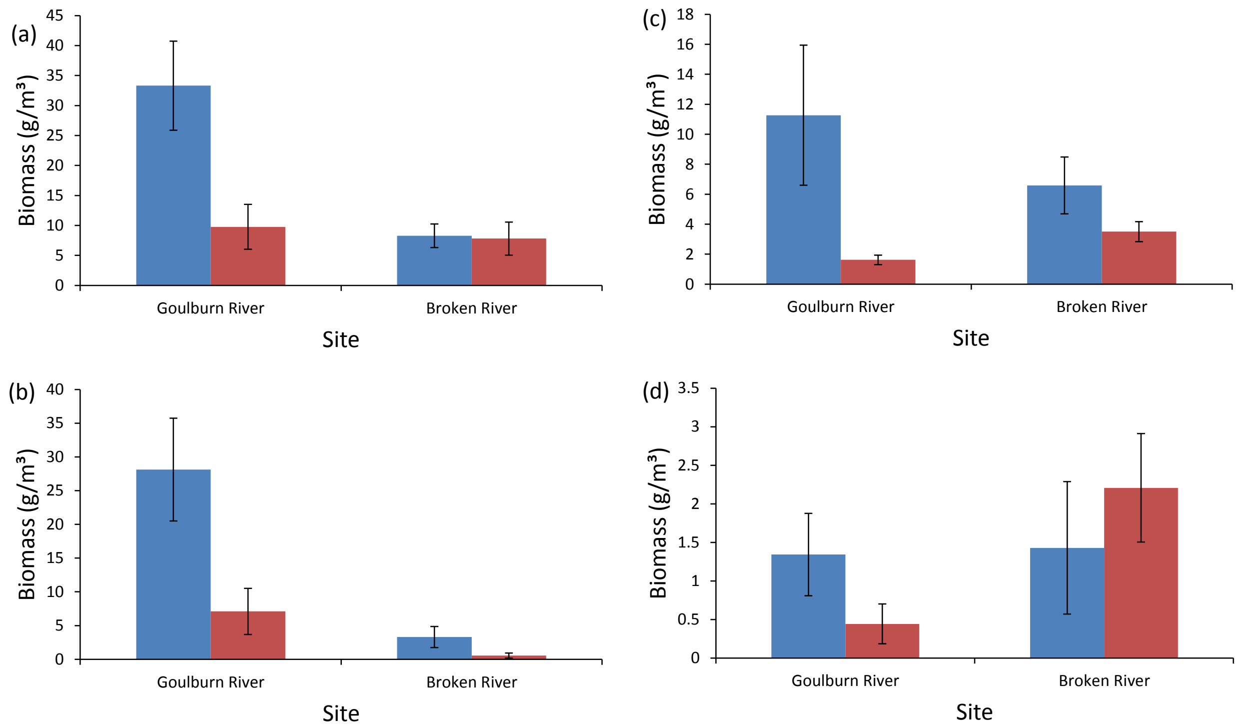


Figure D-2. Biomass (average ± standard error of the mean) of (a) all macroinvertebrates >5mm, (b) crustaceans, (c) EPT (mayflies Ephemeroptera, stoneflies Plecoptera and caddisflies Trichoptera) and (d) dragonflies and damselflies (Odonata) in artificial substrates deployed in the Goulburn and Broken Rivers before and after a Commonwealth environmental water event. Blue = before the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

Four mayfly (Ephemeroptera) species were also common in both years. Three of these decreased in abundance at both sites post- Commonwealth environmental water. However, there was evidence that the environmental water delivery did have a positive effect on the abundance of two of these. Both *Tasmanocoenis arcuata* and *T. tillyardi* experienced a much greater reduction in abundance in the Broken River than Goulburn River, with a less severe reduction as a result of the environmental flow (when data were combined). For *T. arcuata*, the effect of an environmental flow was less evident in 2014-15 than 2015-16. In 2014-15, abundance decreased at both sites (Figure D4c in Webb et al. 2016), whereas in 2015-16 it increased in the Goulburn but experienced a large reduction in the Broken River (Figure D-4a). *Tasmanocoenis tillyardi* abundances suffered similar severe reductions post-Commonwealth environmental water in both rivers in 2014-15 (Figure D4h in Webb et al. 2016), whereas in 2015-16 abundances declined at both sites but not as severely in the Goulburn River, which was associated with the environmental flow (Figure D-4b). Abundances of *Atalophlebia* sp. AV6 were also positively associated with environmental water delivery in the Goulburn River. In both years, abundances decreased in the Broken River post-Commonwealth environmental water while there was evidence the spring freshes in the Goulburn sustained populations of this species, with abundances remaining relatively unchanged in 2014-15 (Figure D4i in Webb et al. 2016) and increasing in 2015-16 (Figure D-4c). In contrast, environmental flows were associated with negative effects on the abundance of *T. tonnoiri*, and while abundances decreased at both sites post-Commonwealth environmental water in 2014-15 and 2015-16, these declines were more severe in the Goulburn River (Figure D-4d; Figure D4g in Webb et al. 2016). Decreases in the abundance of *T. reiki* post-Commonwealth environmental water were also associated with environmental water delivery in the Goulburn River, where negative changes in abundance were much greater (Figure D-4e).

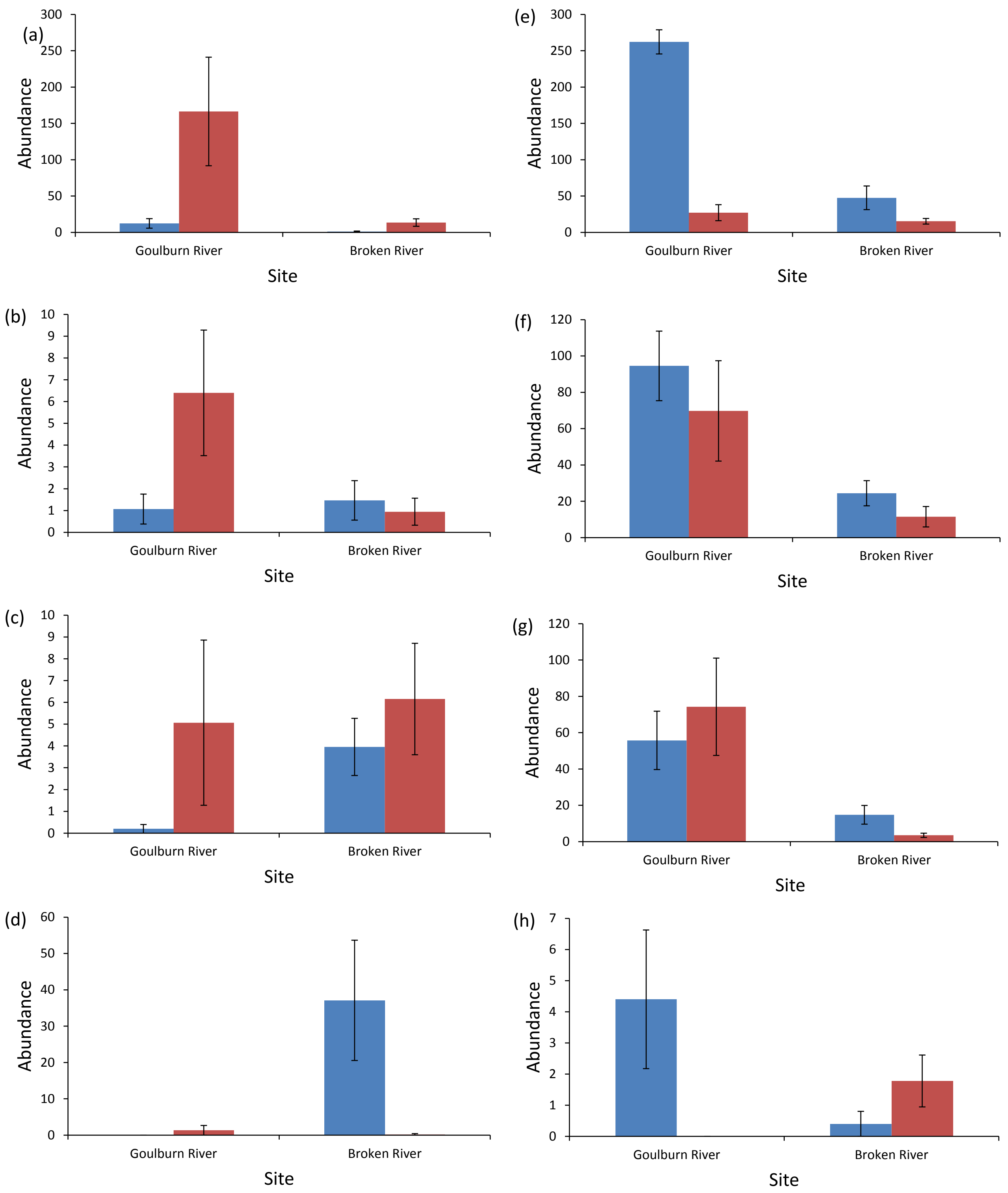


Figure D-3. Average (± standard error of the mean) abundance of Chironomidae larvae (a) *Procladius* sp., (b) *Cryptochironomus* sp., (c) *Cladotanytarsus* sp., (d) *Rheotanytarsus* sp., (e) *Parakiefferiella* sp., (f) *Tanytarsus manleyensis*, (g) *Nanocladius* sp. and (h) *Djalmabatista* sp. in artificial substrates deployed in the Goulburn and Broken Rivers in spring 2015. Blue = before the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

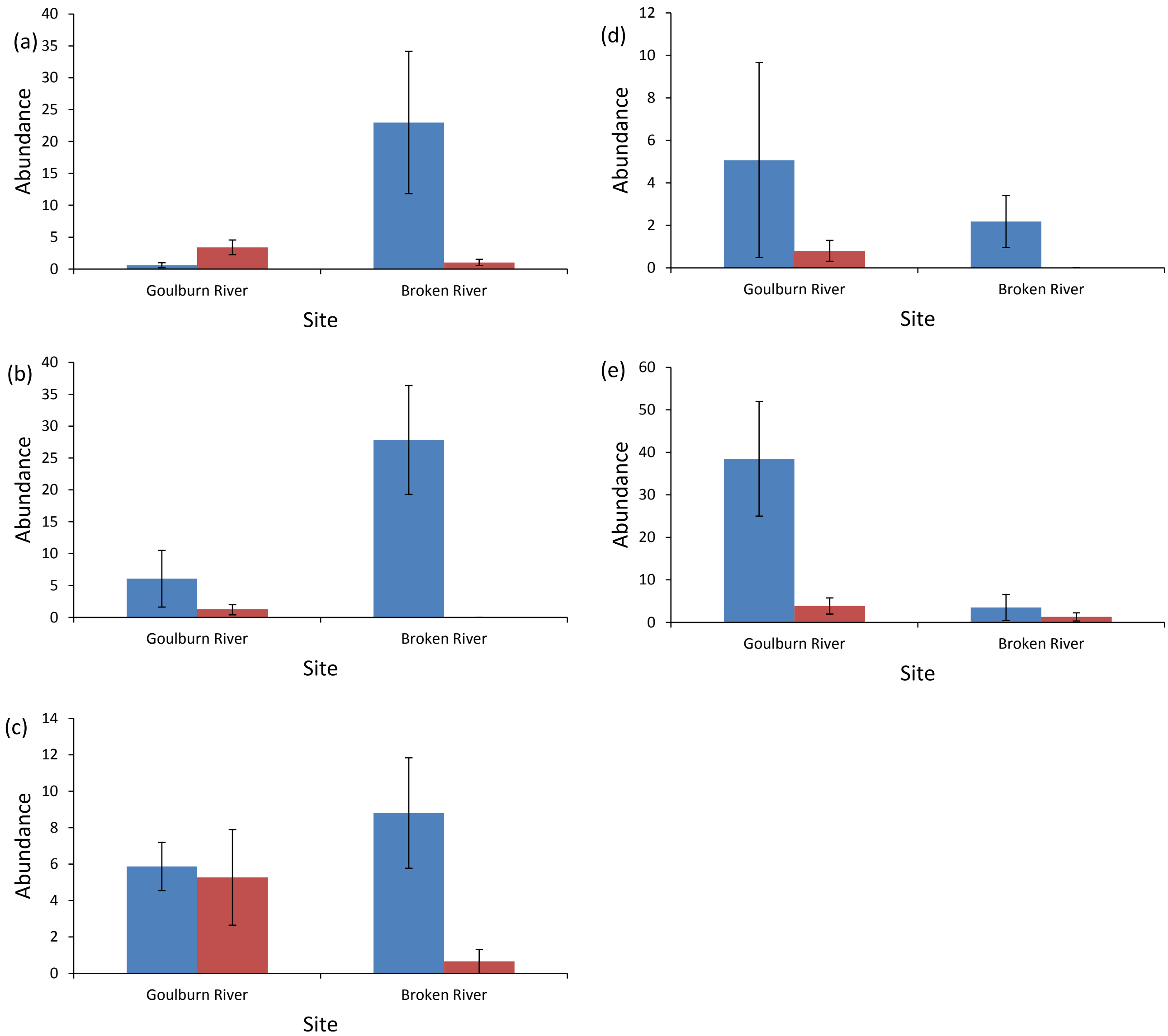


Figure D-4. Average (± standard error of the mean) abundance of Ephemeroptera (a) *Tasmanocoenis arcuata*, (b) *Tasmanocoenis tillyardi*, (c) *Atalophlebia* sp. AV6, (d) *Tasmanocoenis tonnoiri* and (e) *Tasmanocoenis reiki* in artificial substrates deployed in the Goulburn and Broken Rivers in spring 2015. Blue = before the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

Two caddisfly (Trichoptera) species were also common in both years. In 2015-16, the abundance of *Ecnomus pansus* increased at both sites post-Commonwealth environmental water (Figure D-5a), as it did in 2014-15 (Figure D-4j in Webb et al. 2016), and when these data were combined the positive effect on abundance was greater in the Goulburn River, indicating a beneficial effect of environmental flows. Similarly, the abundance of *E. continentalis* also increased post-Commonwealth environmental water at both sites and in both years, although this increase was much greater in the Broken River in 2014-15 (Figure D-4k in Webb et al. 2016) and greater in the Goulburn River in 2015-16 (Figure D-5b). Again, when the two years were examined together the difference in abundance post-Commonwealth environmental water was greater in the Goulburn River and strongly associated with the spring freshes.

D.3.2.2 Probability of occurrence of macroinvertebrate species before and after the spring fresh

The Bayesian statistical modelling reinforced the findings to the qualitative observations of the collected macroinvertebrate data. It appears that there was a decrease in total abundance of macroinvertebrates in both the Goulburn River and the Broken River during spring, but that this decrease in total abundance was less severe in the Goulburn River compared to the Broken River (Figure D-6a). This could be due to the presence of environmental flows in the Goulburn River. It also appears that macroinvertebrate taxa responded in varying ways to the spring fresh. For *Procladius* sp., *Cryptochironomus* sp., *Cladotanytarsus* sp., *Rheotanytarsus* sp., *Ecnomus pansus* and *E. continentalis* the abundance in the Goulburn River increased more than in the Broken River before and after the spring fresh (Figure D-6b-g). This suggests that the spring fresh (i.e., the environmental flows) may have contributed to the increase in abundance of these particular taxa in the Goulburn River. On the other hand, *Parakiefferiella* sp. and *Tanytarsus manleyensis* experienced a greater decrease in abundance in the Goulburn River compared to the Broken River (Figure D-6h-i).

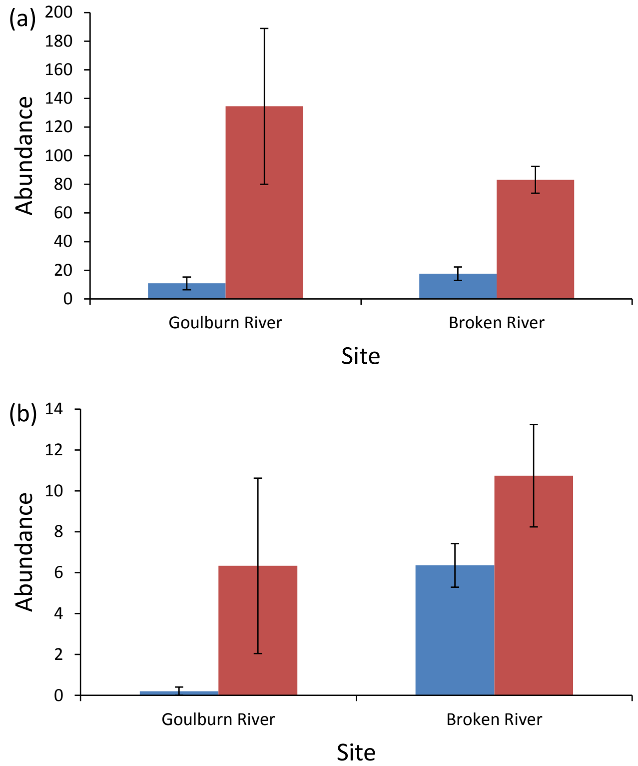


Figure D-5. Average (+ standard error of the mean) abundance of Trichoptera (a) *Ecnomus pansus* and (b) *Ecnomus continentalis* in artificial substrates deployed in the Goulburn and Broken Rivers in spring 2015. Blue = before the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

The macroinvertebrate biomass data of 2015-16 (Figure D-6j) indicated that whilst there was a decrease in total biomass in the Goulburn River, there was a small increase in the Broken River, with there being only a 23% chance that the increase in biomass in the Goulburn River was greater than that of the Broken River.

D.3.3 Replicated edge sweep samples

Due to changes in the methodology between 2014-15-15 and 2015-16, direct comparisons were not made between the data acquired for the two years. The following results are based on 2015-16 sampling alone. A total of 1,365 macroinvertebrates belonging to 75 taxa were caught in the replicated edge sweep samples (RESS) in 2015-16. Macroinvertebrate abundance was always greater in the Broken River than in the Goulburn River, although both sites experienced a decrease in abundance post-Commonwealth environmental water (Figure D-7a). Taxonomic richness was similar between sites, although both sites also had reduced number of taxa in post-Commonwealth environmental water sampling (Figure D-7b).

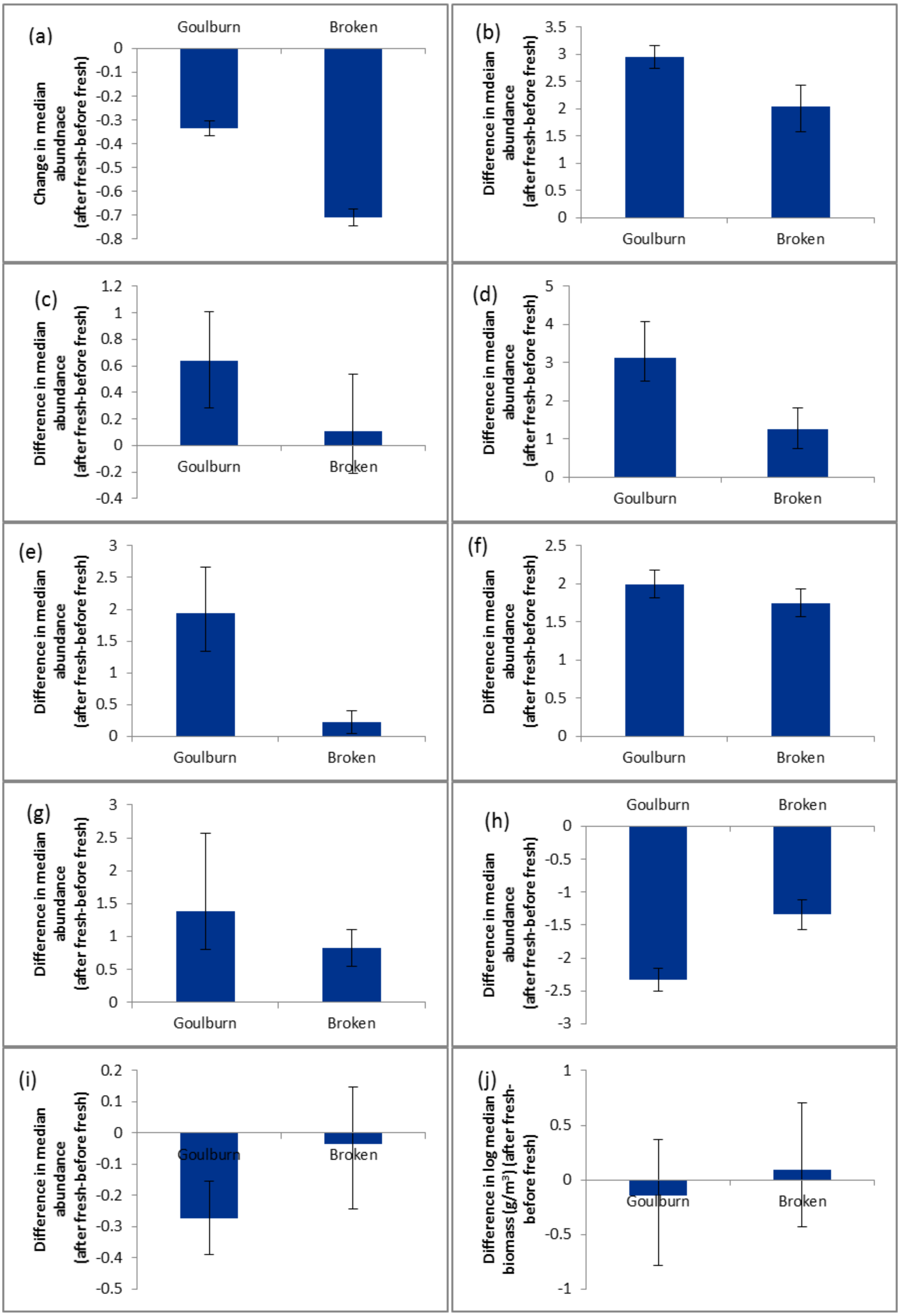


Figure D-6. Change in median total (a), *Procladius* sp. (b), *Cryptochironomus* sp. (c), *Cladotanytarsus* sp. (d), *Rheotanytarsus* sp. (e), *E. pansus* (f), *E. continentalis* (g), *Parakiefferiella* sp. (h) and *Tanytarsus manleyensis* (i) abundance combined across 2014-15 and 2015-16 and total biomass in 2015-16 (j) in artificial substrates deployed in the Goulburn and Broken Rivers Error bars indicate the 95 percent Bayesian credible intervals.

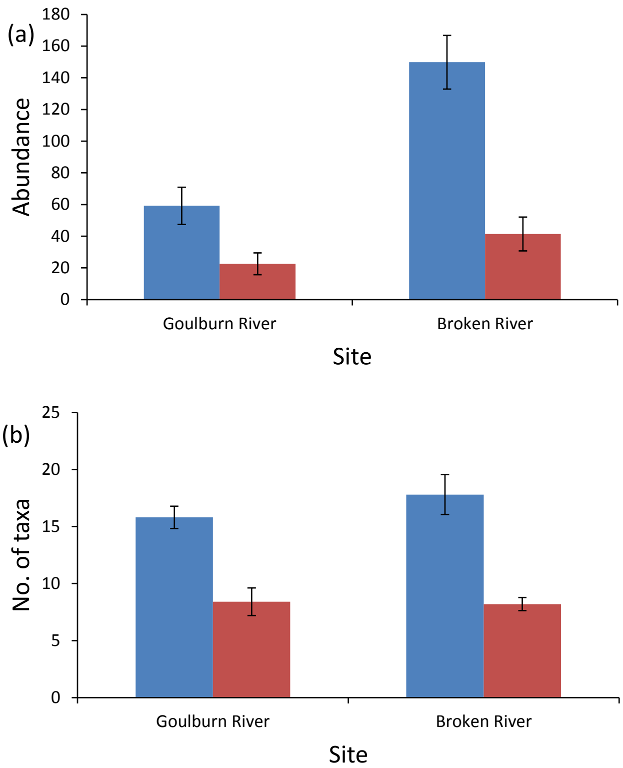


Figure D-7. (a) Total abundance of macroinvertebrates and (b) taxonomic richness (average ± standard error of the mean) from replicated edge sweep samples in the Goulburn and Broken Rivers in spring 2015. Blue = before the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

Biomass increased post-Commonwealth environmental water in the Goulburn River while it remained relatively similar in the Broken River (Figure D-8a). This was also observed in the results of the Bayesian BACI ANOVA model (Figure D-9), where there was a 92% chance that the increase in biomass in the Goulburn River was greater than the Broken River. Biomass and associated changes pre- and post-Commonwealth environmental water were largely driven by Crustacea (Figure D-8b), with both prawn *Macrobrachium australiense crassum* and shrimp *Paratya australiensis* biomass increasing post-Commonwealth environmental water in the Goulburn River (Figure D-8c,d). The biomass of EPT showed a different pattern, decreasing in abundance at both sites post-Commonwealth environmental water (Figure D-8d). It is also important to note that EPT contributed more to biomass in the Broken River than the Goulburn River.

Common taxa that comprised >1% of the total abundance and were present at both sites were examined further. Five of these were Dipteran (fly) larvae. Only the midge *Cryptochironomus* sp. showed any response that might be associated with the delivery of environmental water, becoming absent in the Goulburn River post-Commonwealth environmental water while becoming present in the Broken River (Figure D-10a). Three other midges (*Cricotopus parbicinctus*, *Parakiefferiella* sp. and *Tanytarsus manleyensis*) along with the black fly *Austrosimulium furiosum* decreased in abundance (or became absent) post-Commonwealth environmental water at both sites (Figure D-10b,c,d,e).

Similar to the Diptera, the Hemipteran (bug) *Micronecta annae annae* decreased in abundance at both sites post-Commonwealth environmental water (Figure D-11a), as did Oligochaeta (worms) (Figure D-11b). However, the change in abundance was greater in the Broken River than the Goulburn River, perhaps suggesting the spring fresh lessened the severity of this reduction in abundance. The freshwater prawn *Macrobrachium australiense crassum* increased in abundance post-Commonwealth environmental water, and the increase only occurred in the Goulburn River (Figure D-11c), again suggesting a positive effect of the spring fresh on the abundance of prawns. The mayfly *Tasmanocoenis reiki* also increased in abundance post-Commonwealth environmental water, but this occurred at both sites and to a greater extent in the Broken River (Figure D-11d).

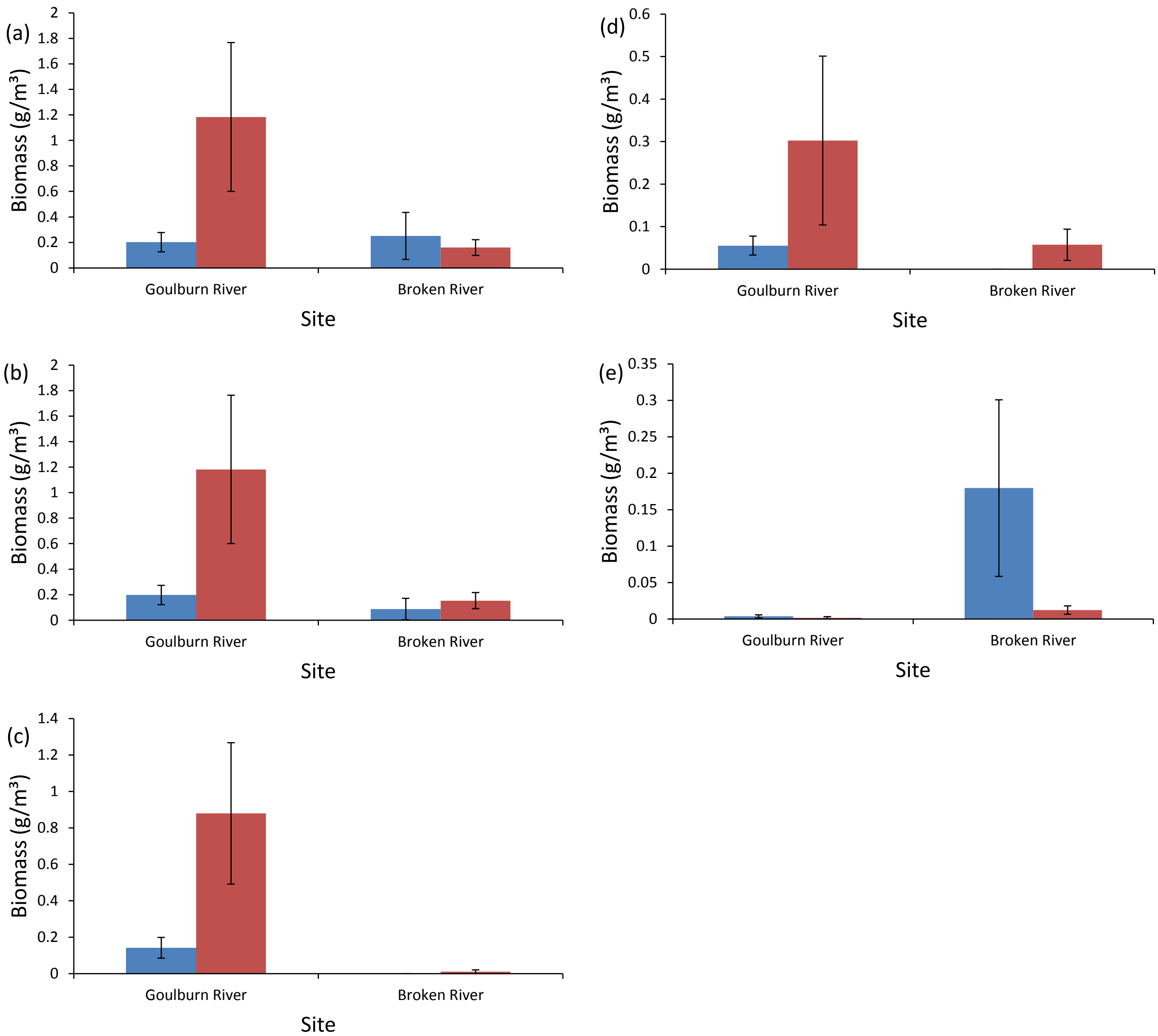


Figure D-8. Large macroinvertebrate (>5mm) biomass of (a) all macroinvertebrates, (b) Crustacean, (c) prawn *Macrobrachium australiense crassum*, (d) shrimp *Paratya australiensis* and (e) Ephemeroptera, Plecoptera and Trichoptera (EPT) (average + standard error of the mean) from replicated edge sweep samples in the Goulburn and Broken Rivers in spring 2015. Blue = before the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

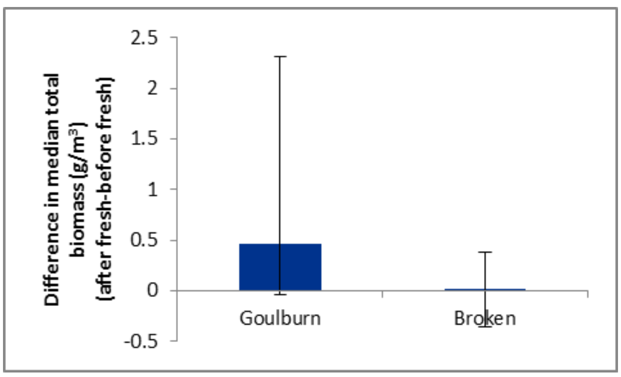


Figure D-9. Change in median large macroinvertebrate (>5mm) biomass before and after the spring fresh in the Goulburn and Broken Rivers in 2015-16. Error bars represent the 95% Bayesian credible intervals.

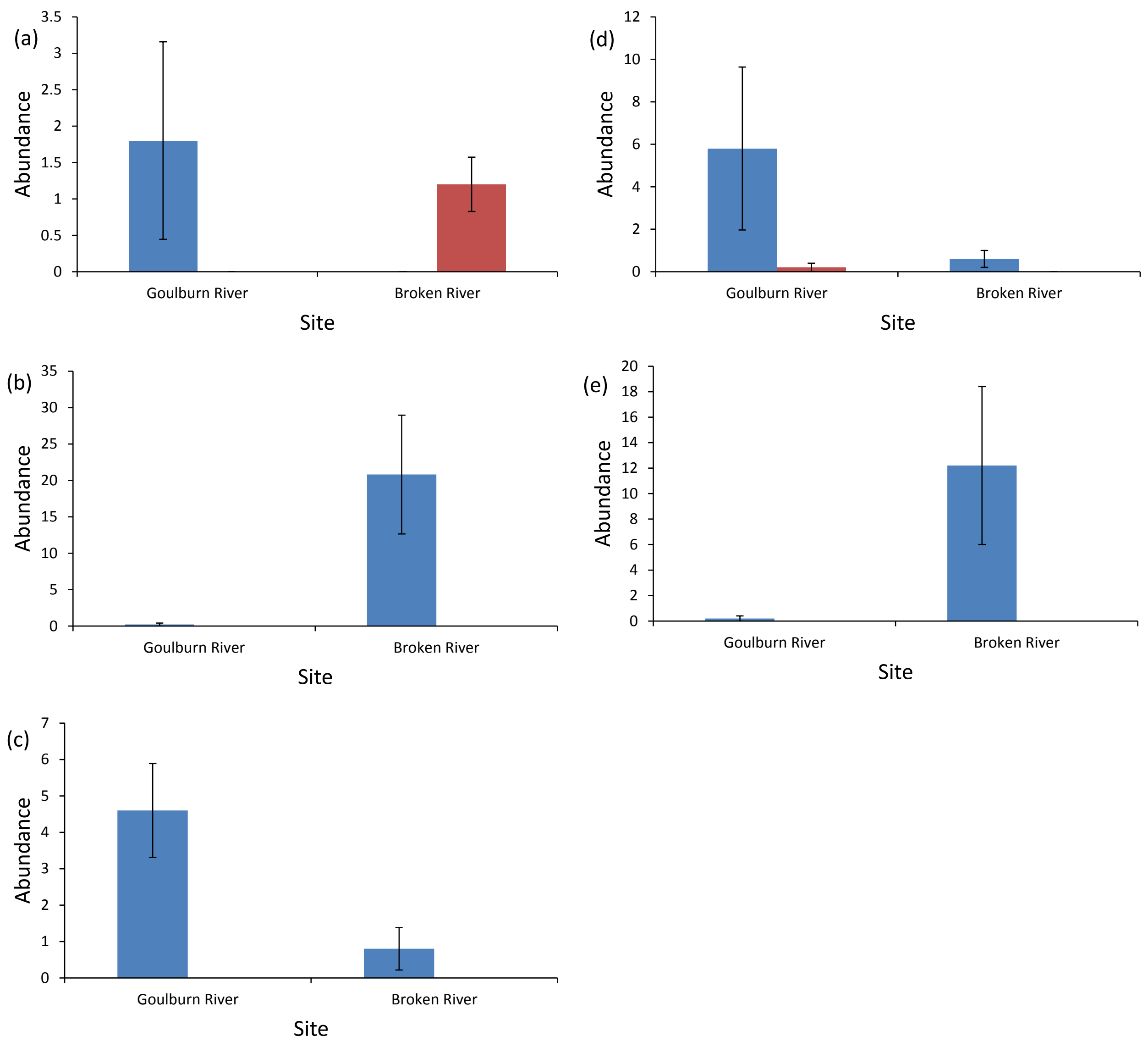


Figure D-10. Average (+ standard error of the mean) abundance of Diptera (a) *Cryptochironomus* sp., (b) *Cricotopus parbicinctus*, (c) *Parakiefferiella* sp., (d) *Tanytarsus manleyensis* and (e) *Austrosimulium furiosum* from replicated edge sweep samples in the Goulburn and Broken Rivers in spring 2015. Blue = before the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

D.3.4 Yellow sticky traps

The abundance of invertebrates caught on the yellow sticky traps in 2015-16 was 38,671 individuals, 8,000 more than were caught in 2014-15. In 2015-16, invertebrate abundance increased with each successive sampling event at both sites, with the greatest increase in abundance post-Commonwealth environmental water in the Goulburn River (Figure D-12a). This also occurred in 2014-15, although the Broken River experienced the greatest increase in abundance (Figure D-12b).

Thysanoptera were the most abundant insect Order caught on the sticky traps (14,935 individuals), followed by Diptera (9,549), Hymenoptera (7,036), Hemiptera (5,726) and Coleoptera (735). Other Orders were much less common (<250 individuals). Thysanoptera and Hymenoptera abundances reflected temporal trends and increased across the sampling period, with much greater abundances post-Commonwealth environmental water compared to pre-Commonwealth environmental water and during the spring fresh (Figure D-13a,b). This is similar to what was observed in 2014-15 (Figure D-10d and D-10a from Webb et al. 2016). Dipteran abundance decreased in each successive sampling event in the Goulburn River, perhaps indicating the spring fresh was suppressing the emergence or activity of flies in the riparian zone, whereas in the Broken abundance pre- and post-Commonwealth environmental water was similar with a large increased observed at the time when the fresh was delivered (Figure D-13c). This differs from 2014-15, where slight declines in abundance occurred at both sites post-Commonwealth environmental water (Figure D-10b in Webb et al. 2016). Hemipteran abundance showed similar patterns at both sites, with a large increase during the fresh followed by a decline (Figure D-13d). The increase in abundance post-Commonwealth environmental water compared to pre-Commonwealth environmental water also occurred in 2014-15 (Figure D-10c in Webb et al. 2016). Coleoptera were the only Order than showed any indication that environmental water was having a positive effect on riparian invertebrates, with a large increase in abundance post-Commonwealth environmental water in the Goulburn River that was not matched in magnitude in the Broken River (Figure D-13e), similar to what was observed in 2014-15 (Figure D-10e in Webb et al. 2016)

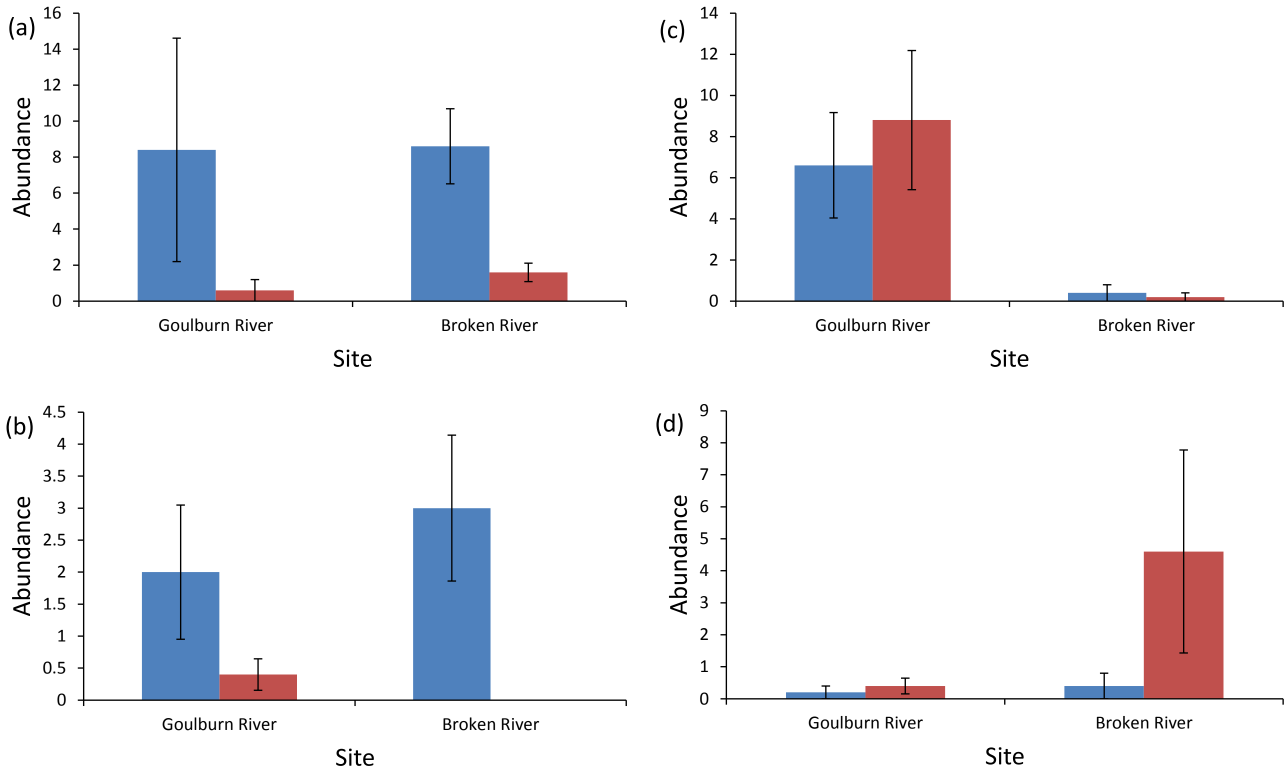
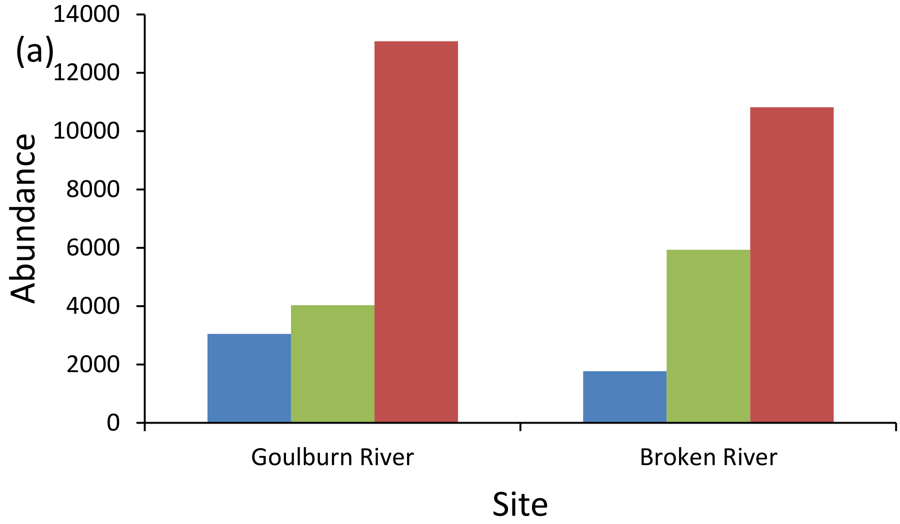


Figure D-11. Average (± standard error of the mean) abundance of (a) Hemiptera *Micronecta annae annae*, (b) worms Oligochaeta, (c) Crustacea *Macrobachium australiense crassum* and (d) Ephemeroptera *Tasmanocoenis reiki* from replicated edge sweep samples in the Goulburn and Broken Rivers in spring 2015. Blue = before the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

Fewer organisms with aquatic life stages were caught on the yellow sticky traps in 2015-16 compared to 2014-15 (3,091 organisms compared to 7,262 organisms). The number of aquatic invertebrates was lower post-Commonwealth environmental water than pre-Commonwealth environmental water in the Goulburn River, whereas the opposite occurred in the Broken River (Figure D-14a). In contrast, the abundance of aquatic invertebrates increased slightly in the Goulburn River post-Commonwealth environmental water in 2014-15, whereas it decreased substantially in the Broken River (Figure D-14b). Individuals from Ephemeroptera, Trichoptera and Plecoptera were rare on the sticky traps, with the aquatic fauna dominated by three Dipteran families: biting midges (Ceratopogonidae), bathroom flies (Psychodidae) and non-biting midges (Chironomidae). Ceratopogonidae abundance decreased at both sites during successive sampling events and did not appear to be affected by the spring fresh (Figure D-14c). In contrast, in 2014-15 its abundance increased post-Commonwealth environmental water in the Broken River (Figure D-14d). The abundance of Psychodidae increased during and after the spring fresh, but this effect was much greater in the Broken River than the Goulburn River and does not appear to be related to environmental water (Figure D-14e). This differs from

2014-15, where Psychodidae abundance decreased at both sites during and after the spring fresh (Figure D-14f).



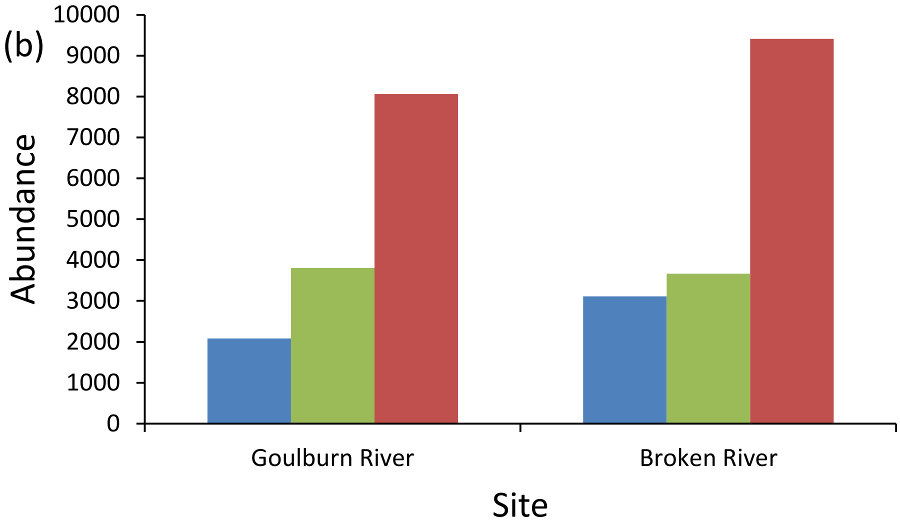


Figure D-12. Abundance of all invertebrates caught on yellow sticky traps in (a) 2015-16 and (b) 2014-15 in the Goulburn and Broken Rivers during spring. Blue = before the Commonwealth environmental water event; green = during the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

The abundance of aquatic Chironomidae was higher pre-Commonwealth environmental water in the Goulburn River than the Broken, but was lower post-Commonwealth environmental water, whereas the opposite occurred in the Broken River (Figure D-15a). Chironomid adult abundance peaked during the spring fresh at both sites, which was also observed in 2014-15 (Figure D-15b), along with an increase in abundance of chironomids post-Commonwealth environmental water in the Broken Creek. Taxonomic richness of chironomids was higher post-Commonwealth environmental water than pre-Commonwealth environmental water at both sites and in both years (Figure D-15c,d).

Six species of chironomids were common on the sticky traps in both 2014-15 and 2015-16, and while there was some indication that responses were affected by environmental flows, these were not always consistent across years. In 2015-16, adult *Cricotopus parbicinctus* abundance increased during the fresh in the Goulburn River and decreased after, whereas in the Broken River it increased slightly post-Commonwealth environmental water (Figure D-16a).In contrast, its abundance increased at both sites post-Commonwealth environmental water in 2014-15 (Figure D-16b). *Microcricotopus parvulus* abundance increased during the fresh at both sites in 2015-

16, and continued to increase in the Goulburn River while it decreased in the Broken River post-Commonwealth environmental water, indicating a positive effect of environmental flows on this species (Figure D-16c). Similarly, its abundance increase post-Commonwealth environmental water in the Goulburn River in 2014-15 (Figure D-16d). During the spring fresh in 2015-16 *Thienemanniella trivittata* increased in abundance at both sites, but disappeared from the Goulburn River post-Commonwealth environmental water (Figure D-16e). However, this is inconsistent with what was observed in 2014-15, with an increase in abundance post-Commonwealth environmental water in the Goulburn River and a decrease in the Broken River (Figure D-16f), making it difficult to attribute a response of this species to environmental water.

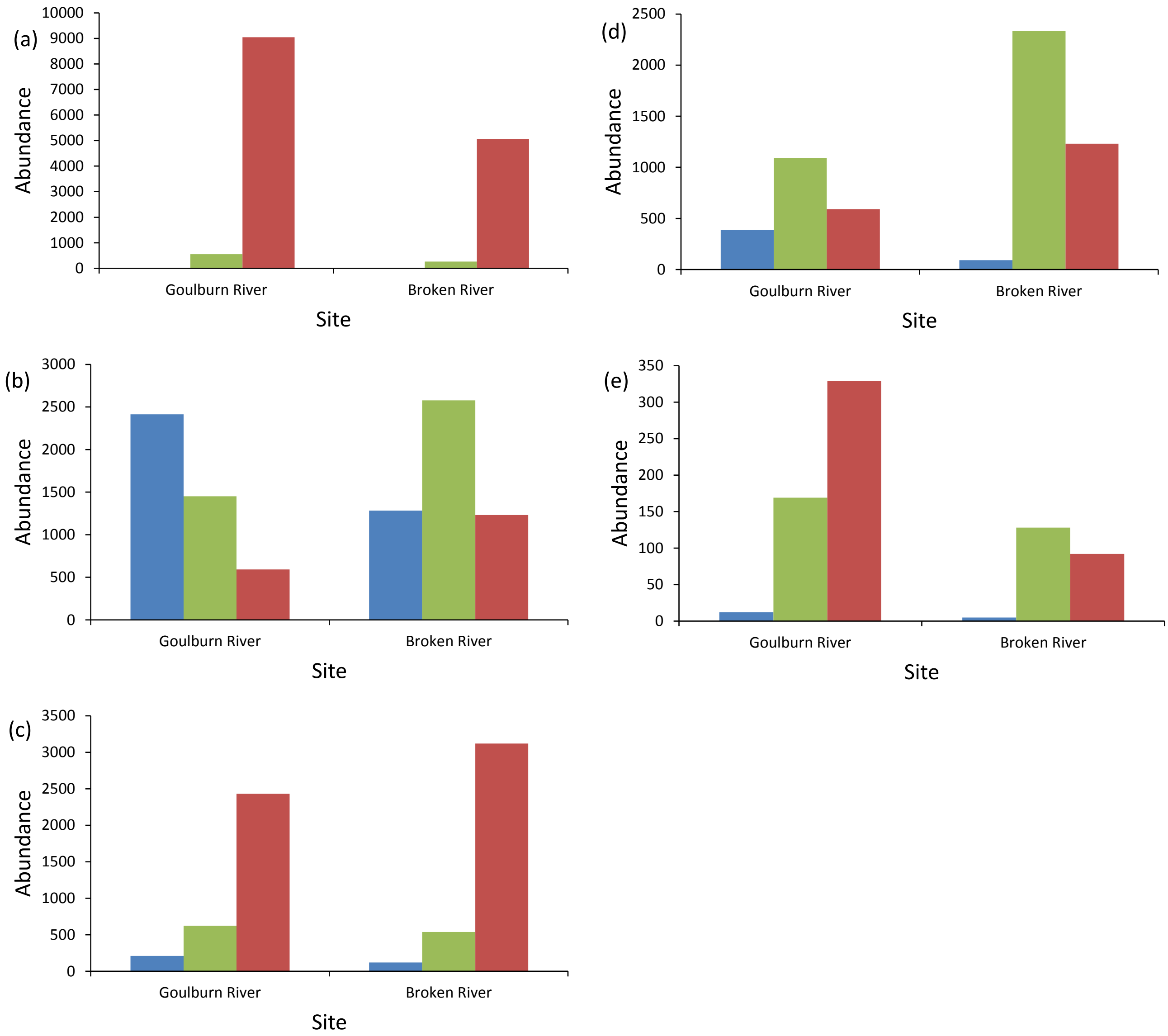


Figure D-13. Abundance of (a) thrips Thysanoptera, (b) flies Diptera, (c) wasps, bees and ants Hymenoptera, (d) true bugs Hemiptera and (e) beetles Coleoptera on yellow sticky traps deployed at the Goulburn and Broken Rivers in spring 2015-16. Blue = before the Commonwealth environmental water event; green = during the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

There appeared to be a negative effect of environmental water on the abundance of *Parakiefferiella variegatus* in 2015-16, with its abundance reduced during and after the fresh (compared with an increase in the Broken River post-Commonwealth environmental water) (Figure D-16g). This differs from what was observed in 2014-15, with abundance peaking during the fresh delivery at both sites, but decreased post-Commonwealth environmental water compared to pre-Commonwealth environmental water (Figure D-16h). *Tanytarsus* *palmatus* abundance was also reduced in the Goulburn River post-Commonwealth environmental water compared to pre-Commonwealth environmental water in 2015-16, whereas its abundance increased during the fresh at both sites and post-Commonwealth environmental water in the Goulburn, indicating a negative effect of the environmental water on this species (Figure D-16i). In contrast, its abundance increased at both sites post-Commonwealth environmental water in 2014-15 (Figure D-16j). Site appeared to be a more important factor affecting *Corynoneura australiensis* than environmental water as its abundance was very low in the Goulburn River in both years (Figure D-16k,l).

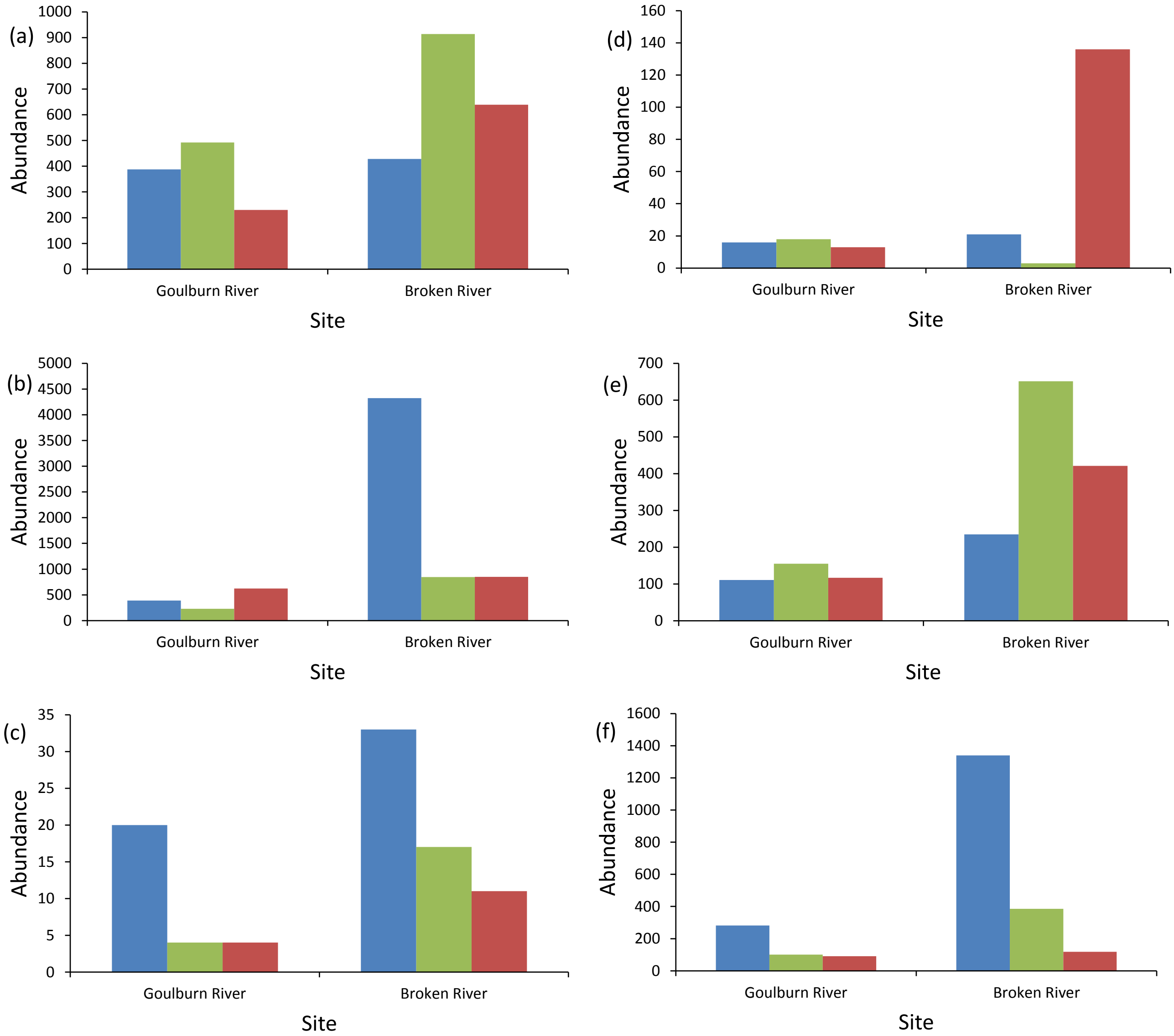


Figure D-14. Abundance of (a) all aquatic insects in 2015-16, (b) all aquatic insects in 2014-15, (c) biting midges Ceratopogonidae in 2015-16, (d) Ceratopogonidae in 2014-15, (e) bathroom flies Pyschodidae in 2015-16 and (f) Psychodidae in 2014-15 on yellow sticky traps deployed at the Goulburn and Broken Rivers in spring. Blue = before the Commonwealth environmental water event; green = during the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

D.4 Discussion

The three monitoring methods continued to provide a large amount of data on macroinvertebrate responses pre- and post-Commonwealth environmental water. The results from the 2015-16 monitoring period largely concurred with those of the previous year, showing that the responses of individual taxa were more informative than species richness and total abundance measures. Importantly, preliminary analyses of biomass data showed macroinvertebrate biomass was also sensitive to environmental water, which has implications for native fish that prey on these animals.

D.4.1 Effects of environmental water on macroinvertebrates

For the environmental water to be considered as having a positive effect on macroinvertebrates, measured parameters would either have to increase in the Goulburn River post-Commonwealth environmental water (but remain unchanged, decrease, or increase to a lesser extent in the Broken River), or decrease in the Broken River (but remain unchanged, or decrease to a lesser extent in the Goulburn River: evidence the environmental flows were reducing the severity of any reductions observed). Environmental flows could benefit macroinvertebrates by potentially increasing food availability through increasing nutrients and carbon concentrations in the stream, increasing riverine productivity, moving woody debris and redistributing organic matter, and introducing terrestrial organic matter into the stream. In the Short Term Intervention Monitoring (STIM) program, these effects were observed in the Goulburn River in response to environmental flows (Webb et al. 2015). Environmental water can also increase the availability of favourable habitats, such as deep pools and slack water habitats (Webb et al. 2015). Alternatively, environmental water can benefit macroinvertebrates by preventing conditions from deteriorating (e.g. environmental flows are used to maintain dissolved oxygen concentrations in Broken Creek (Peter Cottingham & Associates and SKM 2011), and while negative impacts may still occur, these would be less severe than what might happen in the absence of environmental water delivery. This “rescue effect” would become increasingly important under the dry conditions experienced in 2015-16. Environmental water delivery to the Goulburn River, in conjunction with other water delivered, would have prevented conditions from deteriorating to the same extent as observed in the Broken River, which ceased to flow and became a series of pools during the spring survey period.

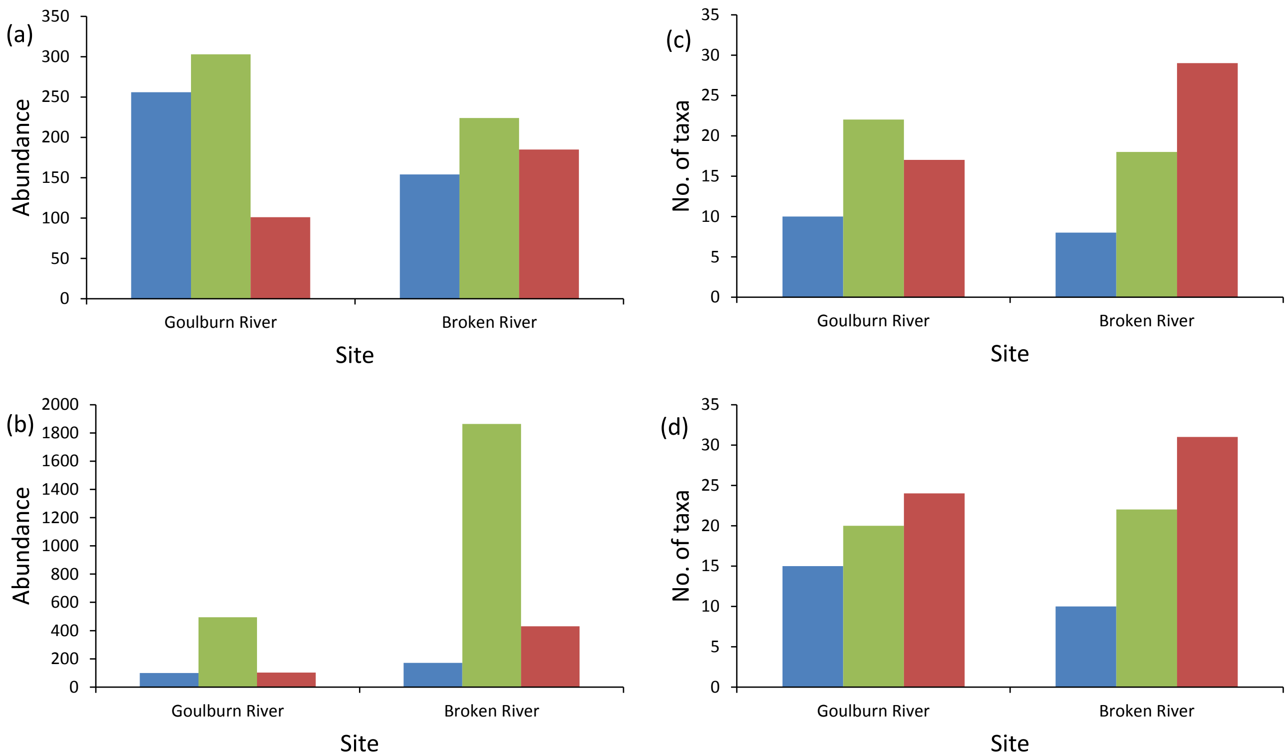


Figure D-15. (a) Abundance in 2015-16, (b) abundance in 2014-15, (c) taxonomic richness in 2015-16 and (d) taxonomic richness in 2014-15 of adult midges (Chironomidae) with aquatic larvae caught on yellow sticky traps in the Goulburn and Broken Rivers in spring. Blue = before the Commonwealth environmental water event; green = during the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

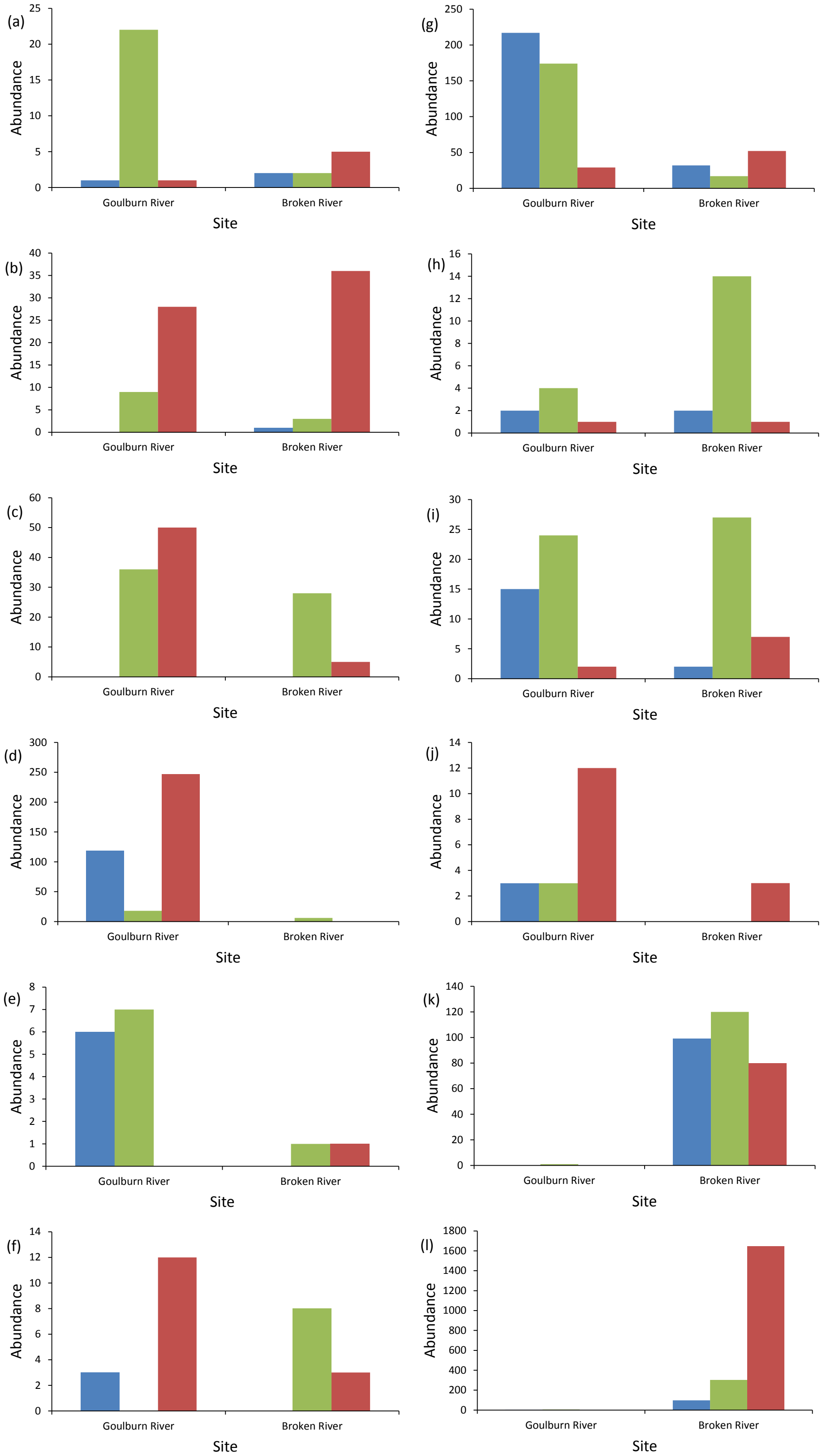


Figure D-16. Abundance of (a) *Cricotopus parbicinctus* in 2015-16, (b) *C. parbicinctus* in 2014-15, (c) *Microcricotopus parvulus* in 2015-16, (d) *M. parvulus* in 2014-15, (e) *Thienemanniella trivittata* in 2015-16, (f) *T. trivittata* in 2014-15, (g) *Parakiefferiella variegatus* in 2015-16, (h) *P. variegatus* in 2014-15, (i) *Tanytarsus palmatus* in 2015-16, (j) *T. palmatus* in 2014-15, (k) *Corynoneura australiensis* in 2015-16 and (l) *C. australiensis* in 2014-15 on yellow sticky traps in the Goulburn and Broken Rivers in spring. Blue = before the Commonwealth environmental water event; green = during the Commonwealth environmental water event; red = after the Commonwealth environmental water event.

Environmental water, delivered as a spring fresh, did not affect macroinvertebrate diversity for any method, which is consistent with the previous year's results (Webb et al. 2016), the lower Goulburn STIM (Webb et al. 2015) and in western Victorian streams (Mackie et al. 2013). In contrast, there was some evidence that environmental flows were having a positive effect on macroinvertebrate abundance, with the decrease in macroinvertebrate abundance post-CEW less severe in the Goulburn River than the Broken River for both artificial substrates and RESS samples. This was also observed in artificial substrates in 2014-15. Such a result would suggest that the environmental flow, while not promoting an increase in macroinvertebrate abundance, was alleviating or preventing abundance from decreasing to the same extent as what was observed in the Broken River.

Macroinvertebrate biomass was one of the most sensitive measures of an effect of environmental flows. The biomass of both artificial substrates and RESS samples was dominated by crustaceans, particularly the freshwater prawn *Macrobrachium australiense crassum*, but also the shrimp *Paratya australiensis* in RESS samples. Interestingly, the two methods showed an opposite effect of environmental flows. Biomass (and specifically crustacean biomass) decreased post-Commonwealth environmental water in the artificial substrates but increased in the RESS samples. It is not clear why this is the case, although it could be due to a change in how *M. australiense crassum* is using habitats after the spring fresh, with *M. australiense crassum* moving out of the channel and into the littoral zone (hence, lower biomass in the artificial substrates and more in the edge habitat samples). The abundance of this species also increased in the edge habitat post-Commonwealth environmental water. One reason for this might be spatial changes in food availability for these animals. Biofilms are an important component of *M. australiense crassum* diets (Burns and Walker 2000). In the STIM, benthic algal biofilms were reduced with environmental water delivery (Webb et al. 2015). If benthic biofilm reduction was greater in the channel (where artificial substrates are deployed) than in the littoral zone (where increased habitat complexity and greater light penetration might reduce effects on biofilms), *M. australiense crassum* may move into the littoral zone where food availability is less affected. Alternatively, the flows may improve the quality of biofilms in the littoral zone.

Some individual taxa also showed responses to the spring fresh. For example, *Procladius* sp. abundance increased in artificial substrates post-Commonwealth environmental water in the Goulburn River, which was associated with the delivery of the spring fresh. As was suggested in 2014-15, this may be due to an increase in habitat availability and quality for genera like this that prefer muddy substrates and inhabit deep water (Cranston Undated). The environmental flow seemed to ameliorate reductions in the abundance for some taxa. For example, two Ephemeroptera species (*Tasmanocoenis arcuata* and *T. tillyardii*), declined in abundance at both sites post-Commonwealth environmental water, but this decrease was much less severe in the Goulburn River. Ephemeroptera (along with Plecoptera and Trichoptera) tend to be associated with flowing water and higher habitat quality (e.g. Scholl et al. 2016), and dry conditions reduce the richness and density of EPT (e.g. Storey 2016). They are also sensitive to multiple stressors, and an experimental study showed negative effects of nutrient enrichment and sediment addition on these was much worse when flows were reduced (Elbrecht et al. 2016).

Other taxa may have been adversely affected by environmental flows. For example, *Tanytarsus manleyensis* was reduced by spring freshes in both 2014-15 and 2015-16. A lack of data on this species makes it difficult to determine why this might be the case, although it may be a function of flow preferences, with studies showing other *Tanytarsus* species preferring lower flow velocity environments (Collier 1993, Maroneze et al. 2011).

Temporal changes in the invertebrates inhabiting the riparian zone were evident, with increases in total abundance (as well as for particular taxa such as Thysanoptera and Hymenoptera) at both sites post-Commonwealth environmental water, presumably reflecting increasing ambient temperatures. There was also evidence that increased insect abundance due to increasing temperatures was later offset by worsening conditions (e.g. too dry or too warm), with peaks in abundance during the flow event followed by large decreases post-Commonwealth environmental water for aquatic insects and Psychodidae at both sites. Other taxa showed a clear preference for site, such as *Corynoneura australiensis*, which only occurred at Broken River. This species possibly prefers low-flow or pool environments for its larvae, which has been shown for the related species *C. scutellata* (Edward and Colless 1968).

Insect abundances increased in the riparian zone of the Goulburn River post-Commonwealth environmental water. Coleoptera (beetles), increased in abundance post-Commonwealth environmental water in the Goulburn

River but not in the Broken River. The chironomid *Microcricotopus parvulus* also increased in abundance post-Commonwealth environmental water in the Goulburn River but not the Broken River, a response that was observed in both 2014-15 and 2015-16. It is possible that these insects were attracted to the water due to the dry climate, and it is uncertain whether the occurrence of environmental flows made this increase in abundance more likely. Monitoring in future years will help us better understand whether these changes in abundances of terrestrial insects are linked to environmental flows.

D.5 Conclusion and recommendations

The monitoring data from the 2014-15 and the 2015-16 periods suggest that macroinvertebrates in the Goulburn River may be responding to environmental flows, but substantial uncertainties remain. Significant increases in the overall macroinvertebrate abundance and biomass have not been observed, but this may be because the flows may have been too small to make an impact on all macroinvertebrate taxa. However, increases in the abundance and biomass of some taxa, along with reduced decreases in abundance of others, both observed post-Commonwealth environmental water, may indicate a role for environmental flows in sustaining macroinvertebrates, particularly under dry climatic conditions. Commonwealth environmental water appeared to also be beneficial for the biomass of invertebrates in the edge habitats of the Goulburn River. This is possibly explained by the movement of *Macrobrachium* (a large-bodied crustacean) to the edge habitats after flow events.

Future monitoring will aim to provide better understanding of the response of the most abundant taxa to environmental flows. In particular, it is recommended that in the 2016-17 monitoring period, further investigation is conducted on the links between primary production and the movement of *Macrobrachium* to edge habitats following flow events. In addition, it is proposed that monitoring could be improved in the third year of monitoring by delaying the post-fresh sampling, in order to better capture the possibly delayed response of the macroinvertebrates to the fresh.

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

Vegetation was sampled on both banks at Loch Garry and McCoy's Bridge, pre and post the delivery of spring freshes in 2014-15 and 2015-16 (Table E-1, Figure E-1). Vegetation was surveyed along transects that ran perpendicular to stream flow. Sampling initially aimed to survey regions of the bank that had previously been surveyed by other programs (i.e. VEFAMP 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, 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	McCoy's Bridge	1,2,3,6,8,10,12,13,15	1,2,3,5,10,12,13,15
	Post-fresh	16 Dec	Loch Garry	1,3,5,8,9,12,13,15	1,3,5,9,10,12,13,15
		17 Dec	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	Loch Garry	1, 3, 5, 8, 9,10,12,13	1, 3, 5, 8, 9,12,13,15
		15 Sept	McCoy's Bridge	1, 2, 6, 10, 12, 13,15	2, 3, 6,10,12,13,15
	Post-fresh	16 Dec	Loch Garry	1, 3, 5, 8, 9,10,12,13	1, 3, 5, 8, 9,12, 13,15
		17 Dec	McCoy's Bridge	1, 2, 3, 6,10,12,13,15	1, 2, 3, 6, 10, 12, 13, 15

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.

In 2015-16 all target locations were sampled in September prior to the spring fresh and again in December, ~ 6.5 weeks after the delivery of the spring fresh with the exception of two transects on McCoy's Bridge. 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 surface cover type(s) were assessed in the same manner. Overstorey vegetation cover was assessed applying the same sampling approach but using a crosswire sighting periscope held vertically at each pointing location. The density of woody recruits was initially assessed within 1m x 1m quadrats positioned at the bottom, middle and top of the bank profile. Due to the very low number of recruits, this approach was modified to increase the surveyed area (see details in Standard Operating Procedure; Webb et al. 2014).

E.2.2 Assessing response to spring freshes

Vegetation responses to the spring fresh have been assessed in three ways: (i) species counts pre and post fresh at each site (ii) qualitative examination of percent foliage projective cover (FPC) of different vegetation types across elevation profiles at each site pre and post spring fresh, and (iii) a hierarchical Bayesian logistic regression, whereby the probability of occurrence of different vegetation types across the elevation profile at each site pre and post spring fresh.

The hierarchical Bayesian logistic regression is formulated as:

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

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

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

$$\begin{aligned} logit(probability.after_i) \\ = int.a + slope.after_j \times I.365_{\ i} + eff.site.after_j + eff.unit.after_k + eff.transect.after_{\ l} \\ + eff.year.after_m \end{aligned}$$

The presence or absence of 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 before and after the spring fresh (*veg.before* and *veg.after*) are modelled separately. The occurrence of vegetation before the spring fresh (veg.before) is a function of the global average across all sites in the absence of inundation (*int.b*), and the effect of inundation in the previous year (*slope.before*) on each site j. There is also a random effect of the site, the sampling unit, the sampling transect, and year (*eff.site*, *eff.unit, eff.transect, eff.year*). The occurrence of vegetation after the spring fresh (*veg.after*) is a function of the global average across all sites in the absence of inundation (*int.a*), and the effect of inundation in the previous year (*slope.after*) on each site j. There is also a random effect of the site, the sampling unit, the sampling transect, and year (*eff.site.after*, *eff.unit.after*, *eff.transect.after*, *eff.year.after*).

All random effects are drawn from a normal distribution with a mean of 0 and standard deviations of *s.transect*, *s. unit*, *s.year and s.site* (random effects before the spring fresh) and *s.transect.after*, *s.unit.after*, *s.year.after*, *s.site.after* (random effects after the spring fresh).

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

$$eff.year_i \sim N(0, s.year^2)$$

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

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

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

$$eff.year.after_i \sim N(0, s.year.after^2)$$

$$eff.transect.after_{jk} \sim N(0, s.transect.after^2)$$

$$eff.unit.after_{jk} \sim N(0, s.unit.after^2)$$

Site level estimates of *slope.before* and *slope.after* were modelled hierarchically and drawn from normal hyper-distributions with means of *mu.slope.b* and *mu.slope.a*, and standard deviations of *s.slope.b* and *s.slope.a*.

$$slope.b_j \sim N(mu.slope.b, s.slope.b^2)$$

$$slope.a_j \sim N(mu.slope.a, s.slope.a^2)$$

Minimally informative prior distributions were assigned to the intercepts *int.b* and *int.a* and *mu.slope.b* and *mu.slope.a* (normal distributions with a mean of 0 and variance of 10). Minimally informative prior distributions were also assigned to *s.slope.a*, *s.slope.b*, *s.site, s.site.after, s.transect, s.transect.after, s.unit, s.unit.after, s.year, and s.year.after* (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 different vegetation species and groups of species.

E.2.3 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 lower panel). A maximum discharge of ~6200 ML/d was released. In contrast to 2014 there were no further releases to meet fish objectives.

E.2.4 Climatic conditions

In December of 2014 and 2015 the soils were extremely dry despite the delivery of spring freshes. Rainfall and air temperatures leading up to and following the fresh probably moderated the level of soil moisture recharge achieved by the spring fresh which in turn would have influenced vegetation responses.

The climatic conditions recorded by the Bureau of Meteorology at Shepparton Airport (Station Number 081125) indicate that December 2014 was hotter (mean max air temp of 30.2 °C cf 28.8°C) and drier (17.4 mm vs 31.8 mm) compared with the long term average (1996-2015). These drier conditions may have limited the responses of vegetation to spring freshes in 2014-15.

Similarly in 2015-16, mean annual rainfall (364 mm) was ~20% lower than the longer term average (1996-2015). These drier conditions are reflected in low flows in the Goulburn River in the months leading up to the October spring fresh in 2015. Both low river flow and low rainfall leading up to the fresh are likely to have produced dry banks and reduced the effectiveness of the fresh in increasing bank moisture. This may have limited vegetation response to the fresh.

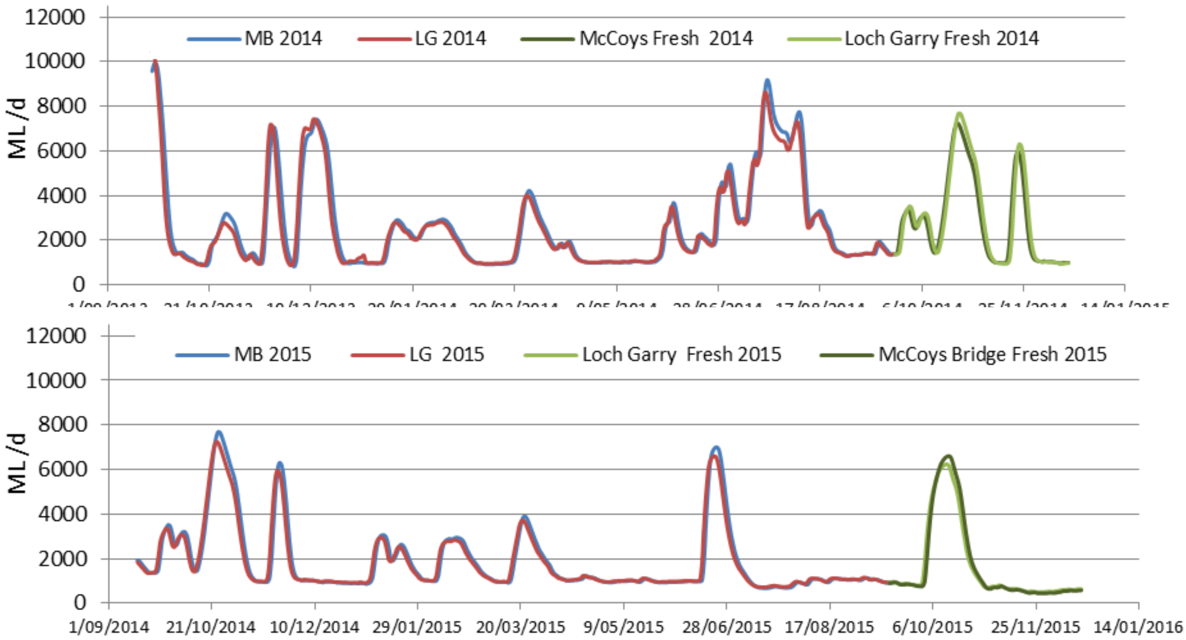


Figure E-1. Goulburn river discharge (ML/d) between pre and post fresh surveys at Loch Garry (light green) and McCoy's Bridge (dark green) in 2014-15 (upper panel) and 2015-16 (lower panel) and over the year prior to vegetation surveys prior to spring freshes at McCoy's Bridge (blue line) and Loch Garry (red line).

E.3 Monitoring results and observations

E.3.1 Patterns of inundation

The duration and depth of inundation experienced by vegetation along the river bank is determined by their position along the elevation gradient and by patterns of river discharge. The elevation inundated by spring freshes are based on rating curves that represent the relationship between river discharge in ML/d and river height in AHD m measured at Loch Garry and McCoy's Bridge. This rating curve was corrected in 2015 and has produced some discrepancy between the elevations reached by freshes reported in 2014-15. New data indicates that the upper elevation reached by the spring fresh at Loch Garry and McCoy's Bridge in 2014 was 100.5 and 95.5 m AHD, respectively. Similar elevations were reached by the spring fresh in 2015 (Figure E-2).

At the lowest elevations surveyed, the total number of days inundated over the year prior to sampling fell by 43% in 2015-16 (146 days) compared to 2014-15 (257 days) reflecting the drier conditions (Figure E-2). Spring freshes represent 17% to 22 % of the total days inundated at the lowest elevation and suggest that smaller flow events between freshes have the potential to exert a strong influence of vegetation.

E.3.2 Patterns across the elevation gradient

The FPC of the aquatic ground layer vegetation was generally greater at elevations inundated by the spring fresh and tended to decline at higher elevations not inundated by spring freshes. This pattern is more apparent when compared with the FPC of grasses, which shows an opposite trend, particularly at Loch Garry, where FPC increased at higher elevations not inundated by the spring fresh (Figure E-3b).

For both the aquatic ground layer and grasses, FPC cover showed a slight shift towards lower elevations in 2015-16 compared with 2014-15. This is consistent with the generally drier conditions leading up to the 2015 pre fresh survey compared with 2014-15. This was most evident for Lesser Joyweed which was eliminated at higher elevations. Increases in the cover of Creeping Knotweed (*Persicaria prostrata*) between 2014-15 and 2015-16 at Loch Garry were mostly restricted to lower elevations.

Woody recruits represented by *Acacia dealbata* and *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.

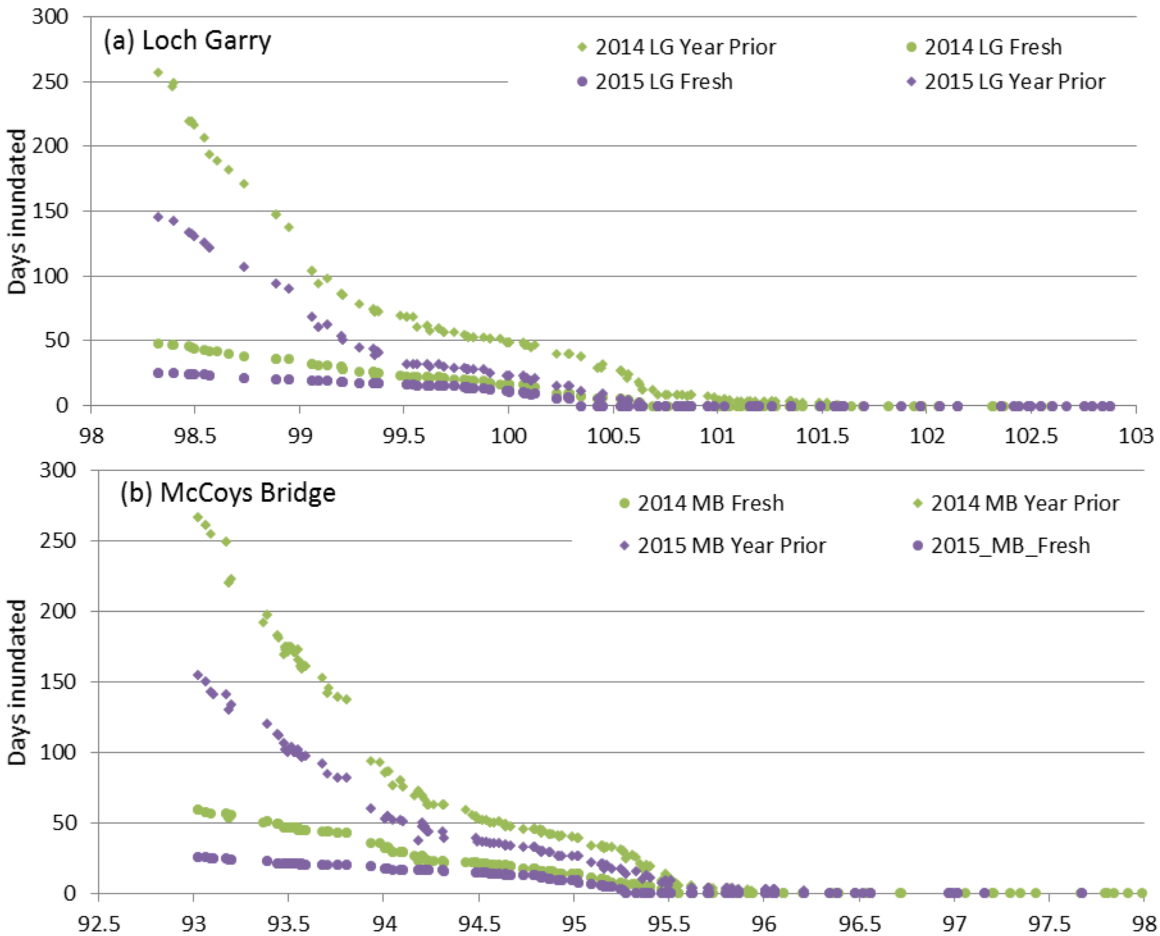


Figure E-2. Days inundated between pre and post fresh surveys in 2014 (green circles) and 2015 (purple circles) and over the year prior to vegetation surveys in 2014 (green diamonds) and 2015 (purple diamonds) at Loch Garry (a) and McCoy's Bridge (b)

E.3.3 Response to spring freshes

Change in species number following the spring fresh was not evaluated in 2014-15 as differences in survey effort along the elevation gradient and between times would have given incorrect inferences. In 2015-16, survey effort was comparable pre and post fresh with the exception of two transects at McCoy's Bridge which were not surveyed pre-fresh. A total of 59 and 66 taxa were detected along surveyed transect in 2015-16 at Loch Garry and McCoy's Bridge. At each site the suite of taxa and the total number of taxa differed between sampling times and total taxon number was slightly lower (3-4 taxa) in December after the fresh. Differences are likely to be caused by seasonal changes in the presence of annual terrestrial herbs and grasses (Table E-2) rather than the fresh.

Table E-2. Plant taxa identified in vegetation surveys at McCoy's Bridge and Loch Garry in September and December 2015, pre and post fresh, respectively. Naming is based on the National Herbarium of NSW. Asterisk denotes exotic species.

McCoy's Bridge		Loch Garry	
Sept 2015	Dec 2015	Sept 2015	Dec 2015
Acacia dealbata	*Acacia dealbata*	*Acacia dealbata*	*Acacia dealbata*
Alternanthera denticulata	*Alternanthera denticulata*	*Alternanthera denticulata*	*Alternanthera denticulata*
*Anagallis sp.**	*Aster subulatus**	*Anthosachne scabra*	*Avena barbata**
*Arctotheca calendula**	*Avena barbata**	*Arctotheca calendula**	*Bromus sp.*
*Aster subulatus**	*Carex appressa*	*Bromus diandrus**	*Callistemon sieberi*
*Avena sp.**	*Carex sp.*	*Callistemon sieberi*	*Carex sp.*
*Bromus diandrus**	*Carex tereticaulis*	*Carex appressa*	*Carex tereticaulis*
Calotis scapigera	*Centipeda cunninghamii*	*Carex sp.*	*Centipeda cunninghamii*
Carex appressa	*Cirsium vulgare**	*Centipeda cunninghamii*	*Cirsium vulgare**
Carex sp.	*Chenopodium ambrosioides**	*Cirsium vulgare**	*Conyza sumatrensis var sumatrensis**
Centipeda cunninghamii	*Conyza sp.**	*Conyza bonariensis**	*Cyperus eragrostis **
*Chenopodium ambrosioides**	*Cynodon dactylon var. dactylon **	*Crassula decumbens*	*Cyperus exaltatus*
*Cirsium vulgare Conyza bonariensis**	*Cyperus eragrostis **	*Cyperus eragrostis**	*Cyperus sp.*
*Conyza bonariensis**	*Cyperus sp.*	*Cyperus sp.*	*Dysphania pumilio*
Conyza sp.	*Dysphania pumilio*	*Epilobium sp.*	*Ehrharta longiflora**
*Cyperus eragrostis**	*Eclipta sp.*	*Eragrostis elongata*	*Eragrostis brownii*
Cyperus exaltatus	*Eucalyptus camaldulensis*	*Eucalyptus camaldulensis*	*Eragrostis elongata*
Cyperus sp.	*Gnaphalium polycaulon*	*Euchiton sp.*	*Eucalyptus camaldulensis*
*Ehrharta longiflora**	*Haloragis heterophylla*	*Galium aparine**	*Gnaphalium polycaulon*
Eucalyptus camaldulensis	*Pseudognaphalium luteoalbum*	*Gamochaeta sp.*	*Haloragis aspera*
*Galium aparine**	*Helminthotheca echioides**	*Holcus sp.**	*Hypochaeris radicata**
*Helminthotheca echioides**	*Juncus amabilis*	*Hypochaeris radicata**	*Juncus amabilis*
*Holcus sp.**	*Juncus sp.*	*Juncus amabilis*	*Juncus flavidus*
*Hypochaeris radicata**	*Juncus subsecundus*	*Juncus aridicola*	*Juncus sp.*
Juncus amabilis	*Juncus usitatus*	*Juncus sp.*	*Juncus usitatus*
Juncus sp.	*Lachnagrostis filiformis*	*Juncus usitatus*	*Lachnagrostis filiformis*
Juncus usitatus	*Lolium sp.**	*Lachnagrostis filiformis*	*Lactuca sp.*
Lachnagrostis filiformis	*Lythrum hyssopifolia*	*Lactuca serriola**	*Leontodon taraxacoides subsp taraxacoides**
*Lactuca serriola**	*Oxalis sp.*	*Lolium sp.**	*Lolium loliaceum**
*Lolium sp.**	*Panicum coloratum**	*Lythrum hyssopifolia*	*Lolium sp.**
Lythrum hyssopifolia	*Paspalidium jubiflorum*	*Oxalis exilis*	*Lythrum hyssopifolia*
Mentha sp.	*Paspalum distichum*	*Oxalis sp.*	*Oxalis exilis*
Oxalis sp.	*Persicaria decipiens*	*Panicum coloratum**	*Oxalis perennans*
*Panicum coloratum**	*Persicaria prostrata*	*Paspalidium jubiflorum*	*Oxalis sp.*
Paspalidium jubiflorum	*Poa labillardierei*	*Persicaria prostrata*	*Panicum coloratum**
*Paspalum dilatatum**	*Polygonum aviculare**	*Piptatherum miliaceum**	*Paspalidium jubiflorum*
Pennisetum sp.	*Rorippa sp.*	*Plantago lanceolata**	*Persicaria prostrata*
Persicaria prostrata	*Rumex sp.*	*Poa labillardierei*	*Plantago lanceolata**
*Piptatherum miliaceum**	*Senecio quadridentatus*	*Rorippa sp.*	*Poa labillardierei*
*Poa annua**	*Sonchus oleraceus**	*Rumex sp.*	*Sonchus oleraceus**
Poa labillardierei	*Verbena officinalis var gaudichaudii*	*Senecio sp.*	*Themeda triandra*
*Polygonum aviculare**	*Verbena officinalis var africana*	*Sonchus oleraceus**	*Wahlenbergia gracilis*
*Sonchus asper**	*Wahlenbergia gracilis*	*Sonchus sp.**	
*Sonchus oleraceus**		*Themeda triandra*	
*Stellaria media**		*Wahlenbergia gracilis*	
Verbena officinalis			
Vicia sp.			

In some cases old species names are still in use and are indicated: *Elymus scaber* (old) = *Anthosachne scabra* (new), *Chenopodium ambrosioides* (old) = *Dysphania ambrosioides* (new), *Pseudognaphalium luteoalbum* (old) = *Helichrysum luteoalbum* (new).

Percent FPC of different vegetation types, pre and post spring fresh in 2014-15 and 2015-16, at Loch Garry and McCoy's Bridge are shown in Figure E-3a-f. Vegetation types examined include the aquatic ground layer, grasses, and several abundant species with an affinity for wet habitats. The aquatic ground layer represents the sum cover of all species that have an affinity for wet habitats and includes the follow taxa: Cyperaceae (sedges), Juncaceae (rushes), and native aquatic herbs. The blue vertical dashed line on graphs represents the elevation water reached during the spring fresh. Values of FPC can be >100% when species are grouped (e.g. aquatic ground layer and grasses Figure E-3a,b) because species can overlap over a vertical profile (e.g. a prostrate ground cover over a taller sedge).

The spring fresh in 2014 increased the FPC of the aquatic ground layer at Loch Garry only (Figure E-3a) and this was largely due to increased cover of Lesser Joyweed (Figure E-3d*)* and Cyperaceae (mostly *Cyperus eragrostis*) (Figure E-3e). In 2015-16 similar increases following the spring fresh were not observed in the aquatic ground layer, and only small and patchy increases in the cover and/or occurrence of Lesser Joyweed and Cyperaceae were detected at lower elevations.

While FPC revealed a limited response of different vegetation types to the spring fresh, the probability of occurrence after the spring fresh differed for the vegetation types examined (Figure E-4a-e). The probability of occurrence increased for the aquatic ground layer (Figure E-4a) and Lesser Joyweed (Figure E-4d); had no discernible effect on Cyperaceae (Figure E-4e) or Creeping Knotweed (*Persicaria prostrata*) (Figure E-4c), and decreased the probability of occurrence of grasses (Figure E-4b). These patterns however are highly variable across vegetation types and the strongest effect is an increase the probability of Lesser Joyweed occurring at lower elevations at Loch Garry after the fresh in 2014-15 and 2015-16 (Figure E-4d). The data reveal that the persistence of this species is strongly linked to water availability. The regression coefficients of the statistical model, provided in Table E-3, indicate the high variability in responses of the vegetation to the spring fresh. The relationship between the duration of inundation in the 365 days preceding the spring fresh (I.365) and the occurrence of vegetation is stronger after the spring fresh, than compared to prior to the spring fresh for Aquatic Groundcover, grasses, *A. denticulata* and *Juncus* sp. This suggests that the occurrence of the spring fresh has led to a greater probability of vegetation occurrence at the same point on the bank.

Table E-3. Regression coefficients (slope.before and slope.after) of probability of vegetation occurrence model. 95 percent Bayesian credible intervals provided for *Slope.before* and *slope.after* represented. Probability that *slope.after* (S.A) is greater than that *slope.before* (S.B) is also shown.

		Vegetation species/grouping						
		Aquatic Ground cover	Grasses	Persicaria prostrata	Alternanthera denticulata	Cyperus eragrosits	Cyperaceae	Juncaceae
Loch Garry	Slope.Before	-1.4 – 0.34	-3.7 - -1.3	-1.4 – 0.35	-0.67 – 1.1	-1.1 – 1.01	-0.73 – 1.2	-0.87 – 1.0
	Slope.After	-1.0 – 0.70	-3.1 - -0.74	-1.6 –0.39	0.11 – 2.0	-1.3 – 0.70	-0.93 – 0.95	-0.93 – 0.91
	Pr (S.A > S.B)	0.67	0.75	0.39	0.85	0.37	0.39	0.50
McCoy's Bridge	Slope.Before	-0.69 – 0.18	-2.6 - -0.94	-1.0 –0.024	-0.17 – 0.66	-0.14 – 0.93	-0.14 – 0.82	-0.48 – 0.54
	Slope.After	-0.64 – 0.26	-1.8 - -0.42	-1.5 - -0.40	0.081 – 0.99	-1.3 – 0.70	-0.24 – 0.72	-0.38 – 0.64
	Pr (S.A > S.B)	0.59	0.86	0.12	0.82	0.24	0.37	0.60

E.3.4 Reponses to inundation the year prior

Conditions leading up to the 2015 spring fresh resulted in the establishment of several water dependent species at the lowest elevations including Lesser Joyweed, Cyperaceae and Juncaceae (Figure E-3d,e,f). There was also a trend for vegetation to shift towards lower elevations along the bank face. This was most evident for Lesser Joyweed, which was almost eliminated at the higher elevations it occupied in December 2014 (Figure

E-3d). This shift is likely to be attributed to the drier conditions resulting from lower annual rainfall and lower river flows over the year prior to the 2015 spring fresh.

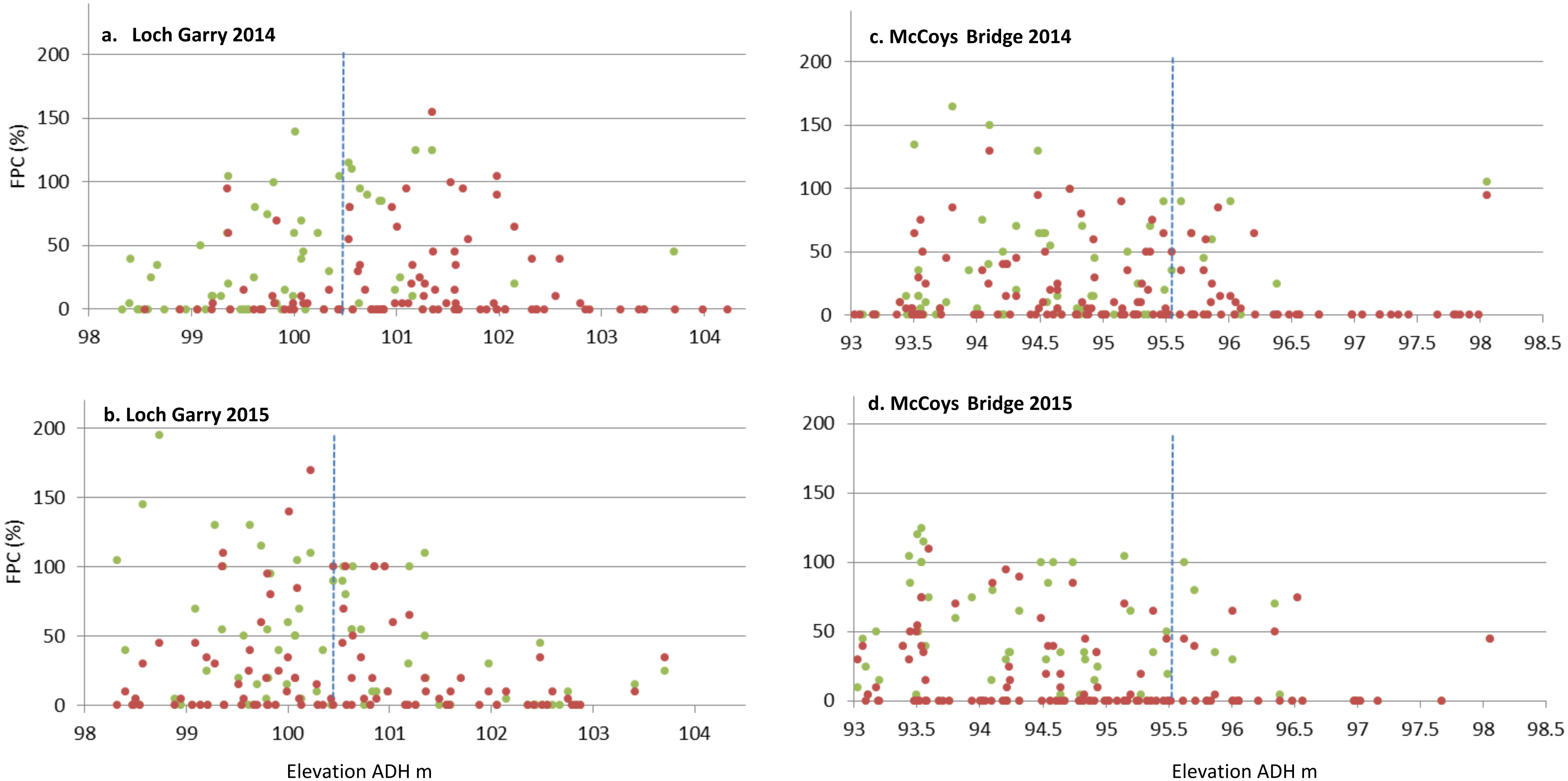


Figure E-3a. Percent foliage projective cover (FPC) of the aquatic ground layer pre fresh (green circles) and post fresh (red circles) at Loch Garry (a, b) and McCoy's Bridge in (c, d) in 2014-15 (a, c) and 2015-16 (b, d). The blue vertical line represents the elevation reach by the spring fresh.

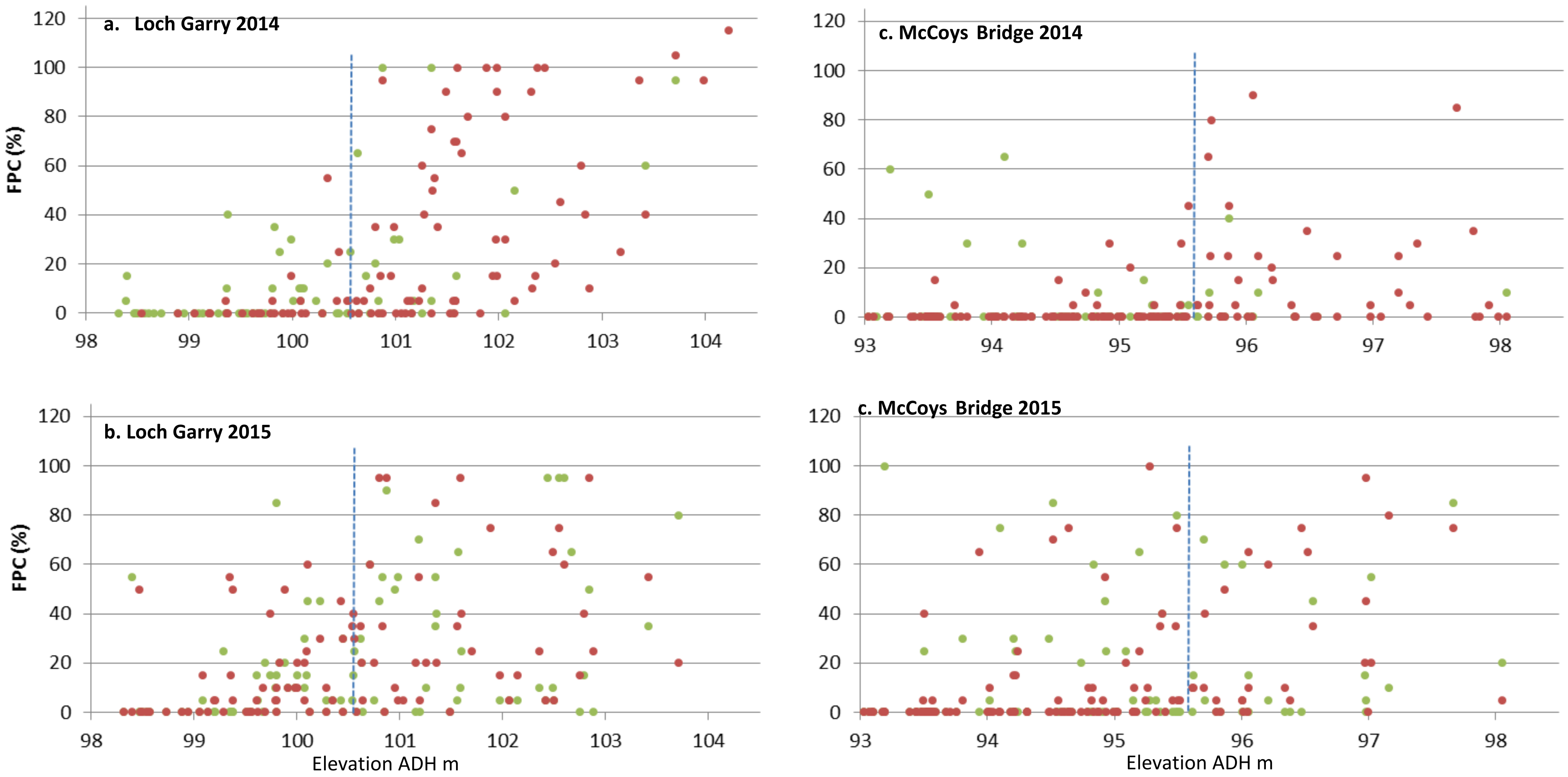


Figure E-3b. Percent foliage projective cover (FPC) of all grasses pre fresh (green circles) and post fresh (red circles) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b, d). The blue vertical line represents the elevation reach by the spring fresh.

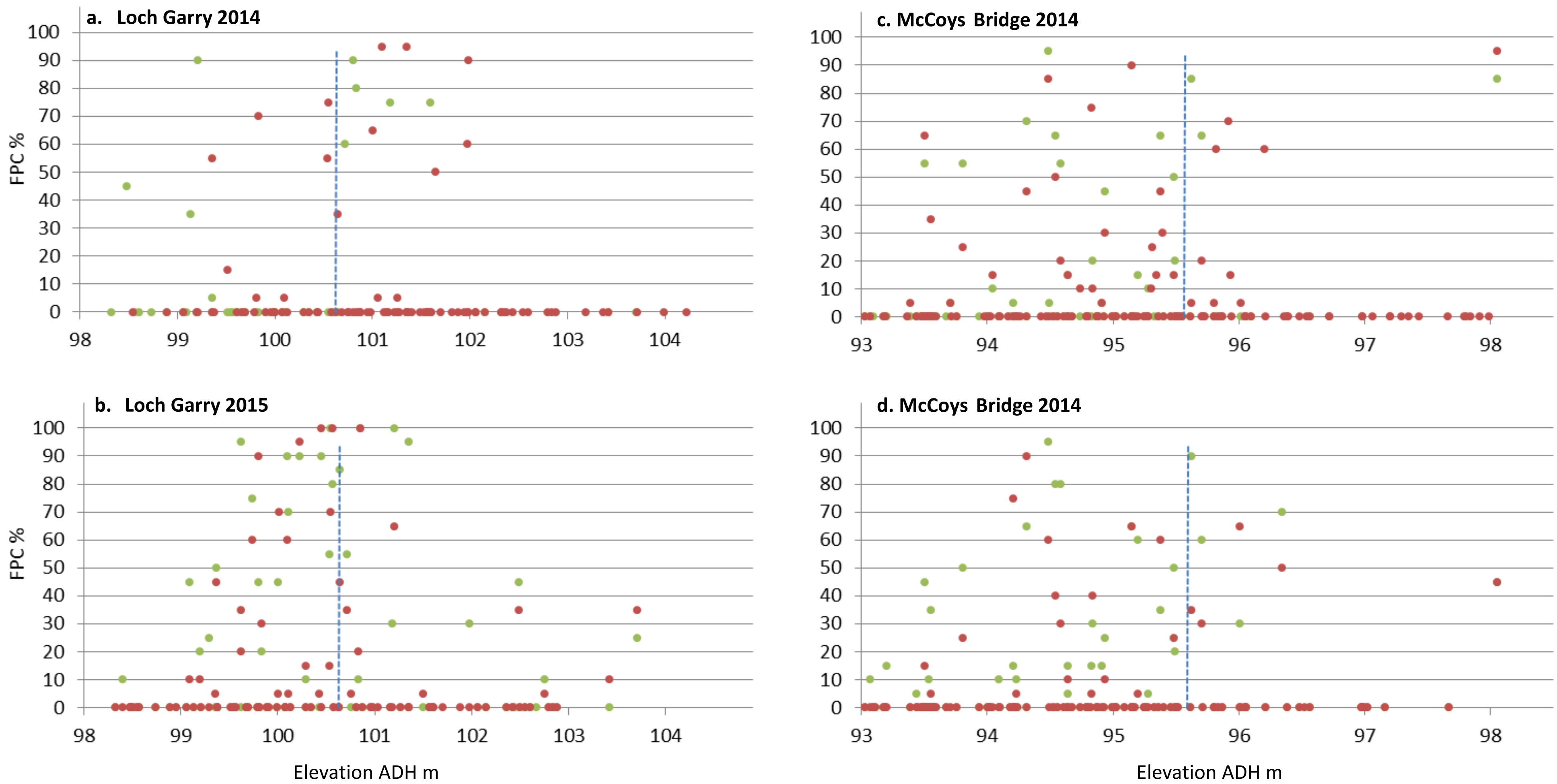


Figure E-3c. Percent foliage projective cover (FPC) of Creeping Knotweed (*Persicaria prostrata*) pre fresh (green circles) and post fresh (red circles) at Loch Garry (a, b) and McCoy's Bridge (c,d) in 2014-15 (a, c) and 2015-16 (b, d). The blue vertical line represents the elevation reach by the spring fresh.

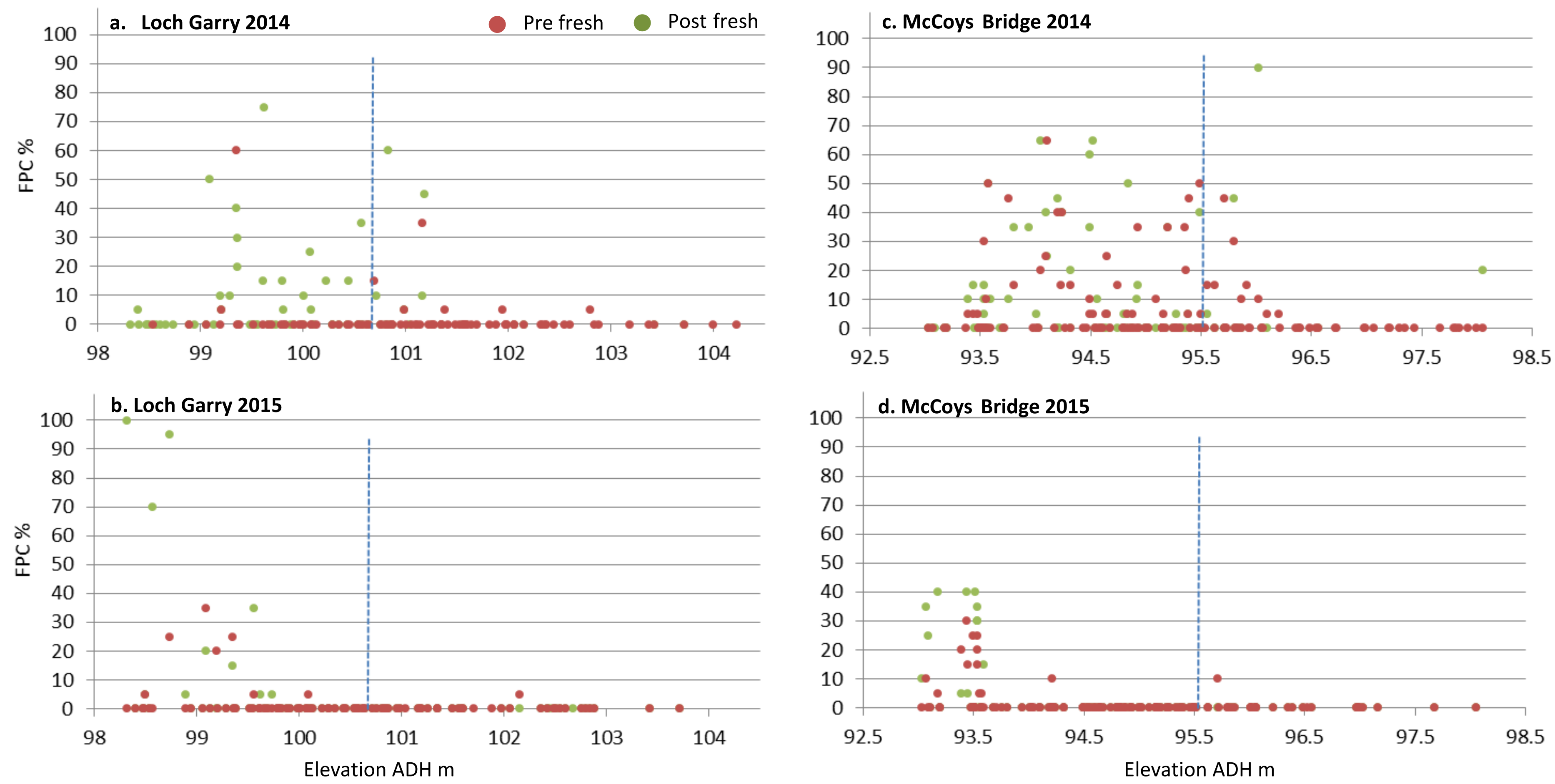


Figure E-3d Percent foliage projective cover (FPC) of Lesser Joyweed (*Alternanthera denticulata*) pre fresh (green circles) and post fresh (red circles) at Loch Garry (a, b) and McCoy's Bridge (c,d) in 2014-15 (a, c) and 2015-16 (b, d). The blue vertical line represents the elevation reach by the spring fresh.

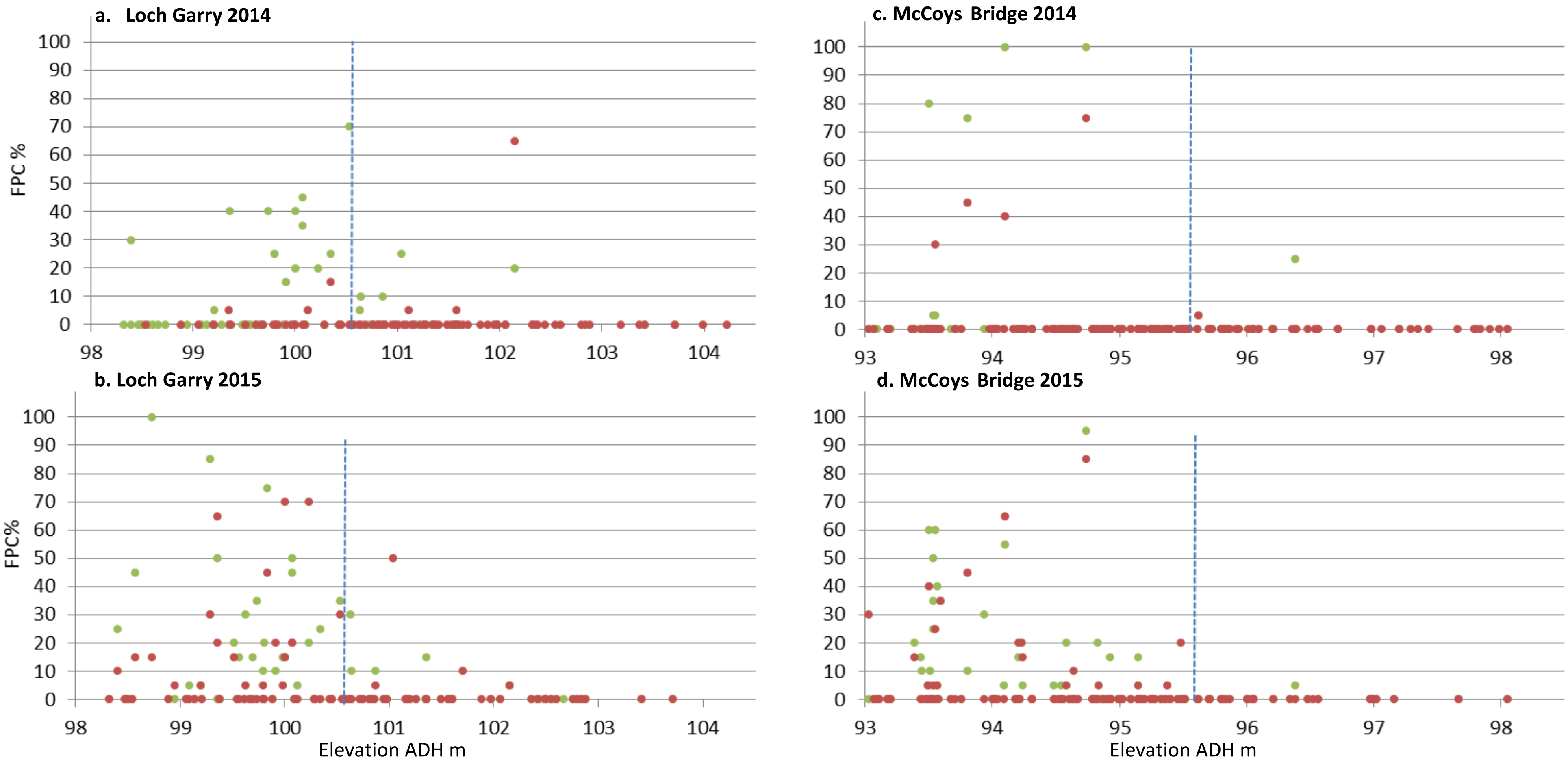


Figure E-3e. Percent foliage projective cover (FPC) of Cyperaceae pre fresh (green circles) and post fresh (red circles) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b, d). The blue vertical line represents the elevation reach by the spring fresh.

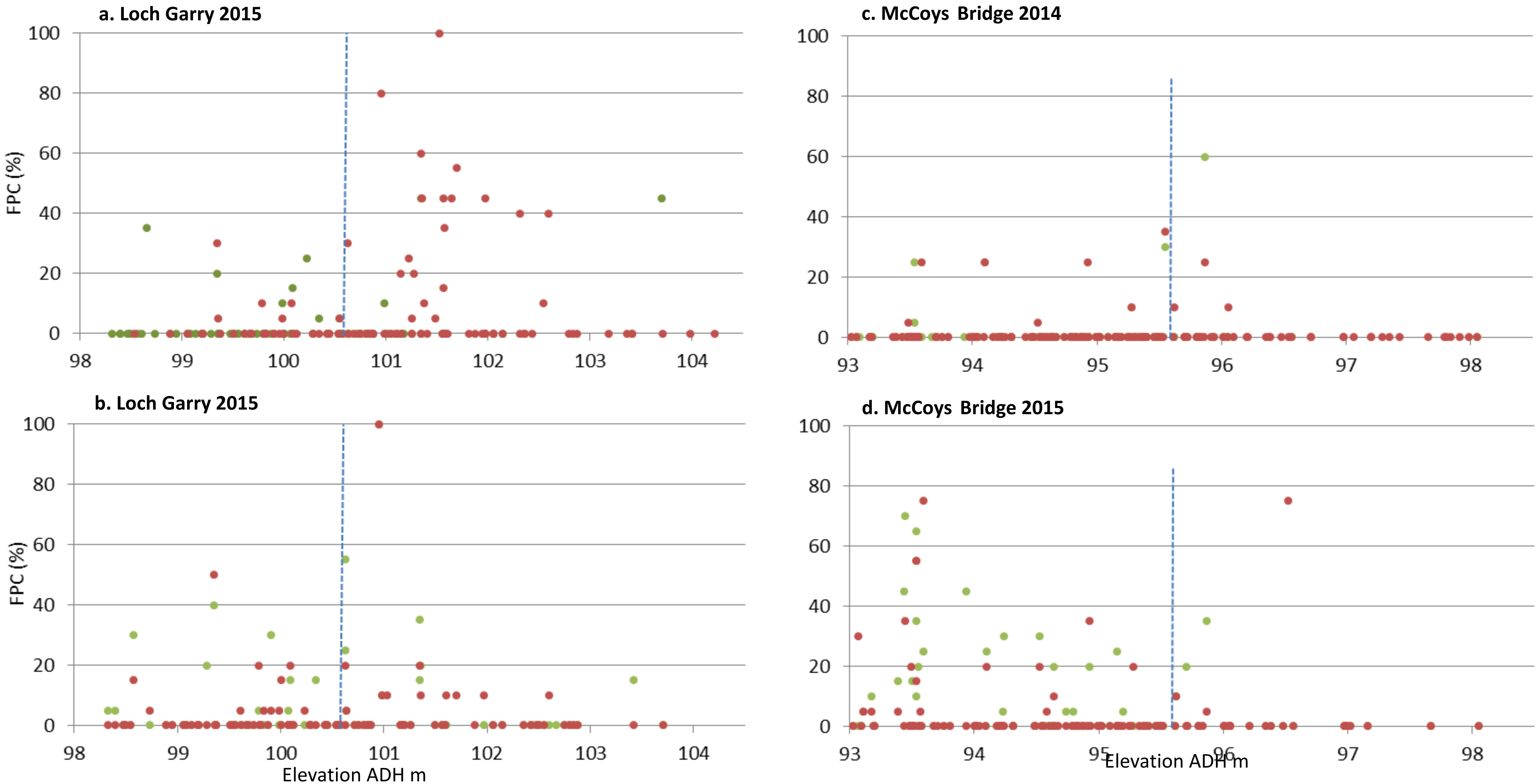


Figure E-3f. Percent foliage projective cover (FPC) of Juncaceae pre fresh (green circles) and post fresh (red circles) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b ,d). The blue vertical line represents the elevation reach by the spring fresh.

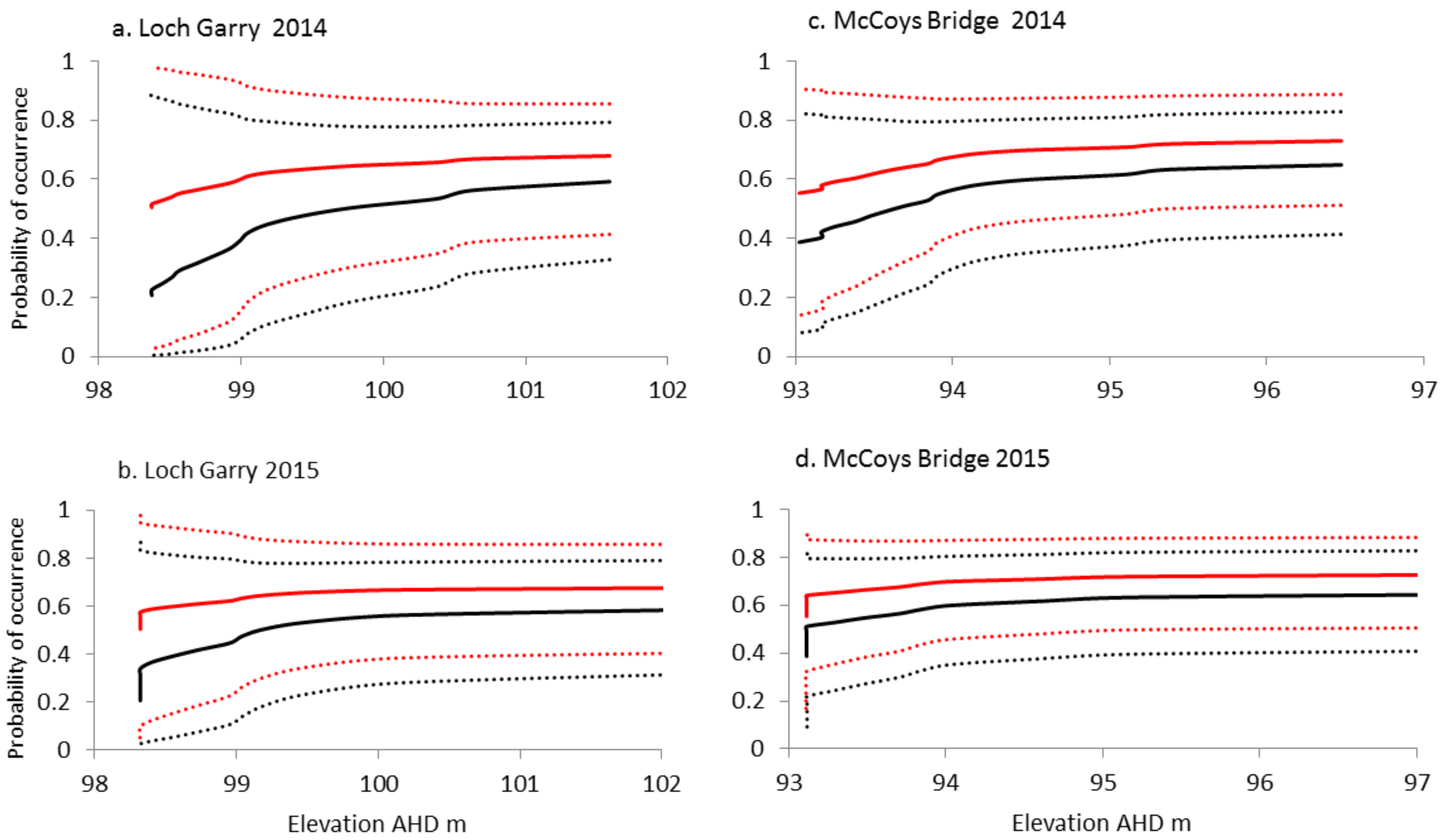


Figure E-4a. Probability of occurrence of aquatic ground cover pre fresh (black line) and post fresh (red line) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b, d). Dashed lines represent the 95% Bayesian credible intervals.

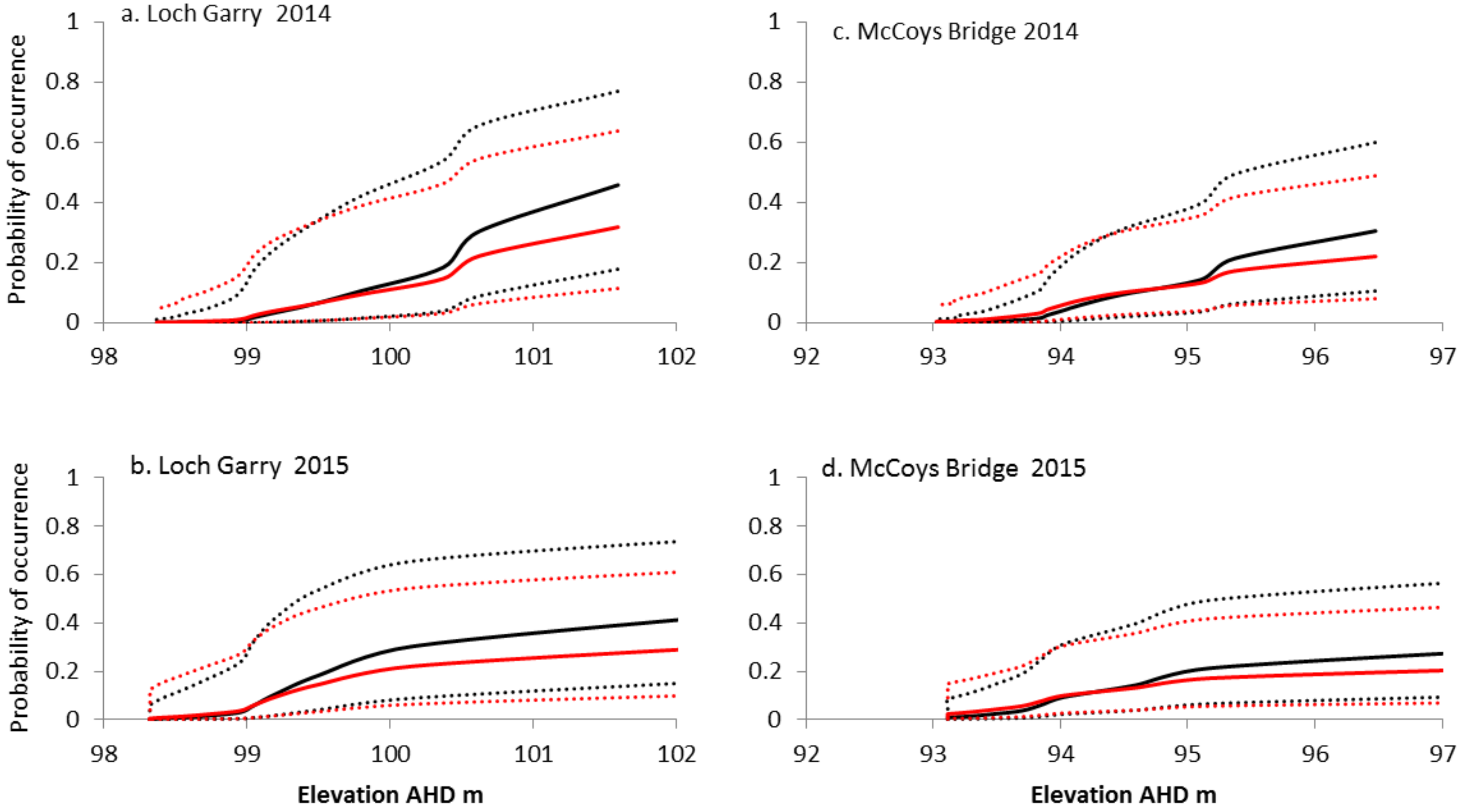


Figure E-4b. Probability of occurrence of all grasses pre fresh (black line) and post fresh (red line) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b, d). Dashed lines represent the 95% Bayesian credible intervals.

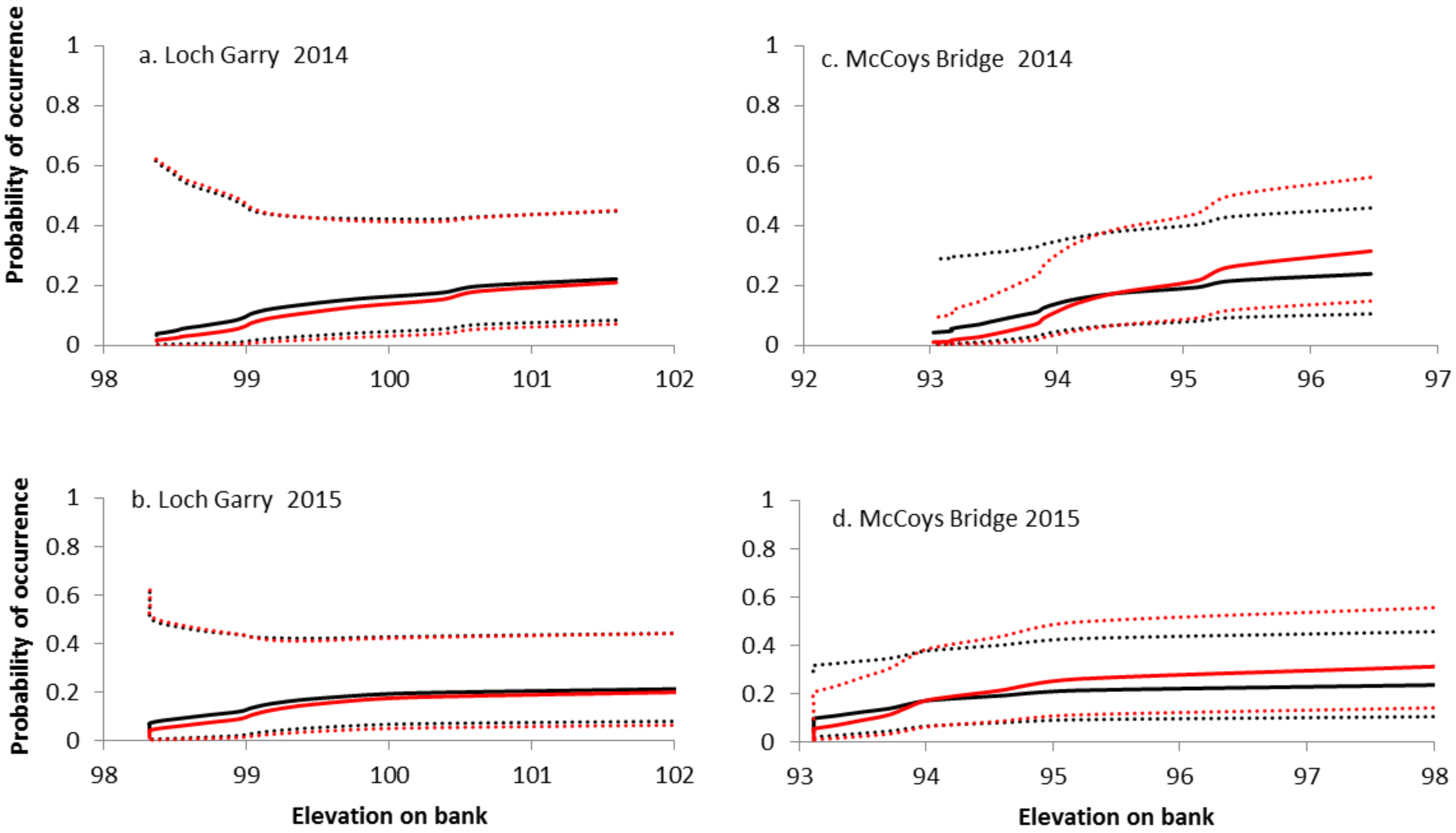


Figure E-4c. Probability of occurrence of all Creeping Knotweed (*Persicaria prostrata*) pre fresh (black line) and post fresh (red line) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b,d). Dashed lines represent the 95% Bayesian credible intervals.

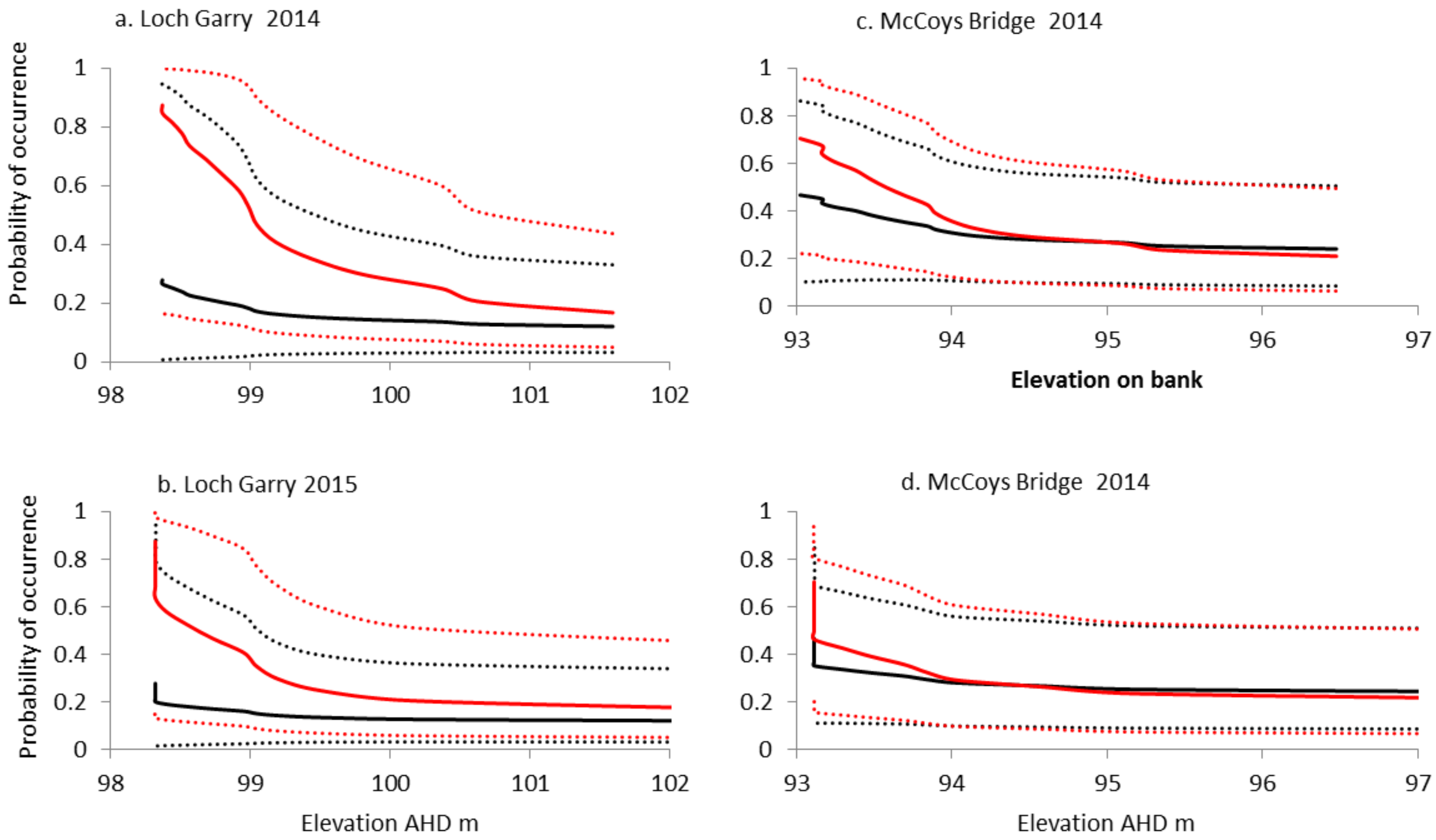


Figure E-4d. Probability of occurrence of Lesser Joyweed (*Alternanthera denticulata*) pre fresh (black line) and post fresh (red line) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b, d). Dashed lines represent the 95% Bayesian credible intervals.

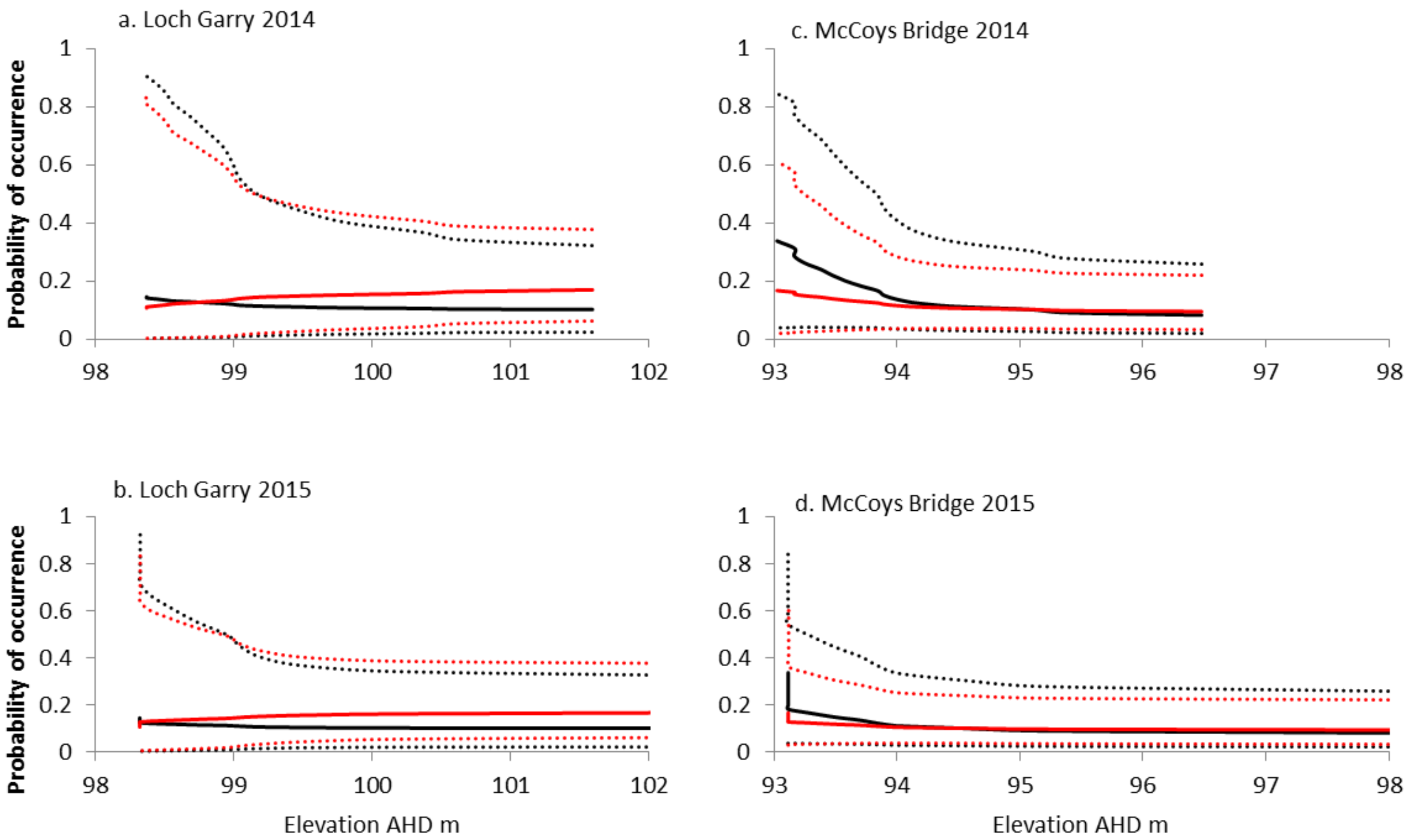


Figure E-4e. Probability of occurrence of *Cyperus eragrosits* pre fresh (black line) and post fresh (red line) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b, d). Dashed lines represent the 95% Bayesian credible intervals.

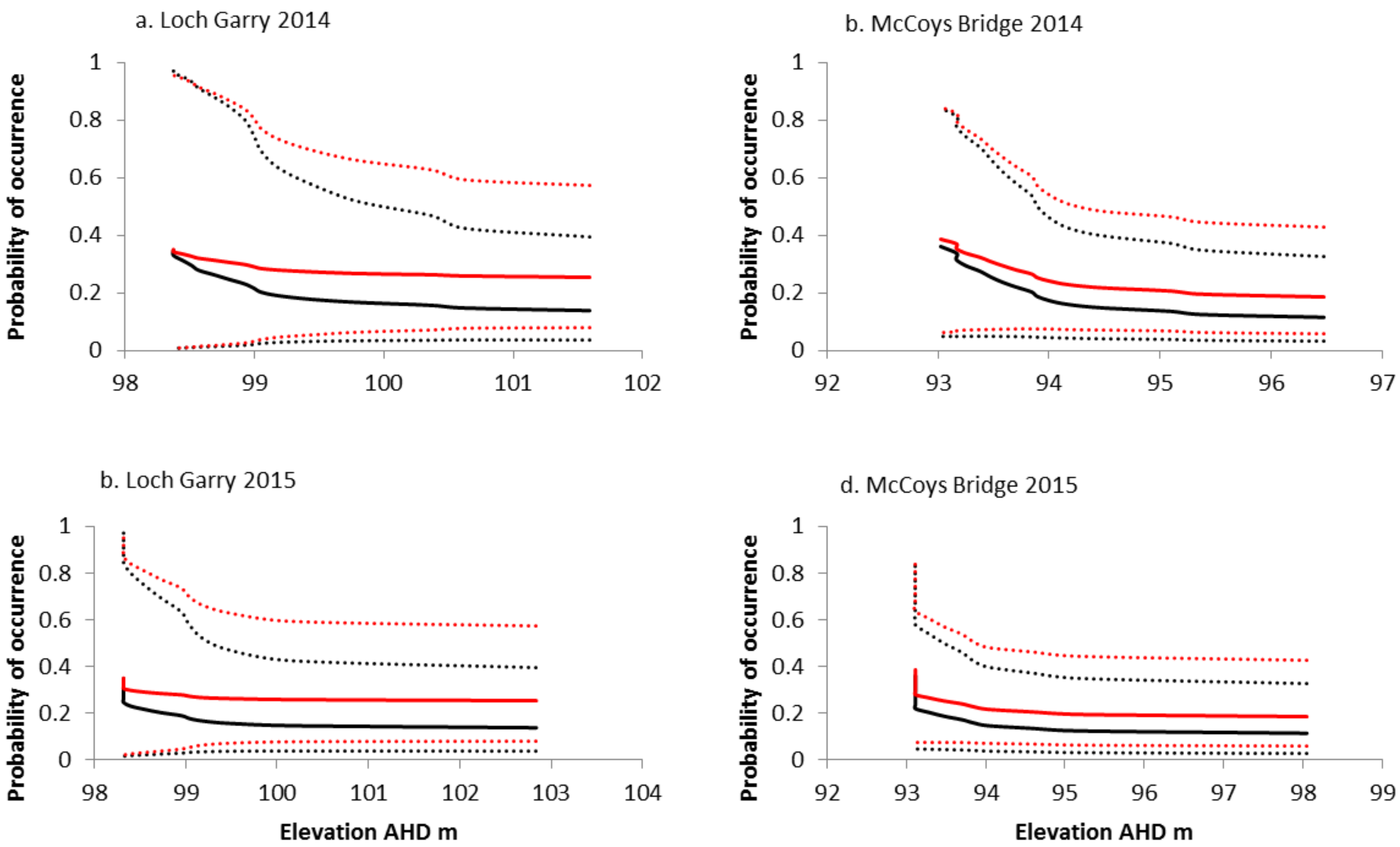


Figure E-4f. Probability of occurrence of Cyperaceae pre fresh (black line) and post fresh (red line) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b, d). Dashed lines represent the 95% Bayesian credible intervals.

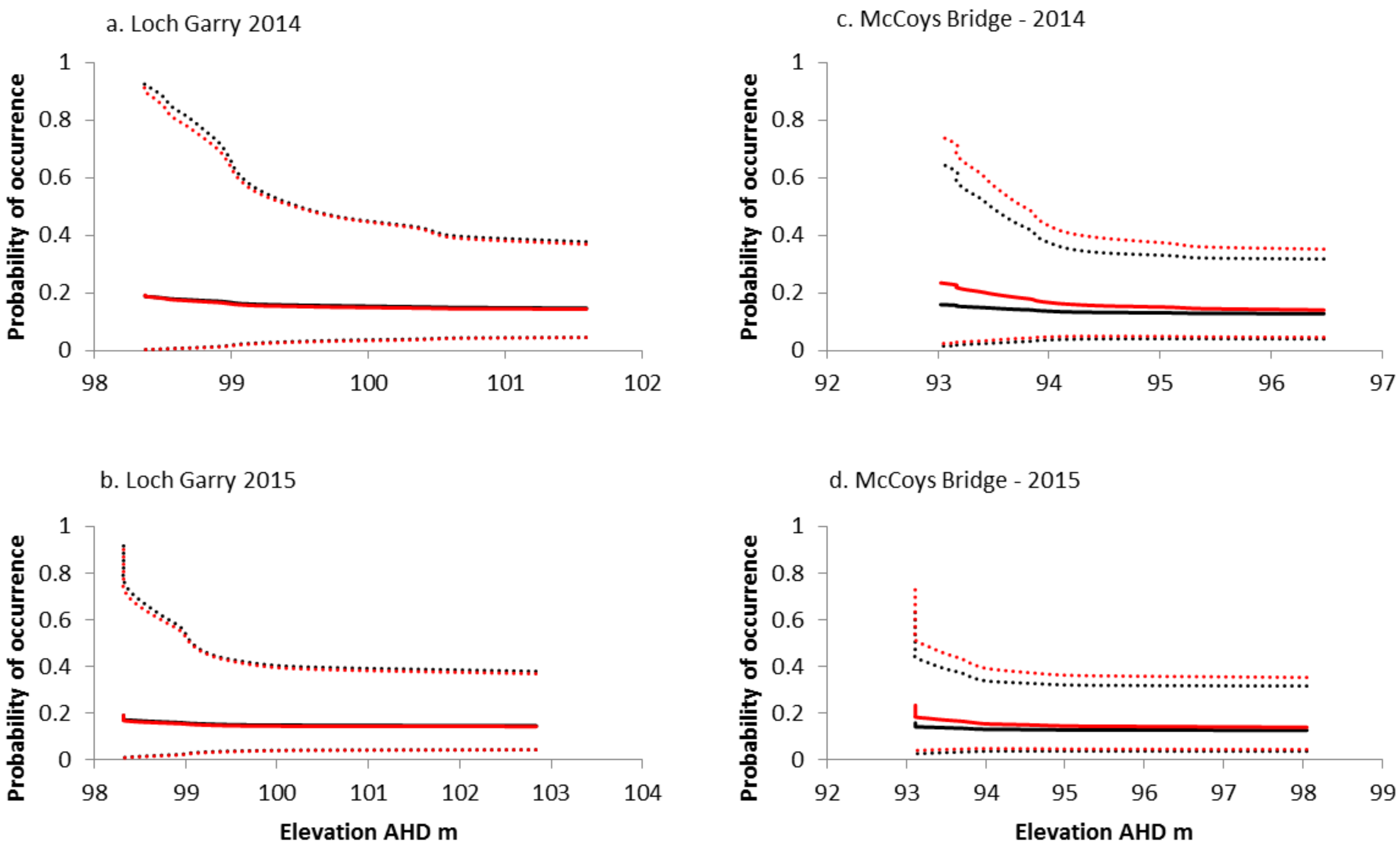


Figure E-4g. Probability of occurrence of Juncaceae pre fresh (black line) and post fresh (red line) at Loch Garry (a, b) and McCoy's Bridge (c, d) in 2014-15 (a, c) and 2015-16 (b, d). Dashed lines represent the 95% Bayesian credible intervals

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Although the spring fresh did not increase the cover of Creeping Knotweed (*P. prostrata*), its cover appears to have increased between 2014-15 and 2015-16 at lower elevations at Loch Garry, but not at McCoy's Bridge (Figure E-3c). As the probability of occurrence did not appear to change, high FPC is likely to indicate that growth of extant plants was favoured by the drier conditions.

E.4 Discussion

Response to spring freshes

Species richness did not change in response to the spring fresh at either Loch Garry or McCoy's Bridge. Seasonal patterns of plant growth, particularly annual species, make it difficult to compare total species number pre and post fresh. Longer term changes assessed in the same season are more appropriate but cannot be attributed to particular flow events.

Spring freshes delivered in 2014 increased the cover of Lesser Joyweed and Cyperaceae. In 2015 the spring fresh produced little change in the vegetation cover, possibly due to the drier conditions in the year prior. However, spring freshes are likely to have contributed to maintaining vegetation along the banks, particularly at higher elevations.

Although there was little change in vegetation cover following the spring fresh in 2015-16, freshes appear to influence the probability of occurrence of the vegetation types examined. Although highly variable, responses indicate that freshes may increase the probability of occurrence of Lesser Joyweed and aquatic vegetation as a group and decrease the probability of occurrence of grasses as a group. The probability of occurrence of Cyperaceae and Creeping Knotweed did not appear to be altered by the fresh.

Another approach to evaluating the influence of spring freshes on vegetation is to examine changes in the cover and probability of occurrence of vegetation along the elevation gradient as it reflects the longer term influence of spring freshes and other inundation events. The cover and probability of occurrence of vegetation associated with wet habitats as a group tended to be higher in regions of the bank inundated by spring freshes and declined at elevation above this. In contrast, the cover and probability of occurrence of grasses as a group tended to be higher along parts of the bank not inundated by freshes.

Vegetation change between freshes

Conditions at other times of the year were found to exert a strong influence of vegetation. The period between the post fresh survey in December 2014 and the pre fresh survey in September 2015 was characterised by drier conditions and a shift in the cover of vegetation towards lower elevations and the recruitment of water dependent species at the lowest elevations.

Difference among sites or channel features

In 2014-15 differences among sites were more apparent with vegetation responses to the spring fresh more evident at Loch Garry than McCoy's Bridge. In 2015-16 differences between sites were not evident.

The influence of bank features on vegetation cover assessed 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.

Knowledge gaps

A key assumption of flow delivery management for vegetation is that freshes wet up the bank profile providing suitable conditions for germination and plant growth. However, there exist no data to demonstrate how the duration and magnitude of flows influence bank soil moisture, how long improved soil moisture conditions are maintained following flow recession, or how antecedent conditions (temperature, rainfall and flows) or site features influence these relationships. Understanding these relationships will greatly enhance the ability to adaptively manage flows. To fill this knowledge gap a pilot study is being developed in collaboration with the GBCMA to test the influence of freshes on bank soil moisture along the elevation profile at surveyed sites.

Providing rigorous evidence of vegetation responses to spring freshes remains challenging, as vegetation communities reflect cumulative responses to flow and climate over short and long time frames. As the dataset builds and a larger range of flow and environmental conditions are sampled the influence of these factors can be better elucidated in quantitative models. In particular, it is necessary to further explore how the duration of the spring freshes affects vegetation cover and establishment. This may be possible with ongoing data collection.

Vegetation responses to flow events can also be patchy and may not always occur along monitored transect resulting in a relatively weak signal. Stage 6 of the Victorian Environmental Flow Monitoring Assessment Program is in development and has proposed trialling broad based approaches to assess vegetation responses to environmental flows. These approaches aim to map vegetation along 1 km river reaches. It is hoped that these approaches will be undertaken along the Goulburn River to complement more targeted surveys undertaken in the LTIM project.

E.5 Conclusion

Seasonal patterns of plant growth, particularly annuals make it difficult to assess the influence of freshes on species diversity. Changes over annual cycles in similar seasons are more appropriate but cannot be attributed to particular flow events.

Spring freshes appear to contribute to maintaining water dependant species on the bank face and limiting the occurrence and cover of grasses and woody species at lower elevations along the bank. This is based primarily on qualitative observations of vegetation cover and probabilities of occurrence along the elevation gradient and associated patterns of inundation. Quantitative analysis of vegetation cover has been problematic because of the high number of zeros in the data, and other statistical approaches that deal with this will be implemented next year. The data do however suggest 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 terrestrial plant establishment.

Flow and climatic conditions during the year prior to the spring freshes exerted a strong influence on vegetation. Dry conditions prior to the spring fresh in 2015 appeared to shift vegetation toward lower and presumably wetter elevations and several taxa colonised the lowest elevations along the river margin. This is consistent with waterway manager observations that a number of water dependant species have established at the river margin.

Maintaining these young plants until they reach more mature and robust life stages and/or develop soil seed banks that will promote recovery from unfavourable conditions is a key objective of flow management in 2016-17. Due to natural freshes occurring in the lower Goulburn and the likely persistence of high water level to at least mid-September the planned spring fresh has been cancelled. This will reduce the impact of prolonged inundation on young plants that have colonised the river margin.

Studies are needed to establish the influence of freshes in replenishing bank soil moisture stores as this is a key assumption underlying flow management for vegetation but remains untested.

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 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 adult 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 drought. 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 River and Murray River 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 (Webb et al. 2014). Briefly, electrofishing was conducted at 10 sites in the Goulburn River during April and May 2016. 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. In addition, ten bait traps were set at each site to comply with VEFMAP (Victorian Environmental Flows Monitoring and Assessment Program) data collection requirements as part of a co-investment arrangement with the Victorian Department of Environment, Land, Water and Planning. Nets were set in late afternoon and retrieved the following morning. At the time of writing, annual ageing of a sample of the selected target species (equilibrium spawners Murray cod and periodic spawners golden perch, silver perch) was being undertaken using otoliths.

A total of 30 adult golden perch collected from the Goulburn River (40–200 km upstream of the Murray River junction) were tagged with acoustic transmitters in autumn 2016. Adult golden perch were also collected and tagged with acoustic transmitters in autumn 2015 (n = 29) and autumn 2014 (n = 29), making a total of 88 fish tagged. Twenty-one acoustic listening stations have been previously 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 2015 using 3 nets set at each site. Light traps were also set at three sites (Loch Garry, McCoy’s Bridge, Yambuna) every 1-2 weeks from October to December 2015 (n=6) using 10 light traps set at each site. The nets and light traps were set in late afternoon and retrieved the following morning.

F.2.2 Statistical modelling

F.2.2.1 Spawning

The golden perch spawning data (2014 and 2015 combined) were analysed with a hierarchical logistic regression (probability of spawning) and a hierarchical log-Poisson regression (abundance of eggs/larvae). The two models had the same structure for the underlying linear model, with the expression for the logistic regression being:

$$y_i \sim Bernoulli(probability_i)$$

$$logit(probability_i) = int + eff.del.Q_j \times Q_i + eff.Te \times Te_i + eff.site_j + eff.net_k$$

The occurrence of spawning normalised to the discharge through the net (*y*) for drift net j at site k during deployment i is driven by a global average across all sites (int), plus the effect of the rate of rise in discharge from the day before the sample to the day of the sample (eff.del.Q) for each site and the effect of water temperature (eff.Te) on the day of sampling. 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).

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

The abundance data were analysed using the same model structure, but with the data being modelled as a Poisson distribution, and with the link function on the linear model being log rather than logit.

Modelled fish spawning occurrence as a function of the change in mean velocity and change in water depth in the channel from the previous day will also occur.

F.2.2.2 Fish movement

The fish movement data (combined data from 2014 and 2015) were also analysed with a hierarchical logistic regression (probability of occurrence of movement). The occurrence of 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:

$$move_i \sim Bernoulli(probability.move_i)$$

$$logit(probability.move_i) = int + eff.Q_j \times Q_i + eff.day1 \times day_k^2 + eff.day2 \times day_k + eff.Fish_j$$

The occurrence of movement (move) for fish j on day k is driven by the global average across all sites in the absence of flow (int) ,the effect of discharge (eff.Q) for each fish, and the effect of the day of year (eff.day1 and eff.day2). The day in each yearly cycle is identified using the 1st of July as day 1. There is also a random effect of the fish *j* (*eff.Fish*).

eff.Q and eff.Fish were modelled hierarchically, with the hyper-priors being normally distributed with means and standard deviations of *mu.eff.Q* and *s.eff.Q* (for *eff.*Q) and *mu.eff.fish* and *s.eff.fish* (for *eff.Fish*). *mu.eff.Q* and *mu.eff.fish* have non-informative normal distributions with means of 0 and variances of 10. *s.eff.Q* and *s.eff.fish* have uniform distributions with limits of 0 and 10.

$$eff.Q_j \sim N(mu.eff.Q, s.eff.Q^2)$$

$$eff.Fish_j \sim N(mu.eff.Fish, s.eff.Fish^2)$$

int, eff.day1 and eff.day2 are drawn from non-informative normal distributions with mean 0 and variance 10. The probability of movement was also determined for the counterfactual scenario with no environmental flows (probability.move_noef).

Modelled fish movement occurrence as a function of mean velocity in the channel was undertaken. The occurrence of movement was also modelled using the counter-factual scenario of no environmental flows.

F.3 Results

F.3.1 Relevant flow components delivered to the lower Goulburn River in 2014/15

Baseflow components delivered to the lower Goulburn River in 2015-16 were partly aimed at maintaining habitat for adult native fish. However, environmental water was not delivered to the Goulburn River specifically for golden perch or silver perch spawning in spring 2015 due to limited water resource availability. Environmental water was delivered to the Goulburn River in October 2015 to provide a within-channel pulse over 4 weeks for vegetation objectives. A maximum discharge of about 6600 ML/d was released. While this flow pulse was delivered primarily for vegetation, there was an expectation that it might result in spawning responses from golden and silver perch.

F.3.2 Monitoring results and observations

Annual surveys (electrofishing and netting)

A total of 913 individuals comprising nine native and three exotic species were collected from the annual electrofishing surveys (Table F-1, Table F-2). Similar to previous surveys, Australian Smelt was the most abundant species collected, comprising 38% of the total abundance for all species, followed by the introduced carp (29%) and Murray River rainbowfish 12%. A number of species of conservation significance were collected, namely Murray cod, trout cod, silver perch and Murray River rainbowfish.

A range of introduced fish species, namely carp, goldfish and eastern gambusia, were also collected. The majority (72%) of carp were young of year (YOY), which may be indicating either (1) recent successful spawning and recruitment, possibly associated with increases in discharge in October 2015 during the carp breeding season or (2) recent spawning in the Murray and movement into the Goulburn system. It is still unclear which of these explains the age of the majority of the carp.

A total of 508 individuals comprising five native species and one exotic species were collected from the annual netting surveys (Table F-1, Table F-2). Similar to the 2015 surveys, carp gudgeon was the most abundant species, comprising 79% of the total abundance for all species. Murray River rainbowfish was the next most abundant species, comprising 19%. A total of 21 carp gudgeon were collected from the bait trap surveys, but these are not further reported here.

Table F-1. Numbers of individual fish species collected from the Goulburn River in electrofishing, fyke net and bait trap surveys in 2016. Asterisk denotes native fish species.

Species	Electrofishing	Fyke Netting	Bait Traps	Total
Silver Perch *Bidyanus bidyanus* *	5			5
Goldfish *Carassius auratus*	22			22
Carp *Cyprinus carpio*	264			264
Eastern gambusia *Gambusia holbrooki*		6		6
Carp gudgeon *Hypseleotris sp.* *	28	403	21	452
Trout cod *Maccullochella macquariensis* *	4			4
Murray cod *Maccullochella peelii* *	83			83
Golden perch *Macquaria ambigua* *	41	3		44
Murray River rainbowfish *Melanotaenia fluviatilis* *	114	94		208
Bony herring *Nematalosa erebi* *	3			3
Flatheaded gudgeon *Philypnodon grandiceps* *		1		1
Australian smelt *Retropinna semoni* *	349	1		350
Total number of individuals	**913**	**508**	**21**	**1442**

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

Species	2015	2016	Total
Silver Perch *Bidyanus bidyanus* *	2	5	7
Goldfish *Carassius auratus*	8	22	30
Carp *Cyprinus carpio*	107	264	371
Eastern gambusia *Gambusia holbrooki*	1	6	7
Carp gudgeon *Hypseleotris sp.**	185	452	637
Trout cod *Maccullochella macquariensis* *	1	4	5
Murray cod *Maccullochella peelii* *	79	83	162
Golden perch *Macquaria ambigua* *	31	44	75
Murray River rainbowfish *Melanotaenia fluviatilis* *	186	208	394
Bony herring *Nematalosa erebi* *		3	3
Flatheaded gudgeon *Philypnodon grandiceps* *		1	1
Australian smelt *Retropinna semoni* *	276	350	626
Total number of individuals	**876**	**1442**	**2318**

Length frequency histograms are presented for five of the six selected target species: Murray cod, golden perch, silver perch, carp gudgeon, Australian smelt. One of the target species, river blackfish, was not collected. This species however appears to be rare in the lower Goulburn River. Age structure histograms are also presented for Murray cod, golden perch and silver perch collected in 2014 and 2015. A length frequency histogram has also been presented for carp captured at the Yambuna site.

Murray cod

The size of Murray cod collected in the 2016 surveys ranged from 75 mm in length and 5.1 g in weight to 672 mm in length and 3.6 kg in weight. Analysis of otoliths from Murray cod collected in 2014, 2015 and 2016 revealed that the population in the Goulburn River ranged in age from 0+ to 41 years, with 0+ (18%), 1 (16%) and 2 (25%) year old fish most prevalent (Figure F-1). The 41 year old fish was not collected in the annual survey but was found dead by a local resident and generously handed on to the project team. Most fish were spawned in 2013 (22%), 2012 (18%) and 2011 (18%), demonstrating recent successful recruitment for this species.

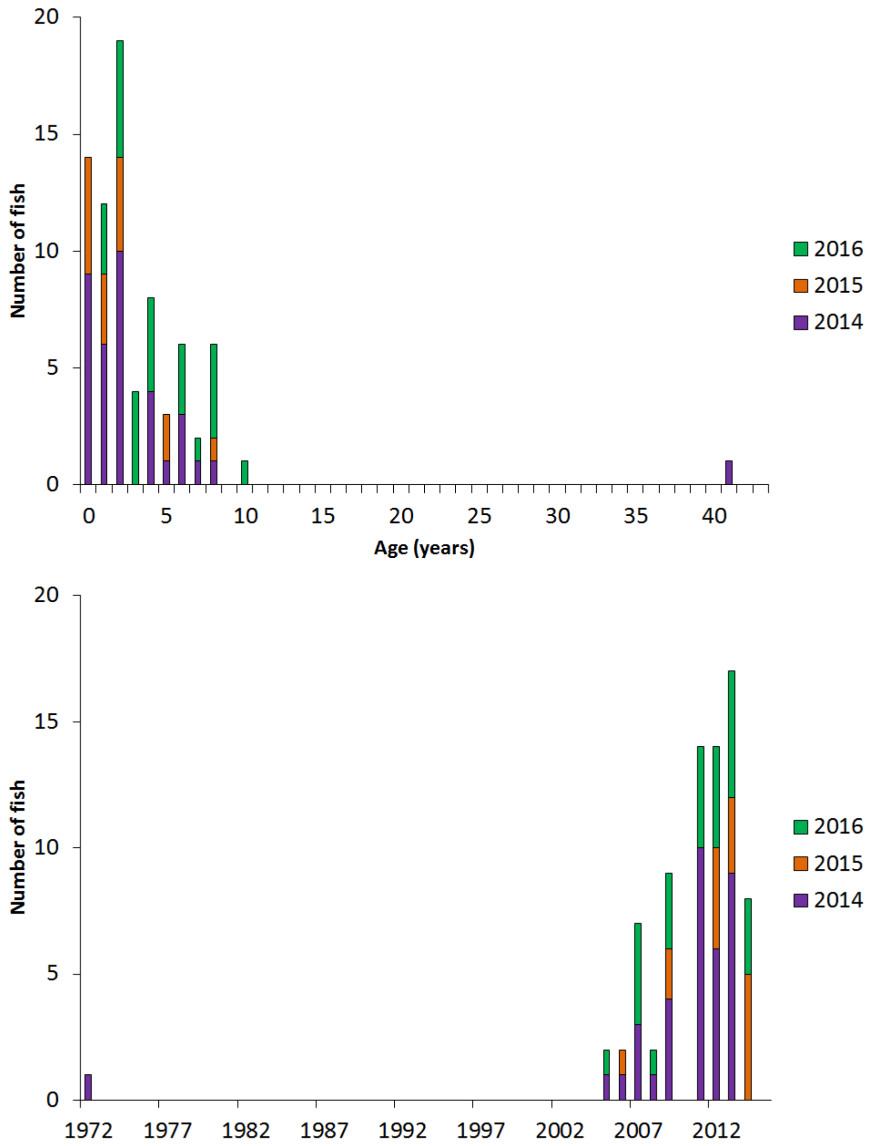

Figure F-1. Age structure (top panel) and number of Murray cod plotted against year of birth (bottom panel) from fish collected in the Goulburn River in 2014, 2015 and 2016. Bar colour denote year of collection

Golden perch

The size of golden perch collected in the 2016 surveys ranged from 37 mm in length and 0.6 g in weight to 540 mm in length and 2.4 kg in weight. Three young of year golden perch (<50 mm in length) were collected at Shepparton. Analysis of otoliths from golden perch collected in 2014, 2015 and 2016 revealed that the population in the Goulburn River ranged in age from 0+ to 21 years, with 2 (18%), 5 (15%) and 11 (11%) year old fish most prevalent (Figure F-2). Most fish were spawned in 2013 (14%), 2009 (14%) and 2008 (11%) indicating episodic recruitment for this species. It is not known whether these fish spawned locally or have recruited from elsewhere in the Murray Darling Basin. Otolith microchemical analyses to be conducted as part of future LTIM Project sampling will shed light on the origin of these fish.

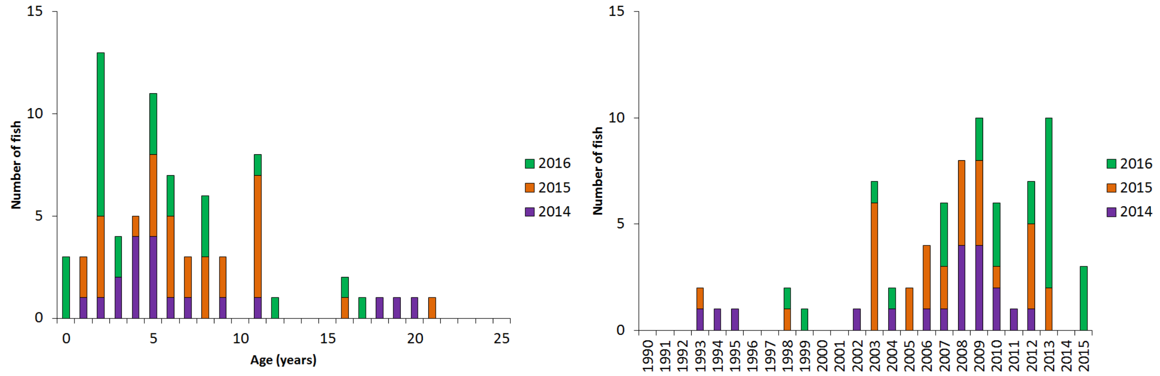

Figure F-2. Age structure (left panel) and number of golden perch plotted against year of birth (right panel) from fish collected in the Goulburn River in 2014, 2015 and 2016. Bar colour denote year of collection.

Silver perch

Five silver perch were collected in the 2016 surveys. There was no evidence of recent recruitment with no young-of-year fish collected. Analysis of otoliths from silver perch collected in 2015 and 2016 (none were collected in 2014) revealed that the population in the Goulburn River ranged in age from 2 to 6 years, with 2 (25%) and 3 (25%) year old fish most prevalent (Figure F-3). Most fish were spawned in 2009 (33%) and 2011 (33%).

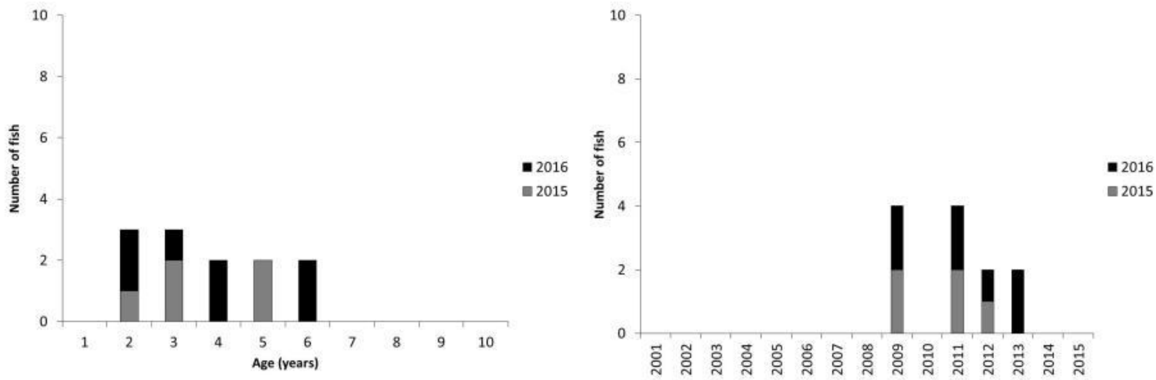

Figure F-3. Age structure (left panel) and number of silver perch plotted against year of birth (right panel) from fish collected in the Goulburn River in 2014, 2015 and 2016. Coloured bars denote year of collection.

Carp gudgeon

The majority of carp gudgeon collected were 20-40 mm in length (Figure F-4). These fish likely represent 0+ year old individuals. Carp gudgeon are a short-lived species (e.g. 1-2 years) and only one or two age classes would generally be expected in the population.

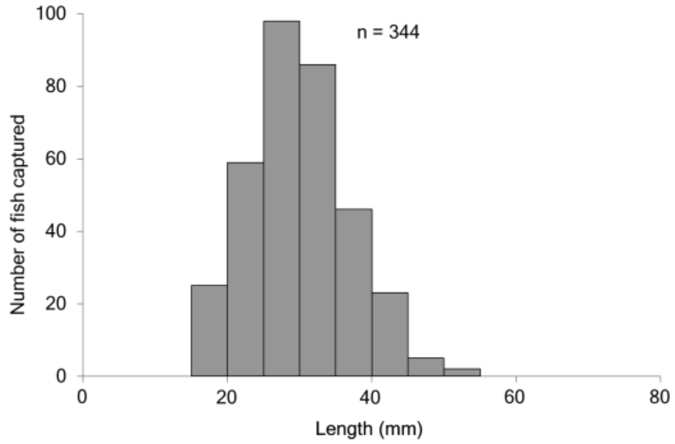

Figure F-4. Length frequency of carp gudgeon collected in the Goulburn River

Australian smelt

The majority of Australian smelt collected in the Goulburn River were 30-60 mm in length (Figure F-5). These fish likely represent 0+ year old individuals. Like carp gudgeons, Australian smelt are a short-lived species (e.g. 1-2 years) and only one or two age classes would generally be expected in the population.

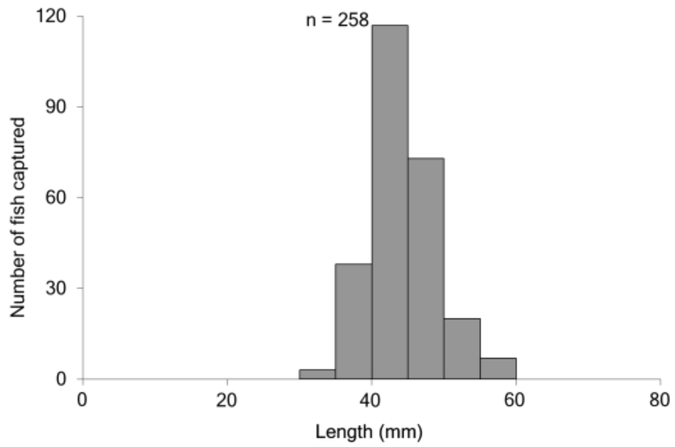

Figure F-5. Length frequency of Australian smelt collected in the Goulburn River

Carp

The LTIM standard method does not require lengths of carp to be measured. However, lengths were measured at one site (Yambuna) to demonstrate the predominance of young-of-year individuals (Figure F-6). Young-of-year carp were predominant at the 3 most downstream sites in particular (Yambuna, Sun Valley Rd and Stewarts Bridge), indicating successful recruitment for fish spawned in spring 2015.

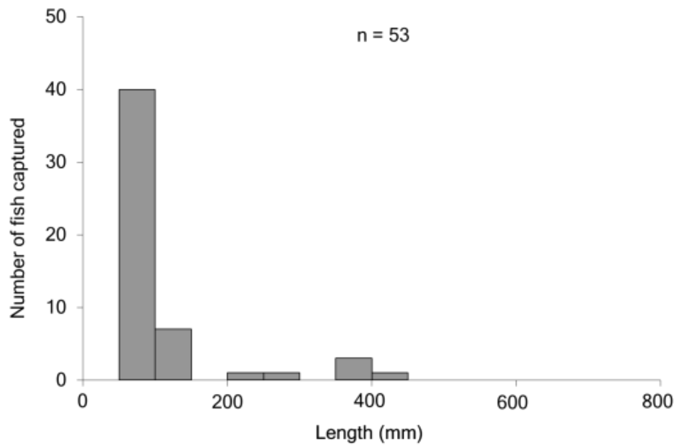

Figure F-6. Length frequency of carp collected in the Goulburn River at Yambuna in 2016

Surveys of eggs and larvae (drift nets and light traps)

A total of 480 individuals representing six native species and one exotic species were collected in the drift net surveys in the spring of 2015 (Table F-3). Murray cod was the most abundant species collected, comprising 74% of the total abundance for all species.

Common carp larvae (n=15) were collected from Yambuna in October 2015, coinciding with an increase in discharge from 780 to 6600 ML/day associated with a within-channel pulse over 4 weeks for vegetation objectives (Figure F-7).

A total of 213 individuals comprising five native species were collected in the light trap surveys (Table F-4). Australian smelt was the most abundant species, comprising 80% of the total abundance for all species. Murray cod was the next most abundant species, comprising 17% of the total abundance. Murray cod were collected from early November to early December during a time of stable low flows.

Table F-3. Numbers of eggs (*e*) and larvae (*l*) of fish species collected in drift net surveys from the Goulburn River in 2015. Species with asterisk are native species.

Species	Pyke Rd	Loch Garry	McCoy's Bridge	Yambuna	Total
Silver perch*					0
Murray cod*	100*l*	105*l*	67*l*	83*l*	355
Golden perch*					0
Common carp				15*l*	15
Australian smelt*	5*e*	15*e*. 1*l*	59*e*, 6*l*	2*e*	88
Flathead gudgeon*	1*l*	1*l*		9*l*	11
Carp gudgeon*	3*l*	3*l*	1*l*	4*l*	11
Total number of individuals	109	125	133	113	480

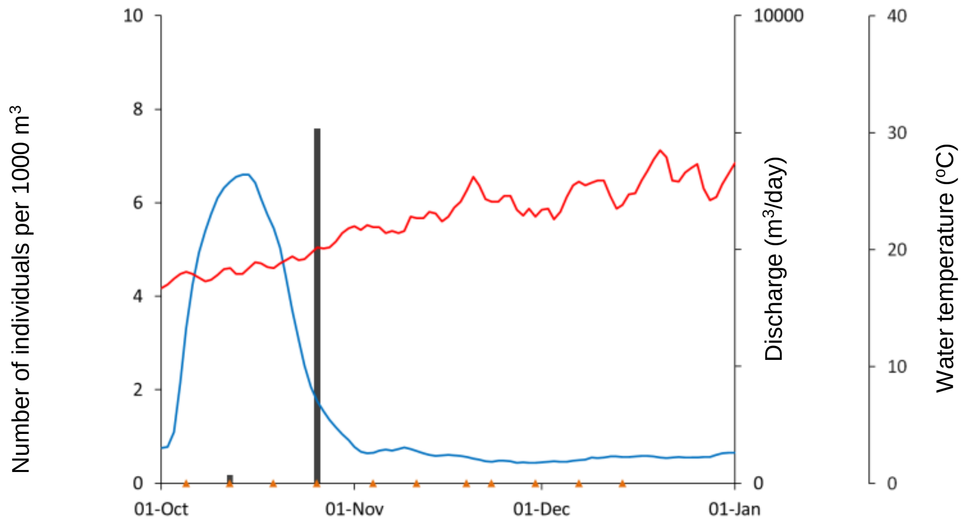

Figure F-7. Adjusted total density of carp larvae (grey bar) per 1000m³ collected in drift nets in the Goulburn River at Yambuna. Red line represents water temperature and blue line represents daily mean discharge in the Goulburn River at McCoy's Bridge. Orange triangles indicate sampling dates.

Table F-4. Numbers of eggs (*e*) and larvae (*l*) of fish species collected in light traps from the Goulburn River in 2014. All species listed in the table are native.

Species	Loch Garry	McCoy's Bridge	Yambuna	Total
Carp gudgeon	4*l*			4*l*
Australian smelt	50*l*	21*l*	1*e*, 99*l*	1*e*, 170*l*
Murray cod	8*l*	18*l*	10*l*	36*l*
Flathead gudgeon		1*l*		1*l*
Murray River rainbowfish		1*l*		1*l*
Total number of individuals	**62**	**41**	**110**	**213**

Movement of golden perch

Of the 58 golden perch tagged in 2014 and 2015, 48 have been detected by the listening stations. Almost one third (14 out of 48) of the fish detected have undertaken long-distance movements (i.e. > 20 km) into the lower reaches of the river; the other 34 fish had no detectable movement (Figure F-8). Several golden perch moved downstream into the Murray River. One of these fish travelled approximately 600 km downstream away from its point of capture in the Goulburn River into the Murray River and from there to near the junction of the Wakool River. Long-distance movements were most common during spring particularly in October–November, but also occurred to a lesser extent at other times (e.g. March). Most long-distance movements occur coincided with increases in discharge, including the spring and autumn environmental flow 'freshes', and at higher water temperatures (Figure F-8).

Movement varied considerably among the two years. In 2014 in October-November, 11 fish undertook long distance downstream movements, before returning back upstream several weeks later, while one other fish moved downstream during this time before returning back upstream several months later. In contrast, in 2015 in October-November, only 2 fish undertook long distance downstream movements. Three of the fish that undertook long distance downstream movements visited the Murray River; all except one of these fish has returned to the Goulburn River. In the 2014 spawning season, the movements of tagged fish into the lower reaches of the river corresponded with the occurrence of golden perch eggs at Yambuna in the lower reach.

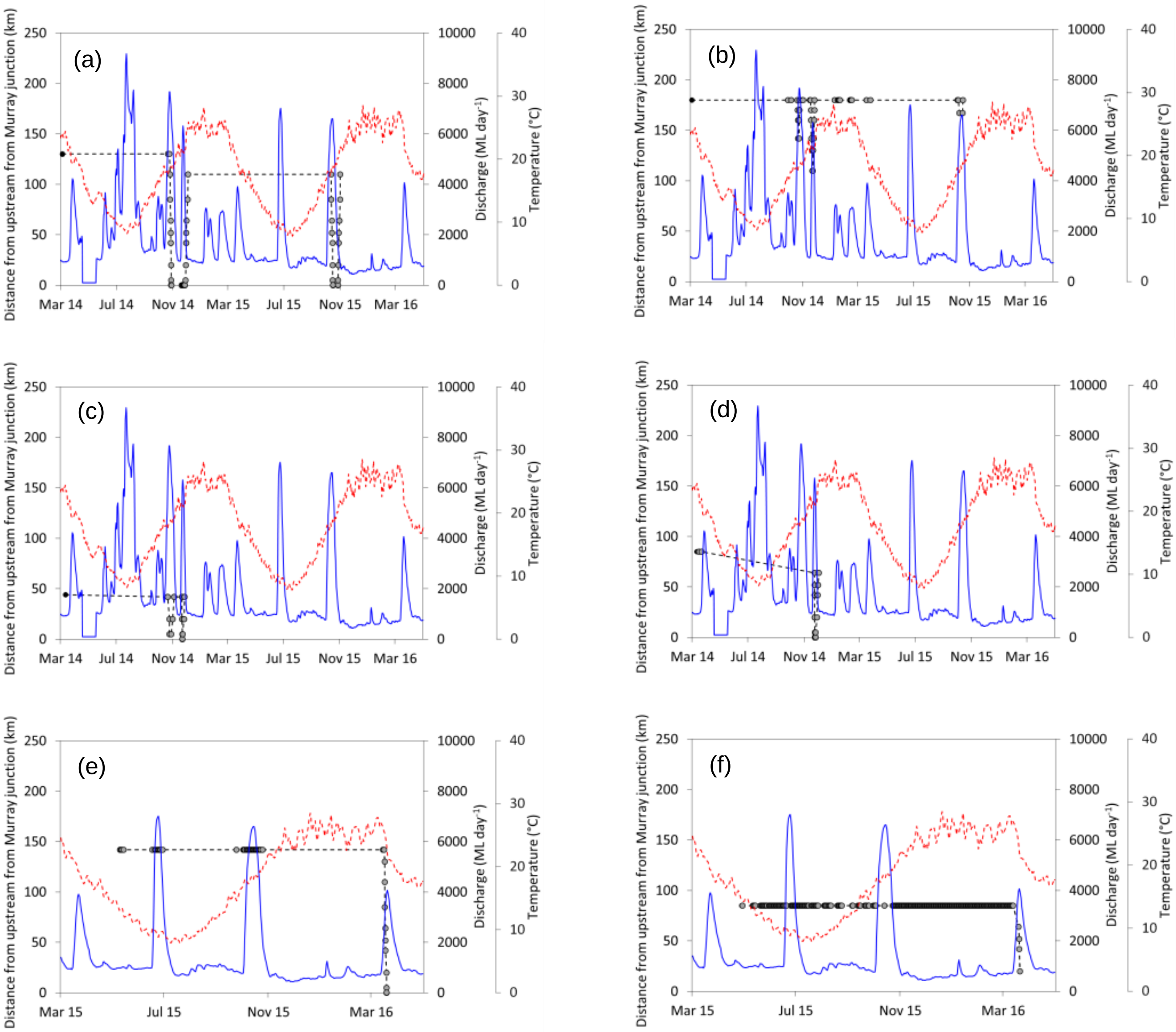

Figure F-8. Examples of movement patterns of golden perch tagged in the Goulburn River in 2014 (a, b, c & d) and in 2015 (e & f). Black circles show date and location of tagging, and grey circles show detections of tagged fish on the listening stations. Red dashed line represents water temperature and blue line represents daily mean discharge in the Goulburn River at McCoy's Bridge.

F.3.3 Statistical results

Probability of occurrence and abundance of golden perch larvae

As shown in Table F-3, no golden perch larvae were collected in drift nets in 2015. As such, the statistical modelling incorporates data from only 2014.

There appears to be a positive influence of all of the hydraulic metrics (i.e., change in discharge, change in mean velocity, and change in mean inundation depth) on the occurrence and abundance of golden perch spawning. This is indicated by the positive regression coefficients identified by the Bayesian hierarchical statistical model (Table F-5 and Table F-6), and by the predicted outputs of the model (Figure F-9). However, temperature does not have such a clear positive relationship to the occurrence of spawning. Positive effect of the regression coefficient (eff.Te) on the occurrence of spawning has a probability less than 0.5 (Table F-5). In addition, it is clear from Table F-5 that the regression coefficients of the hydraulic characteristics for the probability of spawning are generally greater at Loch Garry and McCoy's Bridge compared to Pyke Rd and Yambuna. This suggests that the probability of spawning is more strongly related to river flow and to hydraulic parameters at Loch Garry and McCoy's Bridge.

Table F-5. 95 percent Bayesian credible intervals of regression coefficients and probability of positive effect of regression coefficients of statistical models where the occurrence of golden perch spawning is modelled as a function of hydraulic characteristics. Values of probability close to 1 support the hypothesis of a positive effect.

	Regression Coefficients					**Probability of positive effect of regression coefficient**				
Hydraulic Parameter	**Hydraulic characteristic**				**Temp-erature**	**Hydraulic characteristic**				**Temp-erature**
	Pyke Road	Loch Garry	McCoy's Bridge	Yambuna		Pyke Road	Loch Garry	McCoy's Bridge	Yam-buna	
Change in flow (ML/d)	-0.16-1.73	0.95-5.64	0.69 – 2.03	0.57 – 1.86	-0.62 – 0.55	0.95	1.00	1.00	1.00	0.45
Change in mean velocity (m/s)	-0.75 – 1.22	1.06 – 6.70	0.70 – 2.38	0.65 – 2.31	-0.71 – 0.42	0.73	1.00	1.00	1.00	0.31
Change in water depth (m)	-0.10 – 2.67	0.90 – 4.71	0.66 – 1.90	0.55 – 1.74	-0.65 – 0.53	0.97	1.00	1.00	1.00	0.43

Table F-6. 95 percent Bayesian credible intervals of regression coefficients and probability of positive effect of regression coefficients of statistical models where the abundance of golden perch spawning is modelled as a function of hydraulic characteristics. Values of probability close to 1 support the hypothesis of a positive effect.

	Regression Coefficients					**Probability of positive effect of regression coefficient**				
Hydraulic Parameter	**Hydraulic characteristic**				**Temp-erature**	**Hydraulic characteristic**				**Temp-erature**
	Pyke Road	Loch Garry	McCoy's Bridge	Yambuna		Pyke Road	Loch Garry	McCoy's Bridge	Yam-buna	
Change in flow (ML/d)	0.73-0.85	5.0 – 9.1	2.0 – 2.1	1.9 – 2.0	0.50 – 0.63	1	1	1	1	1
Change in mean velocity (m/s)	0.14 – 0.26	4.5 – 8.5	1.7 – 1.8	1.5 – 1.6	0.20 – 0.31	1	1	1	1	1
Change in water depth (m)	1.3 – 1.6	3.9 – 6.8	1.7 – 1.9	1.6 – 1.8	0.47 – 0.60	1	1	1	1	1

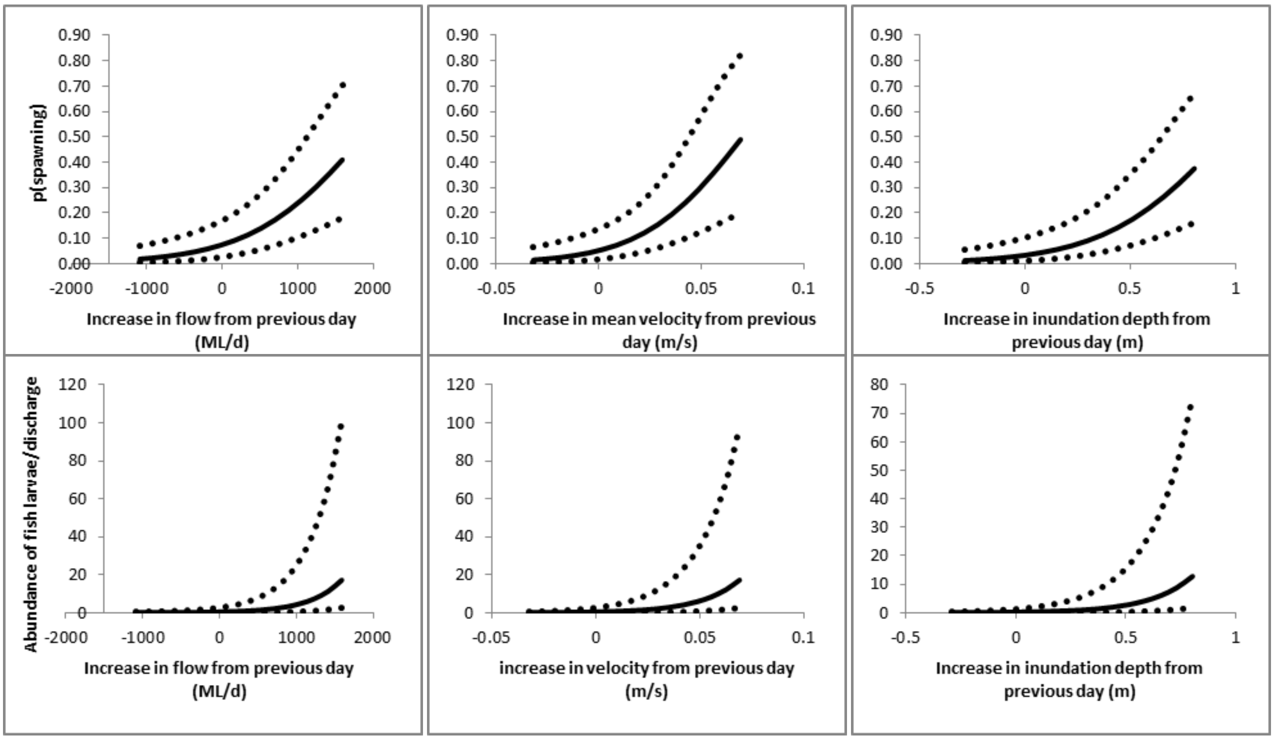

Figure F-9. Predicted probability of spawning occurrence and abundance of larvae/discharge through the net at McCoy's Bridge (at temperature of 20 degrees Celsius). Solid line represents median probability spawning occurrence and dotted lines represent the 95 percent Bayesian credible intervals.

Probability of occurrence of golden perch movement

The statistical modelling indicated that the relationship between the occurrence of movement and flow and hydraulic characteristics varies significantly between fish (Figure F-10). Figure F-11 indicates that the distribution of the probability of fish movement at high flows and velocities is highly positively skewed, with a large proportion of fish likely to not exhibit any movement at all when the flow and mean velocity increases.

The regression coefficients of the statistical model (Table F-7) indicate that there can be a negative or positive relationship between the occurrence of fish movement and the square of the day of the year, whilst there is generally a positive relationship between the occurrence of movement and the day. Table F-7 also indicates that the effect of flow (eff.Q) and velocity (eff.vel) can vary significantly, with 95% Bayesian credible intervals ranging from -2.67 to 2.55 for eff.Q and from -2.11 to 4.02 for eff.vel. With the provision of environmental flows, approximately 39 – 45% of fish experienced a greater probability of movement occurrence due to the increase in velocity, and approximately 40 – 46% of fish experience this greater probability of movement occurrence due to the increase in flow.

F.4 Discussion

Annual surveys (electrofishing and netting)

Significant populations of native fish occur in the lower Goulburn River, including several species of conservation significance, namely trout cod, Murray cod, silver perch and Murray River rainbowfish.Of particular note was the collection of trout cod between Zeerust and Loch Garry. In previous surveys of the Goulburn River from 2003 to 2013, trout cod was only collected upstream of Shepparton, but in the first 2 years (2015 and 2016) of the LTIM Project, the species has been recorded downstream of Shepparton, indicating a more widespread distribution than previously thought and possibly a recent range expansion.

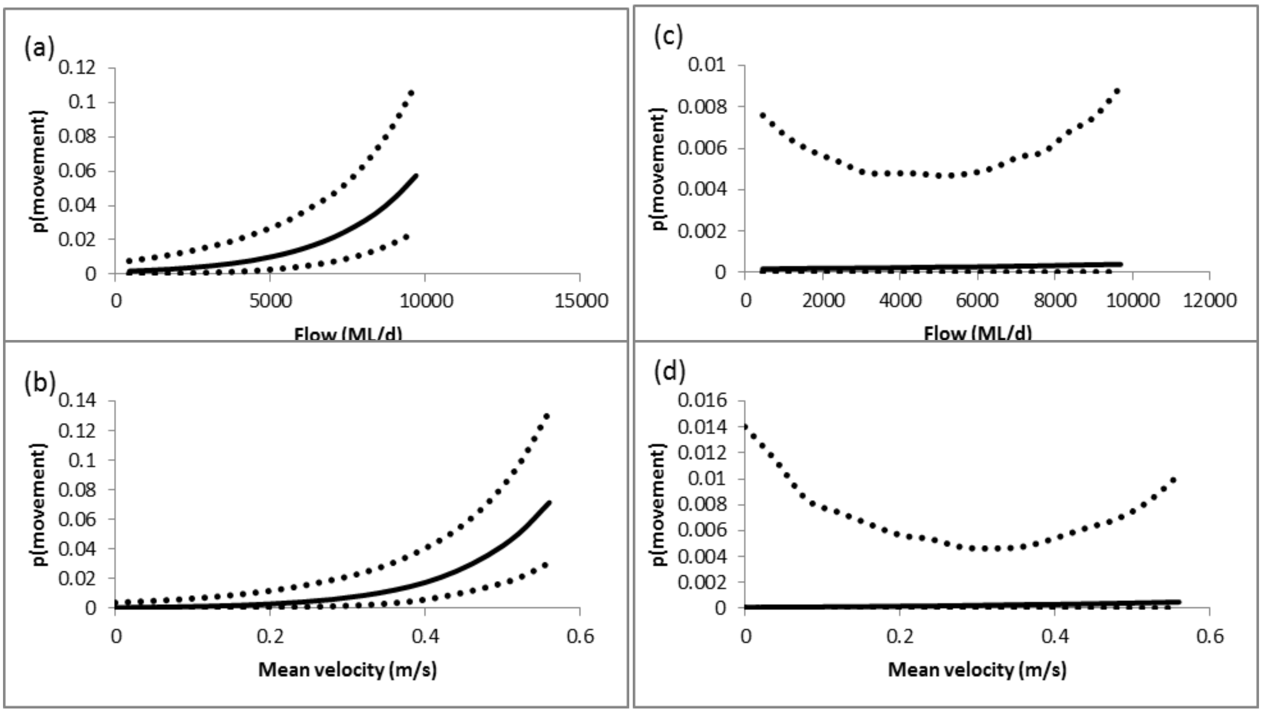

Figure F-10. Relationship between probability of fish movement and flow (a and c) and mean channel velocity (b and d) for two different fish (fish ID 32 and 54) on March 1st.

A major aim of this component of the monitoring program is to determine whether spring freshes that promote golden perch or silver perch spawning translate into increased recruitment of young-of-year fish in the Goulburn River. Several young-of-year golden perch about 1 gram in weight were collected in the Goulburn River in 2016 at Shepparton, but no eggs or larvae of golden perch were collected in the 2015 spawning season. Golden perch fingerlings about 1 gram in weight were stocked by Fisheries Victoria at this site in April 2016 immediately prior to the autumn survey, which may explain this result. Golden perch and silver perch did however spawn 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 unpubl. data). This result suggests that spawning may not necessarily translate into immediate recruitment of young-of-year fish.

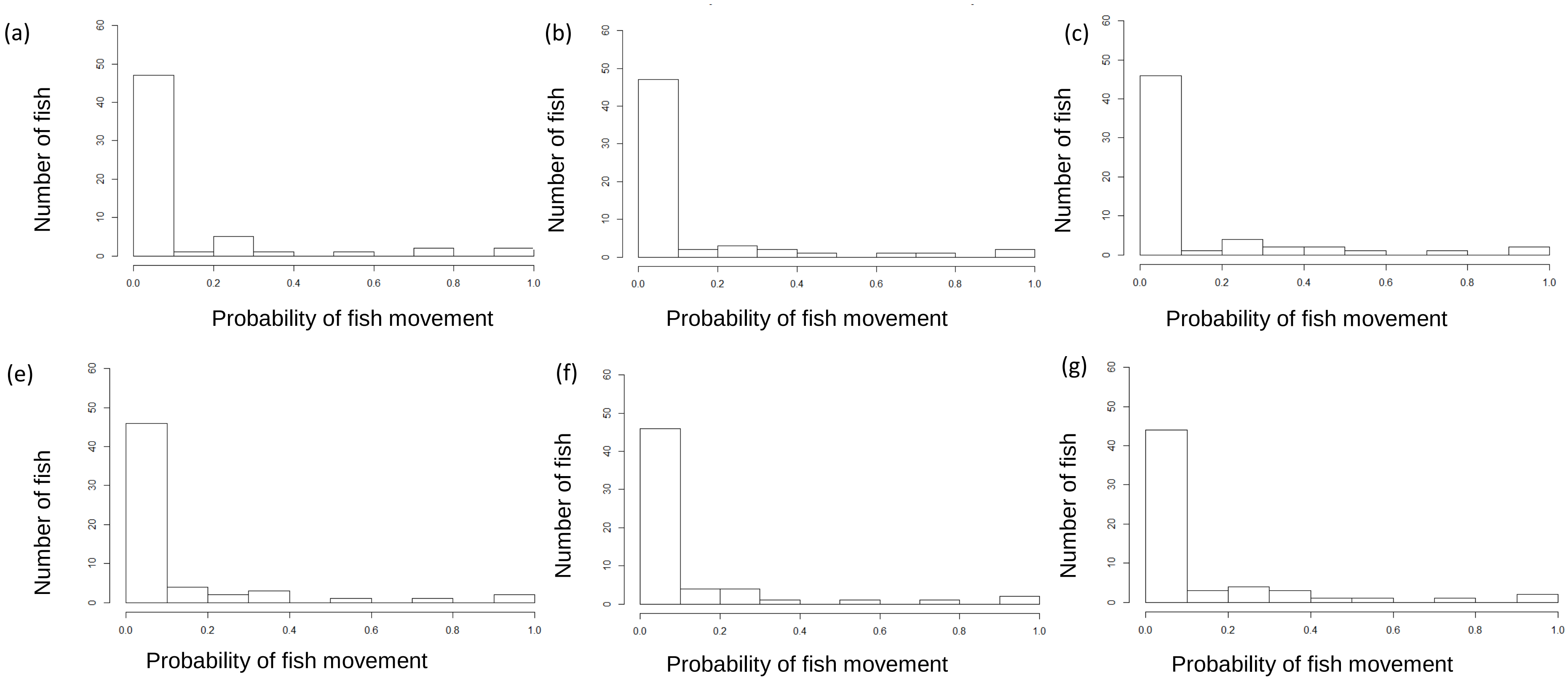

Figure F-11. Distribution of probability of fish movement at Q=3746 ML/d (a), Q=5729 ML/d (b), Q=8373 ML/d (c), v=0.23 m/s (d), v=0.33 m/s (e), v=0.47 m/s (f) on the 1st of March.

Table F-7. 95% Bayesian Credible Intervals of regression coefficients of fish movement Bayesian statistical model. Credible intervals for eff.Q and eff.vel represented as the minimum 2.5th percentile regression coefficient over all 59 fish to the maximum 97.5th percentile regression coefficient over all 59 fish.

	Fish movement occurrence as a function of flow	Fish movement occurrence as a function of velocity
eff.day1	-0.062 – 0.059	-0.075 – 0.051
eff.day2	0.16 – 0.26	0.15 – 0.26
eff.Q	-2.67 – 2.55	NA
eff.vel	NA	-2.11 – 4.02

Otoliths collected from golden perch and silver perch show fish that were spawned between 2010 and 2013 are however present in the population, but is unknown whether these fish were spawned in the Goulburn River, have migrated into the system from elsewhere, or were stocked in the case of golden perch. 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, and also potentially by fish spawned in other river systems. In light of this, determining whether golden perch and silver 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).

Another significant, but negative, finding of the surveys, was collection of large numbers of the introduced pest species carp. Catch per unit effort of carp in the electrofishing surveys (33 fish per hour) was considerably higher than in most surveys in the Goulburn River from 2003 to 2015 (median 14.3 fish per hour) (Koster et al. 2012, Koster unpubl. data).The increase was largely driven by high numbers of young-of-year carp particularly at downstream sites such as Yambuna site, indicating recent successful spawning and recruitment, possibly as a result of a spawning event in the Goulburn River associated with the fresh delivered for vegetation objectives in mid-October 2015. Notwithstanding, it would be valuable to use otolith microchemistry to determine whether the young-of-year carp collected in 2016 were spawned in the Goulburn River, or have migrated into the system from elsewhere. Surveys conducted in the Goulburn River from 2003 to 2013 revealed that young-of-year fish occasionally comprise a large proportion of the carp population following high flows and floods (e.g. autumn 2006, 2009, and 2011). Recruitment from outside of the Goulburn River, such as Barmah-Millewa, is thought to act as a key source of juveniles for the Goulburn River, although this may vary depending on flow conditions (Crook and Gillanders 2006). Identifying the origins of carp in the Goulburn River would be valuable for the management of this pest species, especially if they are responding to flow events otherwise designed to benefit native flora and fauna.

Surveys of eggs and larvae (drift nets and light traps)

The results of this study have provided important information on the linkages between spawning of golden perch and flow, via the ‘counterfactual scenario’ where flows designed to induce spawning were not delivered. Environmental water was delivered in mid-October 2015 to provide a within-channel pulse for vegetation objectives, but no golden perch eggs or larvae were collected. The October flow event appears to have occurred too early for golden perch spawning. Water temperature around the time of the flow peak in mid-October 2015 was only about 17-18° C; the greatest spawning outcomes for golden perch typically occur at water temperatures of 18–20° C (King et al. 2015). Indeed, in 2014, when golden perch exhibited a strong spawning response during an environmental flow fresh in the Goulburn River in November, water temperature was about 20° C. Furthermore, 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 unpubl. data). The lack of spawning observed in spring 2015 improves our knowledge of the conditions required to induce golden perch spawning. Our findings demonstrate that although releases of water can stimulate golden perch spawning, if flows are not coupled with preferred water temperature (e.g. ≥18° C) they may not always achieve this objective. Further assessment in the following years will be important to more reliably determine the role of specific flow and water temperature conditions on golden perch spawning success.

The results of this study also add to understanding of carp spawning dynamics, with carp larvae collected coinciding with the fresh delivered for vegetation objectives in mid-October 2015. Carp spawn in spring-summer amongst submerged vegetation, and flows that provide access to bank vegetation can enhance spawning opportunities (Koehn et al. 2016). Eggs and larvae of carp were rarely collected in surveys conducted from 2003-2013 in the Goulburn River (Koster et al. 2012, Koster unpubl. data) and a study of recruitment sources of carp indicated that the Barmah-Millewa forest floodplain was a major recruitment source for young-of-year carp in the Goulburn River (Macdonald and Crook 2006). The 2015 result suggests that recruitment sources for carp in the Goulburn River vary over time, particularly in relation to flow conditions. To minimise the potential for carp spawning associated with environmental flows in the Goulburn River, consideration could be given to carp management principles such as drawing down water levels immediately after carp spawning events to desiccate eggs (Koehn et al. 2016). In particular, questions remain as to why carp recruitment was observed in 2015 following a flow pulse aimed at improving bank vegetation, when such recruitment was not observed in 2014 when a similar vegetation-targeted flow pulse was delivered, although slightly earlier in spring.

Movement of golden perch

The results of this study have provided important information on the linkages between movement and spawning of golden perch, and the role of river flow as a driver of these processes. Our results demonstrate that golden perch movement increased during the spawning season and corresponded to the timing of spawning. More specifically, movement was mainly downstream into the lower river reaches during elevated discharges. These results provide support for the hypothesis that long-distance movements by golden perch during the spawning season are indeed related to reproduction (Reynolds 1983, O'Connor et al. 2005).

Our results highlight the importance of a rise in streamflow for movement of golden perch, in agreement with previous studies on this species (Reynolds 1983, O'Connor et al. 2005, Koehn and Nicol 2016). In particular, our results revealed that targeted environmental water allocation in the Goulburn River, especially in spring, can promote movement of this species likely related to reproduction, and this is likely to apply to other regulated rivers inhabited by golden perch.

Movement varied substantially among spawning seasons, with movement concentrated in the 2014 spawning season, whereas in the 2015 spawning season there was only limited movement. This result appears to be related to differences in the timing of freshes and therefore water temperature. In 2014, water temperature was about 20° C during the environmental flow fresh in November, whereas in 2015 water temperature was only about 17-18° C during the fresh in October. These findings are an important consideration for environmental water management, as it suggests that although releases of water can promote golden perch movement, they may not always achieve this objective if flows are not coupled with appropriate water temperature.

Some golden perch also undertook movements outside of the peak (i.e. October-November) spawning season (e.g. March). It is possible such movements are related to reproduction, as golden perch spawning and movement behaviour is complex and potentially flexible, and has been reported to occur over a broad time frame (September to March) (Koehn and O'Connor 1990). Such movements could also represent occasional exploratory behaviour. Although golden perch occupy restricted home ranges for extended periods outside the spawning season, such periods are punctuated by occasional bursts of more extensive movement (particularly during periods of increased discharge) that may be related to the exploration and evaluation of new habitat (Crook 2004).

The transmitters implanted into fish in 2014 and 2015 should continue to transmit until 2017 and 2018 respectively. Additional fish were also tagged in 2016, providing data through to 2019. 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 and recommendations

- Targeted environmental water allocation in the Goulburn River can stimulate golden perch movement and spawning, but if flows are not coupled with preferred water temperature (e.g. ≥18° C), they may not always achieve this objective.

- Natural recruitment of young-of-year golden perch and silver perch in the Goulburn River appears to be limited. It is possible that recruitment sources outside of the Goulburn River such as the Murray River act as a key source of recruits for these species in the Goulburn River. Determining whether golden perch and silver perch in the Goulburn River were spawned locally, or have migrated into the system from elsewhere, and relating this to patterns of flow, is an important area for future monitoring.

- Monitoring in 2015-16 detected an increase in the abundance of carp in the Goulburn River, particularly young-of-year fish, possibly as a result of a flow event in the Goulburn River in mid-October 2015, or as a result of flow levels in the Murray River. Consideration could be given to carp management principles such as drawing down water levels immediately after carp spawning events to desiccate carp eggs to minimise the potential for carp spawning associated with environmental flows in the Goulburn River.

Appendix G. Examples of stakeholder communications

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6 Country News, week of Tuesday, Jul 19, 2016 www.countrynews.com.au

Flows boost Goulburn levels

The recent increase in the height of the Goulburn River downstream of Murchison is due to run-off and inflows from tributaries.

Goulburn Broken Catchment Management Authority environmental water co-ordinator Daniel Lovell said these tributaries included the Broken River and Seven and Pranjip creeks.

"With more than 100 mm of rainfall recorded in many parts of the catchment in the past few weeks we're now seeing increased run-off into creeks, with many previously dry waterways starting to flow for the first time in almost a year," Mr Lovell said.

"The extra water from these tributaries flows in to the Goulburn River and 'tops up' the environmental base flow of 500 Ml/day that is being released from Goulburn Weir to the lower Goulburn River.

"In fact, overnight on July 14, the Goulburn River at Shepparton peaked at almost 8000 Ml/day — a river height of just over 5 m — with most of this water coming from Broken River flows."

The minor flood level at Shepparton is 9 m.

A base flow of 500 Ml/day is released from Goulburn Weir year-round to maintain water quality and provide shelter for native fish, water bugs and other animals in the lower Goulburn River.

"Without this base flow, in dry years such as the one we've just experienced, the lower Goulburn River, and the plants and animals that rely on it, would be quite stressed," Mr Lovell said.

"For the past few years, we've also delivered additional water in spring and autumn to try and mimic the more natural flow patterns that would have occurred before dams, weirs and channels altered the river's flows.

"These flows have resulted in significant re-growth of river bank vegetation that prevents erosion and provides critical habitat for small fish and bugs."

Last year's October (spring) flow peaked at 7500 Ml/day (river height at Shepparton of 5.5 m) while the March (autumn) flow peaked at 4500 Ml/day (river height 3.93 m at Shepparton).

Mr Lovell said the main aim of the flows was to improve and extend bank-stabilising vegetation along the river.

The extra water also provided recreational benefits such as improved fishing and boating.

Wherever possible, environmental water deliveries are timed to piggy back on deliveries of water to irrigators and other users.

The water is also 're-used' at wetlands such as Gunbower and Hattah as it makes its way along the Murray River.

■ **Information about proposed environmental water activities in the lower Goulburn River for the next 12 months is available at www.gbcma.vic.gov.au**

Spot the difference . . . The Goulburn River flow in March peaked at 4500 Ml/day (3.93 m) at the Shepparton boat ramp (left). The boat ramp at 4.98 m this month (right).

Figure G-1. ***Country News*** **article, July 2016**

Tweet activity ×

Goulburn Broken CMA @GBCMA
Good Murray cod silver perch & trout cod nos in **#GoulburnRiver @VicEWH @theCEWH @Ecology_Aus** http://bit.ly/1VRBujQ pic.twitter.com/1JntUJTV4V

Reach a bigger audience
Get more engagements by promoting this Tweet!

Get started

Impressions	2,003
Total engagements	44
Link clicks	10
Likes	8
Detail expands	8
Retweets	7
Profile clicks	6
Media engagements	5

Figure G-2. Fish monitoring Tweet

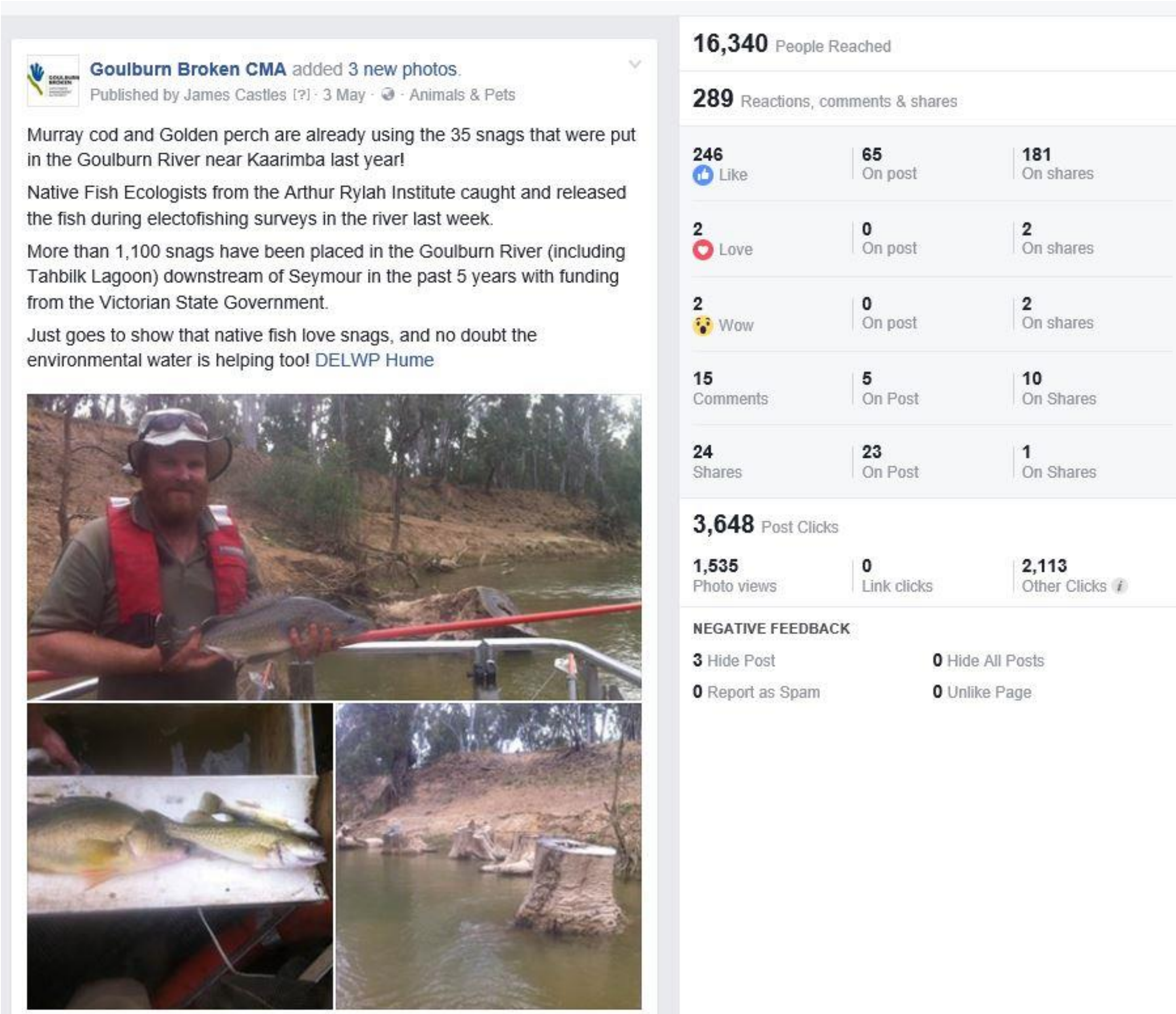

Figure G-3. Fish monitoring Facebook post, May 2016

Media Release

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

December 2015

Banks, plants and native fish respond to environmental flows

Monitoring during summer 2014 and autumn 2015 found environmental flows during those seasons had triggered golden perch spawning and encouraged bank-stabilising plant growth.

Environmental water is water set aside to improve or maintain the health of rivers, floodplains and wetlands and the plants and animals that depend on them.

Environmental water deliveries in 2014/15 to the lower Goulburn River focused on increasing base flows from 250ML/day to at least 500ML/day (river height of 2.5m at Shepparton) throughout the year to increase food and shelter for native fish and water bugs.

Figure G-4. Portion of a GBCMA media release, December 2015

GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

Environmental Water Update

Goulburn River

This year's annual spring environmental flow release from Goulburn Weir is under way.

The aim of the flow is to re-establish river bank and in-stream vegetation to help stabilise the river bank and provide valuable habitat and food for native fish, birds and water bugs.

This is an annual event, however, this flow started slightly earlier than last year's spring flow to improve the chances of seed germination and plant growth before summer.

The fresh reached about 7,000 ML/day at Murchison on October 6 and will gradually reduce to about 800 ML/day by October 23. Flows are planned to be above 3,000 ML/day at Murchison until October 18.

The flow will occur at McCoy's Bridge about four days after being released from Goulburn Weir. As well as benefiting the Goulburn, the flow provides recreational and environmental benefits to many wetlands and downstream along the Murray.

The flow will use a combination of Commonwealth and The Living Murray environmental water.

Check river heights and flows in each Friday's Shepparton News.

Broken Creek

A flow of approximately 250 ML/day is currently being delivered down the lower Broken Creek to increase native fish habitat during the migration and breeding season. The flow is provided by environmental water held by the Commonwealth Environmental Water Holder.

Wetlands

Environmental water is currently being delivered to Reedy Swamp in Shepparton and Barmah Forest on the Murray River, Black Swamp near Wunghnu and Kinnairds Wetland near Numurkah. In addition, environmental water has been delivered to Doctors Swamp near Murchison for the first time. The environmental water aims to promote wetland plant growth and provide habitat for waterbird breeding.

Environmental water held by the Commonwealth and Victorian water holders and the MDBA is being used.

Grants available for fencing, revegetation

Landholders interested in grants to protect sand ridge woodland sites on their property are invited to lodge an Expression of Interest with the Goulburn Broken CMA by November 30.

Goulburn Broken CMA has received $100,000 of funding through the Australian Government's National Landcare Programme for the Sand Ridge Woodland Project. The Sand Ridge Woodland Project is an ongoing partnership between Yorta Yorta Nation Aboriginal Corporation, government agencies and landholders to protect these sites that have been degraded over time though sand mining, clearing, grazing and pest plants and animals.

Grants are available to landholders in the region that extends along the Murray and Goulburn valleys across Yorta Yorta Country for fencing, revegetation, pest animal and weed control and protection of cultural heritage sites.

Landholders interested in finding out more about the grants can contact Jim Begley on (03) 5764 7503 or jimb@gbcma.vic.gov.au

www.gbcma.vic.gov.au

GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

Why do we need environmental water?

Over the years, many of our waterways' natural flows have changed due to the construction of dams, weirs and channels. Environmental water aims to mimic some of the flows that would have occurred naturally before these structures were built and to coincide with key stages in the life cycles of various native plants and animals (eg. providing cues for native fish to spawn or restoring more natural drying and wetting patterns in wetlands).

Environmental water activities

Goulburn River: Delivery of extra water down the Goulburn River last month to improve the health of bank-stabilising vegetation has finished. At its peak this extra water saw the river flow reach 4500ML/day (height of 3.9m at Shepparton). We will now monitor the effects of the extra water. For the next few months the river flows will vary between 540 – 940 ML/day (river height of 2.5 – 2.74m at Shepparton). This water is meeting downstream irrigator, trade and other user demands.

Lower Broken Creek: A minimum flow of 250 ML/day is currently being delivered along the lower Broken Creek to help maintain dissolved oxygen levels and control blue-green algae growth. Dissolved oxygen levels are an important indicator of water quality and low dissolved oxygen levels can stress fish. The flow is currently provide by Commonwealth Environmental Water.

Wetlands: Kinnairds Wetland and Doctors Swamp are now in a natural drying phase. Marsh sandpipers have been reported at Reedy Swamp, which is also going through a natural drying phase. These birds have flown all the way from Siberia but will head back soon as northern hemisphere temperatures warm up. Delivery of 500ML of environmental water to Moodie Swamp will start this month. The water will improve the wetland's vegetation and provide breeding habitat for brolga and other waterbirds.

Barmah: No environmental water has been delivered to the forest's wetlands since the end of January and most wetlands are in a natural drying phase. Later this month a fence will be built around Little Rushy Swamp to keep feral animals off the Moira grass. Barmah is home to the largest area of Moira grass plains in Victoria. The grass provides valuable food and shelter to a range of birds, fish, frogs and other native animals.

Want to know more?

- Visit the "Environmental Water" section on our website
- View our YouTube channel to find out more about our monitoring activities
- Read the 2015/16 Seasonal Watering Plan (Northern Region section) on the Victorian environmental Water Holder's website www.vehw.vic.gov.au

www.gbcma.vic.gov.au

Figure G-5. Two columns published by the CBCMA in the *Country News* (October, 2015, April 2016).