Monitoring and Reporting on the Ecological Outcomes of Commonwealth Environmental Water Delivered in the Lower Goulburn River and Broken Creek in 2013/14

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Executive Summary

The Commonwealth Environmental Water Office short-term intervention monitoring program for the lower Goulburn River and Broken Creek in 2013/14 was able to detect beneficial effects of environmental watering for all monitoring activities undertaken. Collectively, the results underscore the importance of Commonwealth and other held environmental water for maintaining and improving the ecological condition of these two waterways, and improve our ability to deliver targeted environmental flows into the future.

Environmental flows in the lower Goulburn River in 2013/14 were primarily aimed at improving the distribution, abundance and diversity of native fish, macroinvertebrates and vegetation. Commonwealth environmental water was delivered as two large spring freshes in November and December (peaking at ~ 7000 ML/d), improved minimum flows (~ 1000 ML/d), and a smaller autumn fresh (peaking at ~4000 ML/d) in late March. In addition, the Goulburn-Broken Catchment Management Authority attempted to gain some environmental benefits from the inter-valley transfer of irrigation water that occurred in January and February. Overall, some 312 GL of environmental water was delivered to the lower Goulburn River in 2013/14, with 215 GL of this being Commonwealth environmental water.

Environmental flows in Broken Creek do not attempt to mimic any sort of natural hydrograph. Rather, they are aimed at maintaining and improving the environmental values that have accrued since regulation first transformed Broken Creek into a perennially flowing system. Discharges in the system were maintained at an average of ~ 250 ML/d over the period November-April, with the bulk of this water being environmental flows (~ 80%). Overall, some 55 GL of environmental water was delivered to Broken Creek in 2013/14, including 39 GL of Commonwealth environmental water.

Monitoring for the beneficial effects of Commonwealth and other environmental water was undertaken mostly over the period October – March. Individual monitoring programs investigated the effects of environmental flows upon:

Goulburn River

- Physical habitat, measured as slackwater areas and deepwater pools, plus the occurrence of fine sediment smothering of benthic habitats (Chapter 2)
- Primary and secondary riverine production (Chapter 3)
- Riparian vegetation abundance and diversity (Chapter 4)
- Spawning, recruitment and movement of golden perch (Chapter 5)

Broken Creek

- Movement of Murray cod and golden perch in response to discharge and dissolved oxygen (Chapter 6)
- Movement of large-bodied fish through the fishway system (Chapter 7)

Physical habitat monitoring detected beneficial effects of environmental flows upon the provision of slackwater and deepwater habitat, and on the flushing of fine sediments from benthic habitats. Monitoring was undertaken in the lower Goulburn River to assess the effects of environmental flows upon refugia and habitats relevant to outcomes for native fish and macroinvertebrates. Area of slackwater habitat was shown to increase with moderate discharges of 2000 – 4000 ML/d, as low-level benches were inundated. Slackwater habitat will be reduced at higher discharges as depths and velocities over benches increase. Availability of deepwater pools increases with increasing discharge, but the largest increases occur with discharges up to approximately 2500 ML/d. As well as providing valuable information for managing environmental water, these results will help in management of 'non-environmental' flows, such as inter-valley transfers. Sediment smothering of benthic habitats is reduced by large environmental flow events (> 4000 ML/d), and increased by long periods of base flows (< 1500 ML/d). However, the first flow event following a long period of base flows can increase smothering, presumably through remobilizing bank and bed sediments that have accumulated upstream during the low flow period.

Monitoring of riverine productivity detected increases in production associated with environmental flow events, potentially driven by mobilisation of organic matter and nutrients caused by spring freshes. Monitoring assessed the effects of environmental flows in the lower Goulburn River on organic matter supply and retention, water quality (turbidity, nutrients and light climate), primary production (including benthic algae and phytoplankton), and secondary production (measured as abundance and composition of macroinvertebrates and zooplankton). Increased primary production (and gross primary production: ecosystem respiration ratio) was observed during the first spring fresh. This was coincident with increased water-column turbidity and nutrient levels probably caused by environmental flows inundating low-lying benches and mobilizing sediments and organic matter. Environmental flows mobilized pieces of wood within the river channel and increased transport of suspended matter, which can provide habitat and food respectively, for river consumers. Environmental flows also reduced light availability for benthic algae, and directly scoured algae from the river bed. Benthic algae can otherwise build up to nuisance levels under constant low flow conditions. An increase in macroinvertebrate abundance during spring freshes may have been a behavioural response (increased drift during high-flow events). Alternatively, it could be indicative of increased secondary production, with invertebrates taking advantage of increased food sources provided through increased primary production or the addition of terrestrial organic matter to the river channel (e.g. leaf-litter, bark, pieces of wood).

Native vegetation responded positively to spring freshes in 2013/14, and the riparian vegetation of the lower Goulburn River is returning to a flora that includes a number of species adapted to regular inundation. Monitoring in the Goulburn was able to assess vegetation responses in terms of diversity, growth and survival. Different vegetation types are expected to respond differently to environmental flows, with terrestrial species becoming less prevalent, and inundation-adapted species increasing. Analyses of four different 'functional groups' of vegetation confirmed this, with inundation-tolerant species being found lower down on river banks subjected to higher durations and frequencies of inundation, and terrestrial species conversely being more prevalent high on river banks. Rivers with this type of vegetation pattern will have banks that are more resistant to erosion during high flow events, and the vegetation assemblage will be more resilient to disturbance. Inundation-tolerant vegetation will also provide habitat for small fish and invertebrates during inundation events. The monitoring data and associated statistical models were used to make predictions of how bank vegetation would change if environmental flows were not delivered, forecasting considerable differences on the lower bank. Concurrent monitoring undertaken in Broken Creek weir pools, which experience very little variability in flow regime, showed that those assemblages show very strong zonation in terms of the transition from inundation-adapted to terrestrial species compared to the Goulburn River. This type of zonation is not typical of a natural inundation regime, and provides a point of comparison against which to compare the Goulburn River vegetation. Goulburn River vegetation exhibited more gradual zonation, indicating that environmental flows have reinstated a more natural inundation regime. More immediately, new growth of inundation-tolerant native vegetation was observed in the weeks after the two spring freshes were delivered in 2013, providing strong evidence of the benefits of these flow events.

Adult golden perch undertook migrations and spawned in response to spring freshes. The level of spawning was greater than any previously observed, with the exception of spawning during the 2010 flood. In the Goulburn River, golden perch is a species of particular focus, and large amounts of environmental water are delivered for its benefit. Short-term expected responses to environmental water delivery include increased reproduction and larval abundance of the species. Long-term larval monitoring (2003-2012) had mostly failed to detect substantial spawning of golden perch, with the flood year of 2010/11 being the major exception to this. Throughout this previous monitoring, and with the results collected in this program, spawning is associated with increased spring-summer flows, with no spawning detected during years with low and stable spring-summer flows. However, early spawning occurred in 2013/14 at discharge levels similar to those provided as a spring fresh in 2012/13 (~4000 ML/d). We believe that unregulated peak flows that occurred in early spring 2013/14 (when the corresponding period in 2012/13 was characterized by steadily falling discharges) may have played a role in 'priming' the fish for spawning. Acoustic tracking of adult golden perch showed that a substantial proportion of fish (~50% of tagged fish) undertook migrations upon the delivery of environmental flows. Many of these journeys were to the lower reaches of the river, where spawning has previously been observed. A large spawning event took place during the first spring fresh in November 2013. More eggs were found during this fresh than for any other monitoring year but for 2010/11. Spawning took place in the lower reaches of the river, where water temperatures are warmer (19-20°C), consistent with previous research on this species. The multiple years of data collection lead to the strong conclusion that spawning was caused by the environmental flow event, and would not have occurred without the provision of the spring fresh. Electrofishing surveys carried out in April 2014 did not detect any young-of-year fish arising from this spawning event, but there remains the strong possibility that the buoyant eggs and larvae were exported from the Goulburn River with early recruitment taking place downstream in the River Murray.

Golden perch and Murray cod in Broken Creek showed different levels of activity with changing dissolved oxygen levels and undertook movements correlated with higher flows in this system. Movement is a hypothesized positive short-term response to environmental flows which provide longitidinal connectivity and hydrological cues of movement. In Broken Creek, fish kills have been driven by low dissolved oxygen levels, and so behavioural responses of native fish to low dissolved oxygen is of primary interest when using environmental flows to manage water quality in this system. Extreme low dissolved oxygen levels were not experienced during 2013/14, but low levels were seen on several occasions. Murray cod reduced their level of physical activity in response to low dissolved oxygen, while golden perch showed the opposite response, increasing levels of activity. A lack of mortality of tagged fish demonstrates that both species can readily cope with the short-term low levels of dissolved oxygen that occurred during this monitoring period. Both species showed increased movement through the lower Broken Creek system in response to higher flows, mirroring the movement results observed for adult golden perch in the Goulburn River. Discharge patterns in Broken Creek are quite stable at present. If fish movement is an objective for environmental managers, then they may need to deliver more variable flows in Broken Creek.

Similarly, Murray cod and golden perch moved through the Broken Creek fishways more often on higher flow events. Carp also respond to increased flows, but we may be able to deliver flows at a level that induces movement of native fish, but not carp. Complementary to the acoustic tracking described above, PIT-tag monitoring of Murray cod, golden perch, and European carp was used to assess their use of the fishway system installed in lower Broken Creek. Murray cod moved most frequently on higher flow events in spring (300-700 ML/d), but movement dropped off later in the year (summer and autumn). Golden perch showed some movement in response to increasing flows, but use of the fishways was more closely tied to increasing water temperatures (18 and 24°C). Coupled with the spawning results described above, we can speculate that if the aim is to stimulate a golden perch spawning event, then environmental flow should be delivered around November. If the aim is to stimulate upstream movement/dispersal, then flows delivered later in the season (i.e. December-March when water temperatures are closer to those described here) may provide better results. European carp responded to discharge and temperature, but showed little movement through fishways at discharges of less than 400 ML/d. This flow threshold may allow environmental water managers to fine-tune discharges to support movements of native fish, but not carp.

The beneficial effects of environmental flows detected by the individual monitoring programs can collectively be considered to develop a conceptual model of how the lower Goulburn River is responding to Commonwealth environmental water, and environmental flows in general. Spring freshes mobilize sediments and organic matter, increasing nutrient availability and underpinning increased primary production in the form of phytoplankton and benthic algae. This food source may partly explain the increased abundance of invertebrates observed. Spring freshes also improved physical habitat for macroinvertebrates (by scouring fine sediments), larval fish/zooplankton (by increasing the amount of slackwater habitat available), and for adult fish (by increasing the amount of deep pool habitat available). Sediments mobilized by spring freshes would have deposited in the slackwater areas, providing uncolonized, nutrient-rich soils for native vegetation to grow upon following recession of the spring fresh. Freshes are also proving effective at reducing the prevalence of terrestrial vegetation species on river banks, and may also be replenishing bankside seed banks, stimulating a longer-term improvement in vegetation. Finally, the freshes and higher flows stimulated movement of native fish species, and spawning of golden perch. These eggs may have drifted downstream into the Murray River, and subsequent recruitment into the Goulburn River may occur at a later stage by older fish.

The synthesis of these results demonstrates the importance of Commonwealth environmental water for improving the environments of the lower Goulburn River and Broken Creek. In Broken Creek, the effects of environmental flows for maintaining dissolved oxygen levels and preventing *Azolla* blooms were already well characterized by the 2012/13 short-term intervention monitoring program. Without these flows, low dissolved oxygen and subsequent fish kills are virtually assured. The results from 2013/14 highlight the importance of environmental flows for promoting fish movement throughout Broken Creek, which is also important for conservation of native fish populations. Benefits of environmental flows for the Goulburn River were less well known, and the 2012/13 short-term intervention monitoring program did not strongly demonstrate beneficial effects. Results in 2013/14 have greatly improved upon this, and there were no areas within the program that were not able to detect beneficial effects of environmental flows. We can now point to the importance of spring freshes for mobilizing sediments and nutrients, driving increases in primary and secondary productivity in the system, creating slackwater habitat for the germination and growth of native vegetation and for larval fish and microinvertebrates. The freshes promoted movement of native fish and resulted in the largest spawning event for golden perch in the Goulburn River since the 2010 floods. Future monitoring of the effects of

Commonwealth Environmental Water in the Goulburn River will be undertaken through the long-term intervention monitoring (LTIM) project. All data and results from 2 years of short-term monitoring will be available to support that project, and several of the staff involved in short-term monitoring will also work upon the LTIM project. We hope to continue to demonstrate the benefits of Commonwealth environmental water, building upon the understanding that has emerged from these short-term projects.

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1 Introduction

This report outlines the outcomes from Commonwealth Environmental Watering actions undertaken in the lower Goulburn River and lower Broken Creek systems for the 2013/14 water year. The report aims to be relatively approachable for all readers, and so the main body chapters concentrate upon describing the rationale for monitoring various endpoints, the responses observed, and what these mean for the environmental flows programs in the Goulburn River and Broken Creek. Detailed methods and results are contained in a series of appendices, and/or were reported in sufficient detail in the final report of the 2012/13 short-term intervention monitoring report (GBCMA 2012; Stewardson *et al.* 2013).

1.1 Background on the Goulburn River and Broken Creek

The Goulburn-Broken catchment covers 17% of Victoria, and is the largest Victorian sub-catchment of the Murray-Darling Basin. The region supports major agriculture (both dryland & irrigated), food processing, forestry and tourism industries. Although it only makes up 2% of the Murray Darling Basin's land area, the catchment generates 11% of the basin's water resources. It contains Victoria's largest and most important water supply catchment (Eildon) and includes the Municipalities of Moira, Campaspe, Greater City of Shepparton, Mitchell, Delatite, Murrindindi and Strathbogie.

As the major river in the catchment, the Goulburn River extends from the northern slopes of the Great Dividing Range north to the Murray River. Approximately 50% of the average annual discharge of 3200 GL (CSIRO 2008) is diverted to meet human use demands, primarily irrigated agriculture (Gawne *et al.* 2013).

Broken Creek was originally an ephemeral system that filled only during high-flow years when water spilled from the Broken River into the distributary system. A series of weirs along Broken Creek and the regulated diversion of flow from the Broken river at Casey's weir mean that Broken Creek now flows permanently. Mean daily discharge in the system is approximately 230 ML/d (Stewardson *et al.* 2013). The weir pools now support valuable populations of native Australian fish including substantial populations of Murray cod and golden perch that would not otherwise exist. Vertical slot fishways have been installed on the weirs in the lower Broken Creek to facilitate passage of these fish and promote breeding.

1.2 Commonwealth water use and flow-dependent ecological objectives in 2013/14

1.2.1 Lower Goulburn River

1.2.1.1 Environmental watering priorities

The focus for environmental watering in 2013/14 was to continue to encourage long-term improvement in the distribution, abundance and diversity of native fish, macroinvertebrates and vegetation (GBCMA 2013a). The two flow components deemed most important for achieving these outcomes were minimum flows and fresh flows, placing additional emphasis on bank stability and lower bank vegetation re-establishment.

Minimum flows (~550 ML/d) were designed to provide fish habitat and passage, and also fulfilled many macroinvertebrate objectives (encouraging aquatic vegetation for habitat, submergence of snags for habitat and food, and encouraging planktonic production for food). Higher minimum flows (~950 ML/d) were expected to provide for more macroinvertebrate objectives (submergence of additional snags, and the entrainment of litter packs and disruption of biofilms).

The priority for freshes was to deliver the maximum feasible volume in spring/early summer to stimulate golden perch spawning. Associated with these freshes was an aim to inundate lower banks for approximately 14 days to encourage the germination of riparian vegetation, and to allow macroinvertebrates to respond to the inundation of snags.

The final fresh priority was to deliver a summer/autumn fresh that would target macroinvertebrate objectives, including resuspension of fine sediment from macroinvertebrate habitat (GBCMA 2013a).

1.2.1.2 Environmental flows delivered

Commonwealth environmental water was mainly used to provide the above-described peak flow events plus enhanced minimum flows in the lower Goulburn River. In addition, there was a major inter-valley transfer in January and February (Figure 1-1).

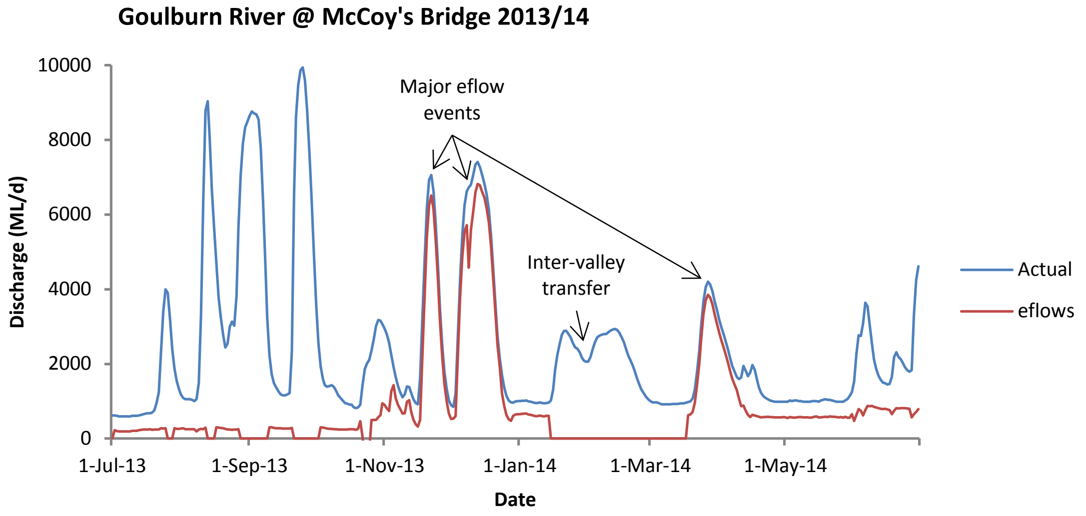

Figure 1-1. Flow regime and environmental flows in the lower Goulburn River for the water year 2013/14. Line colour denotes total flows and environmental flows, as detailed by the key. Major managed flow events (environmental flows and inter-valley transfers) are marked on the figure.

These flows can be compared to the actual and managed flows experienced in 2012/13. The managed flow events were similar in timing to those delivered in 2013/14, but the peak discharges for spring freshes were lower. The major difference between the hydrographs of the two years are the much higher unregulated flows that occurred over winter and early spring in 2012/13 (note different y axis limits in Figure 1-2).

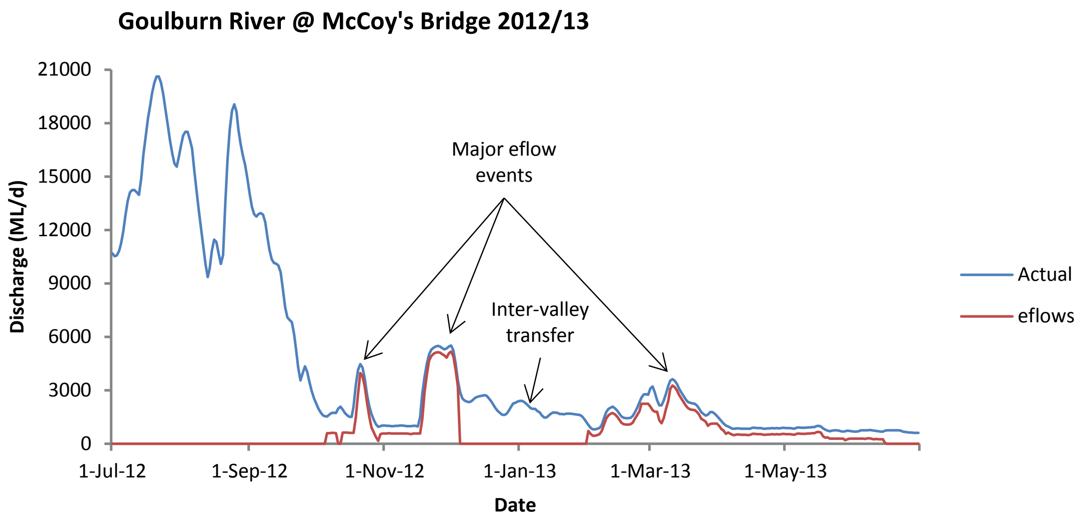

Figure 1-2. Flow regime and environmental flows in the lower Goulburn River for the water year 2012/13. Line colour denotes total flows and environmental flows, as detailed by the key. Major managed flow events (environmental flows and inter-valley transfers) are marked on the figure.

The major environmental flow events emulated natural flow peaks that would otherwise not have occurred in the regulated lower Goulburn River (Figure 1-3). More specifically, Commonwealth environmental water was used to provide two major spring freshes that peaked at around 7000 ML/d (late November, mid-December) and autumn fresh (4000 ML/d, late March) over the period covered by this monitoring program (spring 2013 to autumn 2014).

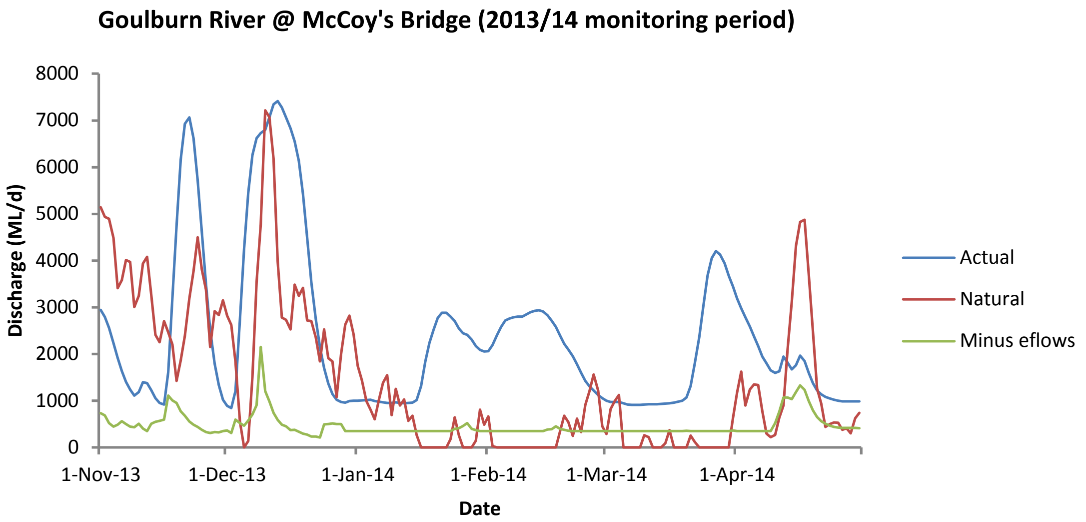

Figure 1-3. Environmental flow delivery in the lower Goulburn River. Graph covers 1/11/13 – 30/4/14, the approximate period of the monitoring program. Lines depict actual discharges, modelled natural discharges without regulation, and discharge minus environmental flow amounts, as depicted in the key.

The Goulburn Broken Catchment Management Authority also attempted to gain environmental benefit from the major inter-valley transfer that occurred from mid-January to late February (Geoff Earl, GBCMA, pers. comm.). Environmental water was also used to maintain baseflows between events at higher levels than would otherwise have been experienced. It is acknowledged that while the fresh events attempted to emulate the natural flow regime, other parts of the environmental flows regime do not correspond to natural conditions, where the river would have virtually dried over summer. In total, over 2013/14, 312.3 GL of environmental water (34% of the total discharge at McCoy's Bridge) was delivered to the lower Goulburn River, including 215 GL of Commonwealth environmental water, 33 GL of Victorian environmental water, and 64 GL of The Living Murray environmental water.

1.2.2 Lower Broken Creek

1.2.2.1 Environmental watering priorities

It is acknowledged that the lower Broken Creek is an artificial system, and so there is little benefit in trying to emulate a natural flow regime. Rather, flow components are specifically designed to fulfil ecological needs that would not have natural occurred in this system. Due to the regulation of the lower Broken Creek its environmental flow needs are relatively fixed from year to year (GBCMA 2013b). Forty megalitres per day is required to operate the fish ladders, allowing fish to migrate and move for breeding, and to escape poor water quality if necessary. Flows to maintain dissolved oxygen levels and prevent *Azolla* blooms are a high priority, as these events can otherwise combine to cause fish kills. Baseflows of 120 ML/d, with occasional flushes up to 250 ML/d have been shown to reduce buildup of Azolla, and disperse blooms when they do occur. Dissolved oxygen levels can generally be maintained by a baseflow of 150 ML/d, but up to 250 ML d-1 may be required for extended periods during hot weather. A flow of 250 ML/d to improve native fish habitat during the migrating/breeding season is also a priority to promote native fish recruitment and dispersal. In 2013/14 the GBCMA was also seeking to provide greater variation in water levels by extending or adding to natural high flow events. This was designed to promote an increase in the cover and diversity of native aquatic and fringing vegetation, and increase the stimulus for native fish migration (GBCMA 2013b).

The hydrograph for the period of monitoring in Broken Creek is shown in Figure 1-4. Environmental flows provide the bulk of the discharge over the period November – April; flows would have been extremely low otherwise, with likely severe consequences for dissolved oxygen and Azolla growth, and therefore for potential fish kills (Stewardson *et al.* 2013). Average discharge was maintained at the proposed ~250 ML/d, before a large natural runoff event in mid-April. While there was some variability in the day-to-day discharge of the system, this was not caused by active management of flow allocations, but by the difficulty of predicting irrigation flow rejections by farmers along Broken Creek (Geoff Earl, GBCMA, pers. comm.). The actual flow regime would probably need to be more variable than experienced to promote aquatic and fringing vegetation growth. Over the 2013/14 period, lower Broken Creek received some 54.5 GL of environmental water (58% of the total discharge at Rice's Weir), including 38.6 GL of Commonwealth environmental water.

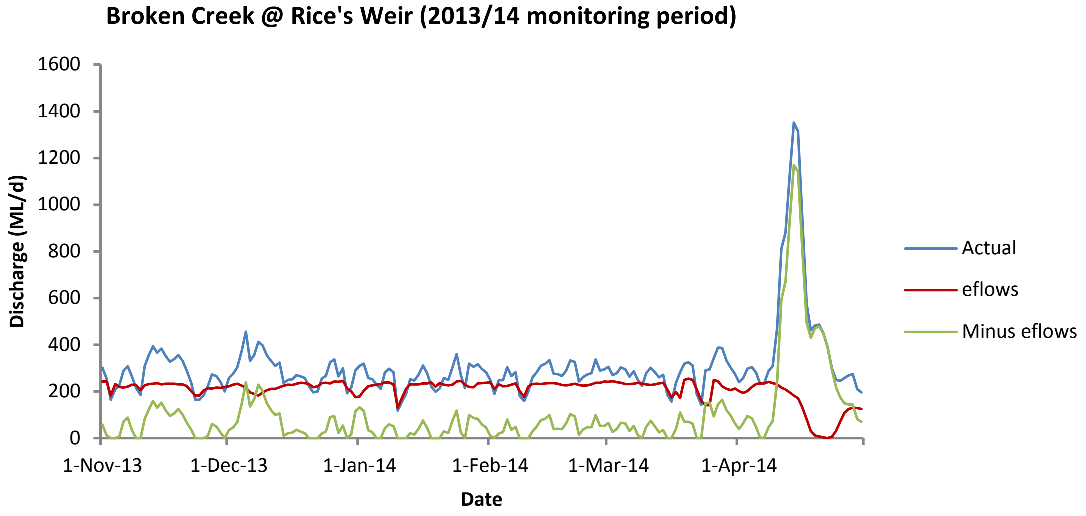

Figure 1-4. Environmental flow delivery in the lower Broken Creek. Graph covers 1/11/13 – 30/4/14, the approximate period of the monitoring program. Lines depict actual discharge, total environmental flows delivered, and discharge minus environmental flow amounts, as depicted in the key.

1.3 Overview of the monitoring program

The short-term monitoring program for 2013/14 was initially designed around a number of key questions.

- Have environmental flows improved physical habitat conditions for fish and macroinvertebrates, in terms of:
    - Slackwater and deepwater habitat,
    - Sediment smothering?
- What has been the contribution of environmental flow releases to riverine primary and secondary productivity?
- Have environmental flows promoted flood tolerant vegetation on the streambank?
- Have environmental flows improved conditions for native fish in terms of:
    - Spawning and recruitment of native fish in the Goulburn River,
    - Migration and dispersal of native fish in the Goulburn River,
    - Responses of fish to flows and dissolved oxygen in Broken Creek,
    - Movement of large-bodied native fish through fishways on Broken Creek?

The monitoring program employed a total of 66 monitoring locations (2 for physical habitat, 2 for primary and secondary productivity, 8 for vegetation, 3 for fish spawning, 13 for fish recruitment, and a total of 54 listening stations for fish migration and dispersal in the Goulburn River. In Broken Creek, 8 fishway monitoring sites were used (Figure 1-5).

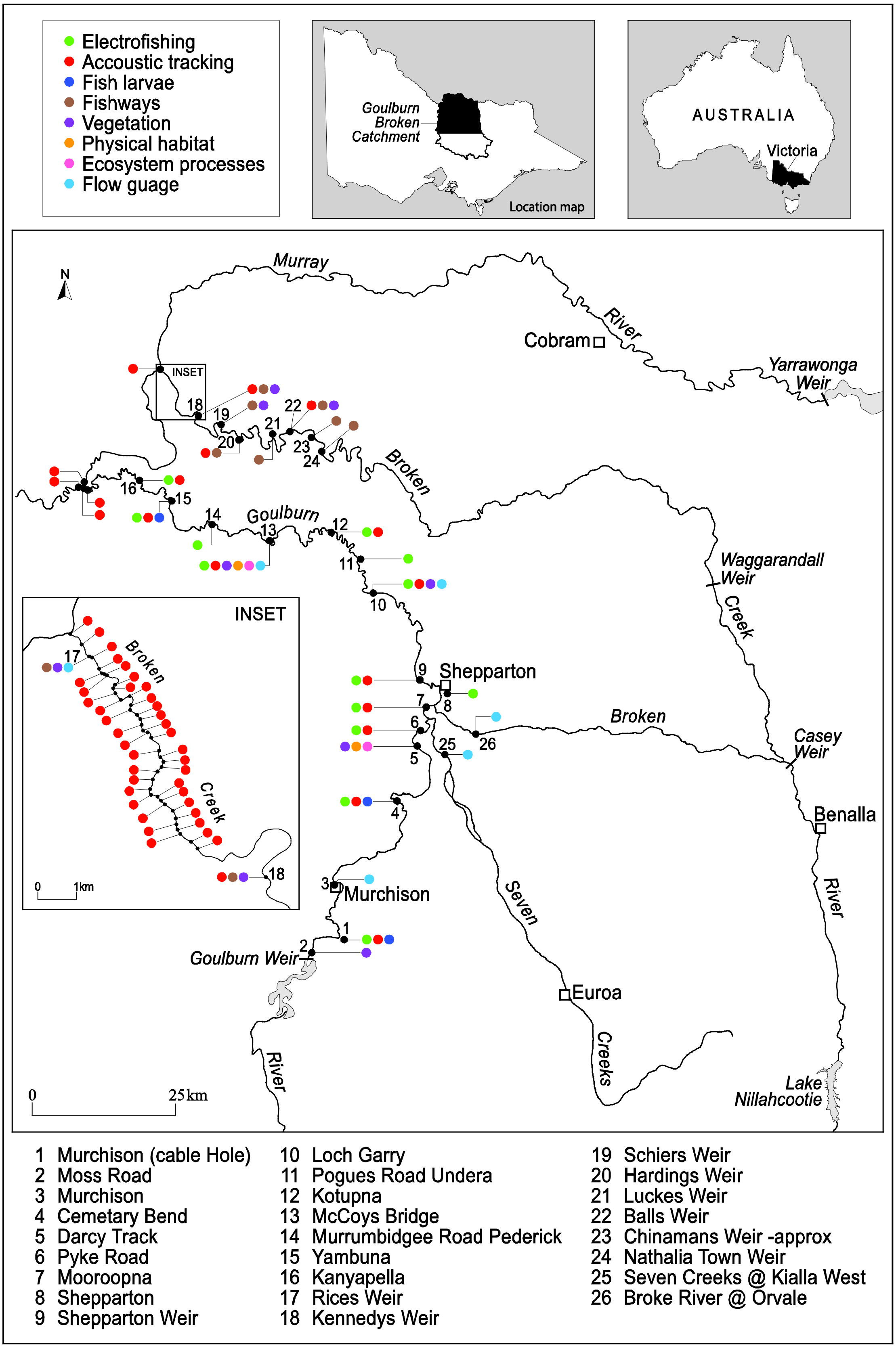

Figure 1-5. Map of the lower Goulburn River and Broken Creek, with all monitoring sites marked, along with flow gauges used to generate discharge data used in this report. Some sites extend into the Murray River, and gauging stations on the Broken River and Seven Creeks were also used. Colours denote different monitoring activities, and some sites were used for multiple activities. Sites named in the data chapters are indicated with site numbers, with the key providing the site name.

1.4 Structure of this report

Following this brief introduction, the data chapters are presented as stand-alone studies. Chapters are ordered so as to move from the physical effects of environmental flows (Physical Habitat) through to the lower levels of the food web (Primary Productivity and Macroinvertebrates) onto effects of flows upon Vegetation and finally upon Native Fish. The two fish monitoring chapters for Broken Creek are presented after the Goulburn River Chapters. Each chapter explicitly links its monitoring to Basin plan objectives and includes a section on the specific benefits of environmental flows.

The report concludes with a qualitative synthesis across the individual that shows how the different programs' results fit together, and where they do not. The report concludes with an overall statement regarding the effectiveness of Commonwealth Environmental Water in the lower Goulburn River and Broken Creek in 2013/14.

2 Physical habitat

Physical habitats are the channel morphologies and processes that support biota and ecosystem processes. Physical habitats play an integral supporting role in many Basin plan objectives including those related to large-scale habitat availability (e.g. Landscape Refugia), macroinvertebrates (e.g. Within Ecosystem Macroinvertebrate Diversity), Fish (e.g. Fish condition, production and larval growth and survival) and Vegetation (e.g. Vegetation Recruitment and Extent). Two physical habitats most directly influenced by flow regulation include hydraulic habitat (such as slackwater and pool habitat) and the condition of the bed substrate, which is influenced by smothering by fine sediment.

Key findings

- Environmental water contributed 60 percent of the available slackwater habitat during the period of the two watering seasons (spring to autumn, October to May inclusive) in 2012/13 and 2013/14. This was a result of environmental water delivered as baseflows and moderate discharge freshes (approx. 2000-4000 ML/d) where benches and bars are inundated (at these higher discharges, slackwaters are highly dependent on inundation of these morphologic features).
- Deepwater habitat (pools > 1m) availability is increased by environmental flows, particularly by baseflows of up to 1000 ML/d. Supplementing baseflows during periods of minimum dam releases during 2012/13 and 2013/14 increased deepwater availability by 12-15%.
- Sediment smothering is highly variable spatially within the channel. However, the volume of environmental water provided as freshes (environmental flows > 700 ML/d) is positively related to reduced smothering, and the relationship is stronger for environmental water delivered for larger freshes (> 4000 ML/d).

2.1 Introduction

Physical habitat provides an explicit link between the manipulation of flow, such as through regulation, and the conditions experienced by biota and ecosystem processes (Figure 2-1). Physical habitat can be directly influenced by a range of flow regulation actions. For example, it is suggested that prolonged low flow can increase sediment smothering while sustained high flows decrease slackwater habitat for fish and macroinvertebrates. Demonstrating and quantifying the explicit relationship between flow regulation and physical habitat not only highlights the impacts, but can also identify the adaptive management actions required to reduce the impacts.

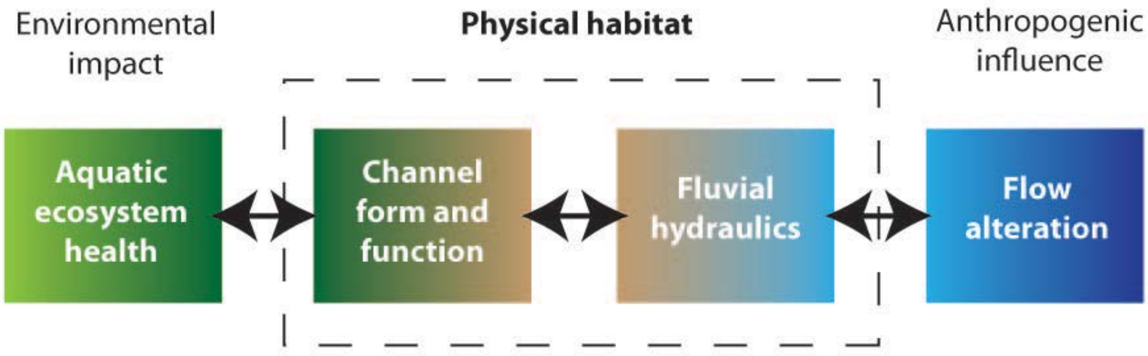

Figure 2-1. How physical habitat provides an explicit link between aquatic ecosystem health and flow alteration.

Channel morphology translates flow into aquatic habitat with variability in characteristics of the flow such as depth and current speed. These characteristics are critical throughout many stages of life for fish and macroinvertebrates. In particular slackwaters, slow-flowing and shallow habitat, have been identified as important refuges and productive zones. Deep-water habitat, or pools, provide physical habitat as refuges for fish. Both slackwaters and deep-water habitat can be reduced under a regulated flow regime. Understanding the response curves for these habitat types relative to flows enables changes in physical habitat to be determined for a range of flows.

Bedload substrates in the Goulburn River include mobile sands and gravels. The surficial and pore spaces (interstices) of these substrates are important physical habitat, particularly for fish and macroinvertebrates (Koehn, O'Connor & Jackson 1994; Price 2007). During low-flow conditions fine-grained sediments can ‘smother’ mobile substrate sediments and infill interstices to reduce the condition of the habitat. Smothering can also impact on ecosystem processes such as decomposition. The anthropogenically-increased levels of fine-grained sediments can exacerbate this problem. Understanding the link between environmental water delivery and substrate condition, specifically sediment smothering, is the focus of this component of the monitoring program.

2.2 Basin Plan objectives, cause-effect diagrams, and how they relate to Physical Habitat

Physical Habitat was not initially a specific objective for the Basin Plan. Rather, it plays an important explanatory role across most Cause and Effect Diagrams (CEDs), as well as across Level 1 Objectives (Figure 2-2). For example, the CED 'Decomposition' is impacted by sediment that may smother biofilms or aquatic macrophyte communities, reducing both primary production and decomposition rates. The CED 'Fish larval growth and survival' can be impacted by reductions in slackwater habitat that impact on the recruitment of larval and juvenile fish.

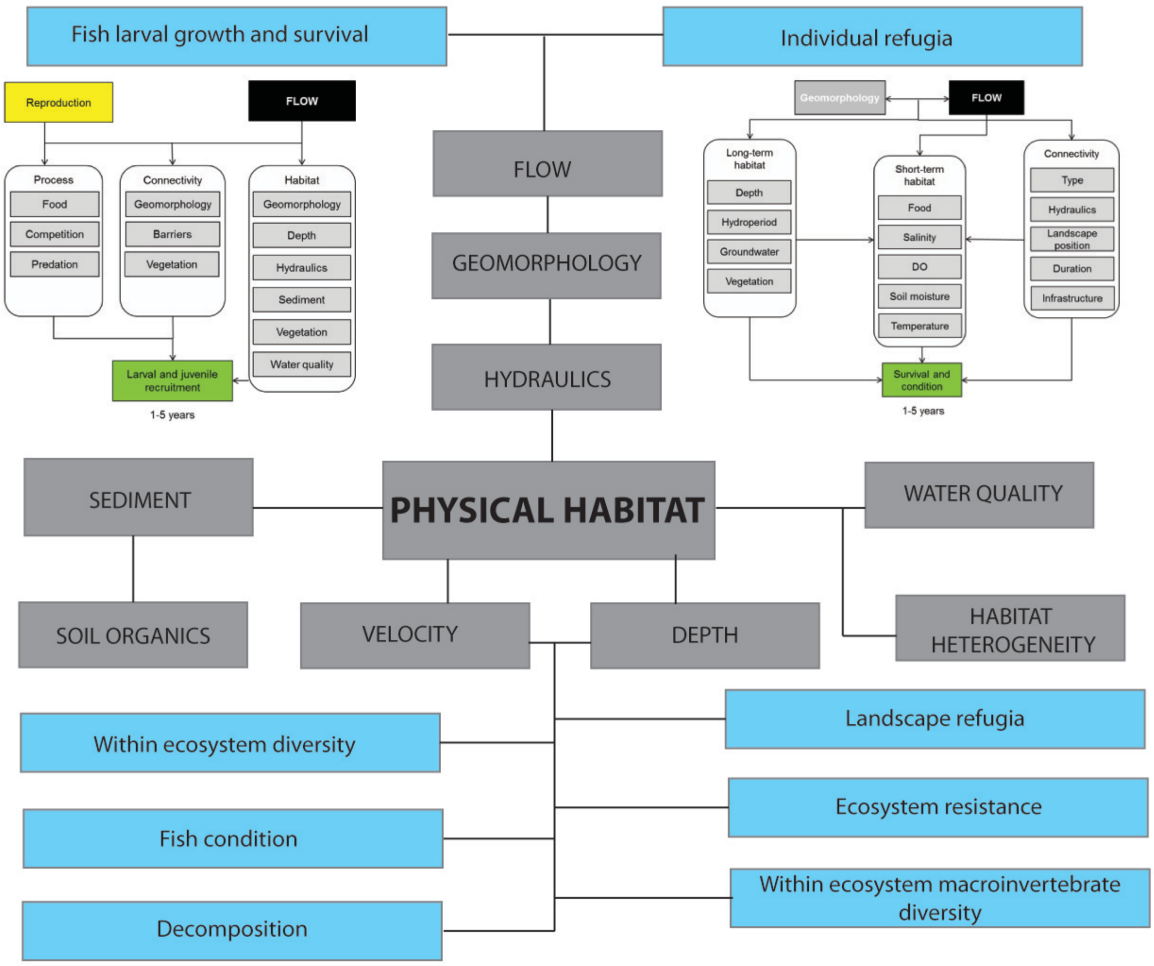

Figure 2-2. Generic cause-effect diagrams related to Physical Habitat (created from CEDs by Gawne *et al.* 2013).

Physical habitat was initially related to CEDs Refugia and Habitat (Table 2-1). Physical Habitat is now a formal Level 3 Objective within the LTIM project, and standard operating procedures have been produced to monitor relationships between environmental flows and hydraulic habitat (e.g. slackwaters and pools using 2-dimensional hydraulic modeling), and bank condition (e.g. erosion rates and mechanisms using erosion pins and qualitative assessments).

Table 2-1. Objective/CED links to Physical Habitat variables measured in this project. Modified from Gawne *et al.* (2013).

Objective/CED	Component	Variable	Hypothesis	Links to 2012/13 program
• Population resilience	• Refugia	Slackwater availability	Slackwater availability is enhanced under environmental flow provisions	Modelled in 12/13 using cross sections, field verification at a site-wide scale using revised protocol for 13/14
• Population resilience	• Refugia	Pool availability	Pool availability is enhanced under environmental flow provisions	Modelled in 12/13 using cross sections, field verification at a site-wide scale using revised protocol for 13/14
• Connectivity/ Sediment transport	• Habitat	Sediment smothering	Freshes reduce smothering of bed sediments	Intensive program undertaken in 12/13, similar protocol for 13/14 to add data points and confirm uncertainties

2.3 Logical basis for monitoring

The STIM program for Physical Habitat was based on commonly applied hypotheses related to environmental flow recommendations. For slackwater habitat, research based on the nearby Broken River (Vietz, Sammonds & Stewardson 2013) was used to inform the expectations for the Goulburn River. Slackwaters were expected to initially increase to peak availability, and then decrease before increasing again at higher discharges as benches are inundated. As such, baseflows were expected to improve slackwater availability, while the influence of freshes is uncertain, dependent on fresh magnitude relative to higher-level bench inundation. Deepwater habitat was expected to increase in stepped fashion with increasing discharge (Figure 2-3).

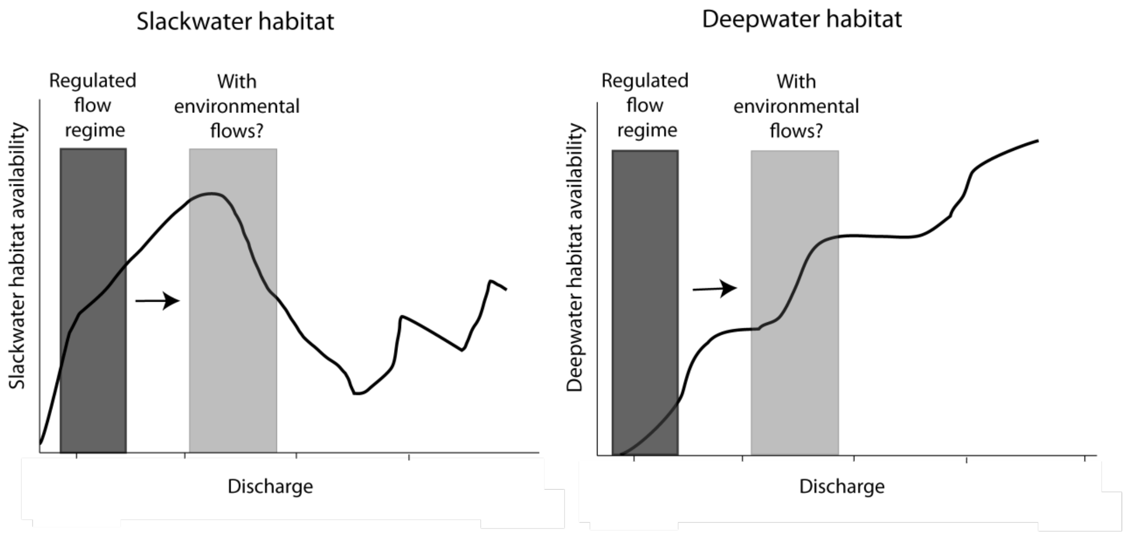

Figure 2-3. Conceptual models of changes in availability of physical habitat (slackwater and deepwater) resulting from environmental flow delivery.

The prevailing hypothesis regarding sediment smothering is that sediment smothering 'builds up' over time during low flows or baseflows. It is considered that freshes are required to scour the bed of surficial and interstitial fines essentially 'resetting' the condition of the bed (Figure 2-4).

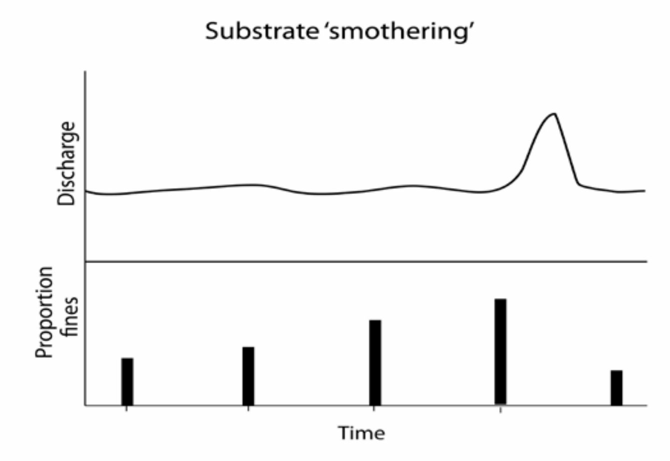

Figure 2-4. Conceptual model of the build-up of fines within the mobile substrate sediment over time and the influence of elevated flows.

2.4 Methods

2.4.1 Study sites

The following section is a summary of methods for Physical Habitat, and for further detail the reader is referred to Stewardson *et al.* (2013), Section 6.4, or Windecker and Vietz (2014). Methods from the 2013/14 program that differed from those of the 2012/13 program are described in more detail.

Over two irrigation seasons (2012/13 and 2013/14) fieldwork was undertaken at two sites along the lowland reaches of the Goulburn River, Northern Victoria (Figure 1-5). Site 1 (Darcy's Track) is upstream of Shepparton (-36.4514, 145.3617), and Site 2 (McCoy's Bridge) is downstream of both Shepparton and the confluence with the Broken River (-36.1786, 145.1241). The sites correspond to sites surveyed for the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP). For each VEFMAP site, 15 transects over approximately 750 metres have been surveyed and these sites extend over at least one meander wavelength.

2.4.2 Slackwater/deepwater habitat assessment

Two different approaches were used to quantify availability of slackwater/deepwater habitat over the two field seasons. In 2012/13 the approach incorporated field measurements that were used to verify hydraulic modeling, and both the field and modeling methods were found to limit the approach. In 2013/14 the approach incorporated field measurement methods that could be used directly to develop relationships with flow. Both of these are discussed below.

In 2012/13, an Acoustic Doppler Current Profiler (ADCP) mounted on a floatable board was passed over transects (by rope or canoe, Figure 2-5a) over a range of discharges to measure velocities and depths. While the ADCP was not accurate in shallow depths, the output (from WinADV) was used to field verify the 1-dimensional HEC-RAS model (a model previously developed for VEFMAP in 2009). The 1-dimensional model provided a depth profile for 1m segments across the cross-section, and was used to extrapolate the extent of habitat over a range of discharge values. The limitation of the ADCP in shallow depths and the inability of the 1-dimensional model to represent velocity across the channel led to these data being less reliable for slackwater habitat modeling with discharge.

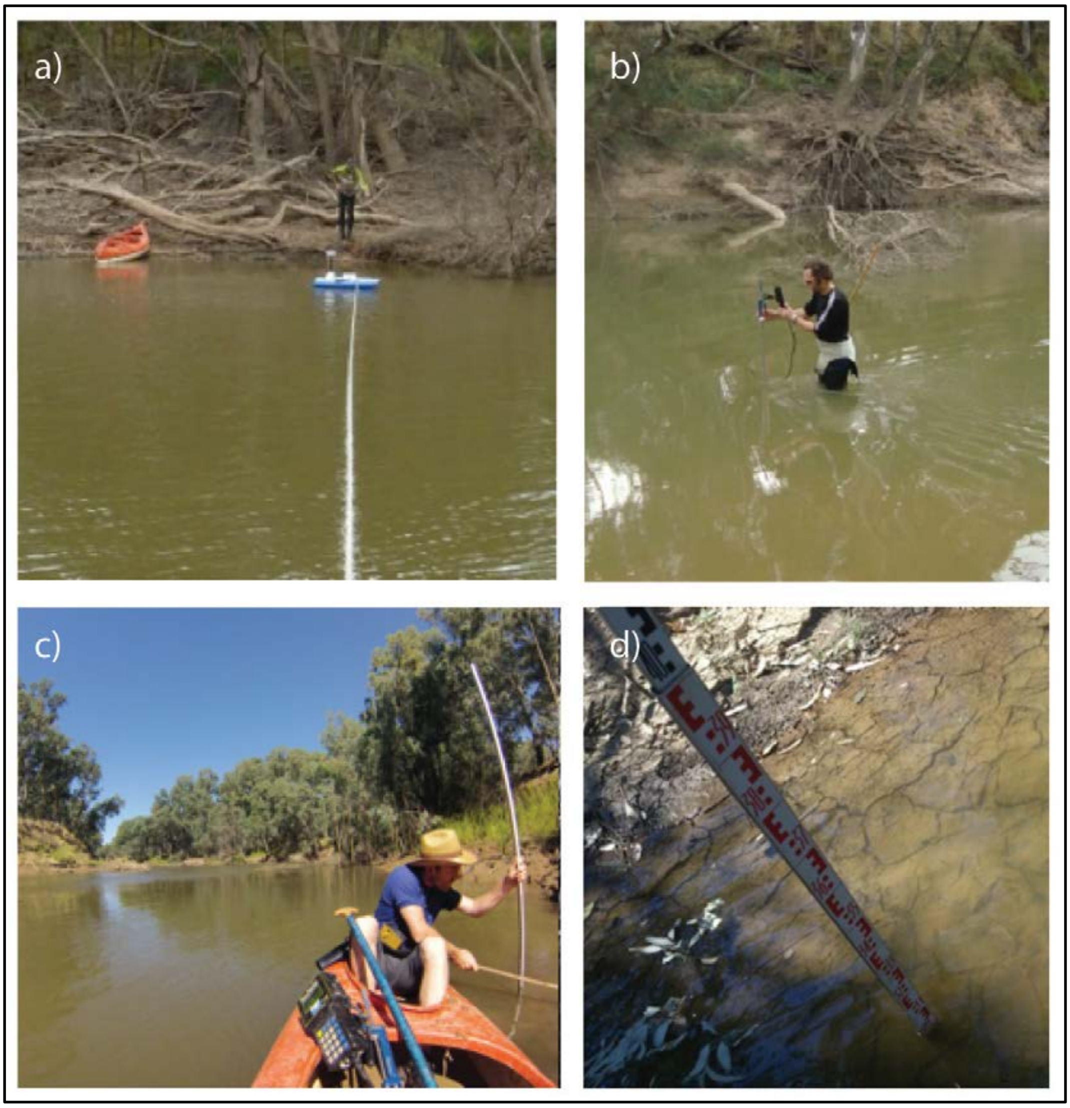

Figure 2-5. a) using the ADCP to assess field hydraulics along transects, b) use of a handheld ADV to test velocity across transects, c) measurement of extent of pool depth along a transect, and d) measuring depth in slackwaters.

2.4.3 Sediment smothering assessment

The 2013/14 monitoring protocol was modified to better capture velocity variation across the channel in the field (and could be used to verify the habitat-discharge curves developed from the 2012/13 approach). Velocity was measured in shallow areas using a hand-held Acoustic Doppler Velocimeter (ADV; Figure 2-5b) that is capable of being used in shallow depths (where slackwater habitat is found). Depth and velocity measurements were manually collected to delineate defined habitats at 10 transects per site (Figure 2-5c and d). This was undertaken over a range of discharges. Slackwater areas were defined as 0.5m deep, velocities < 0.05 m/s (Vietz, Sammonds & Stewardson 2013), and were considered when at least 0.5 m wide. Two pool types were classified (> 1 m and > 1.5 m deep). Transects were traversed by wading or canoe, and the extent of each habitat type measured using a laser distometer. These distances were used as bounds to calculate the width of habitat across transects. The availability of habitat per 100m of river at each discharge was calculated using the average habitat area across all ten transects.

The proportion of fine-grained sediment (silt/clay) in the channel bed (surficial and upper 50 mm) was used to determine the level of smothering. This technique was used in both the 2012/13 and 2013/14 monitoring periods. A modified sediment resuspension technique (Lambert & Walling 1988) was used, where a 300 mm diameter PVC cylinder was placed into the substrate, and the depth recorded, to isolate a column of river water with known volume (Figure 2-6).

Figure 2-6. The method for field sampling of fine-grained sediment in the bed: a) sampling area measurement from bank for random sampling site selection, b) disturbance of bed sediments within cylinder, c) suspended sample collection, and d) collected sample to be transferred to combined 1L sample for subsequent analysis.

The exact location of sampling was adjusted slightly with each visit to prevent resampling the disturbed bed (Figure 2-6a). Following agitation of the riverbed with a metal rod (Figure 2-6b), two 500mL grab samples from the middle of the column were taken (Figure 2-6c), providing a 1L sample containing the suspended clay, silt and fine-grain sand particles (Figure 2-6d). At each location we approached the transect from downstream so that disturbed sediment would not flow into the sample, and each visit we sampled 1m further upstream than the previous visit in order to sample undisturbed sediment. Background samples of undisturbed river water were also collected at each visit for comparison. In the laboratory each sample was oven dried (80°C for 45 hours) and weighed to obtain the mass of liberated sediment, which was then converted to kg/m^2 of bed. Particle size analysis confirmed that of the sediment liberated from the bed, 94% was fine sand or finer, considerably finer than the medium to coarse-grained sands that comprise the bed sediments (Section 6.4, Stewardson *et al.* 2013).

The technique was repeated at three to five points along each VEFMAP transect. All samples were collected at a consistent base flow level (~1000 ML/d) throughout the irrigation season. In the 2013/14 season, sample points were based on fixed distances from the bank to reduce the inherent variability between locations identified during the 2012/13 season.

2.4.4 Data analysis

Flow data provided by Goulburn-Murray Water (Daily Operational Flow, Discrete Daily Verified values, Environmental Flow releases) were used to develop the hydrologic series. For the McCoy's Bridge site, we used data from the nearby gauge (405232), and Darcy's Track data were estimated using the Shepparton gauge (405204). A one-day lag on the Shepparton data was used to quantify flow at Darcy's Track upstream of the gauge. Environmental flows (determined at McCoy's Bridge) were assigned to Darcy's track with a three-day delay. In the few cases where the recorded flow minus the McCoy's Bridge environmental flows resulted in a negative number, the flow was listed as 0.

Slackwater/deepwater habitat results measured in 2013/14 were used to verify results from the 2012/13 modeling. Linear regression was used to relate discharge to slackwater and deepwater habitat availability.

Sediment smothering results were assessed against a range of hydrologic metrics for the period preceding each sample. Metrics were chosen based on consideration of their potential to exert an influence. Metrics included: volume of flow in preceding month, days of flow > X (where X = 2,000 to 10,000 ML/d); days of environmental flows < 700 ML/d (e.g. provided for baseflows), and days of environmental flows > 1500 ML/d (e.g. provided for freshes). It is worth clarifying that 700 ML/d is the environmental flow contribution and was found to be a threshold whereby environmental flows of less than this value were provided for baseflows (baseflows are often of greater magnitude with the remainder made up of 'natural' inflows). Similarly for 1500 ML/d, environmental flow deliveries greater than this threshold were commonly provided for freshes.

Continuous turbidity data were obtained for the Goulburn River at Goulburn Weir (405259) from the Victorian Department of Environment and Primary Industries database to assess the role sediment concentration in the water column might play in influencing sediment smothering.

2.5 Results

2.5.1 Hydrology with and without environmental flows

Environmental water was delivered in a similar pattern during 2012/13 and 2013/14 (Section 1.2.1.2), with two freshes in late spring (October to December), a smaller fresh in March/April, and baseflow provisions throughout the year (Figure 1-1, Figure 1-2). Antecedent conditions are important, with significantly larger winter/spring runoff prior to the 2012/13 monitoring season compared with the 2013/14 season.

2.5.2 Slackwater and deepwater habitat

The field-based methods for measuring slackwater and deepwater habitat in 2013/14 were aimed at verifying the computer modeling based methods from the 2012/13 campaign. Trend and points of inflection in relationships were similar for both 2012/13 and 2013/14 approaches. However, we found that relying on hydraulic modeling alone (as undertaken in 2012/13) can lead to underestimates of slackwater habitat availability compared to field-based methods. This highlights a deficiency in 1-dimensional hydraulic modeling where lateral velocities are of interest. The results indicate that slackwater habitat availability is greatest at low flows (e.g. < 500-1000 ML/d) (Figure 2-7).

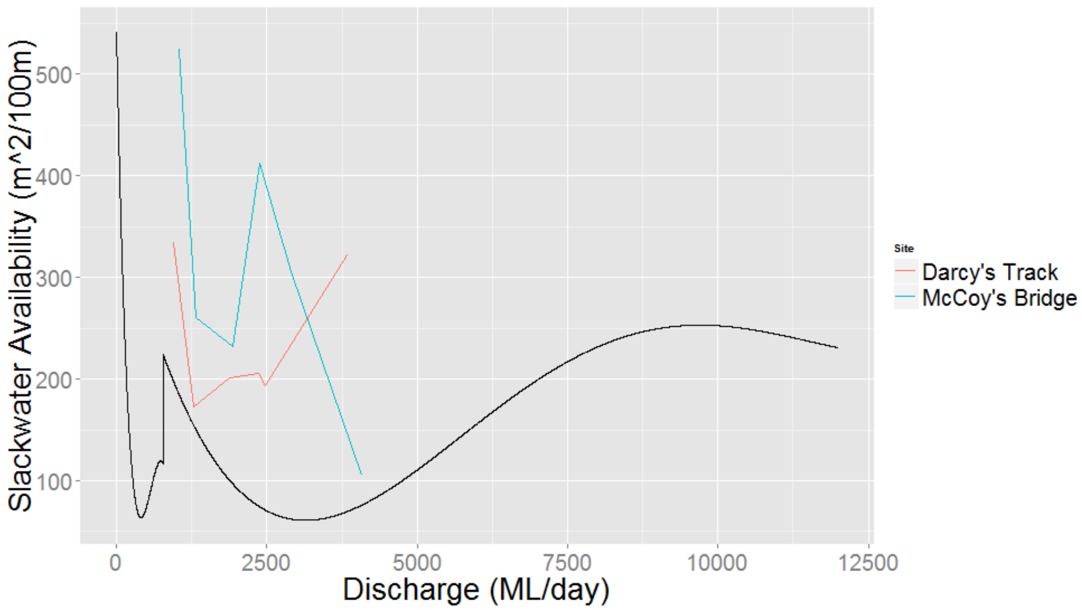

Figure 2-7. Slackwater availability with discharge. Black line is modeled data for Darcy's Track (from 2012/13), and red and blue lines are field data points (from 2013/14) for Darcy's Track and McCoy's Bridge, respectively, that were used to assess appropriateness of modeled data.

As discharges increase, and the bed is inundated, the depth and velocity criteria (V < 0.05 m/s, D < 0.5 m) are surpassed and slackwater habitat declines. With further increases in discharge, slackwater availability increases again, as bars and benches located at higher elevations in the channel are inundated. High discharges, where the channel is half to full bankfull often result in a reduction in slackwater habitat. While these trends correspond to the hypotheses — initial increase to peak and then decrease before increasing again at higher discharges — it is the points at which sharp drops or increases of slackwater occur that are of most interest.

Slackwater habitat is influenced by channel morphology, particularly benches that provide flat surfaces at higher elevations in the channel. During higher regulated discharges, low velocity zones were often small areas along the channel margins unless flows provided shallow inundation over islands (Figure 2-8a) or benches (Figure 2-8b).

Figure 2-8. Slackwater availability for moderate discharges (e.g. flow > 3000 ML/d) due to inundation of (left) mid-channel islands and (right) benches (inundated vegetation in foreground). For Darcy's Track and McCoy's Bridge, respectively.

Benches can often provide extensive areas of slackwater habitat at flows within the higher operational ranges of regulated flows. For example, at McCoy's Bridge the availability of slackwater habitat increased for flows between 2-3,000 ML/d due to the influence of only a few benches such as the one in transect 11 (Figure 2-9).

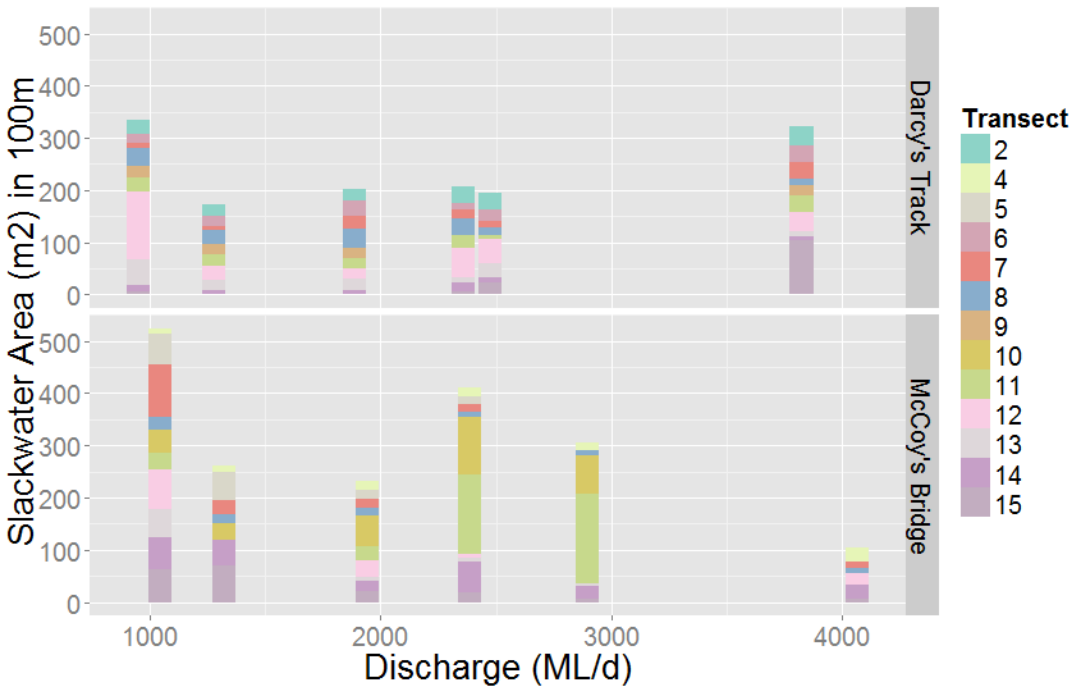

Figure 2-9. Change in slackwater habitat with discharge at the Darcy's Track and McCoy's Bridge sites, respectively. The slackwater availability changes for each transect are represented by colour.

For McCoy's Bridge, flows greater than 4000 ML/d appear to provide very little slackwater habitat, whereas for Darcy's Track, the channel morphology is more diverse. As a result, the slackwater relationship is not dominated by one bench along the site. Nevertheless, for Darcy's Track, moderate discharges of between 3000-4000 ML/d appear to be more likely to create slackwater habitat than higher discharges. Deepwater habitat availability increases with increasing discharge. This trend is observed for the results from the field campaign, as well as the hydraulic modelling which identified changes for higher discharges, particularly those > 4000 ML/d (Figure 2-10).

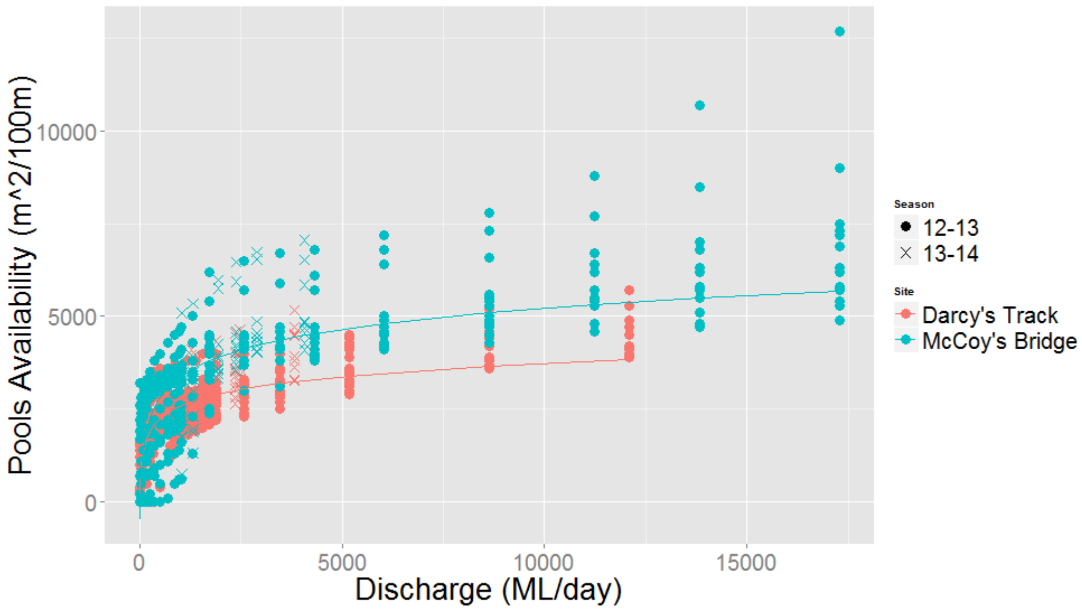

Figure 2-10. Change in deepwater habitat with discharge. From field-measured data 2013/14 for Darcy's Track (red) and McCoy's Bridge (blue).

2.5.2.1 Benefit of environmental flows

Over the period of the two irrigation seasons, environmental water contributed 60 percent of the available slackwater habitat for the period October to May. While benches are important for the provision of slackwater habitat at higher discharges, baseflows provide the greatest contribution to slackwater habitat (McCoy's Bridge, Figure 2-11; Darcy's Track, Appendix A, Figure 12-1).

The results highlight the need to know the elevation of benches so that they can be targeted for inundation to increase the availability of slackwater habitat. Higher flow freshes (e.g. > 3000 - 4000 ML/d) can decrease the availability of slackwater habitat through increasing channel velocities and depths (Figure 2-12). During these periods targeted inundation of benches may be most critical during maturation periods for larval and juvenile fish.

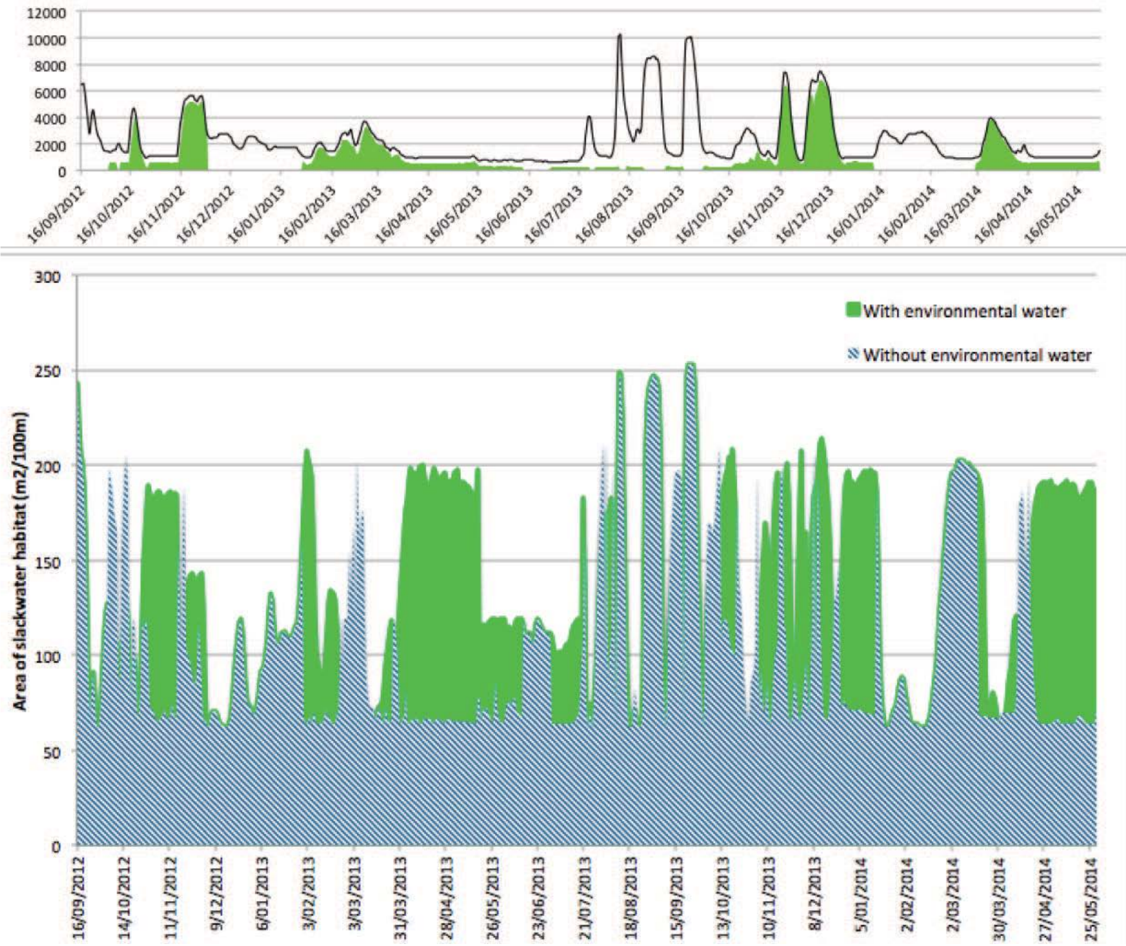

Figure 2-11. Slackwater habitat available with environmental water (green) and without (hashed blue) for the McCoy's Bridge site.

There is a 12 and 15% increase in the total area of deepwater habitat (pools > 1m) with environmental water baseflows over the two seasons for McCoy's Bridge and Darcy's Track, respectively. Environmental water increased deepwater habitat for over 60% of days, due to the positive relationships between discharge and pool habitat.

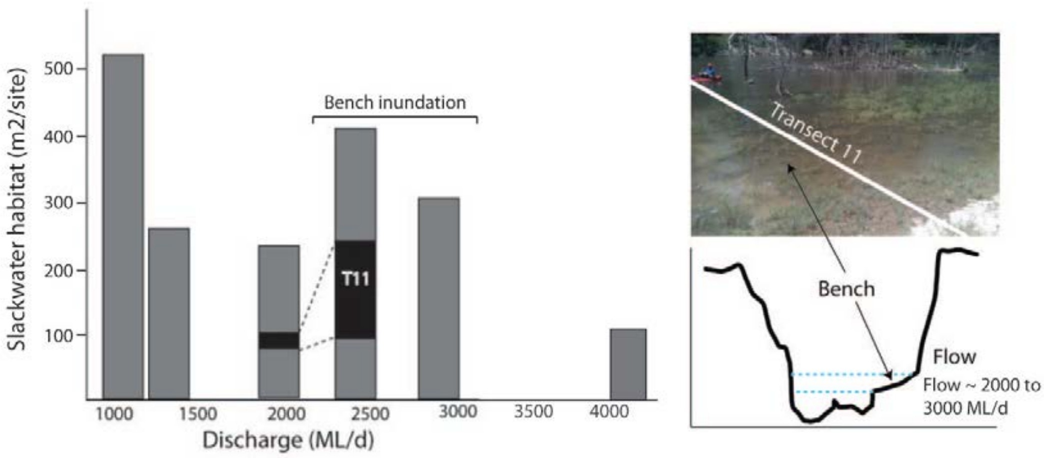

Figure 2-12. Change in slackwater habitat with discharge at McCoy's Bridge, identifying the important role of benches. The step change in habitat measured in the field can be directly related to inundation of one large bench at the site, as identified in this example for transect 11.

If pool habitat was to be maximised, then targeted management of flows could make use of points of inflection in the discharge-habitat relationship (Figure 2-10). Discharges of up to 1000 and 1500 ML/d (for Darcy's Track and McCoy's Bridge respectively) provide the maximum pool habitat availability, with diminishing returns for discharges larger than this (hence the importance of baseflow provisions for deepwater habitat). For a further discussion on the availability of deepwater habitat over time, the reader is referred to Stewardson *et al.* (2013).

2.5.3 Sediment smothering

Sediment smothering was evident within the sand-bed substrates of the channel during visits at low flow levels. Surficial fines overlying the coarser-grained bed sediments were often more than 20 mm deep following longer periods of low flow, and sediment had often infiltrated within the upper layers of the coarser-grained substrate sediment (Figure 2-13). In particular, sediment smothering was most evident at channel margins, whereas higher velocities further into the channel had overturned bed substrates and removed fines.

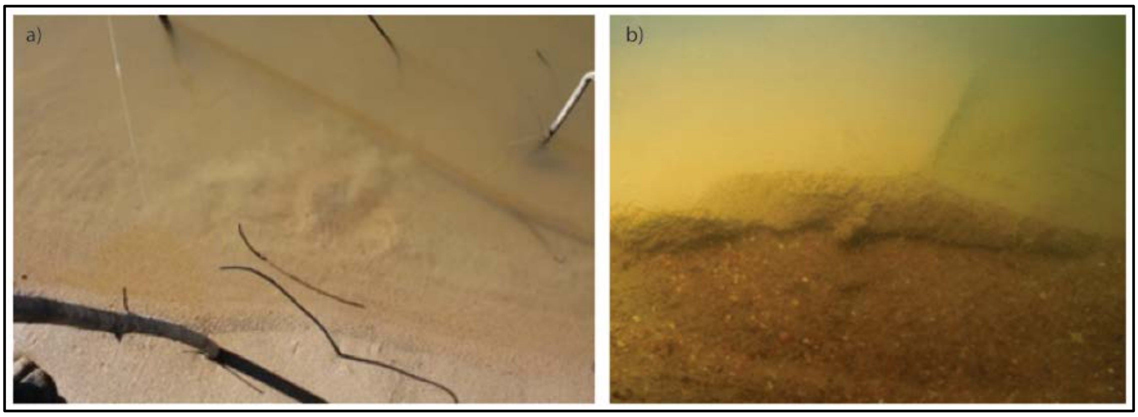

Figure 2-13. Fine-grained sediments settling and 'smothering' mobile sandy substrates at a) channel margins, and b) underwater close-up of the channel bed (with smothering partially washed away by hand), Darcy's Track.

The main finding for sediment smothering is that high levels of sediment smothering are less likely if freshes have been provided, or conversely, are more likely with increasing time since a fresh. The antecedent flow conditions appear to influence the extent of sediment smothering, but only for high levels of sediment smothering. Low levels of sediment smothering (~ < 1 kg/m^2) are equally likely after months of no freshes as they are following a month with more than half the days above fresh level (in this case 4,000 ML/d, Figure 2-14). However, higher levels of sediment smothering (~ > 1 kg/m^2) are more likely when the preceding month has experienced no freshes. This result was statistically significant ($p < 0.005$), and was similar for a range of fresh levels from 2000 to 7000 ML/d (Appendix A, Table 12-1). There is also a similar trend for the volume of flow in the month prior to assessment of the bed condition (Appendix A, Figure 12-2). The converse relationship is demonstrated by the duration of baseflows. The longer baseflows (defined as < 1,500 ML/d) are maintained, the greater the potential for high levels of sediment smothering (Appendix A, Figure 12-3).

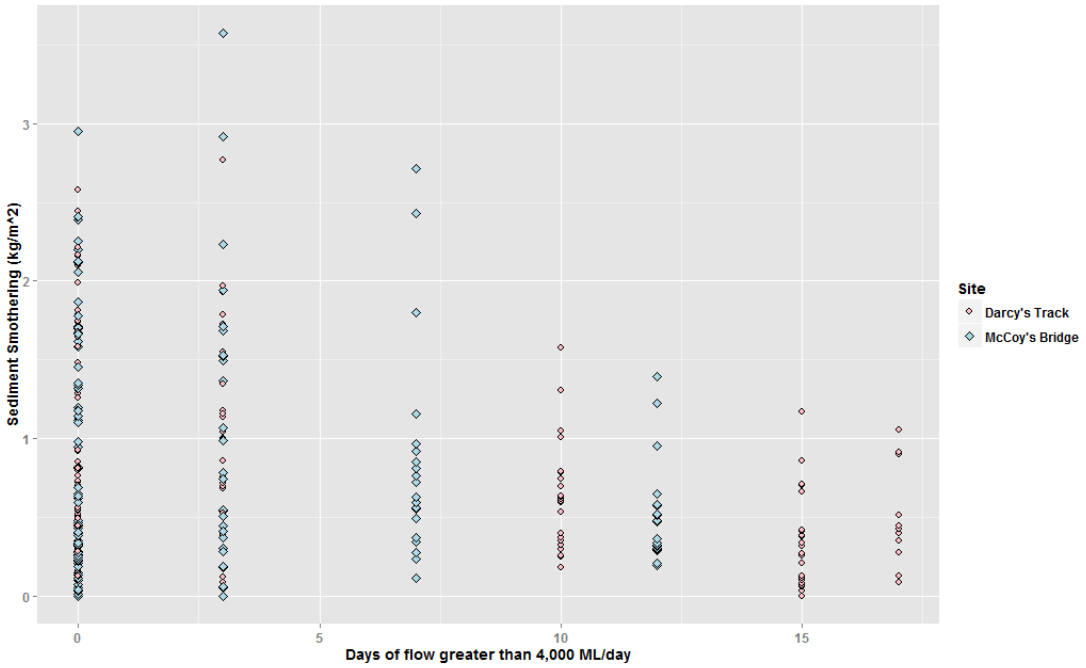

Figure 2-14. Sediment smothering (kg/m^2) relative to the number of days with flow greater than 4000 ML/d in the proceeding 30 days.

2.5.3.1 Benefits of environmental flows

Results from 2012/13 and 2013/14 indicate that freshes or high flow volumes reduce the potential for significant levels of sediment smothering. During the two seasons, environmental water contributed 60% of the total volume of freshes over 2000 ML/d; therefore environmental water plays an important role in reducing high levels of sediment smothering.

There was also a relationship directly between sediment smothering and the number of days of environmental flows. High levels of sediment smothering were decreased when a greater number of days of environmental flows were provided to increase freshes (Figure 2-15).

The main uncertainty is what level of sediment smothering is too much for resident biota? This question appears to remain unanswered for Australian biota and, with the findings here, may drive more explicit recommendations. If it is possible to identify acceptable levels of smothering then this provides two potential options for adaptive management of environmental flows. Firstly, and for example if 1 kg/m^2 is acceptable, then (from Figure 2-14) 7 days of flow above 4000 ML/d in the preceding month should reduce smothering to only 30% being greater than this value (down from 75% for 0 days with flow above 4000 ML/d). Secondly, a relationship was developed from the 2012/13 season that related smothering to velocity, and in that case velocities of > 0.25 m/s were capable of maintaining smothering levels at < 1 kg/m^2 (Stewardson *et al.* 2013) .

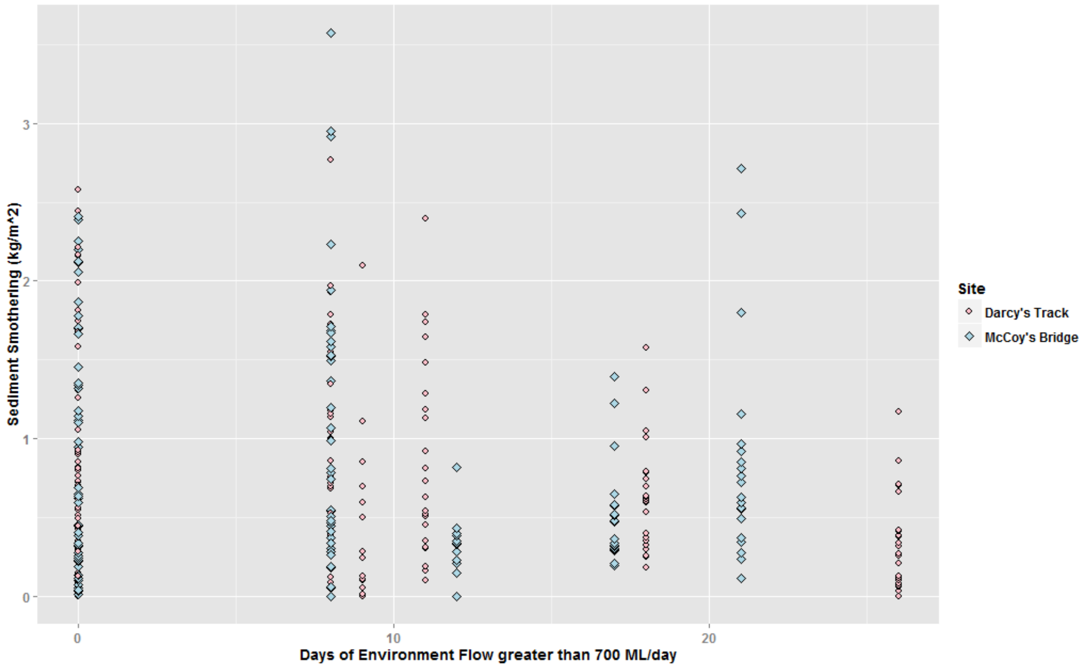

Figure 2-15. Sediment smothering (kg/m^2) relative to the number of days where environmental flows are provided for freshes. Data are plotted for environmental flows > 700 ML/d, since flows of this magnitude were commonly contributed for the purposes of freshes (rather than baseflows).

Relationships between sediment smothering and individual flow events are difficult to ascertain because of the spatial variability in sediment smothering, and the implications of characteristics other than flow (e.g. suspended sediment concentration). Nevertheless, a number of observations of note include the increases in sediment smothering following longer periods of low flow, as hypothesised, as well as from the first fresh of the October to December period (e.g. Darcy's Track, Figure 2-16). Despite this, environmental flow freshes appeared to reduce sediment smothering, a finding evident for both the Darcy's Track and McCoy's Bridge sites (Appendix A, Figure 12-4).

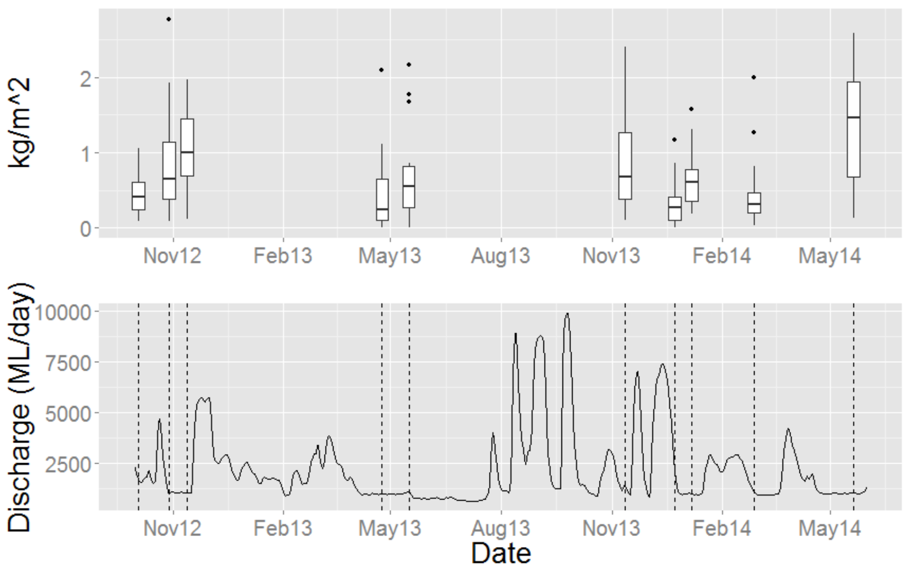

Figure 2-16. Sediment smothering per event sampled relative to discharge for the 2012/13 and 2013/14 seasons for Darcy's Track.

Similar to results from the 2012/13 study (Stewardson *et al.* 2013), there was an increase in turbidity associated with the first fresh following unregulated winter/spring catchment runoff in November 2013 (Figure 2-17). These increases in turbidity may result from banks being susceptible to erosion after higher unregulated winter/spring flows, with environmental flows then liberating sediment. The increases in turbidity could explain increased sediment smothering following these first freshes of the season. However, when viewed in the context of the levels of turbidity over the longer record, the increases in turbidity associated with environmental flow freshes are minor relative to increases in turbidity associated with larger catchment runoff events. For example the increase in turbidity during a catchment rainfall event in August/September, 2013, was more than three times greater than the peak for the first freshes of the irrigation seasons (Figure 2-17).

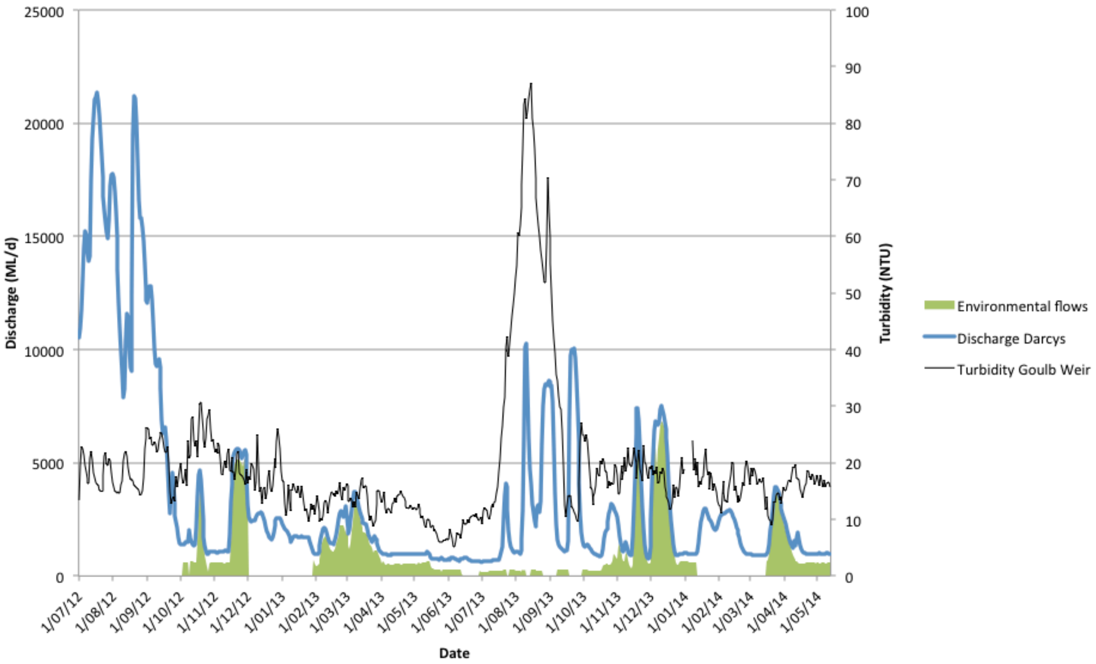

Figure 2-17. Turbidity (from Goulburn Weir gauge) for the period July 2012 to May 2014 compared to discharge (Darcy's Track) and environmental flows.

2.6 Discussion

Basin-plan environmental objectives are likely to be better achieved through improving physical habitat. The links between physical habitat and biota, such as fish and macroinvertebrates, can be linked to changes in bed condition such as through sediment smothering, and the availability of habitat such as slackwaters. For example, fish 'larval growth and survival' has been empirically linked to the availability of slackwaters (Humphries *et al.* 2006), and environmental flows contribute 60% of the available slackwater habitat. The explicit nature of the relationship between discharge and slackwater habitat means that operations can be targeted to maximize slackwater availability during regulated flows (such as intervalley transfers). Targeting benches may be a useful strategy for providing sufficient levels of slackwater availability at moderate discharges (2000 – 4000 ML/d).

There are two uncertainties with relation to slackwater habitat. Firstly, considering the important role of benches there is a lack of certainty about how well benches at the sites represent benches along the system. This affects our ability to estimate appropriate discharges to be targeted for environmental watering actions and other river operations such as intervalley transfers. Secondly, the differences between modeled and field measured slackwater habitat make it difficult to explicitly recommend discharges at which slackwater is maximised by inundating benches. The 2-dimensional modeling being conducted as part of the Long Term Intervention Monitoring project will address this issue, and potentially incorporate a better understanding of the longitudinal variation in bench levels (and hence inundation thresholds) along the system. 2-dimensional hydraulic modeling is expected to be a significant improvement since it has been found to confidently characterise habitats such as slackwaters (Vietz, Sammonds & Stewardson 2013).

Sediment smothering was highly spatially variable within a site, and the findings relied on an interpretation of both years of data. This highlights considerable value in undertaking the second monitoring season. Despite the spatial variability in sediment smothering, there was a statistically significant relationship between smothering and antecedent flow, particularly environmental flows. This provides some confidence that environmental flows are achieving the intended goals.

The question remains, however, how much smothering is too much? Sediment smothering of the bed substrate is a natural process that would have occurred prior to flow management. Of interest are the potentially increased levels of sediment smothering. This may be due to a combination of increased fine-grained sediment supply (e.g. catchment clearing) and the potentially reduced removal under sustained low flow periods (e.g. regulated flows without environmental flows). Ascertaining the 'nuisance levels' of smothering may assist managers to better target the timing, duration and magnitude of environmental flows. Empirical research to identifying the relationships between smothering and biota will assist in identifying how well Basin plan goals such as 'Within ecosystem macroinvertebrate diversity' can be achieved through operational changes in discharge regimes.

Water management, including the management of environmental flows, must be mindful of the potentially negative impacts on physical habitat. In particular, flow regulation has recently been anecdotally linked to rates of 'notching' in the bank, and mass failure erosion in the Goulburn River (Figure 2-18). Reference has been specifically made to constant water levels and rapid rates of drawdown (Cottingham *et al.* 2013). The first fresh following the high winter/spring flows may be of greatest concern in terms of bank erosion and the liberation of suspended sediment enhancing sediment smothering, because, this is when banks may be most susceptible to erosion. Understanding the link between environmental flow management and bank erosion will enable improved management of flows to ameliorate or reduce impacts, and is a focus of the Long Term Intervention Monitoring project for the Goulburn River.

Figure 2-18. Bank erosion ‘notching’ and mass failure (‘slumping’) that has been associated with environmental flow delivery.

2.7 Improving relationships between environmental flows and physical habitat

The role of environmental flows in driving physical habitat condition comes with some uncertainties, partly due to inherent spatial variability between sites, and the limited amount of data collected due to the time consuming nature of collection and analysis. A number of opportunities exist to improve understanding of the relationships between environmental flows and physical habitat, including those being addressed by the LTIM project and further knowledge gaps.

2.7.1 LTIM investigations

- Biota and vegetation respond to more than simple inundation metrics such as depth and average channel velocity. Quantification of hydraulic conditions such as velocity at a sampling point and shear stress (for say investigating macroinvertebrate or vegetation niches) can be valuable to assess the value of environmental flows, and revise delivery options. Understanding geomorphic processes is also dependent on understanding the full range of discharges (not just those present at the time of inspection). These data are most achievable through two-dimensional hydraulic modeling of a site that will be conducted as part of the upcoming Long Term Intervention Monitoring program.
- Bank erosion has been perceived to be linked to the delivery of environmental water. If this link exists it is important to understand how flow delivery may alter

the rate and mechanisms of bank erosion so that issues such as accelerated channel change and increased sediment smothering from liberated sediments can be reduced. This can be achieved through monitoring of bank erosion rates and mechanisms in the field and linking this to flow deliveries. This is being undertaken as part of the LTIM.

- Better defining repeatable cross-sections (VEFMAP), clearly marked on both banks for accurate repeat surveys. Such transects are being set up at two sites on the Goulburn River (McCoy's Bridge, Loch Garry) as part of the LTIM project.

2.7.2 Other knowledge gaps

- In-channel benches provide important habitat for biota (such as through slackwaters), enable inundation of riparian vegetation (with benches often acting as 'internal floodplains'), and enhance nutrient cycling processes. Yet, the variability in bench characteristics (elevation, inundation thresholds, size, vegetation cover etc.) is poorly understood. Understanding these characteristics will improve the ecological and ecosystem benefits provided by environmental and irrigation water flow management. This could be achieved using the LiDAR data collected for the Index of Stream Condition to identify benches, develop simple models to relate elevations to flow, and develop relationships that demonstrate bench area inundated for given flows provided.
- The limited sand-bed habitat found in the Goulburn River suggests that the sediment trapping efficiency of Eildon Dam may have an impact on substrate habitat availability. Quantifying the ecological and geomorphic role this might play in the availability of this type of substrate may lead to options to reduce the negative impact.
- Quantifying the link between bank erosion and suspended sediment concentrations would assist in reducing negative consequences of environmental water delivery for water quality or sediment smothering. This could be achieved through the use of automated suspended sediment samplers with data analysed against discharge derived from regulation or catchment sources. Ascertaining nuisance levels of sediment smothering in the bed for a range of biota would inform freshes delivered for this purpose. This would require an ecological study linking sediment smothering of the substrate to use by biota.

3 Riverine Productivity

Riverine productivity and organic matter supply and retention are key functions in riverine ecosystems, and encompass a number of important patterns and processes. Environmental water has the potential to alter these functions in a number of ways, such as increasing nutrient concentrations and in-stream productivity. This in turn can lead to an increase in the biomass of invertebrate communities, which can support higher-order consumers such as fish and water birds. Environmental water can influence organic matter dynamics through mobilizing woody debris and transporting suspended organic matter. This can support river consumers through provision of food and habitat resources.

Flow influences a range of factors that can alter primary production rate and community composition. Within the Basin Plan hierarchy of objectives, primary productivity is a Level 2 objective, with short-term responses to environmental watering including an increase in primary productivity (MDFRC 2013).

Macroinvertebrate diversity can be influenced by a number of flow variables including duration, timing, and frequency of flows. Within the Basin Plan hierarchy of objectives, macroinvertebrates is a Level 3 objective, with long-term responses to environmental watering including an increase in macroinvertebrate diversity (MDFRC 2013).

We monitored in-stream processes and invertebrate biodiversity at two sites in the Goulburn River using fortnightly sampling to capture any responses to water delivery.

Key findings

- Spring freshes and supplemented baseflows increased gross primary productivity.
- Spring and autumn freshes mobilized, transported and dispersed nutrients.
- Environmental water reduced benthic algal biofilms in the Goulburn River so that algal biomass was always below nuisance levels.
- Macroinvertebrate abundance increased with delivery of the spring freshes, with greater benefit observed for higher-magnitude freshes.
- Environmental water mobilized woody debris and increased transport of suspended matter, which can provide food and habitat for consumers. Greater mobilization was observed for higher-magnitude freshes.

3.1 Introduction

Riverine productivity is a key function in riverine ecosystems and encompasses a range of essential patterns and processes. In this component of the monitoring program we examined various ecological responses to flows including nutrient levels, light climate (turbidity, light levels on stream benthos), in-stream productivity and respiration, benthic algal biofilms, zooplankton and benthic macroinvertebrate communities. These parameters can all be influenced by environmental flows either directly or indirectly.

With the delivery of a single-pulse environmental fresh there is potential for an ecosystem-level response, with an increase in riverine productivity. For example, the amount of water delivered will affect water depth and the area that is inundated, which in turn will influence the depth of light penetration into the water column (light levels, turbidity) and therefore the depth of the euphotic zone. Water quality can also be influenced by flow, with increases in nutrient concentrations associated with water contacting parts of the dry floodplain or river channel which have stocks of nutrients and carbon (Baldwin & Mitchell 2000). The processes initiated by flows can influence benthic algal productivity and phytoplankton biomass (Bunn *et al.* 2006), or lead to decreases in these algal sources with reduced light climate, dilution effects and increased current velocities leading to scouring of biofilms (Stewardson *et al.* 2013). Increases in primary production and organic matter stocks in the river channel can boost the diversity and abundance of zooplankton (Boulton & Lloyd 1992) and benthic macroinvertebrates (Marshall *et al.* 2006) through provision of additional food and habitat resources. Increased productivity of zooplankton and macroinvertebrates may then provide additional food sources for higher-level consumers such as fish and water birds (Balcombe *et al.* 2007; Kingsford *et al.* 2010).

A single-pulse environment fresh may directly influence organic matter supply and retention in a river channel, including the quantity of benthic organic matter standing stocks (Boulton & Lake 1992) and suspension of organic matter in the water column (Egglishaw & Shackley 1971). This is an essential process, as the retention and supply of organic matter within the river channel provides food and habitat resources for river consumers such as macroinvertebrates and fish. In this component of the monitoring program we examine the influence of environmental freshes on organic matter supply and retention, specifically the movement of various size classes of woody debris and the amount of suspension of organic and inorganic matter in the water column.

A major challenge in understanding ecosystem-level responses to environmental freshes is to encompass the multiple components and functions/processes that interact at varying spatial and temporal scales (Kingsford *et al.* 2010). Measuring these patterns and processes in the Commonwealth Environmental Water Office monitoring program allows better insight into how environmental freshes can directly benefit riverine productivity and organic matter and supply.

3.2 Basin Plan objectives, cause-effect diagrams, and how they relate to macroinvertebrate and primary productivity monitoring

Macroinvertebrates is a Level 3 objective within the Basin Plan objectives hierarchy, nested within Biodiversity > Ecosystem diversity (Gawne *et al.* 2013). There are no listed short-term responses of macroinvertebrates (< 1 year). Longer-term (1-5 years) outcomes of environmental watering include improved macroinvertebrate diversity (Table 3-1).

Primary productivity is a Level 2 objective within the Basin Plan objectives hierarchy nested within Ecosystem function (Gawne *et al.* 2013). Short-term responses of environmental watering (<1 year) include increased primary productivity (Table 3-1).

There is one generic cause-effect diagram produced as part of the Logic and Rationale document (MDFRC 2013) that relates directly to how flows can influence macroinvertebrates and primary production (Figure 3-1; Figure 3-2). The monitoring in this report is able to evaluate the <1 year response for primary production. Our monitoring did not directly assess the 1-5 year outcomes of macroinvertebrate diversity, but by examining 2013/14 and 2012/13 monitoring data some information can be gained about this outcome. We focused our monitoring on macroinvertebrate abundance, taxonomic richness, community composition, and SIGNAL Score.

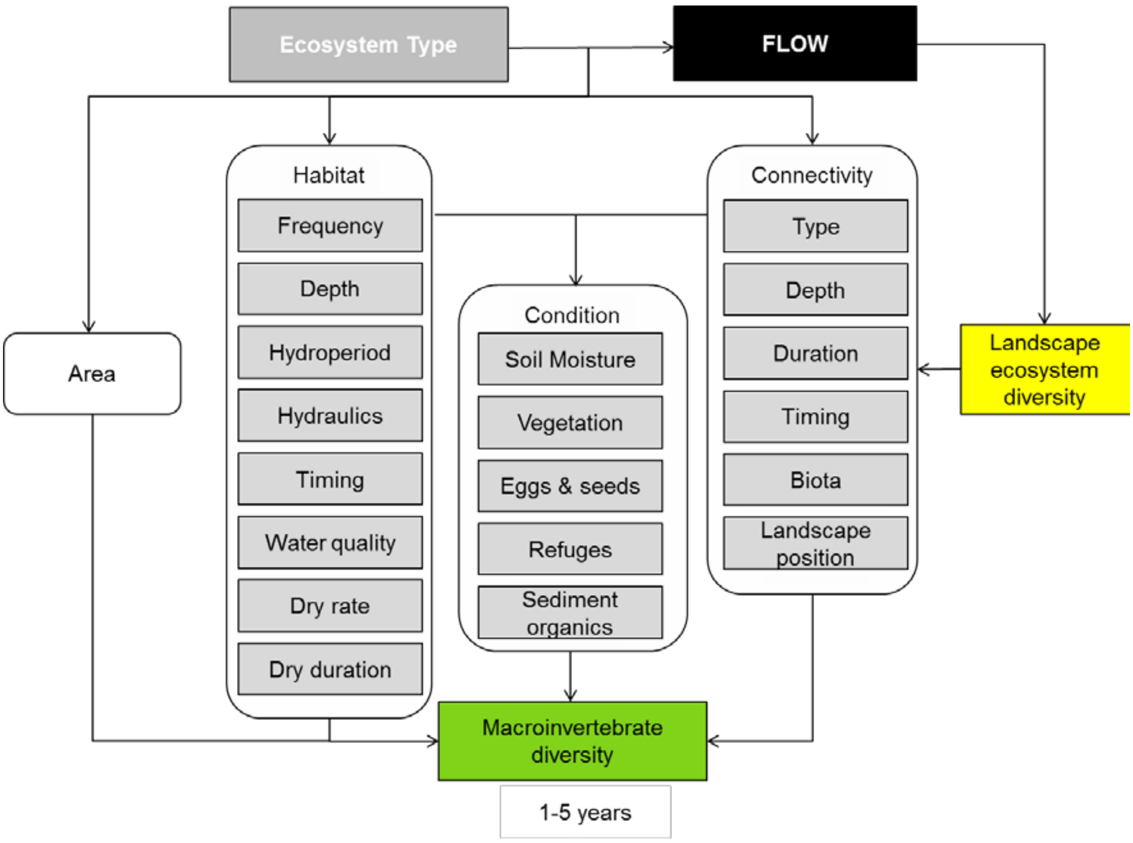

Figure 3-1 Generic cause-effect diagram (CED) for Macroinvertebrate diversity (reproduced from MDFRC 2013).

Table 3-1. Expected outcomes of environmental watering actions for macroinvertebrates and primary production as defined by the Basin Plan objectives hierarchy (modified from Gawne *et al.* 2013).

Level 1 Objectives	Level 2 Objectives	Level 3 Objectives	Expected outcome of watering actions (1-5 years)	Expected outcome of watering actions (< 1 year)	Relevant Cause and Effect Diagram
Biodiversity	Ecosystem diversity	Macro-invert-ebrates	• Macro-invertebrate diversity		Within Ecosystem Macroinvertebrate Diversity
Ecosystem Function	Process			• Primary Productivity	Primary Production

The cause and effect diagram for primary productivity describes how flows can influence the rate of primary productivity and community of primary producers. We focused our monitoring on describing water flows, nutrient concentrations, and light climate (turbidity, light levels) which can all potentially influence rates of in-stream primary production (Figure 3-2).

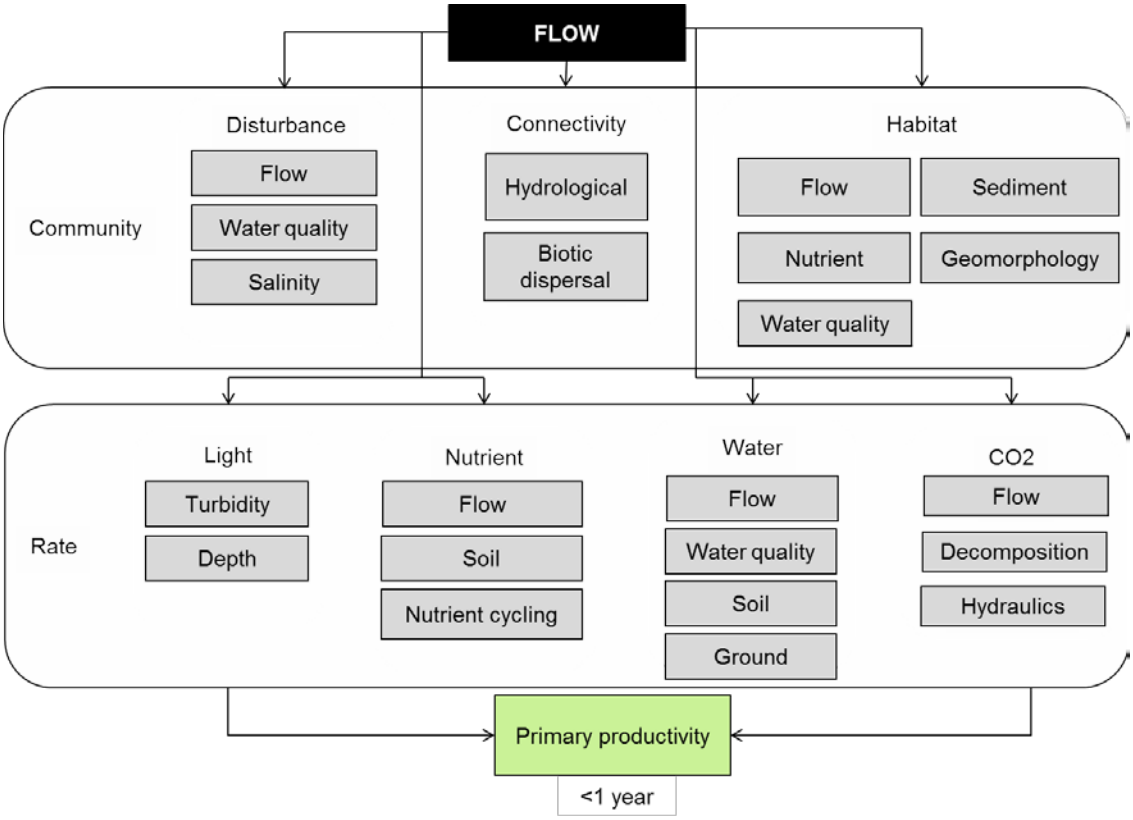

Figure 3-2. Generic cause-effect diagram (CED) for Primary Productivity (reproduced from MDFRC 2013).

3.3 Methods

3.3.1 Study sites and field methods

Sampling took place at two 50m reaches on the lower Goulburn River at Darcy's Track (Darcy) and McCoy's Bridge (McCoys) (Figure 1-5). These sites were also sampled as part of the 2012/2013 CEWO short-term intervention monitoring program (Stewardson *et al.* 2013). Sampling covered in-stream processes (primary function, primary production, organic matter supply and retention) and invertebrate biodiversity.

Sampling commenced mid October 2013 and was completed by late March 2014. Sampling was specifically targeted at addressing local-scale responses to environmental flows using before/after flow comparisons, and comparisons to historical data from the Goulburn River. The hypothesized overall relationships between environmental flows as a driver and ecological responses are shown in Figure 3-3.

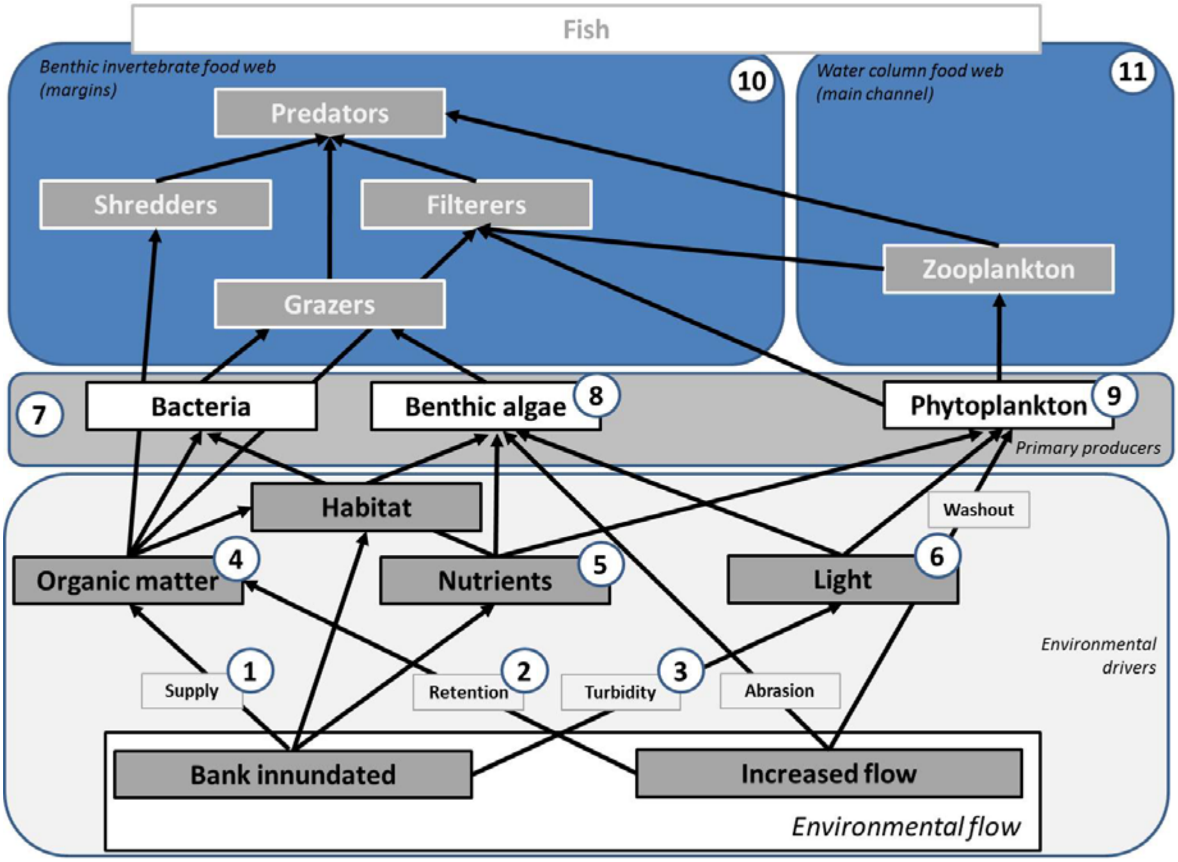

Figure 3-3. Conceptual diagram of effects of environmental flows on ecological responses. The main consequences of environmental flows are inundation of banks and increased in-channel flows. Bank inundation and increased in-channel flows affects energy supply through increases in nutrients and organic matter, but is also associated with increased turbidity, reducing productivity of algae on the river bed (benthic) and in the water column (phytoplankton). Bank inundation and increased in-channel flows also provides additional habitat for algae, bacteria and invertebrates, and access to terrestrially-derived resources. Increased flows directly disturb aquatic biota, but also increase export of organic matter (primarily wood and leaves). Ecological responses measured in the current study are indicated by numbers in circles and referred to in Table 3-2 below.

Details of sampling methods are provided in Stewardson *et al.* (2013). The ecological responses measured in the current study and a brief synopsis how they were measured and the sampling intervals are reported in Table 3-2. Sampling interval was once every two weeks; however there were some parameters that were measured continuously throughout the monitoring period (Table 3-2). It is important to note that the sites were used as replicates to assess the effects of environmental freshes on our ecological response indicators, and any differences in results/outcomes between sites were not of primary interest.

Table 3-2. Ecological responses measured in response to environmental flows. Numbers refer to Figure 3-3. Sampling intervals are either 'regular' (discrete samples taken once every two weeks), or 'continuous' (continuous sampling through the study period).

	Ecological response	How measured	Sampling intervals
1	Organic matter supply	Drift nets	Regular
2	Organic matter retention	Marking and relocation of snags	Regular
3	Turbidity	Turbidity meter at margins	Regular
4	Nutrient concentrations	Water samples (analysis for total nitrogen, nitrate/nitrite, total phosphorus, dissolved phosphorus, ammonia	Regular
5	Light	Loggers at various depths	Continuous
6	In-stream production	Single station measurements of oxygen across day/night cycles	Continuous
7	Benthic algae	Algal biomass and composition on colonization trays	Regular
8	Phytoplankton	Phytoplankton biomass water samples	Regular
9	Benthic invertebrate communities	Benthic invertebrate abundance and composition using sweep nets of 10m edge	Regular
10	Zooplankton communities	Zooplankton abundance and composition from 5m plankton hauls	Regular

Issues that arose during the sampling included stolen equipment from the McCoys site on the Goulburn River. One oxygen logger, all six in-stream light loggers and one replicate of the benthic algae biofilm blocks were stolen in early January 2014. Loggers were replaced on the 20th January 2014. The remaining replicate of the benthic algal biofilm blocks and the in-stream light loggers were then stolen by the next field trip (3rd Feb 2014). Subsequently, there were no benthic algae blocks or in-stream light loggers at the McCoys site, in addition to the missing logger data. Other issues included equipment malfunction and loss of data from both the in-stream light loggers and oxygen loggers at various times during the study.

3.3.2 Data analysis

The most informative data on the effects of environmental flows occurs around the two spring freshes delivered in mid-November 2013 (spring fresh 1) and early December 2013 (spring fresh 2), where there are data before and after each of the flows. These data can be compared with those from during smaller flow peaks with the autumn fresh (March 2014) and intervalley transfers (intervalley transfers 1, late October 2013, and 2, mid-January 2014). Data can also be compared between the lower magnitude freshes during the monitoring period, which includes the environmental water autumn fresh delivered in March 2014 and the similar sized intervalley transfers.

SIGNAL scores were calculated using the methods described in Chessman (2003). A SIGNAL score gives an indication of water quality in the river. Rivers with high SIGNAL scores (range between 1 and 10) are likely to have low levels of salinity, turbidity and nutrients such as nitrogen and phosphorus. High SIGNAL scores also indicate the river is populated with taxa that are sensitive to poor water quality, whereas rivers with low SIGNAL scores indicate the river is populated with taxa that are very tolerant of poor water quality.

Data for benthic invertebrate communities and benthic algae communities were analyzed through multivariate analysis using Primer 6.13 (Plymouth Marine Laboratories). For invertebrate communities data were log(X+1) transformed and Bray-Curtis dissimilarity scores between all pairs of samples were calculated. For benthic algae communities as data were presence and absence data, a simple matching similarity analysis between all pairs of samples were calculated. Both of these data sets were then analysed using non-metric multi-dimensional scaling. To determine whether there was any effect of flow and/or water depth on invertebrates or benthic algae communities from the two sites, analysis of similarities (ANOSIM) was used to test for differences between sampling dates. If significant, similarity percentage (SIMPER) analyses were then performed to determine what taxa drove differences in communities between sampling dates.

3.4 Results

Main results from the riverine productivity and organic matter supply and retention monitoring can be summarized as follows:

- Environmental water enabled the mobilization, transport and dispersal of nutrients in the Goulburn River. Spring freshes increased total phosphorus, total nitrogen and nitrate/nitrite concentrations. Whereas autumn freshes increased only total nitrogen and nitrate/nitrite concentrations. Intervalley transfers had a similar effect on nutrient concentrations as the spring freshes. There were no marked differences on the levels of nutrients between the higher-magnitude spring freshes and lower magnitude intervalley transfers.
- Environmental water enhanced riverine productivity, increasing gross primary productivity (GPP) and the Gross primary production: Ecosystem respiration ratio (GPP: ER ratio). These patterns were more evident at the McCoys site. Spring freshes and environmental water-supplemented baseflows increased GPP and the GPP: ER ratio. There was some evidence that the GPP: ER ratio increased at McCoys with the rising limb of the autumn fresh. Intervalley transfers also appeared to have similar effects on primary productivity as the spring freshes. There were no clear differences in primary productivity between the higher-magnitude spring freshes and the lower-magnitude freshes (intervalley transfers and autumn fresh).

- Reduced benthic algal abundance was associated with the delivery of environmental water (spring fresh 1). Water levels for spring fresh 2 were too high to assess influences on benthic algae and there were inadequate data to assess the influence of the autumn fresh. Intervalley transfers had similar effects in terms of reducing benthic algae, and there were no obvious differences between spring fresh 1 and the intervalley transfers.
- Increased abundances of benthic invertebrates were associated with environmental water spring freshes at Darcy. Lower magnitude freshes (autumn fresh and intervalley transfers) were not associated with any clear macroinvertebrate response.
- Increases in suspended organic matter in the water column coincided with peak flows during spring fresh 2 at Darcy. There was no noticeable response from spring fresh 1 or the autumn fresh. Intervalley transfer 2 also increased suspended organic matter in the water column at Darcy.
- Environmental water was capable of moving small, medium and large sized pieces of woody debris within the river channel. The higher-magnitude spring freshes were capable of moving a larger proportion of pieces of woody debris than the lower magnitude freshes (autumn fresh and intervalley transfers).
- Turbidity levels increased with spring freshes. Turbidity levels did not increase with the autumn fresh. Intervalley transfer 1 had a similar effect on turbidity to the spring freshes. No noticeable response was found with intervalley transfer 2.
- Environmental water increased water depths, and very low levels of light reached the river bed during these periods. These reduced light levels can assist in reducing nuisance algal production. Similar effects were evident for spring freshes, the autumn fresh and intervalley transfers.

Full details and associated tables and figures for the results of the measured ecological responses are provided in Appendix B. Here we provide tabular summaries of those results, and pick out highlights particularly relevant to environmental flow management in Table 3-3.

3.4.1 Benefits of environmental flows

The environmental water delivery resulted in an increase in riverine productivity within the river channel. For some of the measured ecological responses, it was found that the delivery of higher magnitude spring freshes was of greater benefit than the delivery of lower-magnitude flow events (autumn fresh and intervalley transfers). The delivery of spring freshes resulted in increased abundances of macroinvertebrates and mobilization of woody debris within the river channel, which can provide food and habitat for river consumers. In comparison, lower-magnitude freshes did not initiate a macroinvertebrate response, and there was less mobilization of woody debris. These specific ecological responses highlight the advantages of the delivery of higher magnitude freshes over lower magnitude freshes for river health.

Table 3-3. Summary of ecosystem responses to environmental watering in the Goulburn River in 2013/14, ✕ denotes no response, ↑ denotes increase in response.

Ecological response	Spring fresh 1	Spring fresh 2	Intervalley transfer 1	Intervalley transfer 2	Autumn fresh	Appendix B
Nutrient concentrations	↑ TP, TN, NOx	↑ TP, TN, NOx	↑ TP, TN, NOx	↑ TP, TN, NOx	↑ TN, NOx	Figure 13-1
In-stream production	↑ in GPP, GPP: ER ratio	↑ in GPP, GPP: ER ratio McCoys	↑ in GPP: ER ratio	↑ GPP, ER McCoys	✕ Darcy, Some evidence of ↑ in GPP: ER ratio McCoys	Figure 13-2
Benthic algae	↓ algae, ✕ species compositio n	Not assessed, water levels too high for recovery	↓ algae, ✕ species composition	↓ algae, ✕species compositio n	Inadequate data to assess	Figure 13-3
Phytoplankton	✕	✕	✕	✕	✕	Figure 13-4
Benthic macroinverteb rate communities	↑ no's at Darcy, ✕species compositio n	↑ no's at Darcy, ✕species composition	✕	✕	✕	Figure 13-5
Zooplankton communities	✕	✕	✕	✕	✕	Figure 13-6
Organic matter supply	✕	↑ Darcy	✕	↑ Darcy	✕	Figure 13-7
Organic matter retention	Spring freshes combined were capable of moving a large proportion of both small and medium snags and a smaller proportion of large snags		Moved a small proportion of small, medium and large snags	Moved a small proportion of small, medium and large snags	Moved a small proportion of small, medium and large snags	Figure 13-8
Turbidity	↑ turbidity levels at McCoys	↑ turbidity levels at both reaches	↑ turbidity levels at McCoys	✕	✕	Figure 13-9
Light	Low levels light detected, due to increasing water depth	Low levels light detected, due to increasing water depth	Low levels light detected, due to increasing water depth	Low levels light detected, due to increasing water depth	Low levels light detected, due to increasing water depth	Figure 13-10

There were small increases in gross primary productivity associated with spring freshes and environmental water-supplemented baseflows. It also appeared that the rising limb of the autumn fresh increased the gross primary productivity: ecosystem respiration ratio (to > 1) which suggests the ecosystem was supported by in-stream primary production at this time. A similar response was observed to intervalley transfers, which were shaped as low-magnitude, long-duration freshes. Levels of benthic algae never exceeded nuisance levels during this year's monitoring. Hypothetically, if no environmental water had been delivered during the watering season, there could have been similar conditions to what was experienced in 2012/13 (when there was a longer duration of low stable flows between the delivery of freshes from mid-October to mid-November 2012), which resulted in extremely high levels of gross primary productivity (9 mg/L/day), and led to nuisance levels of benthic algae (>100 mg/m^2) (Stewardson *et al.* 2013).

Nutrient concentrations, primarily total phosphorus (TP), total nitrogen (TN) and Nitrates and Nitrites (NOx), peaked with environmental water delivery of spring freshes. The autumn fresh did not increase TP but did increase TN and NOx. Intervalley transfers had a similar effect on nutrients as the spring freshes. These results indicate that environmental water can increase nutrient mobilization, dispersal and transport. This is a similar finding to patterns found in the Edward-Wakool system and Murrumbidgee River (Watts et al. 2013; Wassens et al. 2014). However, in 2012/2013 in the Goulburn River, there was no apparent relationship between environmental water and nutrient concentrations. These differences may potentially be explained by the different antecedent flow conditions between the two monitoring periods. In 2012/2013, antecedent flow conditions were near flood levels (Figure 1-2), so the release of nutrients from dry floodplain and river sediments may have already peaked before the monitoring began. This is in contrast to 2013/2014, where antecedent flows were quite low (Figure 1-1) and the spring fresh was the first major watering event to inundate within-channel benches and bank sediments, releasing nutrients into the water column.

Environmental water mobilized pieces of wood within the river channel. Greater mobilization of woody debris and movement of larger sized pieces of wood occurred with the spring freshes compared to the lower-magnitude freshes (autumn fresh and intervalley transfers). If these pieces of wood were subsequently retained within the river channel it would provide habitat and food for freshwater biota.

Macroinvertebrate abundance increased with environmental flow delivery, primarily with spring freshes. Lower-magnitude freshes (autumn fresh and intervalley transfers) were not associated with any macroinvertebrate response. This result is potentially explained by the increase in organic matter supply and retention within the river channel enhancing available food and habitat resources, or by the increased flows leading to increased drift of macroinvertebrates in the water column (Marshall et al. 2006). This is in contrast with the 2012/2013 monitoring data, where there were no apparent relationships between environmental water and macroinvertebrates. Again, this result might be explained by differences in antecedent flow conditions between the two monitoring periods. The near-flood conditions prior to monitoring in 2012/2013 may have meant that macroinvertebrates communities had previously responded to earlier flows. In contrast, in 2013/2014, antecedent flows were quite low and the spring fresh was the first watering event to which macroinvertebrate communities could respond.

There were consistent patterns across the two years for some of the ecological responses to environmental water delivery. In both years, environmental water deliveries reduced light levels on the river bed, increased turbidity in the water column, reduced benthic algal biofilms, and mobilized woody debris within the channel. These consistent patterns between monitoring periods allow qualitative predictions of how environmental flows can influence specific ecological parameters and riverine productivity.

3.5 Discussion

Riverine productivity and organic matter retention and supply were influenced by the delivery of environmental water in the lower Goulburn River. There was variability in the responses of the measured ecological indicators as well as within sites to flow conditions. Patterns evident in this year's sampling period differed from previous years for some responses. The clearest patterns evident with the delivery of environmental water were changes to nutrient concentrations, in-stream productivity, organic matter retention, and light climate (turbidity, light levels). There were also patterns evident for macroinvertebrates and mobilization of woody debris, with higher-magnitude spring freshes having larger effects than lower-magnitude flow events (autumn fresh and intervalley transfers).

Environmental water (spring and autumn freshes) increased nutrient concentrations in the Goulburn River and therefore nutrient transport, mobilization and dispersal. Intervalley transfers also similarly increased nutrient concentrations. There were several occasions during the sampling period that particular nutrient concentrations exceeded the ANZECC recommended trigger guidelines. This is a potential source of concern, as exceeding trigger values can increase the risk of algal blooms (ANZECC 2000). The increase in nutrient concentrations coinciding with peak flows may be due to the wetting of previously dry sections of the river channel, which can release nutrients and carbon from the sediments and into the water column (Baldwin & Mitchell 2000) or may be a result of the washing in of allochthonous material from river banks (e.g. leaf-litter, bark, wood). Other studies from lowland rivers systems such as the Edward-Wakool system and the Murrumbidgee River have found similar patterns of increased nutrient concentrations with environmental water deliveries (Watts et al. 2013; Wassens et al. 2014).

There were marked changes in in-stream primary productivity with spring and autumn freshes and environmental water-supplemented baseflows at McCoys in particular. Intervalley transfers had similar effects on primary productivity to spring freshes. In general, the system was heterotrophic, relying on external sources of carbon (allochthonous), which is similar to other streams and rivers in south-eastern Australia (Giling *et al.* 2013; Stewardson *et al.* 2013; Watts *et al.* 2013). However, environmental water delivery shifted the basal productivity of the river and increased both gross primary productivity (GPP) and ecosystem respiration (ER). The GPP: ER ratio exceeded 1, indicating the ecosystem was fuelled by in-stream primary producers during these times. Potential reasons for this pattern could be that increases in GPP are supported by the high nutrient concentrations that occurred during peak flow periods. These can increase the productivity rate of in-stream producers (Young, Matthaei & Townsend 2008). Another reason may be that the higher peak flows of the spring freshes may have inundated large areas of dry river bed sediments, releasing stocks of carbon and nutrients into the water column (Baldwin & Mitchell 2000). These results are in contrast to the 2012/2013 monitoring data, where high environmental flows did not increase GPP or the GPP:ER ratio (Stewardson *et al.* 2013). This could be because in 2012/2013 there was no increase in nutrient concentrations with flows, and therefore no increase in primary production.

There was also evidence that GPP, ER and the GPP: ER ratio increased with low flows as well as baseflows that were supplemented by environmental water. These findings were similar to the 2012/2013 monitoring data, and are potentially the result of more stable low flows (Stewardson *et al.* 2013) . These conditions allow for increased algal growth, with an increase in light levels reaching the river bottom due to the reduction of suspended organic matter and turbidity in the water column. This potential mechanism was supported by the current monitoring data, with higher light levels reaching the river bed, lower turbidity values, and the higher production of benthic algae that was evident during the low-flow periods and at times when baseflows were supplemented by environmental water. GPP in this year's sampling (GPP 3 mg/L/day) period did not increase as much as during the previous year sampling (GPP 9 mg/L/day). This is most likely due to the extended stable low flow conditions in 2012/13 compared to the 2013/14 flow conditions.

Benthic algal biofilms were reduced with environmental water delivery (spring fresh 1) and intervalley transfers 1 and 2. This may be a result of the environmental water reducing the accumulation of sediment and detritus upon biofilms, and scouring of biofilms with increased flow velocities. The environmental water may have also caused a reduction in light availability by increasing water depth over biofilms, and increasing suspended sediments in the water column, both of which can shade the biofilms and reduce algal production. This reduction in benthic algal biofilms in response to environmental water is a similar finding to the previous year sampling (Stewardson *et al.* 2013), as well as other lowland river systems, including the Edward-Wakool system (Watts et al. 2013) and Murrumbidgee River (Wassens et al. 2014). During the monitoring period, benthic biofilms did not exceed the nuisance threshold of 100 mg/m^2 (Quinn 1991). Biofilm biomass was generally higher at Darcy than McCoys and this may be a response to the lower turbidity levels at this site during the monitoring period.

Phytoplankton biomass did not respond to changes in flow, but was comparable (0.013 – 0.045 mg/L) to other lowland rivers including the Edward-Wakool river system (0.02–0.2 mg/L; Watts et al. 2013) and Murrumbidgee river system (0.005-0.013mg/L; Wassens et al. 2014). This finding was similar to the 2012/2013 result, which suggests that primary production within the water column is probably not a major carbon source in the Goulburn River.

Primary productivity is a Level 2 objective within the Basin Plan objectives hierarchy and is nested within Ecosystem function (Gawne *et al.* 2013). The short-term predicted responses of environmental watering (<1 year) include increased primary productivity. In terms of this Basin Plan objective our results demonstrate that the environmental water delivered to the lower Goulburn River did increase GPP. In line with the CED for primary productivity, we focused our monitoring on examining water flows, nutrient concentrations and light climate (turbidity, light levels). These monitored parameters were able to elucidate some of the potential mechanisms to explain how primary productivity rate was influenced by environmental water delivery.

Benthic macroinvertebrate communities increased in abundance with environmental water spring freshes but did not respond to lower magnitude freshes (autumn fresh and intervalley transfers). This finding emphasizes the importance of higher-magnitude freshes to macroinvertebrate abundance, which can then support higher-order consumers such as fish and water birds. One water bug, *Micronecta sp.* was predominately responsible for this increase. This species was common in samples during the entire monitoring period. The increase in abundance with environmental water delivery could be due to the flows providing additional organic matter food sources (increased suspended organic matter) and habitat (increased organic matter retention) with the washing in of terrestrial leaf litter and coarse woody debris (e.g. snags). Another mechanism could be the environmental water delivery is instigating macroinvertebrate drift, as invertebrates have been shown to drift downstream with increased flows (Marshall et al. 2006).

Macroinvertebrate richness, species composition and SIGNAL score did not respond to delivery of environmental water. However, previous studies have highlighted the detrimental effect that river regulation can have on reducing macroinvertebrate biodiversity (Poff et al. 1997; Pardo, Campbell & Brittain 1998; Bunn & Arthington 2002). One possible reason that we may not have detected differences with richness and composition is that taxonomic identification only went to family level rather than species level, which may have missed important changes in species in relation to flows. SIGNAL score was developed as an indicator of organic pollution and water quality not to flow changes specifically and so may not respond to changes in flow and the delivery of environmental water (Chessman 2003). Macroinvertebrates is a Level 3 objective within the Basin Plan objectives hierarchy, nested within Biodiversity > Ecosystem diversity (Gawne *et al.* 2013). There are no listed short-term responses of macroinvertebrates (< 1 year), and longer-term (1-5 years) predicted outcomes of environmental watering include improved macroinvertebrate diversity. In terms of the longer-term Basin Plan objective, combining this year's results with the previous year's results did not provide any evidence that the environmental water delivered to the lower Goulburn River has increased macroinvertebrate diversity. In the Goulburn River, the macroinvertebrate community was characterized by a very tolerant and generalist taxa in terms of sensitivity to flows and dietary requirements. These findings could indicate that the more sensitive taxa have already been lost to the system with river regulation and agricultural land use over the years. The biomass or productivity of the macroinvertebrate community may be a more sensitive indicator to changes in flows due to the low diversity of the community in the Goulburn River. This method was successful in detecting a positive response to environmental flow delivery in the Edward-Wakool system (Kingsford et al. 2014), and will be investigated as part of the Goulburn River LTIM project.

Zooplankton communities were dominated by rotifers, which are typical of lowland river systems (Ning *et al.* 2013). Zooplankton communities in lowland rivers have exhibited reduced abundances with increases in flow due to advection and dilution effects from the increasing volumes of water (Basu & Pick 1997). There was no response of zooplankton communities to changes in flows in terms of abundance or community composition. Possible reasons could be that the flows did not inundate backwater areas or wetlands that concentrate zooplankton communities. These findings are in contrast to the 2012/2013 monitoring program, where rotifer relative abundance was lower during large environmental flows (Stewardson *et al.* 2013). However, they are similar to patterns in the Edward-Wakool river system, which also found that zooplankton communities did not respond to environmental water delivery (Watts *et al.* 2013).

Environmental water delivery influenced organic matter retention and supply in the Goulburn River. Environmental water was able to mobilize large amounts of organic matter from the river banks (spring and autumn freshes) and increase suspension of organic matter in the water column (spring fresh 2). Higher-magnitude environmental water spring freshes were capable of moving greater quantities of small, medium and large sized woody debris than lower-magnitude flow events (intervalley transfers and autumn fresh). Potentially, this may have increased the amount of woody debris within the river channel enabling the provision of food and habitat for riverine biota. The Goulburn River was shown to be predominately heterotrophic relying on terrestrial sources of carbon to support riverine productivity; a finding similar to the 2012/2013 monitoring program and the Edward-Wakool river system (Stewardson *et al.* 2013; Watts *et al.* 2013). Woody debris and leaves can also be an important substrate for benthic biofilms (Hladyz et al. 2011).

In summary, environmental water deliveries and intervalley transfers during the monitoring period did influence riverine productivity, and organic matter supply and retention. Higher-magnitude spring freshes were found to provide more benefits than lower magnitude flow events (autumn fresh and intervalley transfers) for the ecological responses of macroinvertebrate abundance and the mobilization of woody debris. Riverine productivity shifted from predominately heterotrophic, reliant on terrestrial carbon, to production from in-stream algal sources. This shift may have been supported by the increase in nutrients that peaked with high flow conditions as a result of inundation of dry river banks and benches. Macroinvertebrate communities increased in abundance with spring freshes. This may have been supported by the increased riverine productivity and organic matter retention and supply providing food and habitat within the river channel.

4 Riparian vegetation

Riparian vegetation plays a key role in the structure and functioning of riverine ecosystems. It binds soils and substrates on river banks, reducing rates of erosion, bank failure, and channel migration. It creates habitat for terrestrial fauna, and provides carbon inputs to the river in the form of shed leaves and bark. When large riparian trees die, they fall into the river creating important habitat for native fish and invertebrates.

Riparian vegetation is predicted to respond to the frequency, duration and timing of inundation events as river levels rise and fall. Within the Basin Plan hierarchy of objectives, riparian vegetation is a level 3 objective, with short-term expected outcomes of watering actions including reproduction, condition, germination and dispersal. Over longer time frames, environmental watering is expected to improve vegetation diversity, and growth and survival (Gawne *et al.* 2013).

We monitored vegetation on the banks of the Goulburn River at four sites, taking advantage of historical monitoring to examine changes over time and different flow regimes. We also monitored vegetation at four sites on Broken Creek, to provide a point of comparison in a system where inundation patterns change very little.

Key findings

- Bankside vegetation in the Goulburn River responded to spring freshes in 2013. New growth of native vegetation was visible in areas inundated by the freshes.
- Environmental flows reduce the establishment of 'terrestrial dry' species on river banks, while promoting 'terrestrial damp' species better adapted to inundation.
- Inundation by environmental flows promotes the growth of species that respond positively to inundation, but the response is complex and depends upon the number of distinct inundation events.
- Following the drought (2008/09 data) and floods (2010/11 data), riparian vegetation is in the process of re-establishing on the banks of the Goulburn River (2012/13, 2013/14 data). We predict that environmental watering will facilitate this re-establishment.
- Assemblages on Broken Creek show strong zonation of vegetation types, indicative of what we might observe in the Goulburn River but for the variability of flows introduced by environmental watering.

4.1 Introduction

Riparian vegetation assemblages are a key component of riverine ecosystems. Apart from their value as living systems in their own right, they also play a major role in the structure and function of other parts of the ecosystem. Vegetation stabilizes river banks, with the roots of riparian plants binding soils together to reduce erosion and promote channel stability (Rowntree & Dollar 1999). Living riparian vegetation provides habitat for terrestrial invertebrates, reptiles, mammals and birds; and is also a supplier of the organic carbon that drives riverine productivity and underpins food webs (Vannote *et al.* 1980). When large riparian trees die, they can fall into channels, providing the large woody debris important as habitat for native fish species (Pusey & Arthington 2003), and also provide habitat and promote the accumulation of food supplies for aquatic macroinvertebrates(Gabriel, Clarke & Campbell 2010).

The effects of flow regulation on riparian vegetation assemblages have been well documented around the world (Nilsson *et al.* 2005). Specific effects of flow regulation include a shift in plant species composition towards more opportunistic 'weedy' taxa that are able to cope with an altered flow regime, compared to endemic species adapted to a river's natural flow regime. Opportunistic taxa are often exotic, and so regulated rivers are characterised by a higher proportion of exotic species in their riparian zones (Greet, Cousens & Webb 2013). Flow regulation also tends to reduce the frequency and extent of flooding of riparian and bankside vegetation, leading to increased abundances of terrestrial-adapted species compared to what would be seen under natural flow conditions (Miller *et al.* 2013).

There are few studies of the response of riparian vegetation to flow restoration – the re-instatement of a more natural flow regime through environmental flows. The Commonwealth Environmental Water Office monitoring programs, both this short-term program and the long-term program that will replace it in 2014, provide a tremendous opportunity to measure the beneficial effects of flow restoration on riparian vegetation.

4.2 Basin Plan objectives, cause-effect diagrams, and how they relate to vegetation monitoring

Vegetation is a Level 3 objective within the Basin Plan objectives hierarchy, nested within Biodiversity > Ecosystem diversity (Gawne *et al.* 2013). Short-term expected responses of vegetation (<1 year) to environmental watering include improvements in vegetation condition, reproductive output, and germination and dispersal rates of seeds. Longer-term (1-5 years) outcomes include improved diversity of vegetation assemblages, and improved growth and survival of individual plants.

Three of the generic cause-effect diagrams produced as part of the Logic and Rationale document (MDFRC 2013) relate directly to vegetation responses (Table 4-1). The monitoring described in this report is able to assess the 1-5 year outcomes of Vegetation Diversity, Growth and Survival. Our monitoring did not assess the <1 year responses detailed above. Vegetation reproduction is very difficult to monitor in the field (Greet, Webb & Cousens 2011; Miller *et al.* 2013), and we had previously reasoned that following the end of the drought in the Goulburn system, we would be unable to detect any response in vegetation condition (Stewardson *et al.* 2013). Similarly, while we could conceivably have monitored vegetation germination and dispersal, we instead chose to concentrate on the vegetation assemblages themselves – the ultimate target of environmental watering.

Table 4-1. Expected outcomes of environmental watering for vegetation as defined by the Basin Plan objectives hierarchy (modified from Gawne *et al.* 2013).

Level 1 Objectives	**Level 2 Objectives**	**Level 3 Objectives**	**Expected outcome of watering actions (1-5 years)**	**Expected outcome of watering actions (< 1 year)**	**Relevant Cause and Effect Diagram**
			• Vegetation diversity		Landscape Vegetation Diversity
Biodiversity	Ecosystem diversity	Vegetation		• Reproduction • Condition	Vegetation condition and reproduction
			• Growth and survival	• Germination • Dispersal	Vegetation Recruitment and Extent

The expected effects of inundation regime on vegetation diversity, recruitment and extent are shown below. We focused our monitoring on relating vegetation assemblage diversity to the frequency, duration and timing of inundation; therefore also assessing the effects of dry period (Figure 4-1).

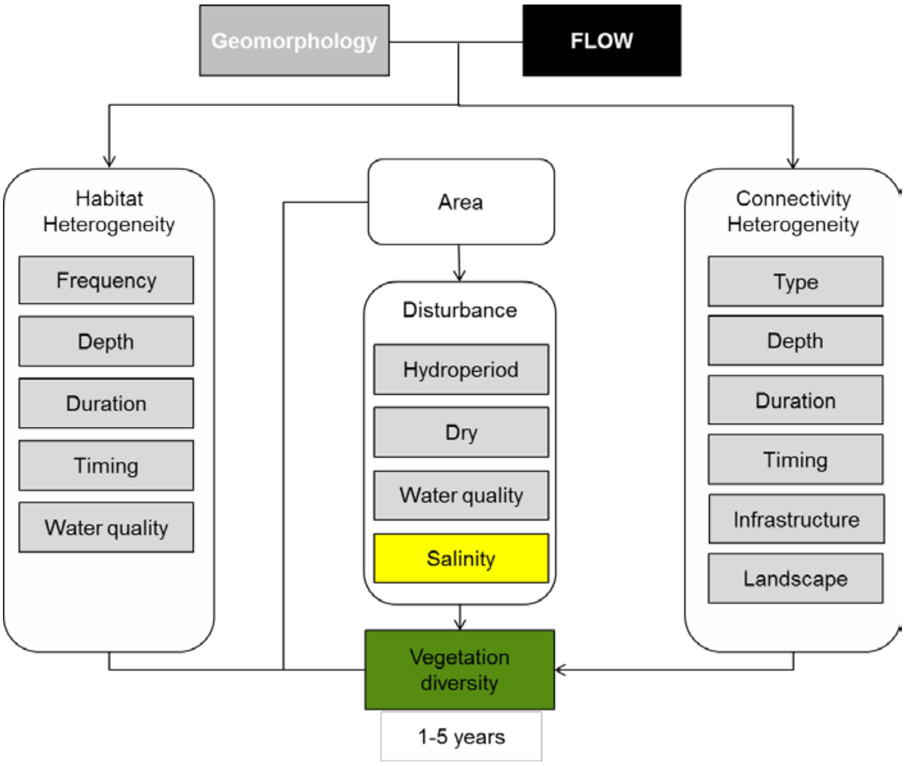

Figure 4-1. Generic cause-effect diagram (CED) for Landscape vegetation diversity (reproduced from MDFRC 2013).

Vegetation growth and survival are also primarily influenced by water conditions (Figure 4-2), which we also characterized using the same flow components as above (frequency, duration, timing).

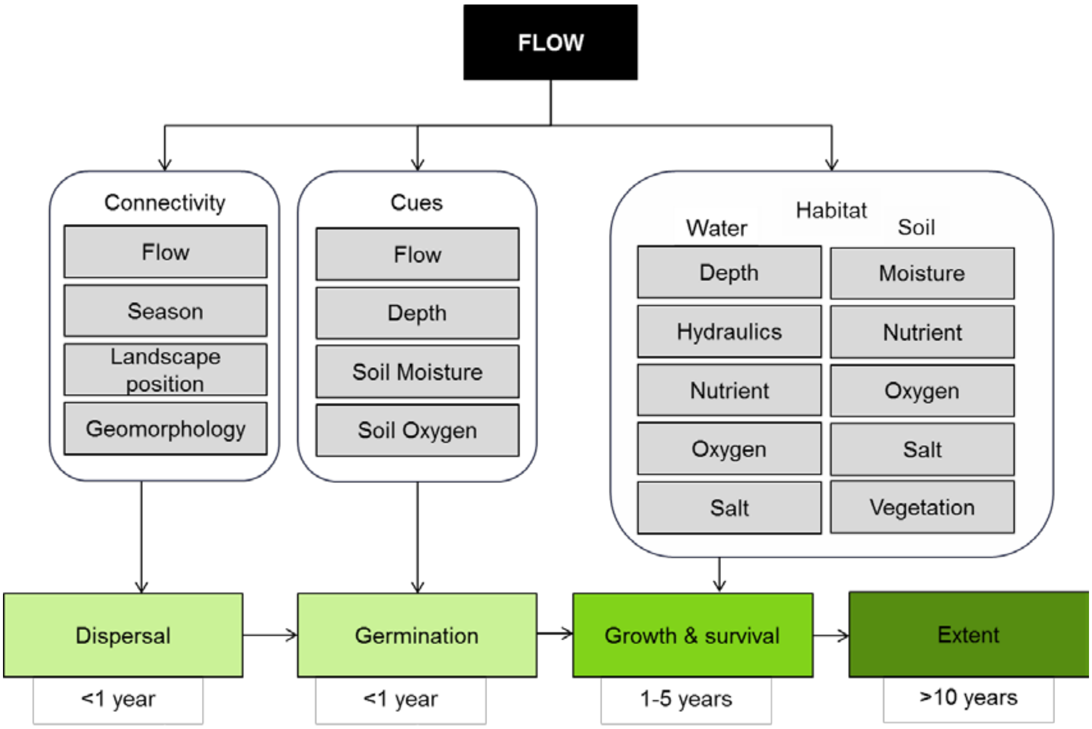

Figure 4-2. Generic cause-effect diagram (CED) for Vegetation Recruitment and Extent (reproduced from MDFRC 2013) .

4.3 Logical basis for monitoring

From the above, it is clear that we were attempting to assess longer-term responses (diversity and growth) in a short-term monitoring program. We achieved this by using a 'space for time substitution' (Downes *et al.* 2002) – we compared vegetation subjected to different inundation regimes to infer what will happen when the inundation regime changes for any given patch of vegetation.

More specifically, we sampled at different elevations on river banks to survey vegetation subject to different inundation regimes. As we sample further and further up the bank, the vegetation is subject to less and less inundation. This means that we expect to see species more typical of terrestrial environment, and less reliant on inundation (left hand side of Figure 4-3). The differences in vegetation subjected to different inundation regimes allows us to describe a relationship between vegetation and inundation, and therefore predict what will happen to vegetation under different flow scenarios.

Moreover, if we sample at sites with flow regimes that change little within or between years, we expect to see much stronger zonation in the types of vegetation, with terrestrial species encroaching far down the bank, and a narrow band of fringing vegetation near the water's edge (right hand side of Figure 4-3).

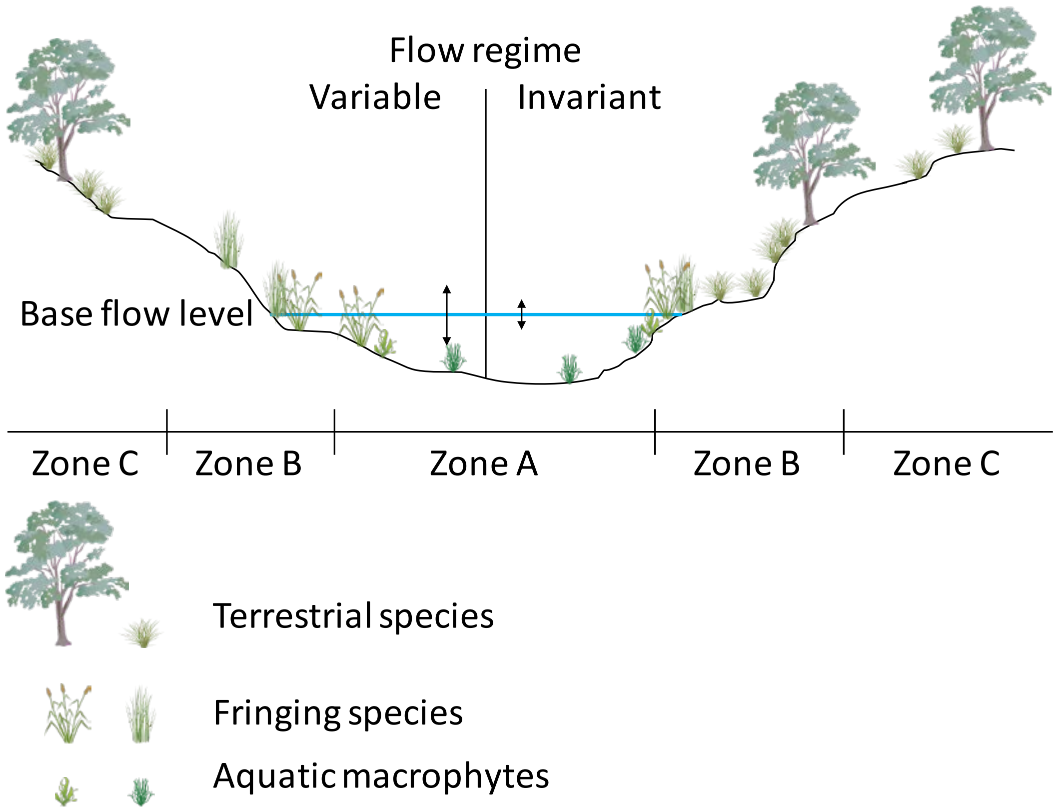

Figure 4-3. Conceptual model of river vegetation assemblages under varying and non-varying flow regimes. Our sampling focused on zone B (Christie & Clarke 1999), the region from the edge of the low water mark to half way up the river bank.

4.4 Methods

4.4.1 Study sites and field methods

The contrasts above (comparing vegetation at different elevations on the river bank, and comparing vegetation between systems with variable and non-variable flow regimes) were established by sampling at four sites on the Goulburn River, which experiences variable flow regimes, including those augmented by environmental flows; and at four sites on lower Broken Creek, for which the weir pool structure means that water levels are almost invariant. These sites were Moss Rd, Darcy Tk, Loch Garry, and McCoy's Bridge on the Goulburn River, and Ball's Weir, Schier's Weir, Kennedy's Weir and Rice's Weir on Broken Creek (Figure 1-5). All of these sites had been sampled previously. The Goulburn River sites were surveyed as part of the Victorian Environmental Flows Monitoring and Assessment Program (Webb *et al.* 2014b) in 2008/09, 2010/11 and 2012/13. The Broken Creek sites were surveyed as part of the 2012/13 CEWO short-term intervention monitoring program (Stewardson *et al.* 2013).

Details of site establishment and survey methods are provided in Stewardson *et al.* (2013). Here we provide a very brief overview only. At each site, we established 10 transects perpendicular to the river channel, and surveyed vegetation within 1 × 1 m quadrats along these transects, concentrating on the 'Zone B' region from the water's edge to just beyond half way up the bank (Figure 4-3) . We attempted to re-survey the exact positions of previously-measured quadrats to provide a repeated measure of vegetation cover over time. The cover of each species identified within a quadrat was recorded using the Braun-Blanquet semi-quantitative scale (Table 5-1 in Stewardson *et al.* 2013).

4.4.2 Data analysis

Because we expect different types of vegetation to respond differently to different inundation regimes, we classified the vegetation species into functional groups (Casanova & Brock 2000) that describe the species adaptation to inundation. The great majority of species classified into one of four functional groups (Table 4-2), and our statistical analyses were carried out on these functional groups.

Table 4-2. Functional groups of vegetation used for statistical analysis. Modified from Casanova and Brock (2000). We have also included our hypothesized response of each group to environmental flows.

Functional Group	Abbreviation	Description	Hypothesized response to environmental flows
Terrestrial Dry	Tdr	Species that germinate, grow and reproduce where there is no surface water and the water table is below the soil surface	Expected to be negatively affected by increased inundation from environmental flows
Terrestrial Damp	Tda	Species that germinate, grow and reproduce on saturated soil	Expected to be positively affected by short periods of inundation, but prolonged inundation should cause negative effects
Amphibious Fluctuation Tolerators – Emergent	Ate	Species that germinate in damp or flooded conditions, which tolerate variation in water-level, which grow with their basal portion under water and reproduce out of the water	Expected to show a similar pattern to Tda species, but able to respond positively to longer periods of inundation before experiencing negative effects
Amphibious Fluctuation Tolerators - Low Growing	Atl	Species that germinate in damp or flooded conditions, which tolerate variation in water-level, which are low-growing and tolerate complete submersion when water-levels rise	As above, but able to respond positively to even longer periods of inundation before experiencing negative effects

The data were analyzed using Bayesian models, building upon those employed by the 2012/13 short-term intervention monitoring project (Stewardson *et al.* 2013) and those employed to analyze data from VEFMAP (Miller *et al.* 2014). Our reasons for using Bayesian models are fully explored in Stewardson *et al.* (2013), but can also be summarized as:

- Much greater flexibility of model structure, allowing us to fit models to the complex data experimental designs that characterize environmental flows monitoring programs;
- An ability to use hierarchical Bayesian models to reduce unexplained uncertainty by considering data from all sites simultaneously; and

- The ability to make quantitative predictions of vegetation cover/diversity under different flow regimes – specifically with and without environmental flows in the Goulburn River.

Full detail of the statistical models is provided in Appendix C. Here we provide a summary of the data employed, the hypotheses tested, and how those relate to Basin Plan expected outcomes (Table 4-3). We used probability of occurrence as a 'measurement endpoint' for early life history survival of vegetation (i.e. the ability to become established upon the river bank). Vegetation cover was used to indicate growth, reasoning that to obtain high covers, plants must have grown from an initial germinant. Species richness was used as an indicator of diversity, as is commonly done in many monitoring programs.

Table 4-3. Summary of hypotheses and analyses of vegetation data. For each hypothesis, we carried out two analyses for each functional group of vegetation (Tdr, Tda, Ate, Atl). One analysis employed data from both the Goulburn River and Broken Creek, and used quadrat elevation as the primary descriptor of inundation regime. The other analysis employed data from the Goulburn River only and used hydrological data to directly quantify inundation.

Hypothesis number and Basin Plan expected outcome	**Vegetation indicator used in analysis**	**Data used & Analysis structure**	
		Vegetation and elevation data from both rivers	**Vegetation and hydrologic data from Goulburn River**
H1: Survival	Probability of occurrence		
H2: Growth	Proportional cover	$y = f(elevation)$	$y = f(inundation)$
H3: Diversity	Species richness		

Analyses that employed data from both sites had to use 'relative elevation' (elevation from the water surface divided by the height of the river bank, with the latter defined as the elevation of the 'break of slope' at the top of the bank) within the channel as the primary indicator of inundation regime. This was because we had no direct inundation data from Broken Creek. These analyses, employing data from both the flow-varying Goulburn River, and flow-invariant Broken Creek, assess the broad relationship between inundation and response that will underpin any environmental flow response. They also show whether fundamentally different patterns emerge in the two different types of system.

The analyses that only employed data from the Goulburn River were able to use the outputs of hydraulic models to directly quantify inundation history (Appendix C). These analyses provide a finer-scale result that we were able to then use to predict vegetation responses under different flow regimes: those with and without environmental flows.

For both sets of analyses, we also assessed the effect of sampling year, to determine whether:

- vegetation patterns in the Goulburn River (with its greater variation in flow regime) were more dynamic than those in Broken Creek; and

- counter-intuitive results obtained for amphibious taxa (lower occurrence and cover with increasing inundation) in the 2012/13 short-term monitoring program (Stewardson *et al.* 2013) were caused by the extreme flow conditions experienced in 2008/09 (drought) and 2010/11 and 2012/13 (post-flood).

4.5 Results

Main results from the vegetation monitoring can be summarized as:

- Riparian vegetation in the Goulburn River responded positively to spring freshes in November 2013. New growth of native forbs (a class or herbaceous flowering plant) was clearly visible on low-lying benches that had been inundated by the freshes.
- We can make quantitative predictions of the effects of inundation by environmental flows. Environmental flows reduce the establishment of terrestrial species on river banks, but promote the establishment and growth of inundation-adapted species.
- Specifically, we predict major differences in vegetation cover for areas low down on the river bank – areas that experience significantly more inundation when environmental flows are delivered.
- However, the effects of environmental flows appear complex, with beneficial effects of increases in inundation duration partly offset by number of inundation events. This leads to some counter-intuitive predictions regarding inundation-dependent species.
- Collectively, these results lead us to the conclusion that following the drought (2008/09 data) and floods (2010/11 data), vegetation is in the process of re-establishing on the banks of the Goulburn River (2012/13, 2013/14 data). We believe that environmental watering has facilitated this re-establishment and will continue to do so in future.
- Assemblages on the Broken Creek show a very strong zonation of vegetation types, caused by the invariant flow regime. This type of zonation is indicative of what we might observe in the Goulburn River if the variability of flows provided by environmental watering did not occur.

4.5.1 Anecdotal observations

The Goulburn River sites were surveyed approximately 2 months after the first spring fresh (see Section 1.2.1.2). At that survey, we observed substantial new growth (identifiable from the size and colour of leaves) of several native forbs (Figure 4-4). This growth was particularly apparent in gently sloping areas of the banks, including the low-elevation benches surveyed in Chapter 2, and would have provided high-quality habitat for larval fish and microinvertebrates (see also vegetative growth in Figure 2-8.b). Although there were no data before the fresh to compare against, the new growth in areas inundated by the fresh, along with the lack of corresponding growth in areas higher up the bank, lead us to conclude that this was a positive response to environmental watering.

Figure 4-4. New growth of Purple Spotted Loosestrife following the spring freshes. Right panel shows a close-up of the new growth (rear of image), with the left showing a large patch of new growth.

4.5.2 Effect of quadrat elevation

Full details of statistical results are provided in Appendix C. Here we provide verbal and tabular summaries of those results, and pick out highlights particularly relevant to environmental flow management.

Terrestrial Dry species were more likely to occur with increasing elevation in the channel for both rivers and both years (Table 4-4). These results are in keeping with expectations concerning this functional group (Table 4-2), reflecting their sensitivity to inundation. Of interest are the differential probabilities of occurrence between the two rivers. Tdr species were only slightly less likely to be found right at the water's edge in Broken Creek, but rare in this area in the Goulburn River (Figure 4-5).

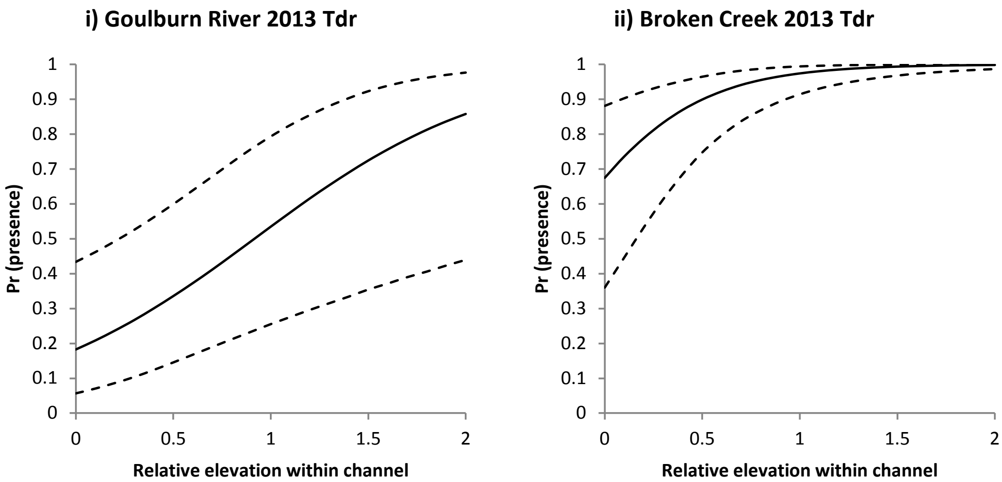

Figure 4-5. Probability of occurrence of Terrestrial Dry species in the Goulburn River (i) and Broken Creek (ii) in 2013/14. X-axis is relative elevation within the river channel (1 = break of slope), Y-axis is the estimated probability of occurrence. Solid line is the median probability of occurrence, with the dotted lines encompassing the 95% credible interval of the estimate.

This reflects the predicted effects of the varying water height in the Goulburn River. Cover of Tdr species followed the same patterns for Broken Creek (i.e. greater cover with increasing elevation), but high uncertainty in predictions meant that there were no strong patterns in the Goulburn River (Table 4-4).

Terrestrial Damp species showed different patterns among the two rivers, with slightly increased probability of occurrence at greater elevations in the Goulburn River, but reduced probabilities in Broken Creek (Table 4-4). These differences again reflect the difference in the flow environment between the two systems, with Tda species taking advantage of the moist conditions near the water's edge in the Broken Creek, but being negatively affected by prolonged inundation in the Goulburn River. Patterns of cover for Tda species were difficult to interpret, with changes from 2012/13 (increase with elevation in the Goulburn, no pattern in the Broken) to 2013/14 (decreases with elevation, both rivers). The 2013/14 results are consistent with a positive growth response following the spring freshes (Goulburn) and some early winter flooding (Broken). In these cases, inundation would have wet the middle and higher parts of the bank, promoting Tda growth in these regions; but prolonged inundation lower on the bank would have reduced growth (sensu Table 4-2).

Amphibious Fluctuation Tolerator – Emergent species showed strong zonation in Broken Creek in both years, being both more prevalent and more abundant near the water's edge (Table 4-4). This pattern is consistent with the lack of variation in water level in that system, and consequently these species being largely restricted to areas near the water's edge. In 2012/13, we noted an unexpected increase in occurrence and cover with increasing elevation in the Goulburn River (Stewardson *et al.* 2013), a result we attributed to the effects of floods stripping out aquatic vegetation from the banks of the Goulburn. This pattern was not seen in 2013/14, but instead of there being the expected negative relationship (i.e. occurrence and cover greater at lower elevations on the bank), there was no strong pattern with elevation. We believe this result reflects the gradual regrowth of Ate species on the lower banks of the river, coupled with survival of existing vegetation higher up on the banks. In future years, we expect the pattern to return to the predicted negative relationship.

Table 4-4. Summary results for Hypotheses 1 and 2: Survival and Growth. H1 results summarise the analyses of probability of occurrence, and H2 the analyses of cover. Abbreviations: Tdr – Terrestrial Dry, Tda – Terrestrial Damp, Ate – Amphibious Fluctuation Tolerator – Emergent, Atl – Amphibious Fluctuation Tolerator – Low Growing, GR – Goulburn River, BC – Broken Creek. '+' indicates a positive relationship between elevation and either survival or growth, '-' represents a negative relationship, and '0' represents no strong relationship. Green cells are those results in line with our expectations (including weak 0 results). Red cells are results that do not agree with our expectations.

Hypothesis (*indicator*)	**Year**	**Tdr**		**Tda**		**Ate**		**Atl**	
		GR	**BC**	**GR**	**BC**	**GR**	**BC**	**GR**	**BC**
H1: Survival (*probability of occurrence*)	2012/13	+	+	+	-	+	-	0	-
	2013/14	+	+	+	-	0	-	0	-
H2: Growth (*cover*)	2012/13	0	+	+	0	+	-	+	-
	2013/14	0	+	-	-	0	-	0	-

Similarly, Amphibious Fluctuation Tolerator – Low Growing species showed extremely strong zonation (higher near the water's edge) in both occurrence and cover in Broken Creek in both years, consistent with those species' affinity for damp environments (Table 4-4). Atl species were almost entirely absent from the banks of the Goulburn River in 2012/13. In 2013/14, while rare, the occurrence of Atl species in the Goulburn followed (very slightly) the expected negative relationship with elevation (i.e. a greater probability of occurrence on the lower bank). Conversely, the cover of Atl species in the Goulburn increased slightly with elevation (greater cover on the higher regions of the bank) in 2013/14, a result we believe may be explained by there being greater cover of older plants higher on the bank, which were not scoured by the 2010 floods.

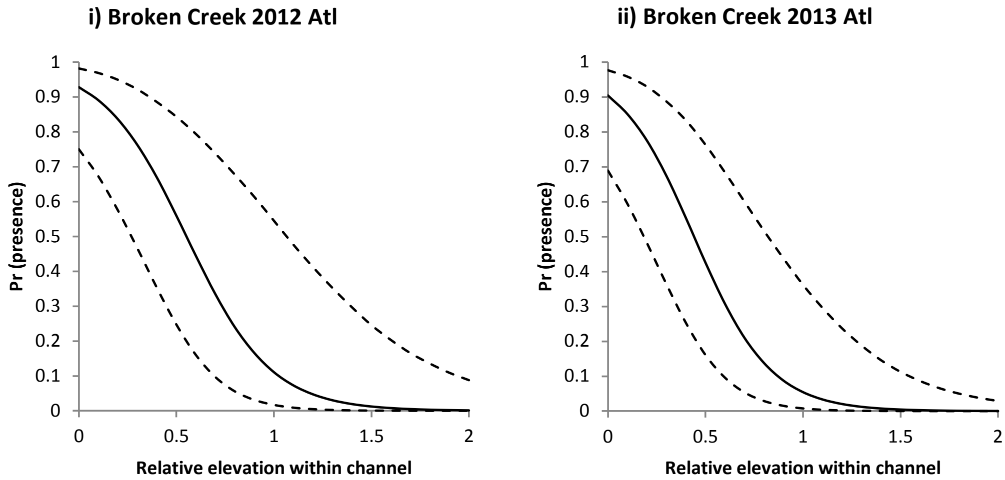

Figure 4-6. Strong zonation in the occurrence of Amphibious Fluctuation Tolerator – Low Growing species in Broken Creek. Interpretation of plots is as for Figure 4-5.

Finally, species richness exhibited a slight negative relationship with elevation in Broken Creek (i.e. more species lower on the bank), reflecting the more favourable environment close to the water's edge, but a positive relationship on the banks of the Goulburn River (Table 4-5). We do not believe this reflects a negative effect of environmental flows on biodiversity, because different species are differently adapted to different inundation regimes. In particular, the Terrestrial Dry functional group contains more species than any of the other functional groups (Appendix C), but these species are less likely to be found in the frequently inundated area low on the banks of the Goulburn River.

Table 4-5. Summary of results for Hypothesis 3 test of effects of elevation on species richness: Table structure and interpretation follows that of Table 4-4.

Hypothesis	**Year**	**Species Richness**	
(*Indicator*)		**GR**	**BC**
H3: Diversity	2012/13	+	-
(*species richness*)	2013/14	+	0

Overall, results were generally consistent between the two years of sampling, with differences in 2013/14 in line with the hypothesis that the Goulburn River is in the process of returning to a more 'normal' vegetation profile as it recovers from the drought and floods experienced between 2000 and 2012. This is reflected in a slightly reduced number of results that ran against our expectations, and the gradual emergence of zonation patterns for Ate and Atl species in the Goulburn River in line with expectations.

4.5.3 Effect of inundation regime

The non-monotonic nature of the function fitted during the analysis of effects of inundation, coupled with the logit, square-root, and log link functions used on the raw data (Appendix C) means that predicted occurrences, covers and richness responses can take quite complex shapes (e.g. Figure 4-7). The x-axis of the prediction plots depicts variation in the duration of a single inundation event during winter-spring. We chose winter-spring because this is when the major managed flow events (spring freshes) are delivered. This oversimplifies things compared to actual changes in flow regimes with environmental flows (see Section 1.2.1.2), but this simplification is necessary so that plots can depict the effect of varying one parameter (inundation duration) on vegetation responses. Beyond this, the directional summaries provided in tables below only tell part of the full story. Interested readers are advised to consider the full results in Appendix C.

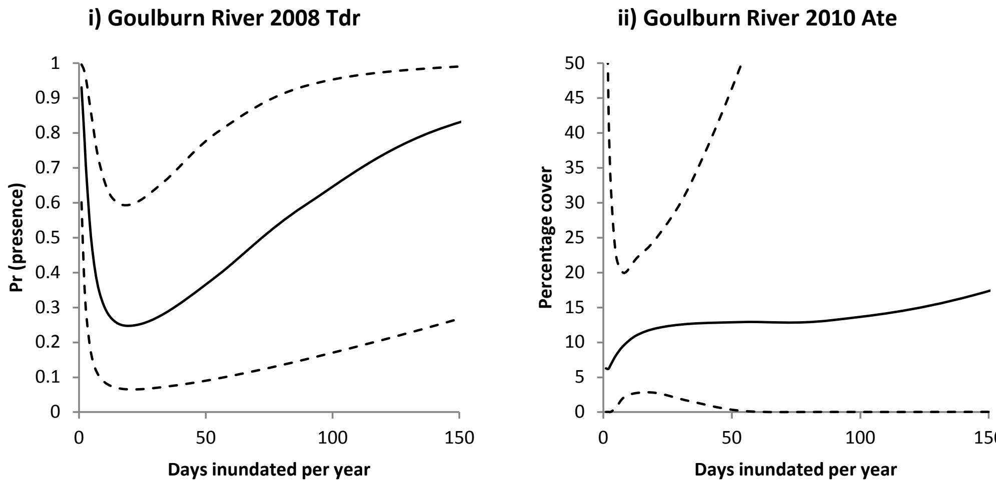

Figure 4-7. Inundation analyses are able to result in oddly-shaped prediction curves. These two examples (one for probability of occurrence (i) and one for percentage cover (ii) show the types of curves possible from the combination of the non-monotonic skewed quadratic function used in the analysis, coupled with the various transformations applied to the raw data.

We deliberately considered data from the four years separately, so as not to have patterns in 2013/14 overwhelmed by patterns from the earlier atypical years. This inevitably increases uncertainty of the fitted relationship, but we thought this was preferable to the alternative. In the descriptions below, we concentrate mostly on the results from 2013/14 analyses.

The occurrence of Terrestrial Dry species exhibits a complex response to inundation, dropping rapidly with small increases in inundation duration, but then rising again (Table 4-6). The result from 2010 was more in keeping with our expectations – a continuous decline in occurrence with increasing duration of inundation. Effects of inundation on cover in 2013/14 also showed this expected pattern, despite the result for occurrence.

Terrestrial damp species are expected to respond favourably to short periods of inundation, with negative effects occurring after longer periods. However, the 2013/14 results display reduced probability of occurrence almost from 1 days inundation. The pattern for cover is closer to expectation, but is classified as 'unexpected' in Table 4-6, as the curve does not reach a peak within 150 days, continuing to rise.

Table 4-6. Effects of inundation - summary results for Hypotheses 1 and 2: Survival and Growth. H1 results summarise the analyses of probability of occurrence, and H2 the analyses of cover. Summaries are for the 2013/14 results only, with full results provided in Appendix C. Abbreviations: Tdr – Terrestrial Dry, Tda – Terrestrial Damp, Ate – Amphibious Fluctuation Tolerator – Emergent, Atl – Amphibious Fluctuation Tolerator – Low Growing, GR – Goulburn River, BC – Broken Creek. '+' indicates a positive relationship between inundation and either survival or growth, '-' represents a negative relationship, and '0' represents no strong relationship. Combinations of these symbols represent predictions with complex curves. Green cells are those results in line with our expectations (including weak 0 results). Red cells are results that do not agree with our expectations.

Year	Tdr		Tda		Ate		Atl		Richness
	H1	H2	H1	H2	H1	H2	H1	H2	H3
2008/09	-+	-+	0	0	+	0	0	0	0
2010/11	-	+0	0	+-	-	+	0	0	-
2012/13	+0	+0	0	+0	+-	+-	0	+-	+-
2013/14	-+	+-	-	+	+	+0	+	0	-

Amphibious Fluctuation Tolerator – Emergent species displayed positive responses to increasing duration of inundation in all years but 2010/11, but only in 2012/13 was there a peak followed by a gradual reduction following excessive inundation. Changes in cover with inundation followed the same pattern in 2012/13, and the general increase observed in 2013/14 is also in line with predictions.

As noted above, Amphibious Fluctuation Tolerator – Low Growing species have been virtually absent in the Goulburn River, and are only now beginning to re-establish following the drought and floods. In 2013/14 probability of occurrence increased with increasing duration of inundation, and in 2012/13 proportional cover exhibited a peak at intermediate durations of flooding. We are reluctant to interpret results from earlier than this.

Species richness could reasonably be expected to respond according to the principles of the intermediate disturbance hypothesis (Connell & Slatyer 1977), with peak richness being seen at intermediate durations of inundation. This pattern was seen in 2012/13, but negative effects (i.e. reduced species richness with increasing duration of inundation) were seen in 2010/11 and 2013/14. As mentioned above, interpretation of richness results is complicated by the differential inundation tolerances of different species, and by the fact that many of the species observed in our monitoring program are Terrestrial Dry species expected to be negatively affected by any increase in inundation.

4.5.4 Benefits of environmental flows

We used the fitted Bayesian model from Section 4.5.3 to predict changes in vegetation for quadrats that would experience a different inundation regime in the absence of the environmental flows experienced in the Goulburn River in 2013/14. Such quadrats are those found low on the river bank. We were able to calculate inundation regimes with and without environmental flows for 63 quadrats at McCoy's Bridge and Darcy Track, and use these to estimate differences in the occurrence and cover of each functional group, and differences in species richness.

Several analyses produced results exactly as expected. For example, the models predicted that environmental flows would reduce the probability of occurrence of Terrestrial Dry species for nearly all the quadrats (Figure 4-8). Similarly, predicted cover of Amphibious Fluctuation Tolerator – Low Growing species increased with environmental flows for all but a very small number of quadrats (Figure 4-9).

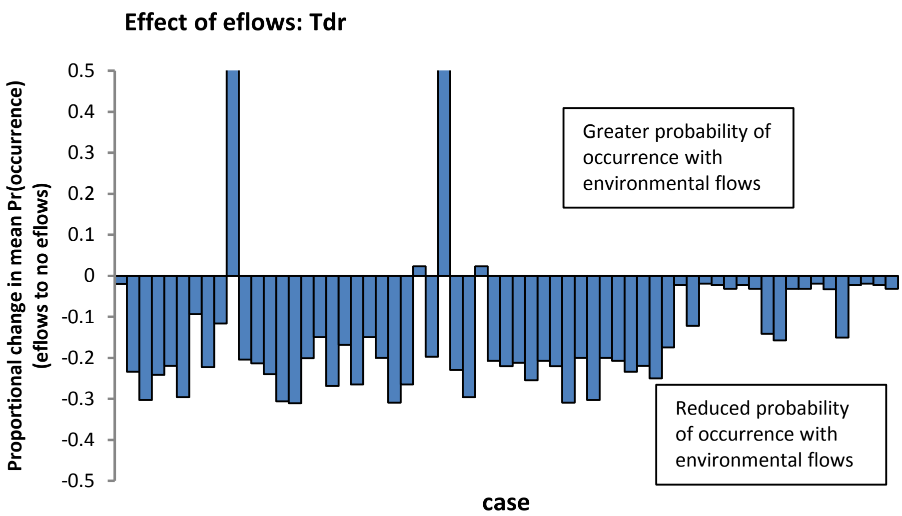

Figure 4-8. Effect of environmental flows upon occurrence of Terrestrial Dry species. Bars show proportional change in the mean probability of occurrence under eflows relative to a no-eflows scenario ([probability with eflows – probability without eflows] / probability without eflows). Here, environmental flows appear to reduce the probability of occurrence of Terrestrial Dry species, as expected.

However, there were also counter instances, with some analyses showing patterns opposite to those expected. For example, the analyses predicted a near-universal reduction in the cover of Amphibious Fluctuation Tolerator – Emergent species under environmental flows (Figure 4-10), despite the occurrence of a positive relationship between cover and inundation duration for this group. In fact, across the 9 analyses undertaken, only just over half predicted ecological responses to the 2013/14 environmental flows in the Goulburn river that were consistent with our expectations based upon their functional group and the initial conceptual model of species responses to inundation (Table 4-7).

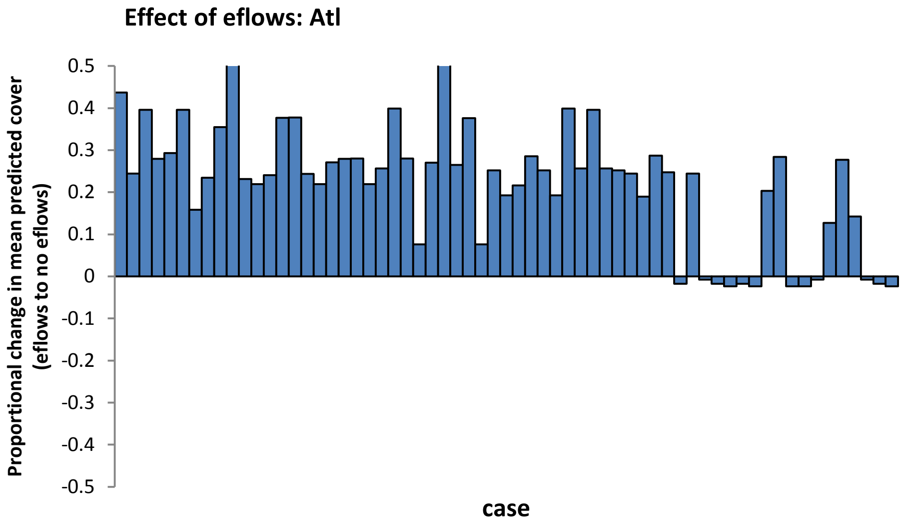

Figure 4-9. Effect of environmental flows upon cover of Amphibious Fluctuation Tolerator – Low Growing species. Bars show proportional change in predicted cover under eflows relative to a no-eflows scenario ([cover with eflows – cover without eflows] / cover without eflows).

This is a marked improvement upon the universally-negative responses to environmental flows that were modelled for the 2012/13 year (Stewardson *et al.* 2013). We believe this achievement occurred through improved data with some taxa re-establishing on the lower banks following the flood and drought years, and through more comprehensive statistical models that take into account the full representation of inundation regime (duration, frequency and timing). Nevertheless, the counter-intuitive behavior of some of the models needs to be explored.

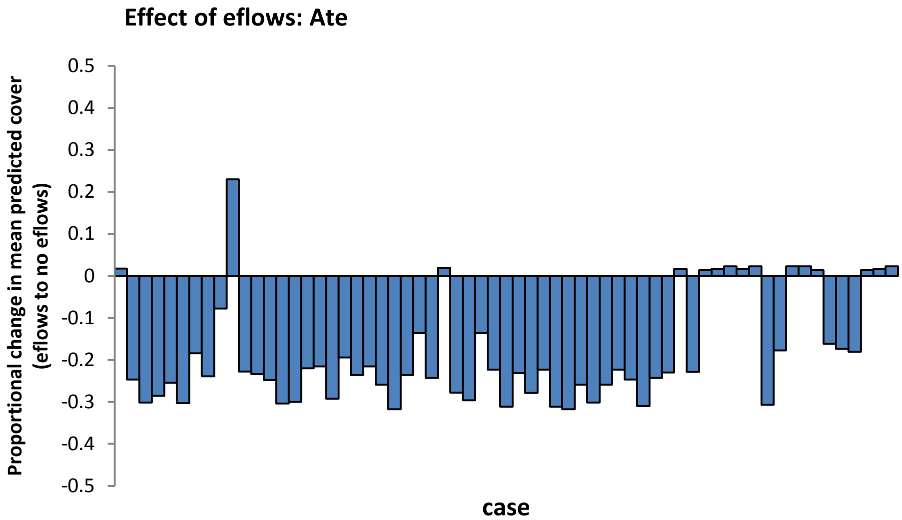

Figure 4-10. Effect of environmental flows upon cover of Amphibious Fluctuation Tolerator – Emergent species. Bars show proportional change in cover under eflows relative to a no-eflows scenario (as defined above). Responses to environmental flows for this example are in the opposite direction to our initial expectations.

Table 4-7. Summary of ecological responses to modelled environmental flows in the Goulburn River in 2013/14. Abbreviations are as for Table 4-4. Ticks represent overall responses in line with our expectations; crosses represent responses against our initial expectations, and occasionally in seeming conflict with the plots of ecological response to increasing duration of inundation (e.g. Figure 4-7).

	Tdr		Tda		Ate		Atl		Richness
	H1	H2	H1	H2	H1	H2	H1	H2	H3
Expectation met?	✓	✗	✓	✓	✗	✗	✗	✓	✓

Figure 4-11 below illustrates the counter-intuitive model behavior identified for some analyses. Panel (i) predicts that occurrence of Amphibious Fluctuation Tolerator – Emergent species will increase with increased duration of inundation. However plot (ii) indicates a reduction in occurrence for most of the 63 quadrats when environmental flows are included in the hydrograph compared to when they are removed. Environmental flows universally increased the duration of inundation for all of these quadrats, so how can the two results be explained?

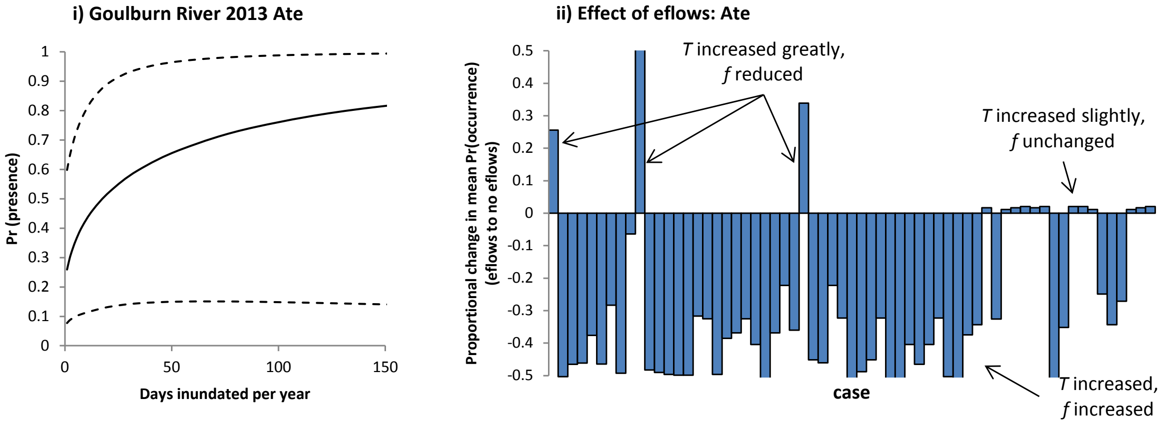

Figure 4-11. Counter-intuitive model behavior when exploring the effects of environmental flows.

The answer lies in the fact that the curve in Figure 4-11.i is a prediction of change in probability of occurrence with an increase in the duration of a single inundation event occurring in winter-spring (See Section 4.5.3). However, for the modelled quadrats in panel (ii), the inclusion of environmental flows in the hydrograph not only causes the duration of inundation to increase, but there are also changes in the number of distinct inundation events (usually an increase), and also in the timing of inundation. Both of these effects are also included in the statistical model of inundation effects. In particular, number of inundation events (f) is used to downweight the effect of total duration of inundation (T) via the variable ϕ that takes a value between 0 and 1 and is fitted during the analysis.

Equation 4-1

$$Inund = T \cdot e^{-f \cdot \phi}$$

This effect is included in the statistical model because multiple inundation events can be expected to have different effects on vegetation compared to a single inundation event of the same total duration. For example, with Terrestrial Dry species, a single long inundation event may be enough to kill plants low on the river bank. If the same total duration is broken into several events, then the plants may be able to recover sufficiently between inundation events to survive. Here, if the fitting of the statistical model results in ϕ taking a value near 1, then the combined effect of inundation duration and number of events – *Inund* – is reduced relative to total duration of inundation as number of inundation events increases. In particular, if environmental flows increase the number of inundation events as well as total duration, then *Inund* may be lower for the environmental flows scenario. Table 14-1 in Appendix C demonstrates that the environmental flows generally increased both *T* and *f* for quadrats, with only a small number of quadrats experiencing a reduction in inundation events, usually coupled with a large increase in inundation duration. For this particular analysis, the fitted value of f was large (0.496 median, 0.054-0.817 95% CI), and so the number of inundation events has a large effect. Therefore, it is not surprising to observe an almost linear relationship between Δf (the change in number of inundation events caused by eflows) and the effect of eflows on probability of occurrence (Figure 4-12).

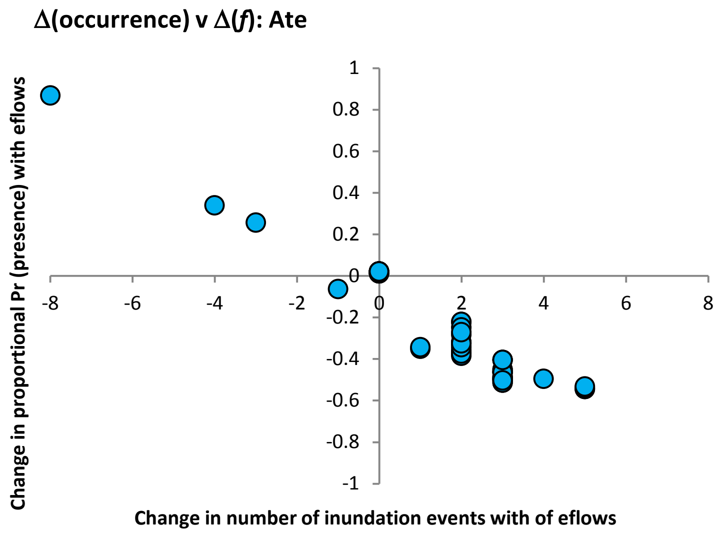

Figure 4-12. Effects of eflows as a function of change in number of inundation events. For analyses with large fitted values of the ϕ parameter, there is a strong relationship.

This is driving the counter-intuitive pattern observed in Figure 4-11.ii, and allows us to identify that the three quadrats with large positive effects of inundation are those for which *f* was decreased, the cluster of quadrats with small positive effects are those for which *f* did not change, and the large group of quadrats with seeming negative effects of environmental flows are those for which *f* was increased by those flows (labels on Figure 4-11.ii).

This result demonstrates that ecological responses to inundation regimes can be complex, and that by modelling the effect of duration of inundation only, we may be over-simplifying the predictions. There remains the possibility that the statistical model is over-stating the importance of the number of inundation events, a possibility we explore in the discussion below, but it is clear that all aspects of the flow regime need to be considered when predicting the effects of environmental flows on bankside vegetation.

4.6 Discussion

4.6.1 Summary of results in terms of Basin Plan objectives

It is difficult to summarize the complex set of results in terms of the broad Basin Plan objectives detailed in Section 4.2, but a basic summary is presented in Table 4-8. From this, it is clear that the simple elevation-based analyses carried out in the Goulburn River and Broken Creek provided the strongest support in line with our expectations. For most of these analyses, plant functional groups and diversity responded as we would have expected given the changes in inundation regime with elevation in the channel, and the different inundation environments of the two rivers.

The inundation-based analyses, while more closely related to the effects of environmental watering, were more complex. The statistical models were a more accurate physical representation of the processes that drive vegetation on the banks of the Goulburn River, but this complexity introduces extra uncertainty into the results. Hence, these models gave mixed results, and generally did not support the expectations of basin plan objectives as well as the simpler models.

The predictions of marginal effects of eflows were based directly upon the inundation models. As outlined above, several results from these models appeared counter-intuitive in terms of initial expectations and the inundation model results. However, these results could be reconciled when the full description of inundation regime (duration, frequency and timing) was taken into account.

Table 4-8. Summary of all results in terms of the Basin Plan objectives. Ticks represent results in line with our expectations; crosses represent results against expectations. Numbers in cells are the number of analyses of that type that agreed and disagreed with expectations. Green cells are those for which the majority of results were in line with expectations; red cells are majority against expectations, and yellow cells are evenly balanced.

Results Section	Elevation	Inundation	Effects of eflows
H1: Survival	13✓, 3✗	3✓, 13✗	2✓, 2✗
H2: Growth	13✓, 3✗	8✓, 8✗	2✓, 2✗
H3: Diversity	4✓	1✓, 3✗	✓

Overall, we believe the results provide multiple lines of evidence supporting expectations of environmental watering benefits for survival and growth of four functional groups of bankside vegetation, and for the diversity of all plant species.

The results have improved our understanding relative to those obtained during the 2012/13 short-term intervention monitoring project. In particular, we have seen more vegetation responses in accordance with functional group-based expectations than was the case in the earlier study. These responses reflect a return towards more typical vegetation dynamics on the banks of the Goulburn River following the drought and subsequent floods.

However, the diversity of analysis outcomes detailed in Table 4-8 means that we do not consider these as strong or definitive results. While the analysis outcomes provide a good indication of the benefits of environmental flows for flood-tolerant vegetation on the banks of the Goulburn River, they are not able to make strong predictions regarding the benefits of restored flow regimes. Below, we explore reasons for this below, and consider changes that may improve our ability to predict responses from vegetation monitoring in the future.

4.6.2 Potential improvements to monitoring

CEWO short-term intervention monitoring in the Goulburn River has leveraged directly off monitoring conducted through the Victorian Environmental Flows Monitoring and Assessment Program (Webb *et al.* 2014b). That program employed quadrat-based measurements of cover and diversity of individual species, and so those methods were repeated for CEWO monitoring, enabling us to directly employ data collected under VEFMAP. As we move into the long-term intervention monitoring program, we will use the new method of point-based transect intersects (Webb *et al.* 2014a). This method has recently been shown to provide superior estimates of vegetation abundance compared to quadrats (Godinez-Alvarez *et al.* 2009). It also frees us of the need to employ Braun-Blanquet cover classes in assessing abundance, with the inaccuracy introduced by this method.

The LTIMP will employ the same vegetation sampling transects at Loch Garry and McCoy's Bridge used in VEFMAP and the short-term intervention monitoring program. Concurrent monitoring planned for late spring 2014 using both quadrat and point-based methods will provide a 'rating curve' allowing us to continue to employ the historic data set generated by VEFMAP and the short-term intervention monitoring program when analyzing the results in LTIMP.

Lack of congruence between vegetation transects and channel cross-section survey transects, which led to difficulty in ascribing elevations to vegetation quadrats was an issue for VEFMAP data (Miller *et al.* 2014). Although the Goulburn River surveys were better quality than those on some other rivers, it has recently been confirmed that vegetation data were not collected directly on the channel survey transects (Meegan Judd, Goulburn Broken Catchment Management Authority, pers. comm.), and this would have led to at least some inaccuracies in the data. For the LTIMP, elevations along vegetation transects will be directly measured using RTK-GPS technology, which is accurate to within ±1 cm. We will also develop new 2-dimensional hydraulic models for the Loch Garry and McCoy's Bridge sites (Webb *et al.* 2014a). Collectively, these improvements to monitoring will mean that we can be much more confident about the inundation regime experienced at vegetation sampling points, and also have greater confidence in the modelled 'no eflows' scenarios.

4.6.3 Potential improvements to statistical models

The models used this year for the short-term intervention monitoring program, particularly those used to analyze the effects of inundation history, were a substantial improvement over those developed for the 2012/13 program. We were able to build upon that earlier experience to produce statistical analyses that more accurately represented the physical and biological components that govern vegetation response to inundation. These models will be carried forward into the LTIMP, and we can identify several areas where further changes to the analysis structure may improve our ability to predict the ecological benefits of environmental flows.

Include sampling year as a hierarchical variable: In 2012/13 we deliberately modelled effects of inundation separately for the four years of sampling data. This was done so that the earlier data collected under atypical hydrological conditions would not overwhelm relationships observed in 2013/14. However, this introduced a large amount of extra uncertainty into the analyses, and may be partly responsible for some of the counter-intuitive results produced from the inundation model (Table 4-8). An alternate approach is to use sampling year as a hierarchical grouping variable (Gelman & Hill 2007), such that while model parameter values are allowed to vary between years, they are expected to be drawn from a common distribution of parameter values. This would have the practical effect of drawing the relationships from different years closer together, and reducing unexplained variation in predictions (Webb, Stewardson & Koster 2010). Currently, with only four years of data available, a hierarchical model may do a poor job of accurately modelling between year variation (Gelman 2006). However, with more years of data to be collected under the LTIMP, this becomes a viable option.

Include bank slope and aspect as co-variates: Vegetation response to inundation will be partly governed by the physical environment in which a plant is found. Steep banks do not retain the freshly deposited sediments that promote plant growth, nor do they capture seeds dispersed downstream. This effect was demonstrated in the anecdotal observations of good growth of native forbs along near-horizontal low-level benches that were inundated by the spring freshes. These areas would have captured fresh, nutrient-rich sediments mobilized by the flow events, and also been a collecting point for dispersed seeds. Information on bank slope can be generated from the channel surveys that will be done to develop the 2-dimensional hydraulic model, and may improve our ability to predict which areas will and will not develop healthy vegetation assemblages in response to environmental flows. Similarly, but likely to be less important in an open system such as the Goulburn River, the amount of sunlight that falls upon a bank may affect vegetation growth and survival. Banks that face north will receive more light, which may promote growth; but will also be hotter during summer, which may reduce survival. The potential effects of bank aspect are thus both positive and negative, but could be assessed by including this information in the analysis.

Consider new ways of including number of inundation events in models: The initially counter-intuitive results that emerged from the analysis of marginal effects of environmental flows demonstrated the importance of the number of inundation events upon vegetation endpoints, as well as the duration of inundation. However, we were initially skeptical (and retain some suspicion) that the effect of number of inundation events was being over-estimated for some models. In Equation 4-1, there is little effect of number of inundation events if the weighting parameter ϕ has a fitted value near 0, and this was seen for some analyses. However, with higher values of ϕ, then number of inundation events takes on increasing importance, as evidenced by Figure 4-12. We could have forced the models to behave in a more intuitive manner by ignoring the number of inundation events in model fitting and prediction. Had we done so, the results for the analysis of effects of environmental flows would have been much easier to interpret. However, the fact that the data used to fit the models are telling us that frequency of inundation is important for some endpoints shows that we were correct to retain this variable, even if it complicated the interpretation of model predictions. That being said, as part of the LTIMP, we will investigate ways of including this variable in the model that may reduce its impact upon model predictions and more closely emulate how multiple inundation events affect plant growth, survival and diversity. Possible options include: allowing ϕ to take negative values, such that multiple inundation events actually improves vegetative responses relative to single events (if a functional group responds better to multiple short-term inundation events than to one long-term event); and taking the log of the number of inundation events, so that the change from 1 event to 2 or 3 has a much greater proportional impact upon plant responses than would moving from 10 to 11 or 12.

4.7 Conclusion

Overall, short-term intervention monitoring of vegetation responses in the Goulburn River and Broken Creek in 2013/14 improved our understanding of vegetation responses to environmental flows relative to work undertaken in 2012/13. We are able to draw specific conclusions with regards to the fulfilment of Basin Plan objectives, and it appears that vegetation in the lower Goulburn River is responding positively to environmental flows as the system continues to recover from years of drought followed by two floods. The lessons learned during this short-term monitoring program will be taken forward to improve our monitoring and analysis of data as part of the Lower Goulburn long-term intervention monitoring project, which has recently commenced.

5 Spawning, recruitment and movement of golden perch

Altered flow regimes are a major reason for significant declines in native fish abundance in Australia's Murray-Darling Basin over the past 50–100 years. Environmental flows delivered under the Basin Plan aim to restore native fish populations.

In spring-summer 2013/14, approximately 190 GL of environmental water was allocated to the lower Goulburn River. One of the main targets of the environmental water allocation was golden perch (*Macquaria ambigua*). Spring-summer freshes are expected to trigger spawning and movement, particularly for golden perch, and subsequent recruitment and increased abundance.

Within the Basin Plan hierarchy of objectives, fish are a level 3 objective, with short-term expected outcomes of watering actions including reproduction and movement (Gawne *et al.*, 2013).

We monitored spawning, recruitment and movement responses of golden perch to flows in the lower Goulburn River between Goulburn Weir and the Murray River junction.

Key findings

- Golden perch spawned in association with environmental flow releases (spring fresh) in November 2013 in the lower Goulburn River. We believe that spawning would not have occurred without the allocation of environmental water.
- Whilst increased flows in spring-summer 2013 promoted golden perch spawning, it appears that they did not lead to localised recruitment of 0+ fish in the lower Goulburn River.
- The fate of eggs and early life stage golden perch spawned in the Goulburn River is unclear, although it is possible that early life stage golden perch may have drifted downstream into Murray River.
- Long-distance (> 20 km) movement of adult golden perch was associated with increased flows (~6500-12000 ML/d), including environmental flows, in the lower Goulburn River. The timing of the movements coincided with the appearance of golden perch eggs in the lower reaches, which suggests that reproductive behaviour could be a driver of the movements.

5.1 Introduction

Fish are significant indicators of the impacts of changes to flow regimes on riverine ecosystems and in Australia's Murray-Darling Basin (MDB) altered flow regimes have led to major reductions in native fish populations. In spring-summer 2013/14, approximately 190 GL of environmental water was allocated to the lower Goulburn River. One of the main targets of the environmental water allocation was golden perch (*Macquaria ambigua*). In particular, spring-summer freshes were delivered that aim to facilitate spawning, recruitment and movement of golden perch in the lower Goulburn River (Peter Cottingham & Associates and SKM 2011).

The aims of the current study were to determine:

- Whether golden perch spawn in association with environmental flow releases in spring-summer 2013/14 in the lower Goulburn River
- Whether there is successful recruitment of golden perch following environmental flow releases in spring-summer 2013/14 in the lower Goulburn River
- Whether movement of golden perch is associated with increased flows in the lower Goulburn River

The spawning and recruitment responses of golden perch to flows have been monitored annually in the lower Goulburn River since 2003/04 as part of a larger project funded by the Victorian Recreational Fishing Grants program (2003-05) and the Goulburn Broken Catchment Management Authority (GBCMA) (2006-2012) (Koster *et al.* 2012). Between 2010 and 2013, GBCMA also provided funding for a project to investigate the movements of golden perch in the lower Goulburn River. In 2013/14, funding to continue the assessment of spawning, recruitment and movement of golden perch was provided by the Commonwealth Environmental Water Office and GBCMA. This report documents the findings from 2013/14 as well as integrating the earlier data.

5.2 Basin Plan objectives, cause-effect diagrams, and how they relate to fish monitoring

Native fish populations are a key element of the Basin Plan's goal to protect Biodiversity (Level 1 objective) (Table 5-1) (Gawne *et al.* 2013).

Table 5-1. Expected outcomes of environmental watering for fish as defined by the Basin Plan objectives hierarchy (modified from Gawne *et al.* 2013).

Level 1 Objectives	Level 2 Objectives	Level 3 Objectives	Expected outcome of watering actions (1-5 years)	Expected outcome of watering actions (< 1 year)	Relevant Cause and Effect Diagram
Biodiversity	Ecosystem diversity	Fish	• Abundance • Fish diversity	• Reproduction (egg/larval abundance)	Fish Reproduction
Ecosystem Function	Connectivity	Population Resilience	• Distribution	• Biotic dispersal	Biotic dispersal

Reproduction in particular has been identified as critical to supporting native fish populations, and is a key expected outcome for environmental water (Gawne *et al.* 2013). Biotic dispersal or movement is another key element of the Basin Plan's goals, to protect Ecosystem Function (Level 1 objective) (Table 5-1). Movement within and between water-dependent ecosystems is critical to supporting connectivity of native fish populations and is also a key expected outcome for environmental water (Gawne *et al.* 2013). In the case of the Goulburn River, spring-summer freshes are expected to trigger spawning and movement, particularly for golden perch, and subsequent recruitment and increased abundance. The monitoring described in this report is able to assess the 1-5 year predicted outcomes of Reproduction and Biotic Dispersal.

The expected effects of spring-summer freshes on fish reproduction and biotic dispersal are shown below. We focused our monitoring on relating fish spawning and movement to the frequency, duration and timing of spring-summer freshes (Figure 5-1, Figure 5-2).

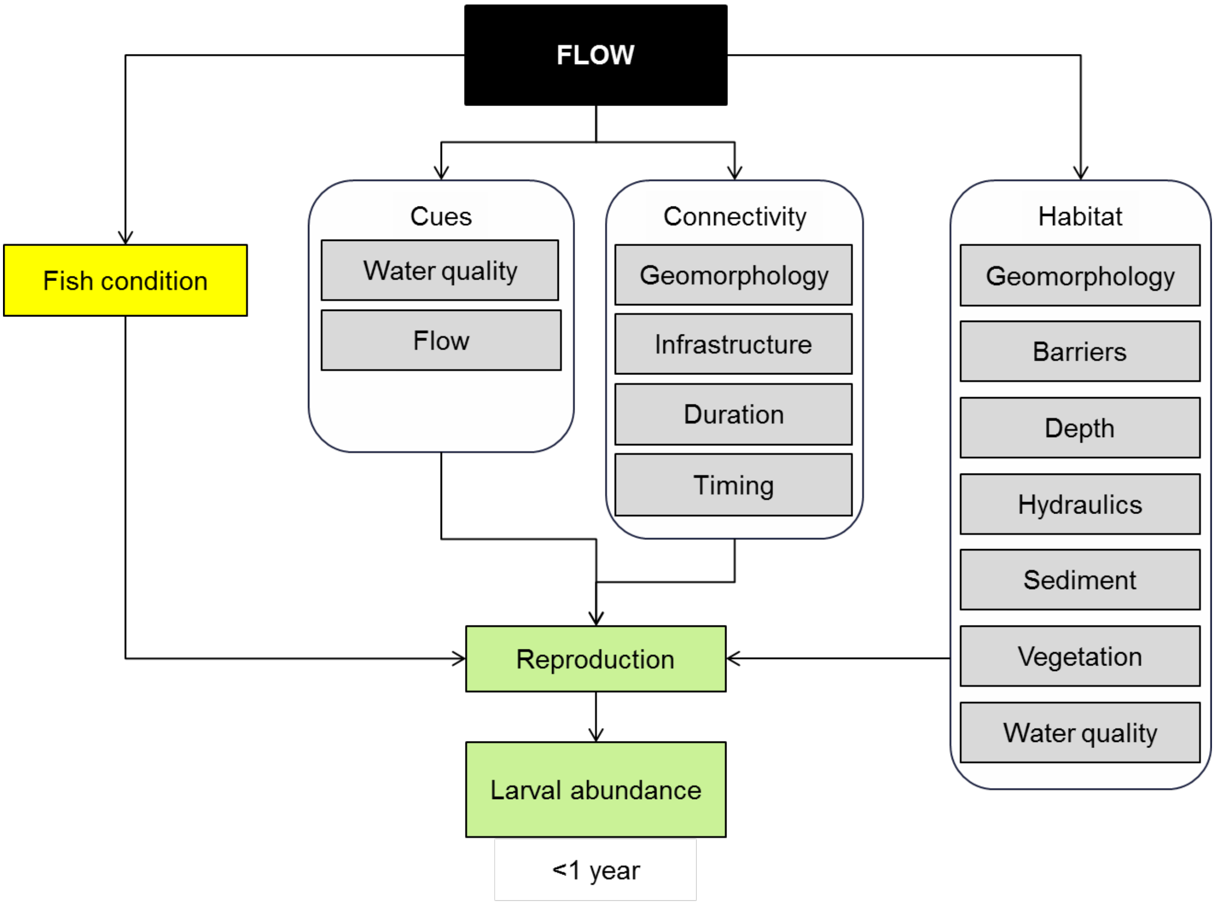

Figure 5-1. Generic cause-effect diagram (CED) for Fish Reproduction (reproduced from MDFRC 2013).

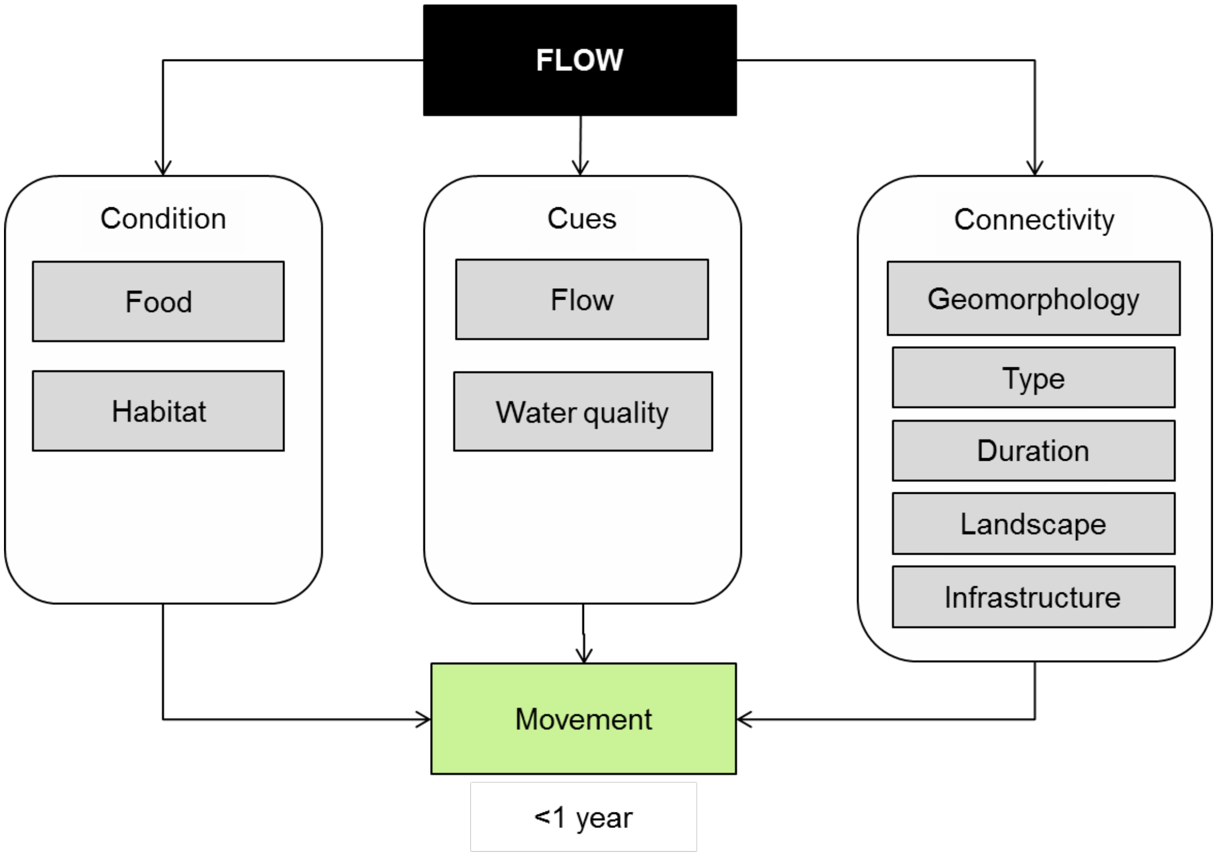

Figure 5-2. Generic cause-effect diagram (CED) for Biotic dispersal (reproduced from MDFRC 2013).

5.3 Methods

5.3.1 Study sites and field methods

5.3.1.1 Spawning

Fish eggs and larvae were collected at three sites in the lower Goulburn River using 2 drift nets set at each site in 2013 (Table 5-2, Figure 1-5). Sampling was conducted every 2 weeks from October – December, with additional sampling conducted twice per week coinciding environmental flow releases. The nets were set in late afternoon (1600–2000 hours) and retrieved the following morning (0800–1100 hours). Full details of methods can be found in (Stewardson *et al.* 2013).

Table 5-2. Details of the drift sampling sites in the lower Goulburn River. See also Figure 1-5.

Site	Lat	Long
Murchison (Cable Hole)	-36.69	145.230
Pyke Road	-36.427	145.357
Yambuna	-36.131	145.003

5.3.1.2 Recruitment

Electrofishing sampling was conducted at 13 sites in the lower Goulburn River during March 2014 to investigate recruitment of golden perch (i.e. presence and abundance of young-of-year fish) (Table 5-3, Figure 1-5). Sampling was conducted at each site during daylight hours in all habitats within the river channel. At each site the total time during which electrical current was applied was about 1800 seconds. Golden perch collected were counted and measured for total length. The age of any potential young-of-year fish was determined from otolith growth increments.

Table 5-3. Details of the electrofishing sites in the lower Goulburn River. See also Figure 1-5.

Site	Lat	Long
Murchison (Cable Hole)	-36.69	145.230
Cemetery Bend	-36.516	145.322
Pyke Road	-36.427	145.357
Mooroopna	-36.392	145.369
Shepparton	-36.381	145.394
Shepparton Weir	-36.354	145.353
Loch Garry	-36.242	145.287
Pogues Road Undera	-36.203	145.268
Kotupna	-36.164	145.222
McCoy's Bridge	-36.177	145.123
Murrumbidgee Road Pederick	-36.156	145.035
Yambuna	-36.131	145.003
Kanyapella	-36.095	144.925

5.3.1.3 Movement

Golden perch were collected from a range of sites in the lower Goulburn River between 40 and 200 km upstream of the Murray River junction using electrofishing. Fish were tagged with acoustic transmitters in September 2010 (n = 14), March 2011 (n = 17), and April 2012 (n = 15), making a total of 46 tagged fish.

Twelve acoustic listening stations were deployed in September 2010 in the lower Goulburn River between Goulburn Weir and the Murray River junction (a distance of approximately 250 km) (Figure 1-5). Each listening station was placed a minimum of approximately 20 km apart. Two listening stations were also deployed in the Murray River 0.1 km upstream and downstream of the Goulburn River junction. Data were downloaded from the listening stations every three months throughout the study.

5.3.2 Data analysis

Generalised additive mixed models (GAMMs) were used to examine the probabilities of fish moving. Data were blocked into 5-day time steps. For each time step, individuals were classified as 'moving' if they were recorded on a listening station other than the last known location during the time step. The direction of movement (upstream or downstream) was also recorded. Individuals were classed as 'not moving' if they were not recorded on a listening station different from their last known location. We examined four groups of models using the following combinations of binary response variables: 1) moving versus not moving; 2) downstream move versus upstream move or not moving; 3) upstream move versus downstream move or not moving; and 4) downstream move versus upstream move.

The potential explanatory variables examined were: 1) current mean flow; 2) current mean water temperature; 3) mean flow in previous time step; 4) mean water temperature in previous time step); 5) flow difference (mean flow t1 – t0); 6) water temperature difference (mean temperature t1 – t0); 7) fish length (mm); 8) time step; 9) day of the year; 10) moon phase; 11) spawning season (September-February); and 12) zone (upstream, middle, downstream) (Table 5-4). For each of the four response variables, we examined 6 models with different combinations of explanatory variables. Flow variables (i.e. flow and previous flow) were log-transformed to conform to the assumptions of the statistical model. The relative support for each of the models (model fit vs. number of explanatory variables used) was assessed by calculating the information-theoretic indices, Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC). More plausible models have lower AIC/BIC values.

Table 5-4. Explanatory variables included in the six models for each of the four groups of models.

	Current flow	Current water temperature	Previous flow	Previous water temperature	Flow difference	Water temperature difference	Fish length	Time step	Day of year	Moon phase	Spawning season	Zone
Model 1			*	*	*	*	*	*	*	*	*	*
Model 2	*	*			*	*	*	*	*	*	*	*
Model 3			*	*	*	*	*	*		*	*	*
Model 4	*	*			*	*	*	*		*	*	*
Model 5			*	*	*	*	*	*	*	*		*
Model 6	*	*			*	*	*	*	*	*		*

5.4 Results

5.4.1 Spawning

A total of 282 eggs and 4 larvae of golden perch were collected in the drift sampling in the lower Goulburn River (Figure 5-3). Eggs/larvae were collected from only the most downstream site (Yambuna), coinciding with the rising limb/peak of an environmental flow release in mid-November 2013 (Figure 5-4). Flow during this release increased from 958 to 7052 ML/d, with eggs/larvae collected at flows of around 4747 and 7052 ML/d. Water temperature around this time was around 19-20°C (Figure 5-4).

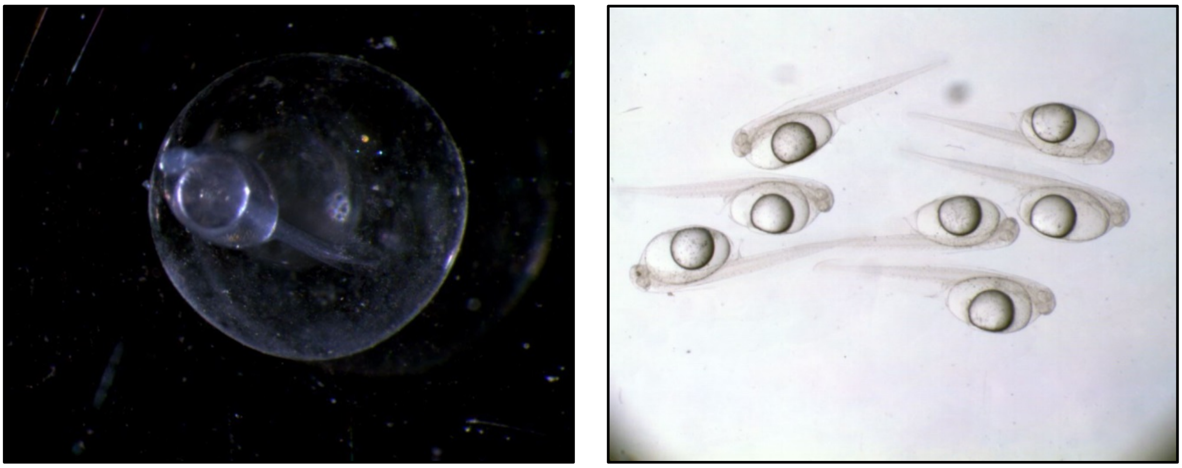

Figure 5-3. Golden perch egg (left panel) and larvae (right panel) collected in drift sampling in 2013.

No eggs or larvae were collected during the first environmental water release from late October to early November (maximum discharge ~ 3170 ML/d) or the third release from early December to late December (maximum discharge ~ 7411 ML/d). We explore potential reasons for this finding in the Discussion.

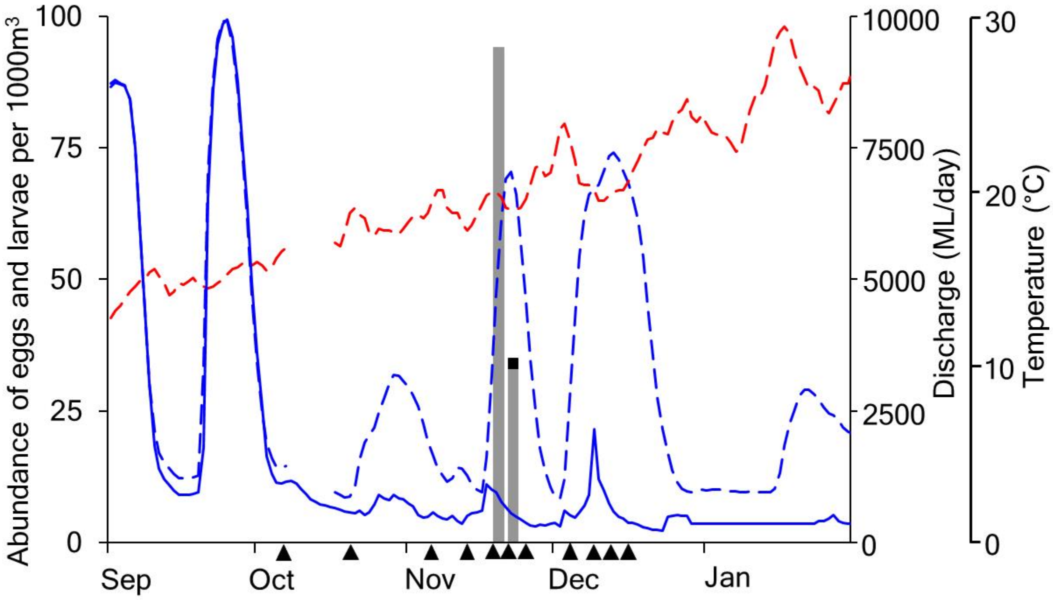

Figure 5-4. Adjusted total density of golden perch eggs (grey bar) and larvae (black bar) per 1000m^3 collected in drift nets in 2013 in the lower Goulburn River. Solid triangles on x-axis indicate sampling events. Red dashed line is instantaneous water temperature and blue line is daily mean discharge (dashed blue line denotes environmental water) in the Goulburn River at McCoy's Bridge.

5.4.2 Recruitment

A total of 50 golden perch were collected in the electrofishing surveys in the lower Goulburn River in 2014. The golden perch population in the lower Goulburn River was comprised of mostly large, older fish (Figure 5-5).

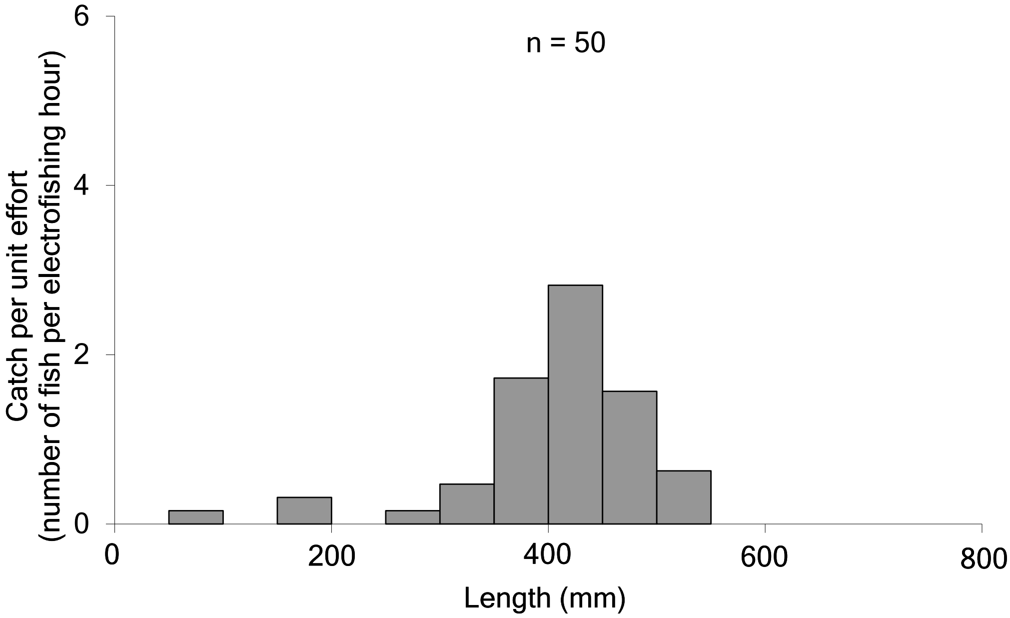

Figure 5-5. Length frequency of golden perch in the lower Goulburn River in 2014.

Several smaller fish (i.e. 98-200 mm total length) were collected, indicating some recruitment in recent years (Figure 5-6). However, the results of otolith ageing revealed that no young-of-year fish were collected, indicating thus far a lack of localised recruitment in the Goulburn River following the 2013 spawning event.

Figure 5-6. Small golden perch collected in electrofishing surveys in autumn 2014.

5.4.3 Movement

About half (21 out of 46) of the fish tagged in the Goulburn River were detected undertaking long-distance (i.e. > 20 km) movements (Figure 5-7). Long-distance movements were most common during spring and early summer (i.e. September–December), which coincides with the spawning season of golden perch. Most long-distance movements coincided with increases in flow, including environmental flow releases (e.g. from 1420 to 11069 ML/d in October 2010, from 1113 to 5202 ML/d in November 2011, from 1044 to 5316 ML/d in November 201 2, and from 1220 to 9913 ML/d in September 2013) (Figure 5-7).

Thirteen of the tagged fish undertook initial downstream movements over distances of 25–200 km. All of these fish travelled to at least the lower 130 km (i.e. Loch Garry) reach of the river, with ten fish travelling to at least the lower 85 km (i.e. Kotupna) of the river. Three of these fish also visited the Murray River. Most (9 of 13) fish that moved downstream returned upstream, usually within 4 weeks. In the 2010, 2011, 2012 and 2013 spawning seasons, the occurrence of golden perch eggs/larvae at Yambuna in the lower reach coincided with the movements of some of the tagged fish (2010: n = 6, 2011: n = 3, 2012: n = 2, 2013 n =1) into the lower reaches of the river.

Eight of the tagged fish undertook initial upstream movements over distances of 20–75 km. Half of these fish travelled to the most upstream listening station (i.e. Murchison) about 10 km below Goulburn Weir, before returning back downstream, usually within 3 weeks.

Full details of statistical results are provided in Appendix D. In summary, results particularly relevant to environmental flow management were:

- The probability of fish moving (any direction) increased with increasing flows and on later days of year (Figure 5-8).

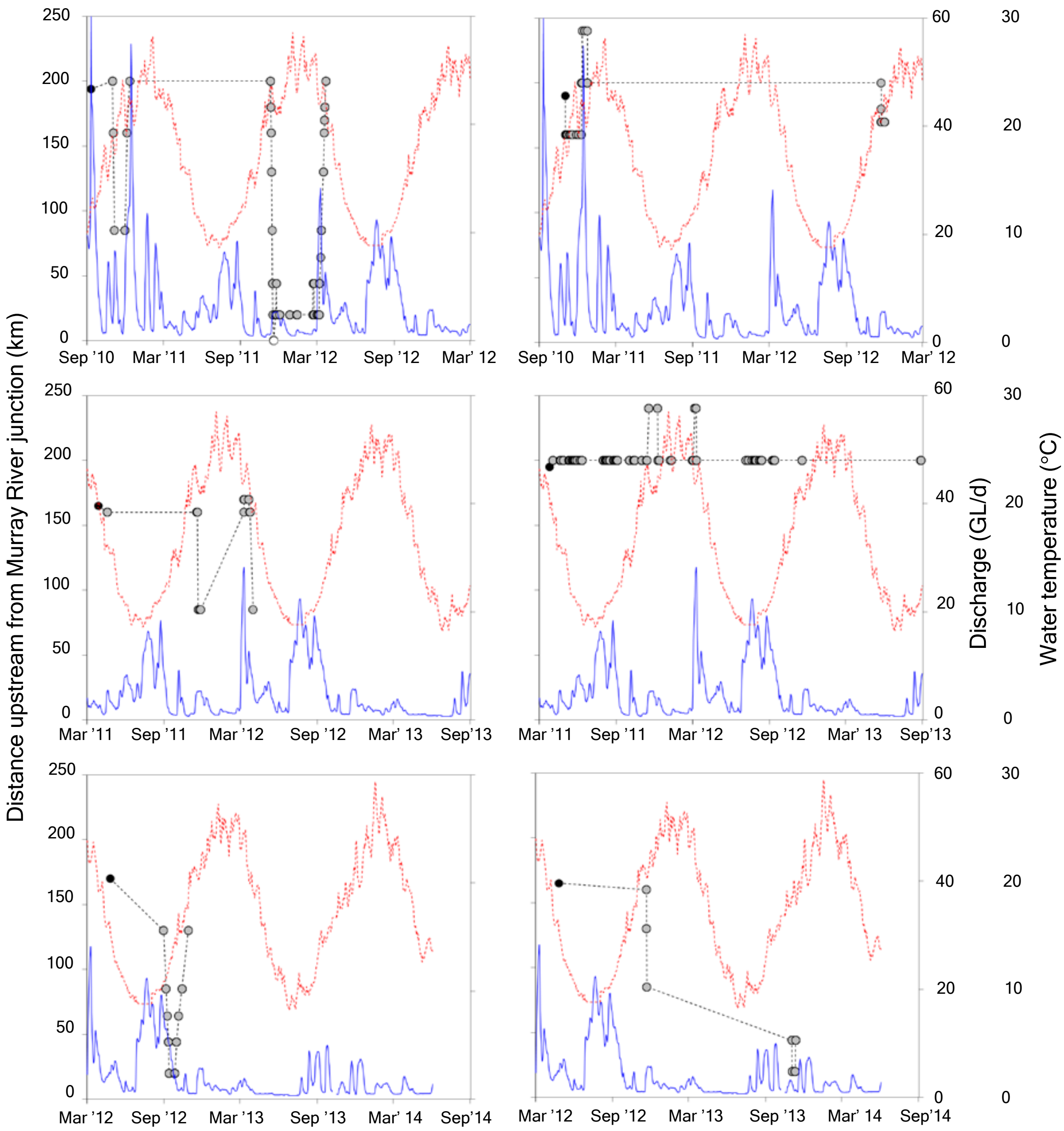

Figure 5-7. Examples of movement patterns of golden perch tagged in the lower Goulburn River. Black circles show the date and location of tagging and grey circles show detections of tagged fish on the listening stations. White circles show detections on listening stations in the Murray River. Red dashed line is instantaneous water temperature and blue line is the daily mean discharge in the Goulburn River at McCoy's Bridge, respectively.

- There was a non-linear or dome-shaped relationship between the probability of fish moving downstream and current flow and water temperature (Figure 5-9). The probability of fish moving downstream peaked when current flow and current water temperature increased to about 12000 ML/d and 18-19 °C, respectively.

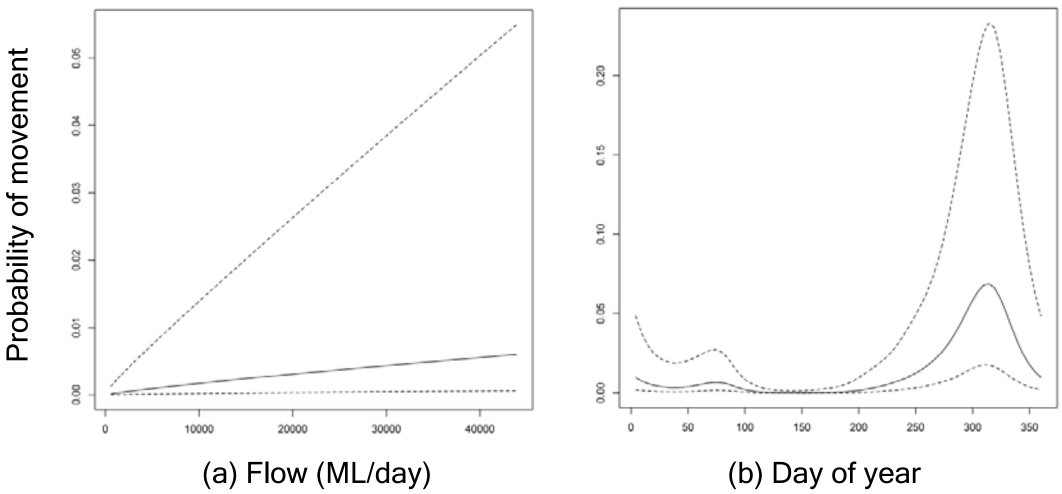

Figure 5-8. Probability of golden perch movement versus (a) flow and (b) day of year, for the moving versus not moving model (Model 6). Dotted lined denotes 95% confidence bands.

- The probability of fish moving upstream was greater at higher flow differences and higher previous flows (Figure 5-10). There was also a non-linear or dome-shaped relationship between the probability of fish moving upstream and previous water temperature (Figure 5-10). The probability of fish moving upstream peaked at previous water temperature of approximately 22 °C.

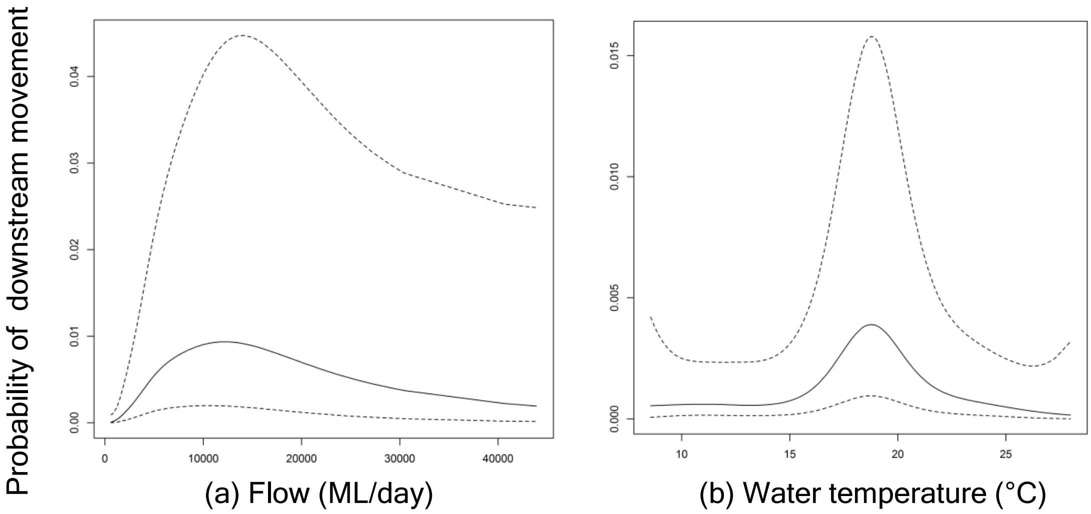

Figure 5-9. Probability of golden perch movement versus (a) flow and (b) water temperature for the downstream movement versus not moving / upstream movement model (Model 4). Dotted lined denotes 95% confidence bands.

- There was a non-linear or dome-shaped relationship between the probability of fish moving downstream (versus upstream) and current flow (Figure 5-11). The probability of fish moving downstream (versus upstream) peaked when current flow increased to about 6500 ML/d.

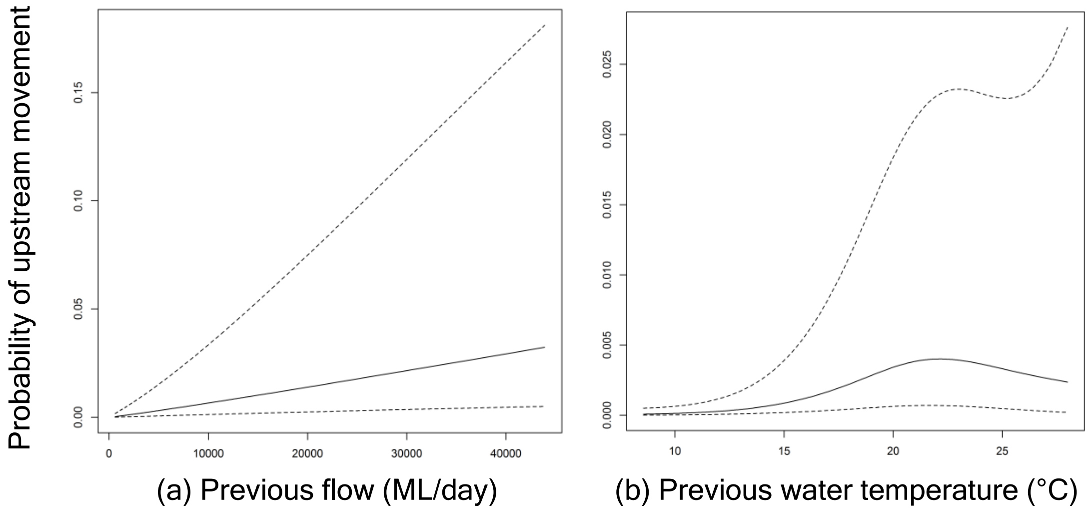

Figure 5-10. Probability of golden perch upstream movement versus (a) previous flow and (b) previous water temperature for the upstream movement versus not moving / downstream movement model (Model 5). Dotted lined denotes 95% confidence bands.

- Hence, while the analysis of 'downstream movement versus upstream movement or not moving' indicates downstream movement peaked when current flow increased to ~ 12000 ML/d, the analysis of 'downstream movement versus upstream' movement (i.e. considering only data classed as 'moving') suggests that when current flow exceeds about 6500 ML/d, fish may be more likely to change direction (i.e. move upstream).

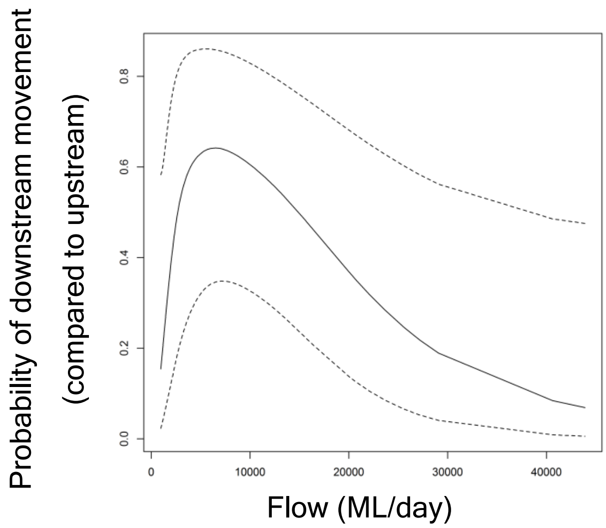

Figure 5-11. Probability of golden perch downstream movement versus flow for the downstream versus upstream movement model (Model 4). Dotted lined denotes 95% confidence bands. Values are on logit scale.

5.4.4 Benefits of environmental flows

Environmental flows promote spawning and movement of golden perch in the lower Goulburn River. Golden perch spawned in association with an environmental flow release in November 2013. Golden perch spawning was also detected in 2011 and 2012 coinciding with environmental flow releases. Although increased flows in spring-summer 2013 promoted golden perch spawning, it appears that they did not lead to localised recruitment of age 0+ fish in the lower Goulburn River. Long-distance movement of adult golden perch was also associated with increased flows, including environmental flows.

5.5 Discussion

5.5.1 Spawning

Reproduction is critical to supporting native fish populations, and is a key Basin Plan objective for environmental water (Gawne *et al.* 2013). In spring-summer 2013/14, environmental flow 'freshes' were released into the lower Goulburn River that aimed to promote golden perch spawning. There was a clear association between increased flows and spawning by golden perch, with eggs and larvae collected in the lower Goulburn River during an environmental flow release in mid-November 2013. Similarly, in surveys of eggs/larvae conducted from 2003–2012 in the lower Goulburn River, golden perch spawning was only detected in association with increased flows in spring-summer (Koster *et al.* 2012). In years characterised by low and stable spring-summer flows, no spawning has been detected (Koster *et al.* 2012). These findings support previous suggestions that golden perch spawning is dependent on increased flows in spring-summer (Mallen-Cooper & Stuart 2003; King, Tonkin & Mahoney 2009) and serves to demonstrate the benefit of environmental water allocations for golden perch reproduction. Indeed, the clear associations between increased flows and spawning by golden perch in this survey, and the surveys conducted from 2003–2012 (Koster *et al.* 2012), provide strong evidence that spawning would not have occurred without the allocation of environmental water in November 2013. The finding that no golden perch eggs or larvae were collected on a subsequent similar magnitude environmental water release shortly afterwards in December 2013 also suggests that additional flow events may not necessarily achieve an increased level of spawning, although this will be further investigated by larval sampling to be undertaken as part of the Goulburn LTIM project.

Golden perch eggs/larvae were collected in 2013/14 only at the most downstream site in the lower reaches at Yambuna. Similarly, in the surveys of eggs/larvae conducted from 2003–2012, most (75%) golden perch eggs/larvae were also collected at Yambuna, with the remainder at Pyke Road (24%) near Shepparton and Cable Hole (1%) near Murchison (Koster *et al.* 2012). These results suggest that golden perch spawning activity in the lower Goulburn River is concentrated in the lower reaches of the river. The finding that spawning activity was concentrated in the lower reaches of the Goulburn River contrasts with the suggestion by Cockayne *et al.* (2013) that golden perch spawning occurs in the upper reaches in the Fitzroy River. It is possible that the location and spatial extent of spawning is determined by prevailing hydrological conditions: for example, eggs and larvae were recorded at all three sites in the Goulburn River during major flooding that occurred in 2010/11. Water temperatures might also influence the spatial extent of spawning. Golden perch typically spawn when water temperatures reach around 18-21° (Humphries, King & Koehn 1999; King, Tonkin & Mahoney 2009; Zampatti & Leigh 2013). As water temperatures in the Goulburn River are generally warmer with increasing distance downstream from Goulburn Weir, the lower reaches of the river may be more suitable for spawning. Determining the spatial extent of golden perch spawning is an important area for future research and will form part of upcoming Goulburn LTIM project.

Much higher numbers of golden perch eggs/larvae were collected in 2013/14 compared to the surveys conducted from 2003–2012 (Koster *et al.* 2012). In these previous surveys, eggs/larvae were collected only in five spawning seasons with most (94%) of these collected during a period of major flooding in the lower Goulburn River in 2010/11. Levels of spawning of golden perch are thought to be enhanced during flood conditions (King, Tonkin & Mahoney 2009). However, the collection of greater numbers of eggs/larvae in 2013 compared to 2010 suggests that overbank flows may not necessarily achieve an enhanced level of spawning relative to an appropriate within-channel flow. Determining the optimum or most appropriate flow conditions for spawning is an important area for future research to aid the development of flow recommendations aimed at restoring suitable flow patterns for golden perch, and will form part of upcoming monitoring on the Goulburn River as part of the LTIM project.

Environmental flows have been delivered to the lower Goulburn River to trigger golden perch spawning in each of the last three years (i.e. 2011, 2012, 2013). The timing and duration of the environmental flows, and water temperature around the time of the releases (about 19–21° C), has been similar in each year. Despite these similarities, levels of spawning were much higher in 2013 compared to 2011 and 2012. The magnitude of the environmental flows was higher in 2013 (~7052 ML/d) compared to 2011 (~5050 ML/d) and 2012 (~5600 ML/d), although in 2013 most (73%) eggs/larvae were collected when the flow was around 4747 ML/d (i.e. similar flow magnitude to 2011 and 2012) prior to the flow peak. One possible explanation for the higher levels of spawning in 2013 may be the flow conditions in the pre-spawning period (late winter-early spring). Higher flows in the pre-spawning period are hypothesized to improve pre-spawning condition of adult fish and may enhance spawning activity (Chee *et al.* 2009). In 2013, there were several flow pulses (between 8685 and 9459 ML/d) throughout August–September in the lower Goulburn River, whereas in 2011 and 2012 flow typically decreased throughout August–September. Higher flows in the pre-spawning period were also a characteristic of 2010, when large numbers of golden perch eggs were collected. Whilst this study has shown that increased flows can promote golden perch spawning, further assessment of spawning in more years with different flow conditions would be needed to better understand the roles of factors such as antecedent flows in spawning.

5.5.2 Recruitment

The golden perch population in the lower Goulburn River consisted of mostly large, older fish, consistent with the results of previous surveys in the lower Goulburn River (Koster *et al.* 2012). Increased flows in spring/summer, which promote golden perch spawning, might also be expected to promote subsequent recruitment into the juvenile/adult population. Although golden perch spawned in the lower Goulburn River in 2013/14, no young-of-year fish were collected in the March electrofishing surveys. Similarly, no young-of-year fish were collected in electrofishing surveys in autumn following spawning events in 2005, 2006, 2010, 2011 and 2012. Thus, whilst increased flows can promote golden perch spawning, it appears that this may not necessarily lead to localised recruitment of age 0+ fish. This result might indicate that the lower Goulburn River does not contain suitable habitat for the recruitment of juvenile golden perch. Alternatively, given that golden perch lay buoyant eggs that drift downstream on river currents, 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. Determining the origin and migratory history of golden perch in the lower Goulburn River is an important area for future research.

5.5.3 Movement

Dispersal or movement is critical to supporting connectivity of native fish populations, and is a key Basin Plan objective for environmental water (Gawne *et al.* 2013). Increased flows, particularly in spring-summer, are expected to promote movement by golden perch within the Goulburn River (Peter Cottingham & Associates and SKM 2011). The results of this study show that long-distance movements by golden perch were associated with hydrological events, water temperature, and time of year. In particular, downstream movement increased with increasing flow (to about 12000 ML/d), water temperature (to about 18-19° C) and spawning season (September-February), while upstream movement increased with previous flow and previous water temperature (to about 22° C), flow variation and day of year. These findings support previous suggestions that movement of golden perch is associated with increasing flows and water temperature, particularly during the spawning season (Reynolds 1983; O'Connor, O'Mahony & O'Mahony 2005; Koster *et al.* 2014). The links between flows and movement have important implications for the development of environmental flow recommendations aimed at restoring suitable flow patterns for golden perch. In particular, the results suggest that increased flows provide important movement cues for golden perch within the Goulburn River, and also into the Murray River. The non-linear or domed-shaped nature of some of the relationships also suggests that flow (and water temperature) thresholds may exist, and hence flows above these levels may not necessarily achieve an increased level of movement.

In the 2010, 2011, 2012 and 2013 spawning seasons, the occurrence of golden perch eggs/larvae at Yambuna in the lower reaches corresponded with the downstream movements of some of the tagged fish into the lower reaches of the river, raising the possibility that at least some fish moved downstream to spawn. Long-distance downstream movements by golden perch during the spawning period have also been observed in the Murray River (O'Connor, O'Mahony & O'Mahony 2005). Upstream movements during the spawning period have also been reported (Reynolds 1983; O'Connor, O'Mahony & O'Mahony 2005) however, and were also observed in the current study. These results indicate that adult golden perch display a spatially and temporally complex pattern of movement potentially influenced by reproductive behaviour, as well as hydrological conditions and water temperature. Elucidating the spawning season movement requirements of golden perch is an important area for future research on this species, and also forms part of upcoming monitoring on the Goulburn River as part of the LTIM project.

Three fish visited the Murray River before returning to the lower Goulburn River. This finding is consistent with a previous study that shows golden perch regularly undertake movements between the lower Goulburn and Murray rivers, characterised mostly by temporary occupation followed by return of fish to the original location (Koster *et al.* 2014). Four fish also travelled to the most upstream listening station about 10 km below Goulburn Weir, before returning back downstream. Whether the weir obstructed the movement pathways of these fish is unknown, although Goulburn Weir is a major barrier to fish movement (McGuckin & Bennett 1999). Determining whether fish approach the weir and the extent to which movement pathways are blocked would be valuable.

In conclusion, this study has provided important information about the ecology of golden perch and responses to flows in the lower Goulburn River. The study has demonstrated the existence of long-distance downstream and upstream movements and the importance of increased river flow as a movement and spawning cue. The results suggest that spawning activity is concentrated in the lower reaches of the river, and that adult fish move downstream during increased flows to the lower reaches possibly to spawn, although some fish also move upstream. It is recommended that future flow releases to trigger golden perch spawning/movement occur between late October and late November, as this period coincides with the observed peak spawning/movement period. Future environmental water delivery and monitoring should also investigate the effects of larger flow magnitudes (e.g. > ~7000 ML), and antecedent flow conditions, to more reliably understand the flow conditions that are needed to promote spawning and movement. That information can then be used to help actively manage environmental flows in the future.

6 Movement responses Murray cod and golden perch to flows and dissolved oxygen


Hypoxia (low dissolved oxygen) is a serious water quality issue in the Murray-Darling Basin. In response, strategies to minimise dissolved oxygen depletion, such as provision of environmental flows to improve water quality, have been established.

The capacity of a system to respond to disturbances such as low dissolved oxygen is a key element of the Basin Plan's goal to ensure Resilience (Level 1 objective). However, there is limited understanding of the major strategies that enable biota to resist, adapt or recover from disturbances such as low DO. Accordingly, we monitored the movement responses of Murray cod and golden perch to dissolved oxygen and flows in the lower Broken Creek.

Key findings

- Extended periods of low dissolved oxygen did not occur during the study period, but we did detect behavioural responses to changes in dissolved oxygen and flows.
- Decreases in dissolved oxygen were associated with decreased activity for Murray cod, and increased activity for golden perch. These findings are consistent with previous knowledge concerning the behavior of demersal or sedentary species (i.e. Murray cod) and active, schooling species (i.e. golden perch).
- Fish moved to shallower depths during periods of lower dissolved oxygen. Many other fish species also shift to near the surface of the water column during low dissolved oxygen events. This result suggests that releasing a smaller volume of water that flushes only the surface of a weir pool may still be an effective strategy if larger volumes of water to completely flush out the pool are not available.
- No evidence of mortality of tagged fishes was detected, which suggests that these species can tolerate occasional short-lived depletion in dissolved oxygen. Responses to more extensive periods of dissolved oxygen depletion, however, are unknown.
- Changes in flow (i.e. freshes) appear to be important for promoting longer-distance movements of Murray cod and golden perch. Delivery of environmental water to Broken Creek that includes variations in flow may be more desirable for promoting fish movement than providing a constant discharge. Changes in flow may also need to be coupled with a particular flow magnitude or threshold (e.g. 200 ML/d).

6.1 Introduction

Hypoxia (low dissolved oxygen) has the potential to inflict major adverse impacts upon native fish populations (Beesley *et al.* 2013). The Broken Creek in northern Victoria has a diverse native fish fauna, which includes several species of recreational angling value and/or conservation significance, in particular Murray cod (*Maccullochella peelii*) and golden perch (*Macquaria ambigua*). Major fish kills have become a serious problem in the Broken Creek in recent years (Koehn 2005; Rees 2006). The most likely explanation for the fish kills is low dissolved oxygen concentrations (hypoxia) in conjunction with little or no flow (Koehn 2005; Rees 2006). In response, strategies to minimise dissolved oxygen depletion, such as provision of environmental flows to improve water quality, have been established for the Broken Creek (GBCMA 2012). In spring-summer 2012/13 and 2013/14, environmental water was allocated to the lower Broken Creek. The aim was to maintain dissolved oxygen levels, and to increase native fish habitat and allow dispersal of native fish throughout Broken Creek (GBCMA 2012). There remains considerable uncertainty, however, concerning how fish respond to low dissolved oxygen / flows, and therefore the most appropriate way to deliver environmental water to satisfy the ecological requirements of fish.

The aims of the current study were to examine relationships between low dissolved oxygen events, flows and the behaviour of native fish in Broken Creek using acoustic telemetry. In particular, the study aimed to determine how fish respond to low dissolved oxygen in terms of:

- Their levels of activity (i.e. do fish shut down physiologically?)
- Their position in the water column (i.e. how do fish respond to vertical dissolved oxygen stratification?)
- Whether fish move away from reaches affected by low dissolved oxygen

6.2 Basin Plan objectives, cause-effect diagrams, and how they relate to fish monitoring

The capacity of a system to respond to disturbance is a key element of the Basin Plan's goal to ensure Resilience (Level 1 objective) (Table 6-1) (Gawne *et al.* 2013).

Table 6-1. Expected outcomes of environmental watering for fish as defined by the Basin Plan objectives hierarchy (modified from Gawne *et al.* 2013).

Level 1 Objectives	Level 2 Objectives	Level 3 Objectives	Expected outcome of watering actions (1-5 years)	Expected outcome of watering actions (< 1 year)	Relevant Cause and Effect Diagram
Resilience	Ecosystem & population resilience	Fish	• Individual survival and condition • Changes in distribution and abundance • Movement	• Individual condition • Changes in distribution and abundance • Movement	Resistance Avoidance Recovery

Maintaining water quality to ensure that it does not affect environmental values is also a key Basin Plan goal (Level 1 objective) (Gawne *et al.* 2013). There is, however, limited understanding of the major strategies that enable biota to resist, adapt or recover from disturbances such as poor water quality (Gawne *et al.* 2013). In the case of the Broken Creek, spring-summer baseflows are expected to maintain water quality, and increase native fish habitat and allow dispersal of native fish. Previous monitoring in spring-summer 2012/13 that assessed the effect of flow on dissolved oxygen levels in Broken Creek provides strong evidence that environmental flows maintain moderate to high dissolved oxygen concentrations (4-8 mg/L) (Stewardson *et al.* 2013). The monitoring described in this report focuses on fish movement behaviours to dissolved oxygen and flows to improve understanding of biotic strategies that enable native fish to resist, adapt or recover from disturbances (Figure 6-1, Figure 6-2, Figure 6-3).

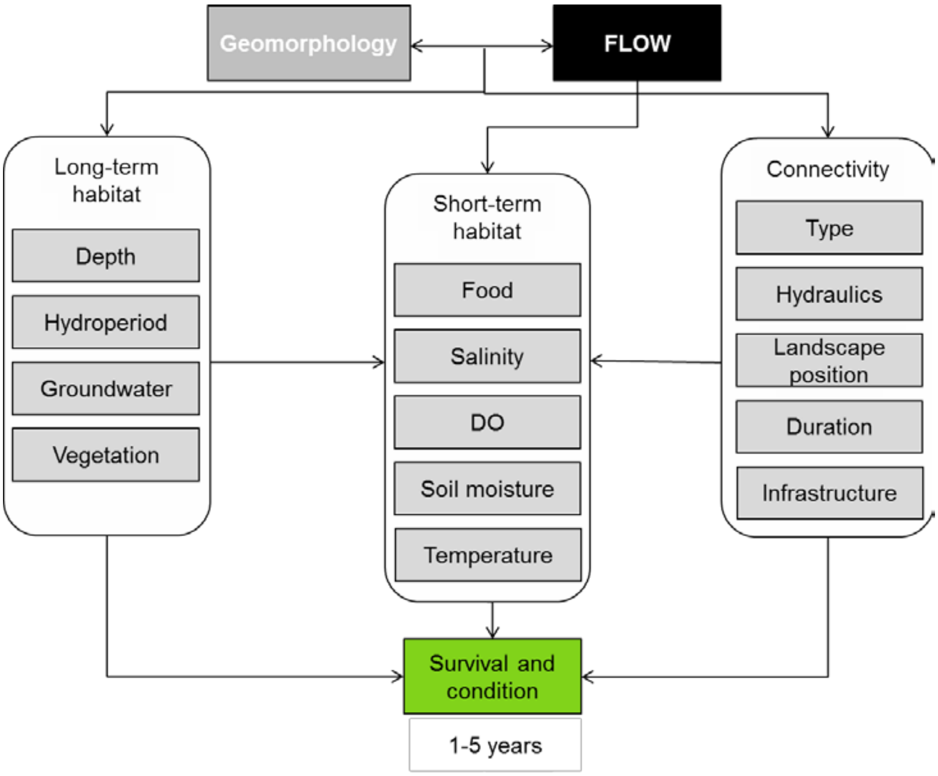

Figure 6-1. Generic cause-effect diagram (CED) for Individual refugia (reproduced from MDFRC 2013).

6.3 Methods

6.3.1 Study sites and field methods

Murray cod (n = 23) and golden perch (n = 15) were collected from Broken Creek between 0.1 and 4 km upstream of Rice's Weir, by using boat-electrofishing in August 2012 (Figure 1-5). This reach was selected for the study because low dissolved oxygen and fish deaths have been identified as a concern in the lower sections of the creek immediately upstream of Rice's Weir. Fish were tagged with acoustic transmitters in September 2010 that measure acceleration (activity) and depth of tagged fish. Larger fish were also tagged with PIT tags (passive integrated transponder) to provide information on movement through fishways where PIT tag readers are installed (Chapter 7).

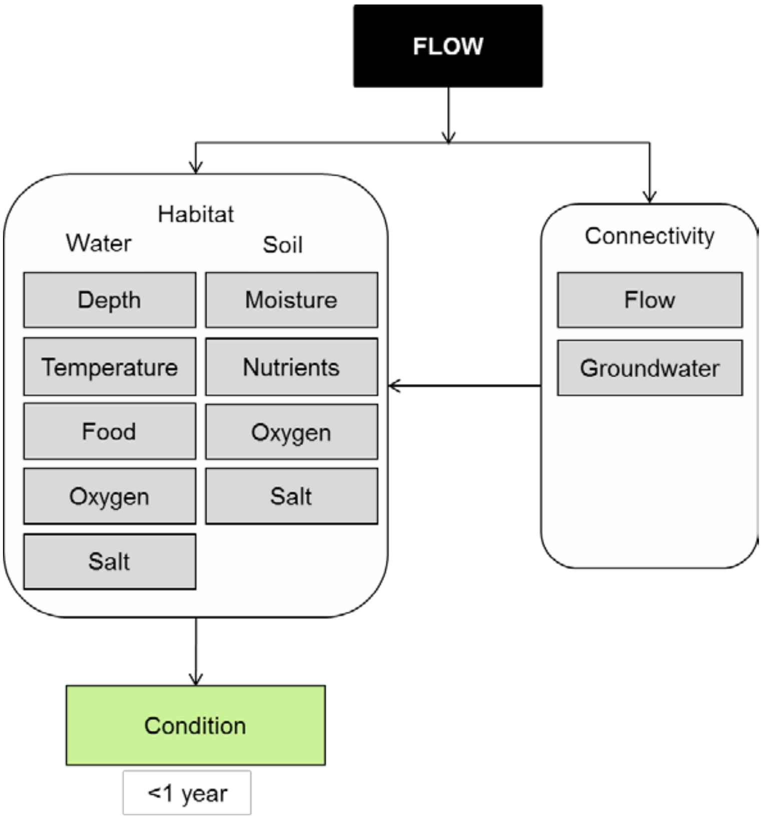

Figure 6-2. Generic cause-effect diagram (CED) for Ecosystem resistance (reproduced from MDFRC 2013).

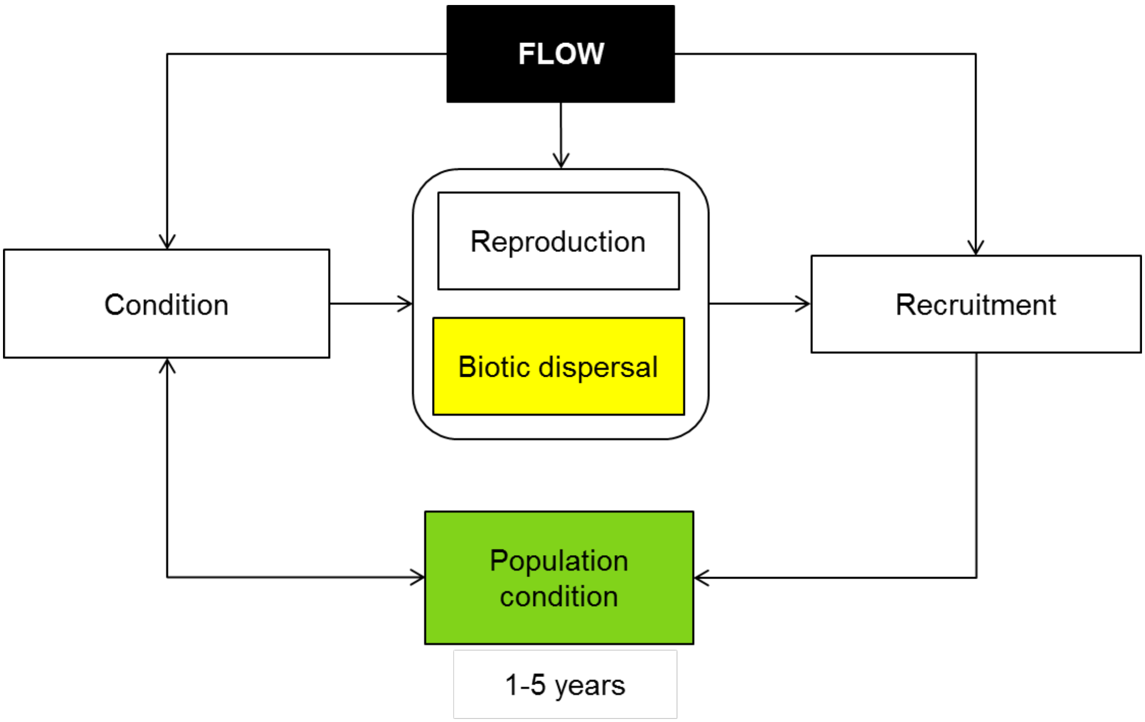

Figure 6-3. Generic cause-effect diagram (CED) for Ecosystem recovery (reproduce from MDFRC 2013).

Forty-two acoustic listening stations were deployed in August 2012 in Broken Creek between the River Murray junction and Magnusson's Weir near Nathalia (a distance of about 50 km) (Figure 1-5). Thirty seven of these listening stations were deployed between Rice's Weir and 7 km upstream at about 200 m intervals to provide precise information on fish locations within these reaches. Data were downloaded from the listening stations monthly for the duration of the study.

6.3.2 Data analysis

Bayesian analyses were used to examine relationships between the mean hourly depth, activity of Murray cod and golden perch, and environmental variables (Kéry 2010). The environmental variables considered were, mean hourly flow, change in hourly flow, mean hourly dissolved oxygen, change in hourly dissolved oxygen, mean hourly water temperature, diel period, and previous hourly activity or depth. For activity, a quadratic term for temperature was also included to account for the possibility of peak activity.

6.4 Results

Main results from the acoustic monitoring can be summarized as:

- Extended periods of low dissolved oxygen did not occur during the study period. Nonetheless, the study has provided useful information on behavioural responses to changes in dissolved oxygen and flows.
- Levels of activity and position in the water column of Murray cod and golden perch were influenced by changes in dissolved oxygen. These results highlight the importance of environmental flows to maintain adequate dissolved oxygen concentrations in Broken Creek and other streams in the Murray-Darling Basin.
- No evidence of mortality of tagged fishes was detected, which suggests that these species can tolerate occasional short-lived depletion in dissolved oxygen.
- Responses to more extensive periods of low dissolved oxygen concentration (e.g. >2-3 days duration), however, are unclear and this is an important area for future research.
- Changes in flow (i.e. freshes) appear to be important for promoting longer-distance movements of Murray cod and golden perch.

6.4.1 Hydrology, dissolved oxygen and water temperature

Flow, water temperature and dissolved oxygen data were obtained from the gauging station at Rice's Weir. Flow was typically lowest around June-August (~50-100 ML/d) and highest around September-October (~600-700 ML/d) in each year (Figure 6-4). Environmental water was delivered in 2012/13 and 2013/14 to provide a minimum of 250 ML d^{-1} at Rice's Weir from September to December/January in each year. A minimum of 200 ML d^{-1} was then delivered from about late January to April/May. Several increased flow events driven by rainfall runoff from the catchment also occurred during the study. The use of water for irrigation resulted in flow variations at times.

DO generally remained above 4 mg/L over the study period (Figure 6-4); hypoxic stress in fish is typically evident once dissolved oxygen concentrations fall below 4 mg/L (McNeil & Closs 2007).

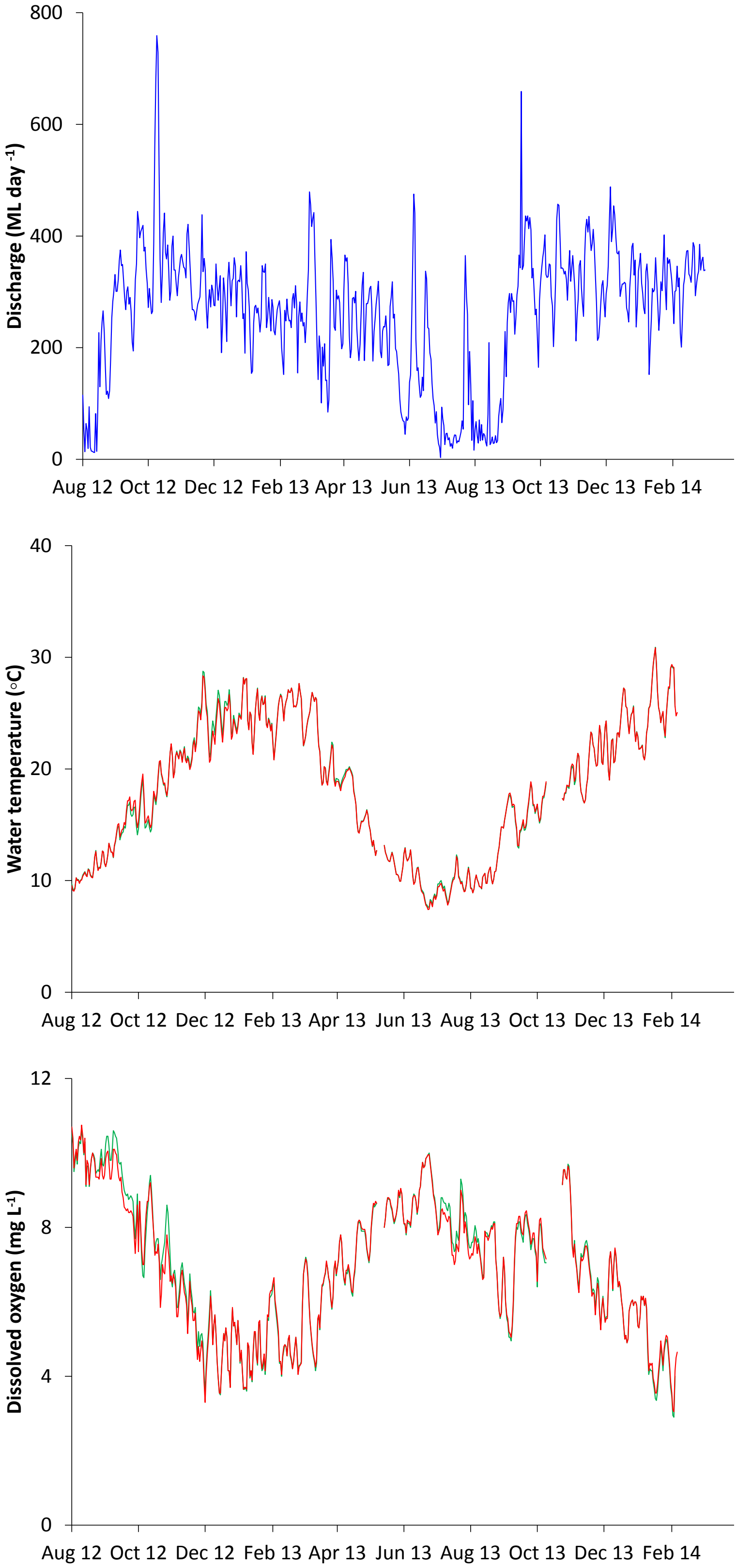

Figure 6-4. Discharge (top panel), water temperature (centre panel) and dissolved oxygen (bottom panel) in Broken Creek at Rice's Weir. Red line represents surface and green line represents bottom.

However, there were short periods (i.e. < 1–2 d duration) when DO decreased to about 3 mg/L between late November 2012–early February 2013, and between late January–early February 2014. DO at the bottom (mean 7.2 mg/L) and surface (mean 7.7 mg/L) were generally similar, although there were occasional short periods (< 1 d duration) when bottom DO was about 2-3 mg/L lower than surface. Maximum temperatures of around 33° C were reached in January and minimum temperatures of around 7° C occurred in June (Figure 6-4). Water temperatures at the bottom (mean 18.3° C) and surface (mean 18.7° C) were generally similar. Dissolved oxygen levels were lowest during the summer, most likely driven by water temperatures and thermal stratification (Stewardson *et al.* 2013). It is only during these times that flow management needs to be considered to maintain dissolved oxygen levels.

6.4.2 Activity and depth patterns

All of the tagged fish were detected moving. Murray cod and golden perch activity tended to gradually increase from August through to a peak in November-December and then decline or plateau to February (Figure 6-5, Figure 6-5).

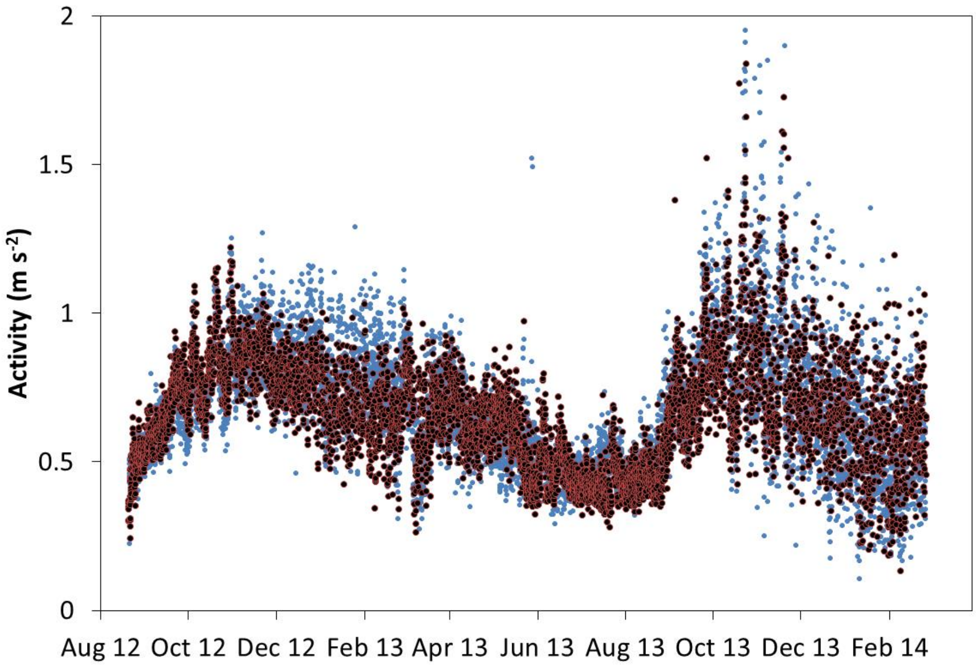

Figure 6-5. Hourly mean activity patterns of Murray cod in Broken Creek. Black circles with red outline represent night and solid blue circles represent day.

Murray cod activity exhibited several pronounced spikes in October, coinciding with sharp rises in temperature. The results of the Bayesian analyses indicate that activity in both species was strongly influenced by previous activity and change in dissolved oxygen, whilst water temperature also influenced activity of golden perch (Table 6-2b). Negative changes (i.e. decreases) in dissolved oxygen were associated with decreased activity for Murray cod and increased activity for golden perch. As an example, if dissolved oxygen decreased by 10%, activity decreased by 4.8% in Murray cod and increased by 4.5% in golden perch. The model suggested a peak activity of golden perch when water temperatures were around 21.2°C.

The depth at which individuals of both species were found was strongly influenced by previous depth and change in dissolved oxygen (Table 6-3). Decreases in dissolved oxygen were associated with decreased (shallower) depths for both Murray cod and golden perch. As an example, if dissolved oxygen decreased by 10%, depth decreased by 9% in Murray cod and 12% in golden perch. The results also indicate that depth of Murray cod, and to a lesser extent for golden perch, was influenced by diel period; depth was greater during the day or dusk compared to night (Figure 6-7, Figure 6-7). For instance, depth decreased by 7% for Murray cod and 6% for golden perch at dawn compared to during the day.

Table 6-2. Influence of environmental variables on activity of (a) Murray cod and (b) golden perch in Broken Creek. Lower Bound – lower 95% high density interval. Upper Bound – upper 95% high density interval.

Parameter	Estimate	Lower Bound	Upper Bound	Estimate as a % of standard deviation
(a) Murray cod				
Previous activity	0.298	0.297	0.299	182%
Water temperature	0.038	0.036	0.040	23%
Water temperature squared	-0.029	-0.030	-0.028	18%
Dissolved oxygen	0.012	0.010	0.014	7%
Change in DO	0.063	0.050	0.077	39%
Flow	0.027	0.026	0.029	17%
Change in Flow	-0.019	-0.023	-0.014	11%
Dusk compared to day	-0.009	-0.013	-0.005	5%
Night compared to day	-0.009	-0.011	-0.006	5%
Dawn compared to day	-0.003	-0.007	0.001	2%
Mean day activity	0.703	0.685	0.723	
Standard deviation (Overall)	0.164	0.163	0.165	
(b) Golden perch				
Previous activity	0.249	0.248	0.251	186%
Water temperature	0.068	0.066	0.070	51%
Water temperature squared	-0.017	-0.019	-0.016	13%
Dissolved oxygen	0.014	0.011	0.016	10%
Change in DO	-0.088	-0.104	-0.073	66%
Flow	0.018	0.016	0.019	13%
Change in Flow	-0.010	-0.017	-0.003	7%
Dusk compared to day	-0.001	-0.006	0.004	1%
Night compared to day	-0.010	-0.014	-0.007	7%
Dawn compared to day	-0.010	-0.015	-0.006	7%
Mean day activity	0.733	0.704	0.762	
Standard deviation (Overall)	0.134	0.133	0.134	

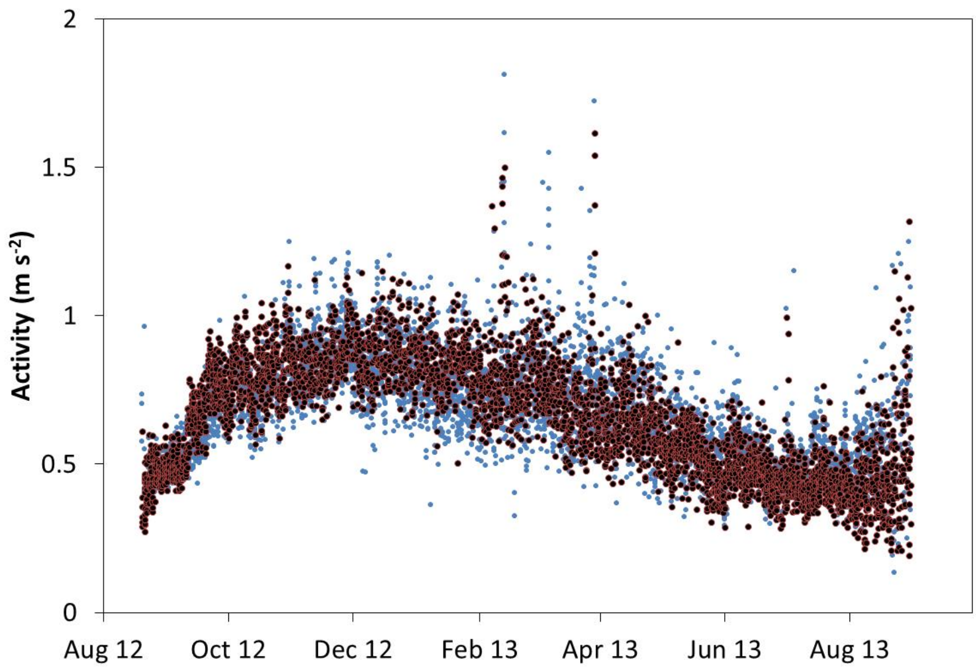

Figure 6-6. Hourly mean activity patterns of golden perch in Broken Creek. Black circles with red outline represent night and solid blue circles represent day.

6.4.2.1 Longitudinal movements

Most Murray cod remained close to their capture point and occupied small lengths of stream (median total linear range: 2.1 km). Five of the six (80%) Murray cod ≥ 650 mm TL undertook occasional larger (> 5 km) upstream and downstream movements, particularly around August-October (Figure 6-9). Two (9%) smaller (410-440 mm TL) Murray cod moved > 5 km. Movements of Murray cod > 5 km typically coincided with flow rises (i.e. from 194 to 440 ML/d in September 2012, 65 to 245 ML/d in August 2013). One of the larger Murray cod (650 mm TL) undertook an extensive (~ 30 km) upstream journey away from its usual location in September 2012, before returning to the area it previously occupied in November 2012 (Figure 6-9). This individual undertook another extensive upstream (~ 50 km) journey away from its usual location one year later in August 2013, before returning downstream about 20 km to near Harding's Weir in October 2013. These movements coincided with flow rises (i.e. from 185 to 449 ML/d in September 2012, 65 to 281 ML/d in August 2013).

Similar to the Murray cod, most golden perch remained close to their capture point and occupied small lengths of stream (median total linear range: 3.6 km). Two golden perch undertook extensive (i.e. 25-50 km) upstream journeys away from their usual locations in November-December 2012 (Figure 6-10). These upstream movements occurred a few days after a flow peak, although water levels had dropped back to around baseflow levels (i.e. from 371 to 192 ML/d in November 2012, 251 to 174 ML/d in December 2012). Two golden perch also moved downstream into the Murray River. These movements coincided with flow rises (i.e. from 83 to 289 ML/d in September 2012, 108 to 223 ML/d in January 2013). One of these golden perch was last detected moving through a fishway at Yarrawonga Weir in the Murray River in mid-November.

Table 6-3. Influence of environmental variables on depth of (a) Murray cod and (b) golden perch in Broken Creek. Lower Bound – lower 95% high density interval. Upper Bound – upper 95% high density interval.

Parameter	Estimate	Lower Bound	Upper Bound	Estimate as a % of standard deviation
(a) Murray cod				
Previous depth	0.413	0.412	0.414	275%
Water temperature	-0.001	-0.003	0.001	1%
Water temperature squared	0.010	0.009	0.011	7%
Dissolved oxygen	0.031	0.030	0.033	21%
Change in DO	0.215	0.202	0.227	143%
Flow	0.001	0.000	0.003	1%
Change in Flow	-0.014	-0.018	-0.009	9%
Dusk compared to day	0.009	0.004	0.015	6%
Night compared to day	-0.067	-0.069	-0.064	45%
Dawn compared to day	-0.090	-0.094	-0.087	60%
Mean day depth	1.218	1.183	1.252	
Standard deviation (Overall)	0.150	0.149	0.151	
(b) Golden perch				
Previous depth	0.501	0.499	0.502	327%
Water temperature	0.020	0.018	0.023	13%
Water temperature squared	0.001	-0.001	0.003	1%
Dissolved oxygen	0.046	0.044	0.049	30%
Change in DO	0.272	0.252	0.289	177%
Flow	-0.016	-0.018	-0.014	10%
Change in Flow	0.006	-0.002	0.013	4%
Dusk compared to day	0.030	0.024	0.035	20%
Night compared to day	-0.037	-0.041	-0.034	24%
Dawn compared to day	-0.071	-0.076	-0.066	46%
Mean day depth	1.233	1.203	1.263	
Standard deviation (Overall)	0.153	0.152	0.154	

6.4.3 Benefits of environmental flows

No evidence of mortality of tagged fishes was detected. In the absence of environmental flows to maintain adequate dissolved oxygen concentrations, however, responses are likely to differ.

Movements of Murray cod and golden perch throughout Broken Creek were associated with changes in flow. This result suggests that environmental water allocation that includes variations in flow can enhance or promote movement of these species.

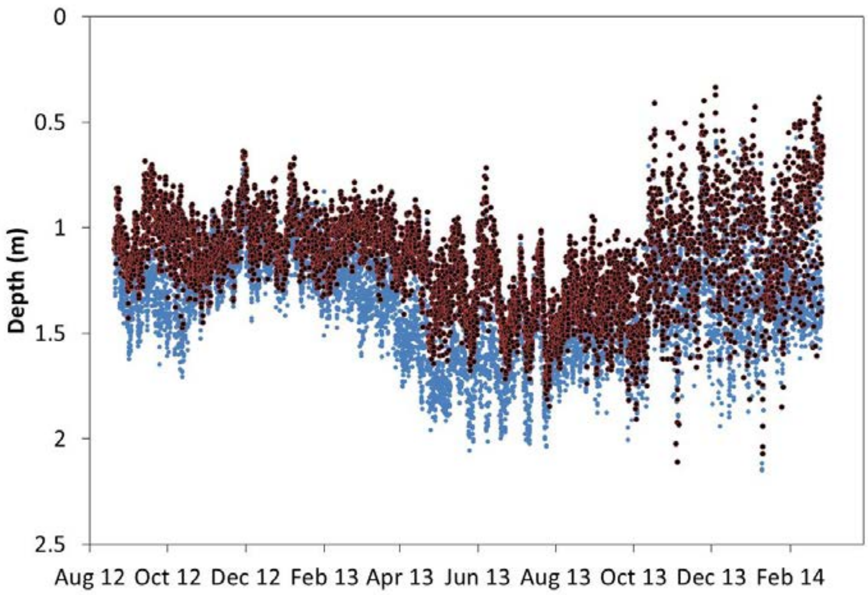

Figure 6-7. Hourly mean depth patterns of Murray cod in Broken Creek. Black circles with red outline represent night and solid blue circles represent day.

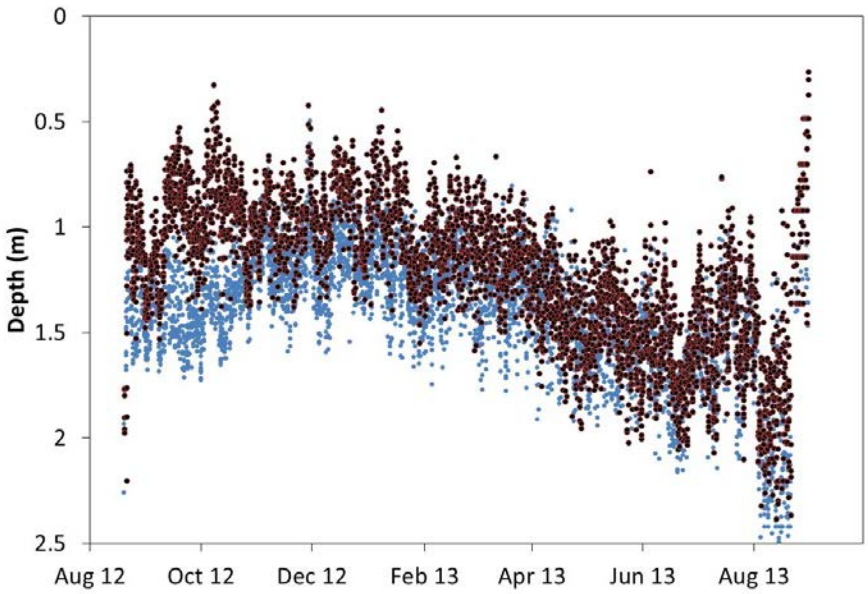

Figure 6-8. Hourly mean depth patterns of golden perch in Broken Creek. Black circles with red outline represent night and solid blue circles represent day.

6.5 Discussion

This study aimed to determine how fish respond to low dissolved oxygen in Broken Creek. Dissolved oxygen concentrations occasionally decreased to about 2.5-3 mg/L during the study, but these events were short-lived (i.e. < 1-2 days duration). Whilst this limits inference on fish movement responses to extreme low dissolved oxygen events, the study nonetheless has provided useful information on behavioural responses to changes in dissolved oxygen and flows. In particular, decreases in dissolved oxygen were associated with decreased activity and depth for Murray cod, and increased activity and decreased depth for golden perch, whilst changes in flow (i.e. freshes) were associated with longer-distance movements of both Murray cod and golden perch.

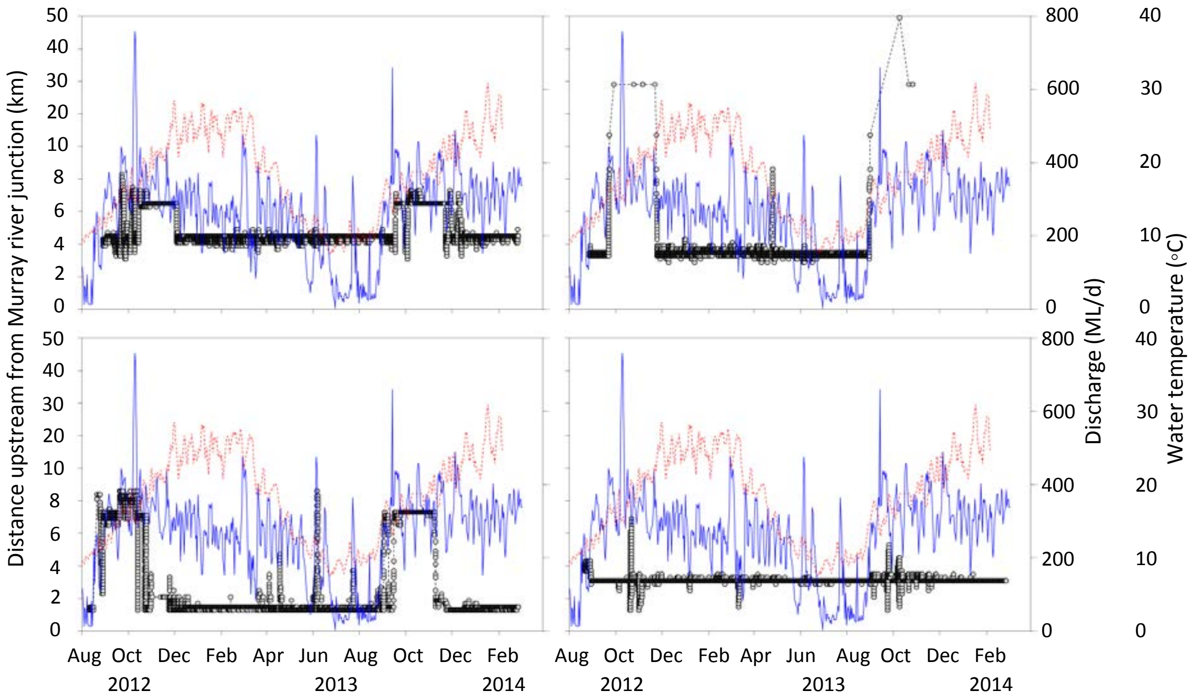

Figure 6-9. Examples of movement patterns of Murray cod tagged in Broken Creek. Grey circles show detections of tagged fish on the listening stations. Red dashed line and blue line represents mean daily water temperature and discharge at Rice's Weir, respectively.

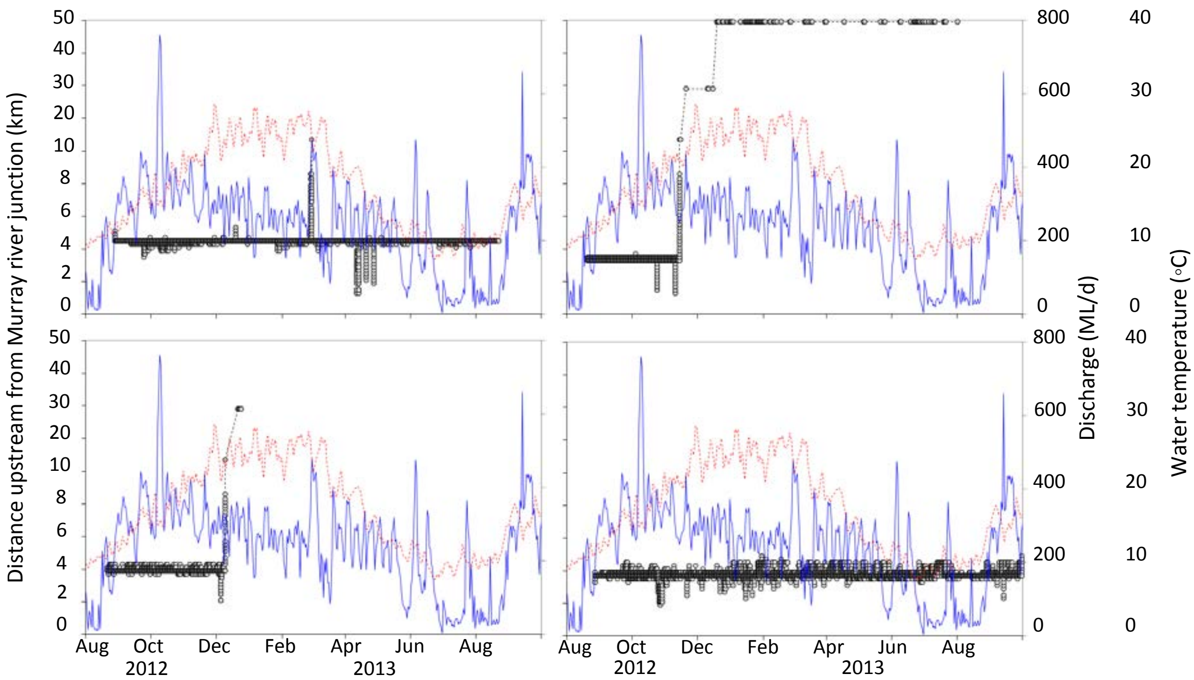

Figure 6-10. Examples of movement patterns of golden perch tagged in Broken Creek. Grey circles show detections of tagged fish on the listening stations. Red dashed line and blue line represents mean daily water temperature and discharge at Rice's Weir, respectively.

Changes in activity are a common fish behavioural response to reduced dissolved oxygen (Kramer 1987). In the present study, both species were influenced by dissolved oxygen conditions. The results were consistent with research on other species that suggests demersal or sedentary species (i.e. Murray cod) tend to reduce their levels of activity during low-dissolved oxygen events, whilst active, schooling species (i.e. golden perch) tend to increase their levels of activity(Herbert *et al.* 2011; Poulsen *et al.* 2011). This result highlights the importance of strategies such as environmental flows to maintain dissolved oxygen concentrations in Broken Creek. Significantly, no evidence of mortality of tagged fishes was detected in the current study, demonstrating that both Murray cod and golden perch are capable of tolerating short term oxygen depletion to ~2-3 mg/L. If fish are exposed to longer periods of dissolved oxygen depletion, however, the risk of mortality may be increased.

Fish also change their vertical position within the water column in response to reduced dissolved oxygen (Kramer 1987; McNeil & Closs 2007). The decrease in depth of Murray cod and golden perch during decreases in dissolved oxygen shows that both species may respond to low dissolved oxygen by moving to the surface of the water column to access the generally higher dissolved oxygen levels at shallow depths. The finding that both species exhibited vertical habitat changes in response to changes in dissolved oxygen has important implications for the delivery of environmental water to satisfy their ecological requirements. For example, if low dissolved oxygen or stratification occurs in a pool, releasing a smaller volume of water that flushes only the surface may still be an effective strategy if larger volumes of water to completely flush out the pool are not available. Determining the volume of water needed to flush the surface to maintain water quality is an important area for future work, but may be informed by the hydrodynamic model developed for Rice's Weir weir pool in the 2012/13 short-term monitoring project (Stewardson *et al.* 2013).

Another important finding of this study is that longer-distance longitudinal movements of Murray cod and golden perch were associated with hydrological events. In particular, changes in flow (i.e. 'freshes') appear to be important for promoting the movement of these species throughout Broken Creek, and also into the Murray River. Dispersal or movement is critical to supporting connectivity of native fish populations, and is a key Basin Plan objective for environmental water (Gawne *et al.* 2013). Typically, longer-distance movements coincided with changes in flow, but only when flow was above about 200 ML/d. Thus, whilst changes in flow might be expected to increase the probability of movement, this may only be realized at a particular flow magnitude or threshold (e.g. 200 ML/d). Changes in flow associated with movement were typically driven by rainfall runoff from the catchment, or the use of water for irrigation. However, the allocation of environmental water over spring-summer increased the magnitude of flows and therefore may have played an important role in promoting movement. Whether longer-distance movements would have occurred without the increase in flow magnitude provided by the allocation of environmental water is unclear, particularly as there were few instances of smaller flow changes. Further assessment of movement in more years with different flow conditions, would be needed to better understand the roles of flow variation and magnitude in fish movement.

This study has also provided important information on diel habitat shifts of Murray cod and golden perch. Both species moved closer to the surface at night compared to during the day. Such behavior is consistent with a predator avoidance response, where fish would be more vulnerable during the day. This type of diel habitat shift is consistent with previous research for golden perch (Crook *et al.* 2001). Previously, knowledge of this behaviour was lacking for Murray cod, although this species has been shown to use positions low in the water column during the day in the Ovens River (Koehn 2009).

7 Fish Movement through Fishways

Australian native fish are highly mobile and need to move in order to obtain food, migrate, access habitat, and to spawn. Unfortunately, the construction of dams and weirs for irrigation has reduced longitudinal connectivity, and altered the timing and magnitude of natural inflows. This has in turn, adversely affected instream inhabitants such as fish by directly restricting movement, and also by removing environmental cues for movement.

Construction of fishways on barriers and delivery of environmental water are however, helping to mitigate the adverse impacts of river regulation on fish movement, but evidence of successful environmental water deliveries for native fish benefits are limited. In order to determine the effects of environmental water on upstream fish movement, we trapped fish at eight fishways along Broken Creek to assess fish passage throughout the spring-summer-early autumn period between 2012 and 2014 – a total of 12 sampling occasions.

The project helps to address the Basin Plan's environmental watering plan objectives, and the proposed asset watering objectives for native fish in Broken Creek to '*Improve native fish habitat and passage*' and '*supply sufficient flow to operate the fishways and provide fish access to appropriate habitat all year'.*

Key findings

- Murray cod movement increased at higher discharges and water temperatures.
- Increasing the discharge from 300ML/d to 700ML/d during the September/October period doubles the probability of Murray cod moving through the Broken Creek fishways. However, this effect diminishes after December.
- Golden perch and Murray cod movement increased during flooding in 2010/11, and again during delivery of Commonwealth environmental water in September 2013.
- Golden perch were more likely to move at around 18°C to 24°C, which typically occurs during September/October, meaning they move at the same time as Murray Cod. However, movement was not closely linked with discharge.
- Movements for common carp were at their lowest early in the season when creek discharge is less than 400ML/d. However, increasing creek discharge from 300ML/d to 700ML/d will triple the number of carp moving through the fishways.

7.1 Introduction

Longitudinal connectivity is important for maintaining native fish populations (Mallen-Cooper 1996), and instream barriers adversely affect the movement behaviour of fish (Jones & Stuart 2008). With this in mind, vertical slot fishways were constructed on each of the low-level weirs along Broken Creek between Barmah and Numurkah during the late 1990's and early 2000's. Further, Environmental Water Allocations (EWA) are now being used to help mitigate the adverse effects of weir/dam construction and flow alteration on instream biota along Broken Creek, as provision of environmental water is known to stimulate spawning in native fish (Koster *et al.* 2014), while movement is also likely (O'Connor, O'Mahony & O'Mahony 2005; Koehn *et al.* 2009). Environmental water for Broken Creek is being provided by the Commonwealth Environmental Water Holder and managed through the Goulburn-Broken Catchment Management Authority.

7.2 Basin Plan objectives, cause-effect diagrams, and fishway monitoring

The cause and effect diagrams relevant to the Broken Creek fishway investigation include 'biotic dispersal' (Figure 7-1) and 'hydrological connectivity' (Figure 7-2), and both stem from the ecosystem function objectives hierarchy documented in MDFRC (2013)(Table 7-1), or relate specifically to the Basin Plan's environmental water objective '*protection and restoration of ecosystem functions of water-dependent ecosystems*'. The monitoring described in this report is able to assess the <1 year outcomes of Biotic Dispersal and Movement.

Table 7-1. Expected outcomes of environmental watering for biotic dispersal as defined by the Basin Plan objectives hierarchy (modified from Gawne *et al.* 2013).

Level 1 Objectives	**Level 2 Objectives**	**Level 3 Objectives**	**Expected outcome of watering actions (1-5 years)**	**Expected outcome of watering actions (< 1 year)**	**Relevant Cause and Effect Diagram**
Ecosystem Function	Connectivity			• Biotic Dispersal	Hydrological Connectivity
				• Movement	Biotic Dispersal

7.3 Logical basis for monitoring

7.3.1 Conceptual model

This investigation monitors the upstream movements of fish through the Broken Creek fishways (fishway trapping) throughout the spring-summer period 2012/13 – 2013/14. In order to guide the project design and analysis, a conceptual model was developed using previous fish movement information from Broken Creek (O'Connor & Koster 2005) and other regulated systems (Figure 7-3). The conceptual model proposes that elevated flows during the spring period will result in the highest number of fish moving through the Broken Creek fishways.

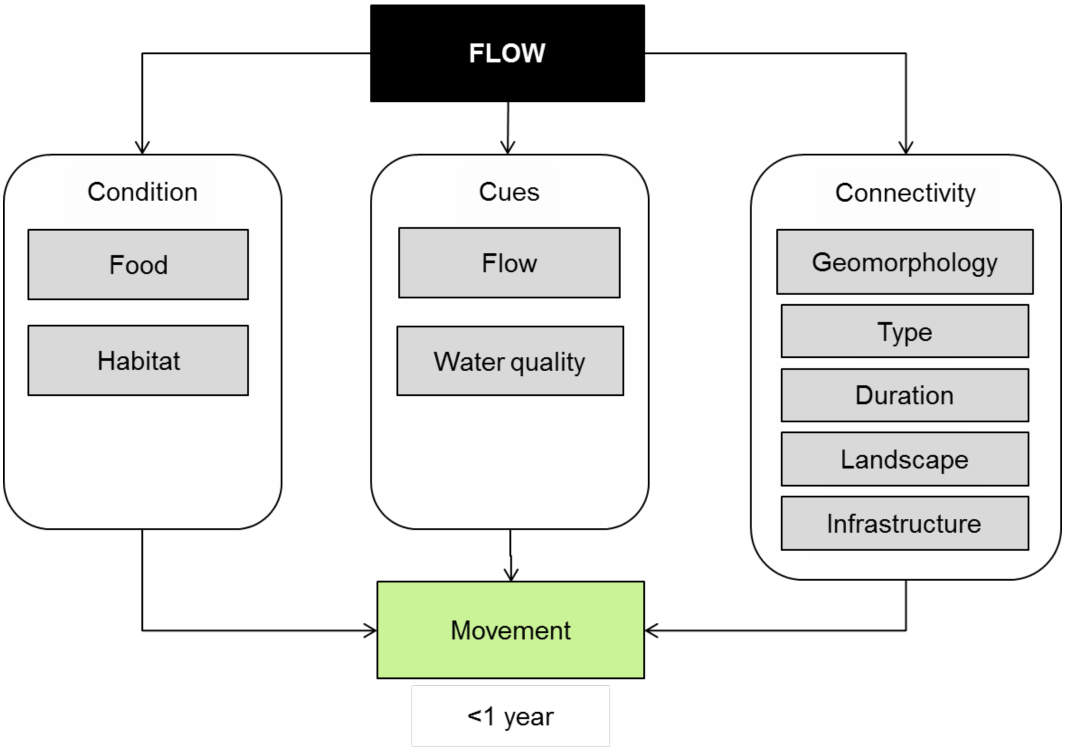

Figure 7-1. Generic cause-effect diagram (CED) for the effects of flow on biotic dispersal (reproduced from MDFRC 2013).

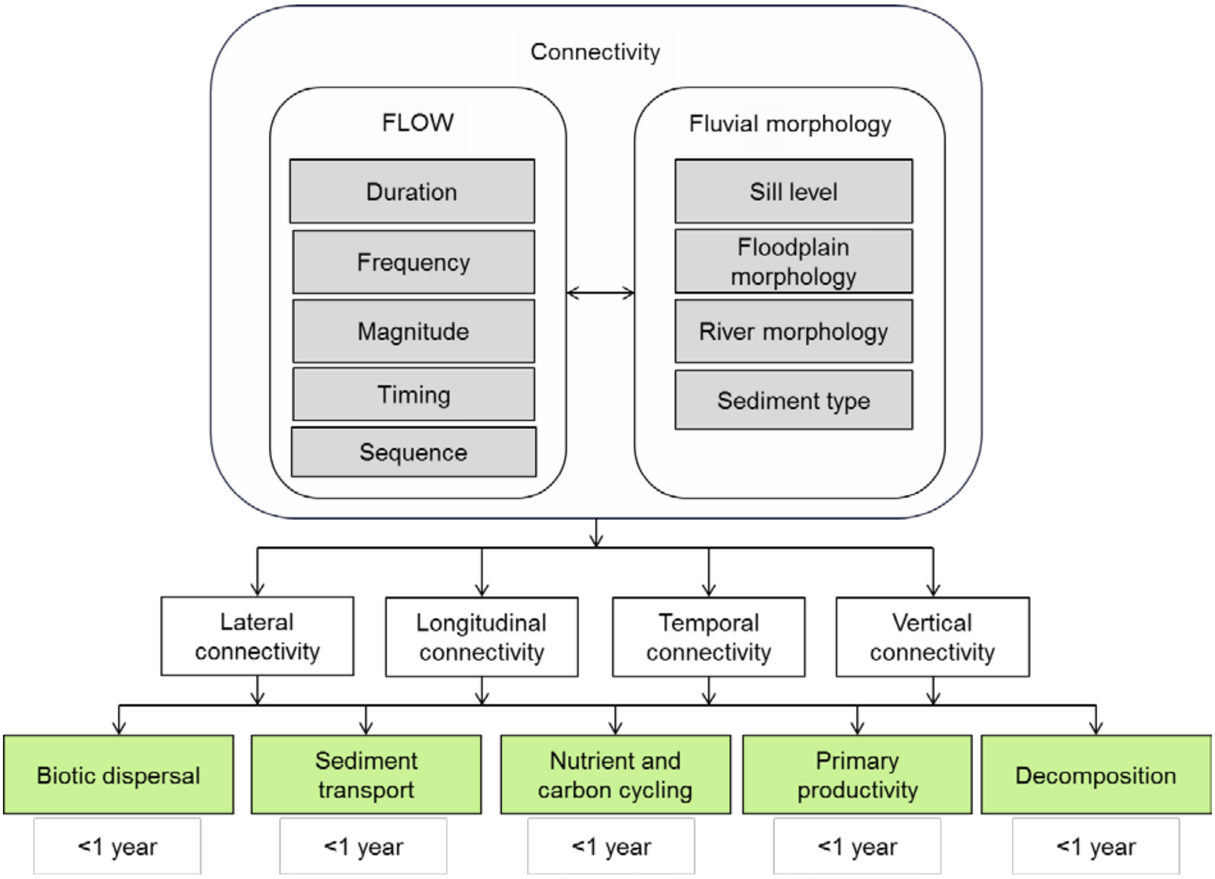

Figure 7-2. Cause-effect diagram (CED) depicting the hydrological connectivity influences of flow and fluvial morphology (reproduced from MDFRC 2013).

Two hypotheses were developed from the conceptual model: 1) The movement of fish through the Broken Creek fishways will increase with river discharge and, 2) The movement of fish through the Broken Creek fishways will increase from September – January. These hypotheses were tested using fishway trapping data and fish movement data.

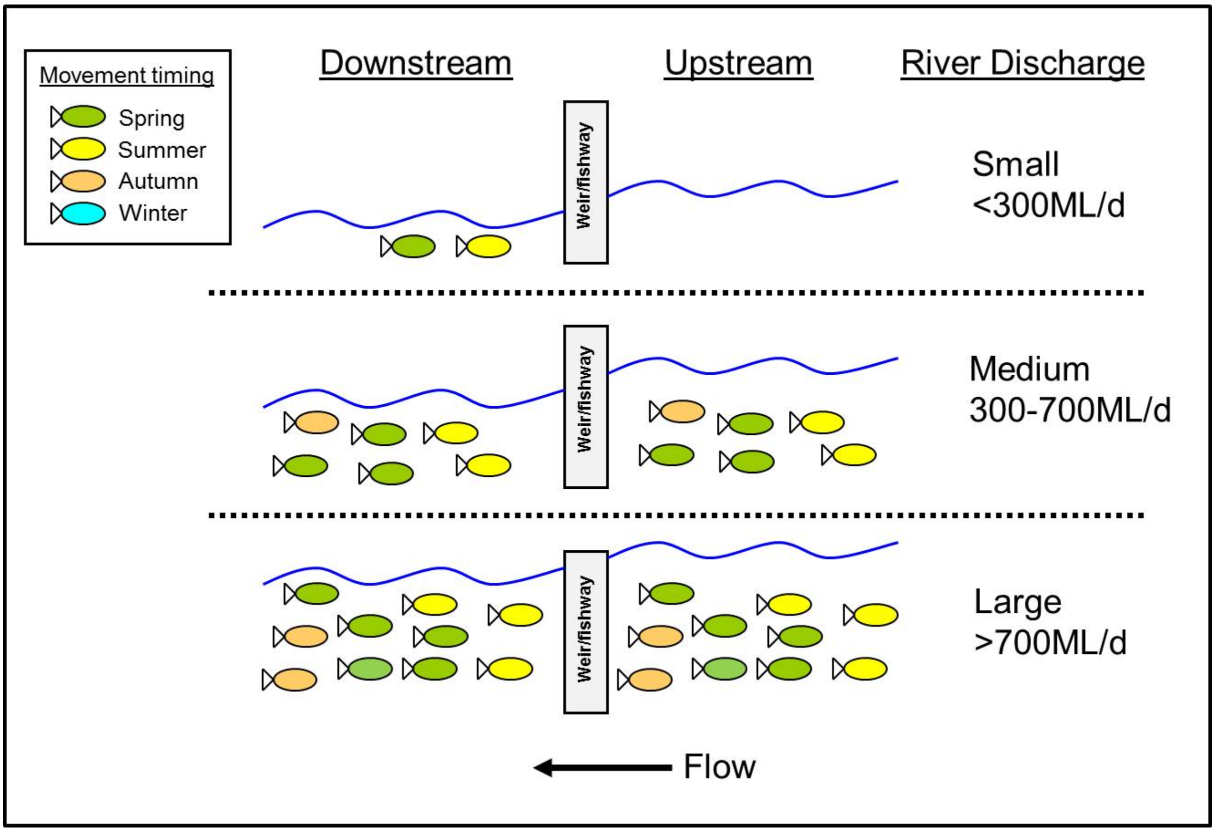

Figure 7-3. Conceptual model of fish movement through the Broken Creek fishways- more fish move through the Broken Creek fishways during high flows in the spring-summer period. Our sampling focused on the timing of movement in relation to environmental cues (flow and water temperature).

7.4 Methods

7.4.1 Study sites and field methods

The Broken Creek flows for approximately 200km in a westerly direction from Boosey Creek to the Murray River at Barmah. Ten low level weirs control flows along the Broken Creek between Numurkah and Barmah, these were constructed to regulate flows for agricultural purposes. Mean daily discharge in the creek is approximately 230 ML/d (range zero to 2139 ML/d). Each of the ten low-level weirs has a vertical-slot fishway to allow fish passage. Each fishway is generally operated from August – May, for the irrigation season. For a more detailed site description including riparian vegetation, list of native fish species, and details on the fishway specifications please refer to (Stewardson *et al.* 2013).

The trap design and sample procedures followed those documented in Stewardson *et al.* (2013). Fishway trapping (24h per sample) was conducted monthly between

September 2013 and February 2014 to collect fish moving upstream. All fish collected were counted and identified, and Passive Integrated Transponder (PIT) tags were implanted into fish >200 mm. PIT tags allow fish to be recorded as they move through the network of PIT readers systems installed along the Broken Creek. Fish implanted with PIT tags from previous research programs on Broken Creek (McKinnon & Shepheard 1995; ARI 2006; O'Connor & Amtstaetter 2008; O'Connor & O'Mahony 2008), were also included in the study. PIT tag movement data, creek discharge and water temperature were averaged by month (July 2009 to June 2014) for the analysis, and descriptive statistics were also used.

7.4.2 Data analysis

Bayesian analysis (Kéry 2010) was used to analyse the trapping data. Results presented refer to data analysed for both the 2012/13 and 2013/14 periods unless otherwise stated. Three Bayesian models were considered for the most common species (Murray cod, common carp, golden perch), with all models including the effects of flow, temperature and trip (i.e. sample date) as fixed variables. Site (or weir) was either excluded or included as a fixed or random effect for each model.

Each model was compared using information criteria to determine which model had the most support (See Chapter 6). Catch data for each species were transformed when necessary (e.g. log transform) to meet the assumptions of the statistical analysis. Data from a previous study (O'Connor & Koster 2005) were also used to inform the prior probability distributions for the Bayesian analysis. If the 95% high density interval (HDI) did not include zero, the parameter was considered to influence the rate at which fish use the fishway.

7.5 Results

Main results from the fishway monitoring can be summarized as:

- Common carp were most abundant species captured during fishway trapping, followed by golden perch, silver perch and Murray cod.
- Increasing the flow from 300ML/d to 700ML/d during the September/October period will double the probability of Murray cod moving through the Broken Creek fishways. However, the effectiveness of this environmental flow delivery diminishes after December.
- PIT tag data indicated that movement of both golden perch and Murray cod increased during flooding in 2010/11, and again during delivery of Commonwealth environmental water in September 2013
- Flows in excess of 350ML/d during September and October are required to stimulate common carp to movement, with a flow of 600 ML/d tripling the number of fish moving the fishways.

7.5.1.1 PIT tagged fish

- A total of 1044 fish comprising three native fish species and three alien fish species have been implanted with PIT tags since 2005 – these fish have been PIT tagged over numerous programs along Broken Creek.
- A total of 255, 267, and 21 golden perch, Murray cod and silver perch respectively were PIT tagged. A total of 481 carp were also PIT tagged.
- A total of 194 individual fish (Murray cod, golden perch and carp) have subsequently been recorded on the Broken Creek PIT reader system.
- Movements of Murray cod and golden perch appeared to increase with increasing discharge and water temperature.
- Common carp movements were more consistent throughout the year, but appeared to increase with increasing discharge and water temperature.

The number of PIT tagged fish recorded (per month, 2005 - 2014) moving through the Broken Creek fishways was plotted against mean monthly water discharge and water temperature (Figure 7-4). The number of golden perch and Murray cod moving through the fishways appeared to increase with water discharge and water temperature during the large flood event in 2010-11, however this relationship was not as clear from 2012 onwards for golden perch, given the relatively low discharges, but a pattern was still present. Similarly, the movement pattern of carp appeared to increase with increasing water discharge and temperature, but movement through the fishways was also more consistent (Figure 7-4).

7.5.2 Fishway Trapping

A total of 207 fish, represented by five species, were captured from fishway trapping (Table 7-2). Common carp were the most common species sampled, followed by golden perch, silver perch, Murray cod, and goldfish. Common carp were collected in all trips with the exception of October 2013, while the highest catches were recorded in October 2012 and March 2013. Low numbers of Murray cod were captured throughout the sampling season, with six being captured in October 2012 (Table 7-2). Golden perch were recorded on all trips with the exception of September 2012, with the highest catches being recorded in September 2013 and October 2012. Silver perch were caught in low numbers over the 2012/13 and 2013/14 season. Goldfish were only recorded on one trip in 2012. Murray cod were the smallest and largest fish being recorded moving through the fishways (150-710 mm), while golden perch approximately 450 mm were common.

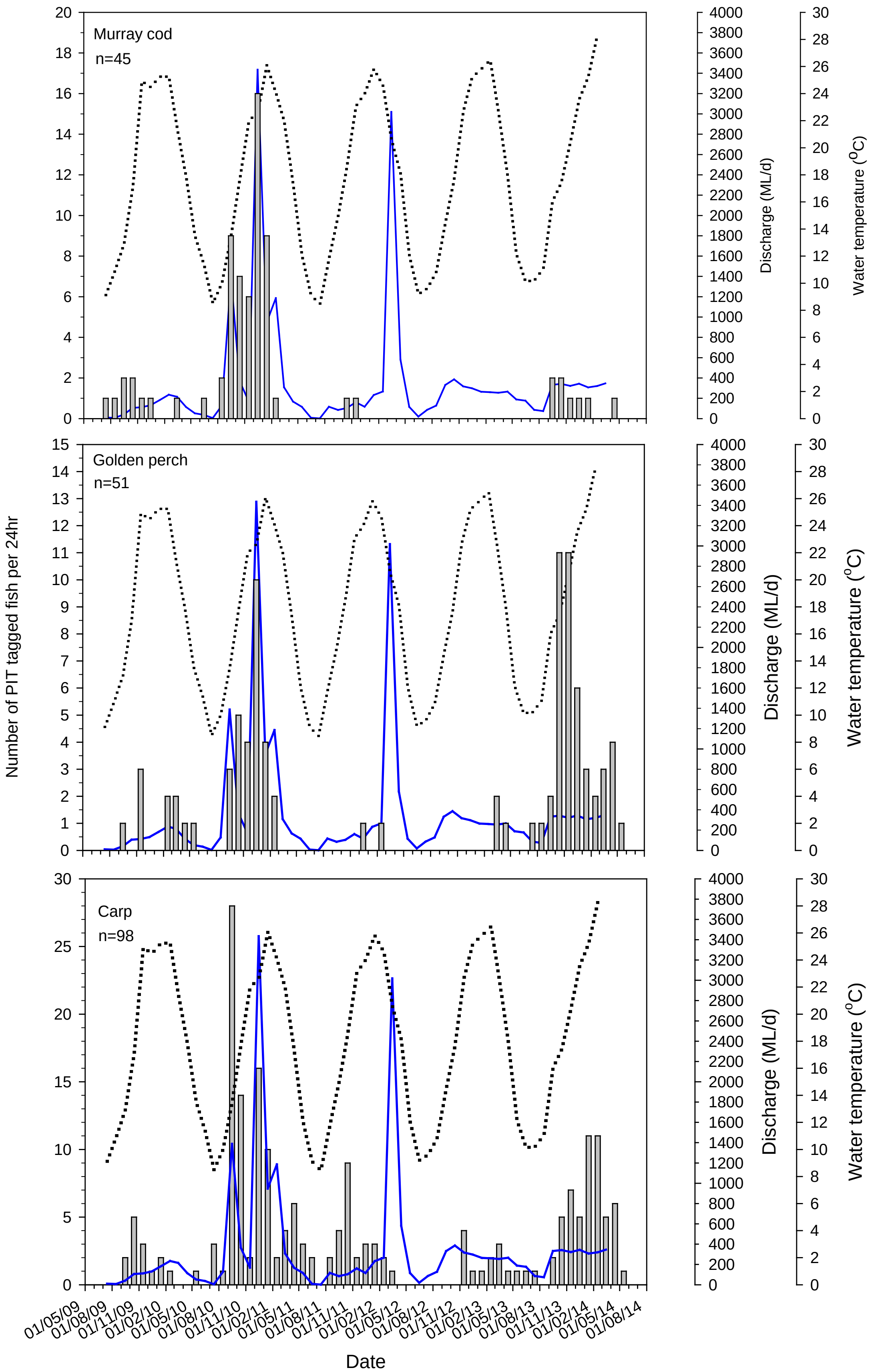

Figure 7-4. Number of PIT tagged fish recorded at fishways along Broken Creek per month. Solid line is Broken Creek discharge at Rice's Weir, dotted line is water temperature at Rice weirs.

Table 7-2. Total number of fish collected in fishway traps (all eight) from September 2012 to February 2014.

Trip	2012-13 Sept	Oct	Nov	Dec	Jan	Mar	Sub-total	2 yr total
Species								
Common carp	3	21	19	16	6	22	**87**	
Goldfish	0	1	0	0	0	0	**1**	
Silver perch	0	0	3	1	0	3	**7**	
Murray cod	2	6	0	0	0	0	**8**	
Golden perch	0	8	2	2	2	8	**22**	
Total	**5**	**36**	**24**	**19**	**8**	**33**	**125**	
Common carp	3	0	5	8	10	10	**36**	**123**
Goldfish	0	0	0	0	0	0	**0**	**1**
Silver perch	1	1	1	3	2	1	**9**	**16**
Murray cod	3	1	0	1	2	0	**7**	**15**
Golden perch	12	5	1	5	4	3	**30**	**52**
Total	**19**	**7**	**7**	**17**	**18**	**14**	**82**	**207**

7.5.3 Bayesian Analysis

7.5.3.1 Main points

- The majority of samples were collected (89 of 96) during low flow periods (<400 ML/d). Seven samples were collected when discharge was >550 ML/d, but 6 of these occurred during one trip.
- Murray cod movement increased with elevated flow (>500ML/d) early in the spring-summer season i.e. Sept/Oct. This coincided with the commencement of environmental flows.
- Both water temperature and flow were found to influence carp movement through the fishway, but the association was not as strong as for Murray cod.
- Golden perch movement was influenced by water temperatures, but flow did not influence movement. Golden perch were more likely to move around 18°C, which typically occurs during Sept/Oct, like Murray cod.
- Silver perch were recorded in low abundances such that the data could not be analysed. No clear pattern of movement was evident from the observations.

7.5.3.2 Murray cod

The movements of Murray cod upstream through fishways were found to be associated with flow and number of days past September 1st (Figure 7-5). The probability of movement through fishways was highest when flows exceeded 600 ML/d around day 45 i.e. mid-October. This probability reduced as time progressed or as flows decreased.

7.5.3.3 Golden perch

Golden perch movements were found to be associated with water temperature, with movement increasing at 18 and 24˚C (Figure 7-6). This result contrasts that obtained during the 2012/13 season (only), which found that movement was related to both increased discharge and water temperature. Weir sampled also showed an effect with Chinaman's weir passing the highest abundances of golden perch per 24hrs, followed by Kennedy's weir (Table 16-4).

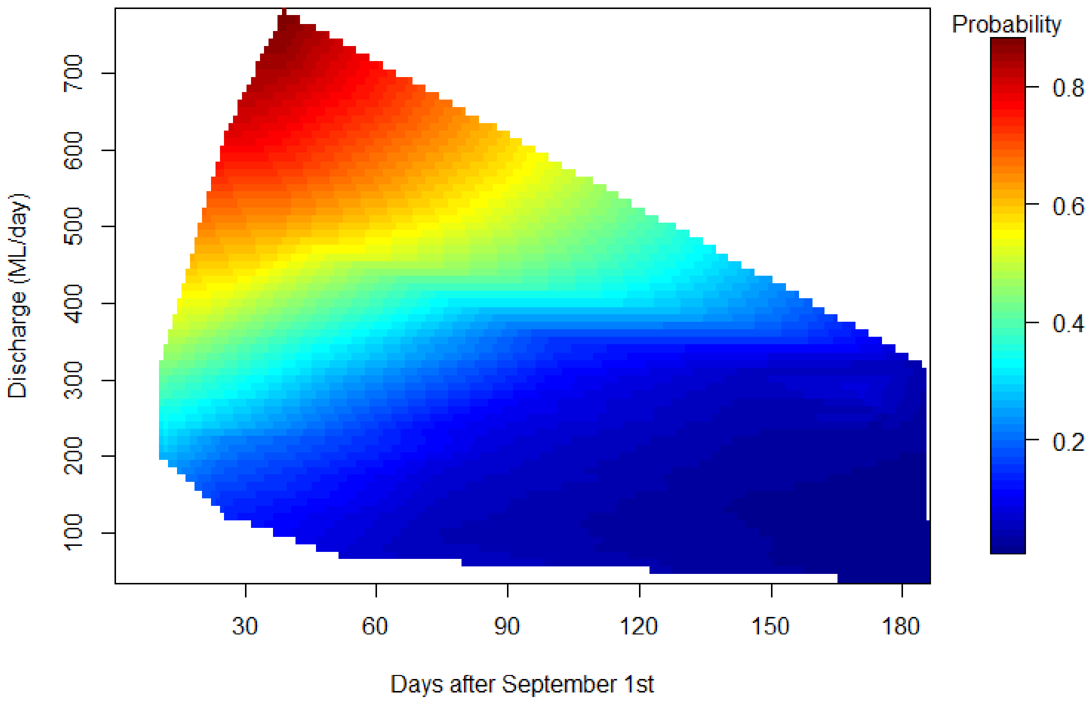

Figure 7-5. The probability of a Murray cod moving through a fishway on Broken Creek in relation to creek discharge and time (days after September 1st. Colour of plot denotes probability movement (as shown in the key) under the combination of driving conditions on x and y axes.

7.5.3.4 Silver Perch

The results from the silver perch caught indicate that the data follow a Poisson distribution. However, the consistently low numbers of fish captured prevented any meaningful statistical analysis. On average, we would expect to catch one silver perch every eight days.

7.5.3.5 Carp

The movement of carp was associated with both water temperature and flow (Figure 7-7). This result is in contrast to the results from the 2012/13 sampling season, which found that neither water temperature or flow were associated with fish movement. The effect of flow was strongest up to approximately 550 ML/d, after which it reduced. Less flow is required to induce carp movement at higher water temperatures, but flows in excess of 300 ML/d are required to stimulate fish to move when water temperatures are less than 18°C (Figure 7-7).

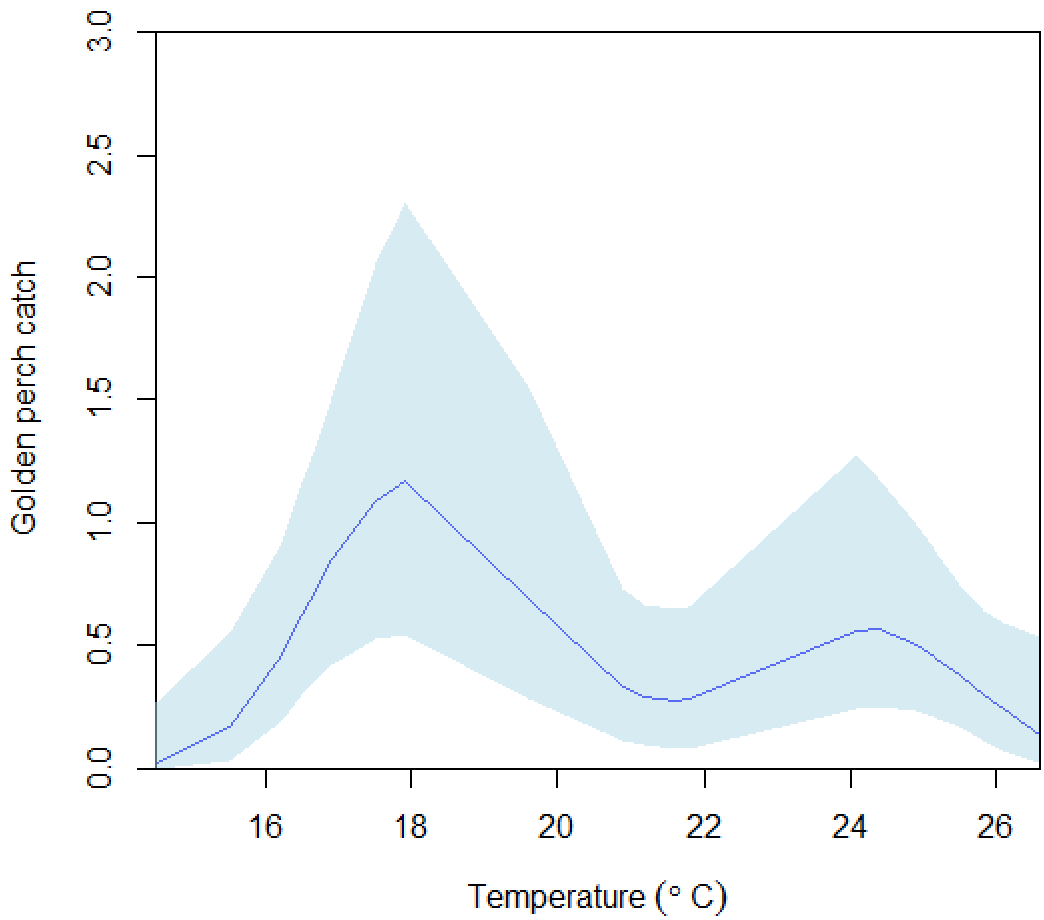

Figure 7-6. The estimated number of golden perch per day as a function of water temperature. Shaded area represents the 95% credibility intervals of expected catch.

7.5.4 Benefits of environmental flows

- Sampling of fishways occurred during environmental water delivery, as fish generally move during warmer months of the year, when environmental flow delivery and irrigation was occurring.
- Environmental flow delivery during September and October enhanced Murray cod movement through the Broken Creek fishways.
- Carp responded to flow, however they moved consistently throughout the seasons. Environmental flow delivery in excess of 400 ML/d during September and October may benefit carp movement, with movement otherwise increasing with water temperature.
- The movements of silver perch were not able to be modelled as the data failed the underlying assumptions of Bayesian analysis.

- The movements of golden perch were not associated with environmental flows in the 2012/13 and 2013/14 study period, but they were aligned with water temperatures. Therefore, environmental flow delivery at water temperatures around 18°C and 24°C will benefit golden perch the most.
- In contrast to trapping data, the PIT tag data (including historical data) indicated that golden perch will respond to large discharges (flooding) and rising water temperatures by increasing their movement through fishways.

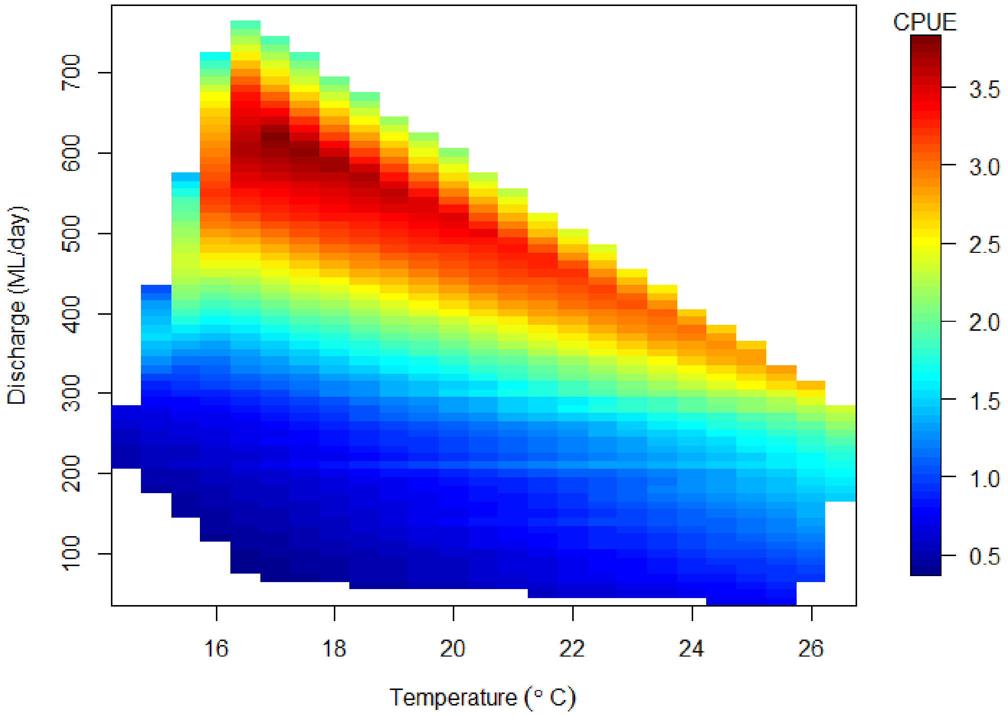

Figure 7-7. Expected number of carp per weir (per 24 hr sample) at recorded temperature and discharge combinations.

7.6 Discussion

7.6.1 Murray cod

The results documented in this investigation suggest that delivery of environmental water in Broken Creek should be targeted towards Murray cod, as their results were clear and positive. Delivering environmental water during the early spring-summer period (i.e. September/October) will increase the probability of upstream movement of Murray cod, and as such, address the objectives of the environmental watering plan, namely objectives 1 and 2 - to protect and restore water-dependent ecosystems of the Murray-Darling Basin, and to protect and restore the ecosystem functions of water-dependent ecosystems.

The value of environmental water delivery was demonstrated during September and October of each year of sampling, with more fish moving during flow events compared with later periods. The results for Murray cod are not surprising given that prior research has found that they are most active in spring/early summer (Koehn et al. 2009), and spawn in later October-December (Humphries 2005). In fact, Murray cod are known to migrate large distances (<130 km) for spawning-related activities, sometimes returning to the same site afterward (Koehn & Harrington 2006; Koehn et al. 2009). These movement data also provide important records of Murray cod moving through fishways, as few studies have documented this.

Murray cod showed a decline in fishway usage later in spring/summer (when water temperatures increased), with the effect of environmental water on movement probabilities substantially reduced after December. This result is important as it enables waterway managers to target pre-spawning migrations with environmental water, rather than trying to provide flows to cue spawning activities. Subsequent irrigation flows are likely to provide suitable maintenance flows for completion of spawning activities.

Importantly, anecdotal evidence suggests that environmental flows delivered later in the season may help ameliorate the adverse impacts of low dissolved oxygen levels on Murray cod, and so fish kills, in the lower reaches of the creek, and therefore, they must still be considered. Further, colonization from adjacent areas, such as the Murray River and Barmah-Millewa Forest, may also be aided by environmental flows during warmer months.

These results should be considered against the backdrop of relatively low flow (average 314 ML/d, range 84-759 ML/d) that occurred in Broken Creek over the two sampling seasons. The PIT tag data, which have been accumulating over a much larger time period, indicate that Murray cod will move during the warmer months when flooding occurs (i.e. ~ 1000 ML/d). Therefore results presented here may be less applicable in the event of flooding in Broken Creek.

7.6.2 Golden Perch

The movement cue for golden perch was most closely aligned with water temperature and weir, rather than flow. This is in contrast to results from 2012/13 which found that movement was related to both flow and water temperature. However, the 2012/13 sampling season included a flow in excess of 700 ML/d, to which fish responded, while flows during the 2013/14 sampling season rarely exceeded 400 ML/d. This suggests that higher discharges (i.e. somewhere between 400 and 700 ML/d) are required to cue golden perch movement through the Broken Creek fishways.

Despite this, these results support previous findings on golden perch movement, which found them to be particularly active between September and February/March (Mallen-Cooper 1996; O'Connor, O'Mahony & O'Mahony 2005), with a correlation between water temperatures and movement rates (Reynolds 1983; O'Connor, O'Mahony & O'Mahony 2005; Jones 2007). Our results show that golden perch are active during these periods.

However, like Murray cod, golden perch movement increased during flooding in 2010/11 and again during early spring in 2013, which corresponds to rising water temperatures and increasing flows. Delivery of environmental water for golden perch in Broken Creek should therefore aim to coincide with water temperatures around 18°C, which will also link with the environmental water delivery option for cueing Murray cod movement. Delivering environmental water during this period will help to meet the Basin's plans objective of protecting and restoring water-dependent ecosystems of the Murray-Darling Basin; and protecting and restoring the ecosystem functions of water-dependent ecosystems.

The life-history of the target species should also be considered when planning environmental water deliveries for Broken Creek. If the aim of the environmental flow is to stimulate golden perch spawning, then it is best done around October-November for the mid-Murray (King, Tonkin & Mahoney 2009). However, if the aim is to stimulate upstream movement/dispersal, then targeting 18°C and later on in the season (i.e. December-March) may provide better results (Mallen-Cooper 1996). Similarly, delivering larger volumes (>400 ML/d) of environmental water will stimulate more golden perch to move compared with smaller volumes (i.e. <400 ML/d).

Similarly, golden perch also undertake downstream movements in the Broken Creek, with higher flows resulting in more fish moving over Kennedy's weir (O'Connor et al. 2006). The same study also suggested that smoother flow delivery (i.e. weir approach velocity/turbulence) is likely to reduce behavioral inhibitions of fish moving downstream at instream structures. As such, delivering water in a fashion that facilitates downstream migration over the weirs will help to minimise the impact of instream barriers.

7.6.3 Common carp

Delivery of environmental water for native species unavoidably results in delivery of environmental water for exotic species, such as common carp. This investigation has, however, demonstrated that delivering environmental water at low discharges (<400 ML/d) early in the season (when water temperatures are <18°C), does not result in a significant increase in carp movement through the fishways. These results fit with the MDBA's environmental watering plan – to ensure that water-dependent ecosystems are resilient to climate change and other risks and threats. They also fit neatly with delivery of environmental water for Murray cod, which respond to water delivery early in September and October when water temperatures are increasing, but still remain cool.

In contrast, delivering environmental water when water temperatures are in excess of approximately 20°C, will benefit common carp, and less water is required to achieve the same degree of movement. However, we do not recommend withholding environmental water during such periods; the overall net benefit for other native fish species, such as golden and silver perch, also merits consideration during warmer periods.

The results from the Bayesian modelling of carp movement differed slightly between the first and second sampling seasons, with the first season indicating that flow did not influence movement, but the second indicating a slight effect of flow. This is likely due to the sampling being limited to two seasons, with additional sampling likely to clarify the role of flow on carp movement.

Despite the role of flow being somewhat unclear for common carp, it is known that elevated flows provide greater access to lateral habitats, such as low-lying floodplains, which common carp are known to prefer (Jones & Stuart 2009). Common carp use low-lying floodplain habitats for spawning when temperatures exceed approximately 17°C in early spring (Stuart & Jones 2006a). Environmental watering strategies for Broken Creek should therefore consider that passage of common carp through the fishways is not likely to be influenced by creek discharge below 400 ML/d early in the spring season, but that a spawning event may occur.

These findings should also be considered in the context of the relatively low flows that occurred during the 2012-2014 period. Large flow events (including flooding) are likely to influence the behavior of common carp given that they are known to have flexible movement strategies and take advantage of suitable floodplain conditions when they become available (Jones & Stuart 2009). Some common carp for example, are known to migrate more than 100 km to access floodplain habitats when they become available (Stuart & Jones 2006b; Jones & Stuart 2009).

Further, another investigation documented significant numbers of common carp juveniles drifting out of the Barmah-Millewa forest floodplain and migrating up through the Rice's weir fishway (the lowest fishway on Broken Creek) during the 2000 flood event (Stuart & Jones 2002). Similarly, PIT tag movement data from this investigation indicated that common carp movements peaked during the spring-summer flooding of the Broken Creek during 2010/11, but movement continued at a low level during non-flooding periods.

These data suggest that the Barmah Millewa forest may be a significant source of common carp for Broken Creek, and a Broken Creek carp management/environmental watering plan should consider the broader context within the region.

7.6.4 Silver Perch

In depth analysis was not undertaken on silver perch due to the low abundances collected throughout the investigation. The low abundances are however, consistent with previous findings on the Broken Creek (e.g. O'Connor & Amtstaetter 2008; O'Connor & O'Mahony 2008). Similarly, the timing of movement (November, December and early March) documented during this investigation is also consistent with a previous fishway investigation on the Murray River (Mallen-Cooper 1996).

Given the lack of data, providing environmental watering recommendations for silver perch based on this investigation would be premature. Environmental water managers in the Broken Creek should instead be guided by spawning and recruitment data for silver perch collected from the Murray River, until sufficient data specific to the species can be obtained from Broken Creek. Silver perch are known to spawn from November to February and during within and overbank flows (Mallen-Cooper & Stuart 2003; King, Tonkin & Mahoney 2009). A previous investigation along the Murray River found that silver perch increased their spawning activity (i.e. increased number of eggs/larvae detected) during the delivery of environmental water (King *et al.* 2009).

8 Synthesis of results across programs

Environmental flow regimes are developed to benefit rivers as a whole. Ecological benefits of environmental flows to physical habitat and riverine processes are hypothesized to flow on to higher-level ecological responses. Nevertheless, monitoring is normally undertaken as a series of semi-independent programs aimed at different environmental responses.

This program was no different. We implemented six different monitoring programs all aimed at individual responses or groups of related responses. To provide a more holistic overview of the entire monitoring program, and what benefits environmental flows are having for the Goulburn River and Broken Creek systems as a whole, we undertook a qualitative synthesis of the individual monitoring program, and produced a conceptual model showing how the different results underpin, explain, and complement each other.

Key findings

- Sediments mobilized by environmental flows increased water-column nutrient levels and mobilized organic matter, driving increases in primary production and creating food for higher-order ecological responses.
- Environmental flows increased pool and slackwater habitat for native fish. Slackwater environments would also have trapped nutrient rich sediments and seeds, leading to improved native vegetation and providing habitat for larval fish.
- Environmental flows caused movement of native adult fish in both rivers, and spawning of golden perch in the Goulburn. This is the first time that major spawning has been detected following managed environmental flows in the Goulburn River.
- Golden perch larvae appear to have been exported from the Goulburn River system, suggesting that recruitment occurs at a much larger multi-basin scale.
- This monitoring program has, for the first time, provided strong evidence for the beneficial effects of environmental flows on the physical, chemical, and biological function of the lower Goulburn River. The lessons learned will be used to inform the Commonwealth long-term intervention monitoring project, commencing in 2014.

8.1 Introduction

The different monitoring activities that make up the 2013/14 short-term intervention monitoring program were undertaken largely in isolation of one another. However, many of the individual results complement each other, allowing a qualitative synthesis of the outcomes from different activities to better explore the narrative of environmental flows in the lower Goulburn River and Broken Creek during 2013/14. In this section, we draw together the disparate results across programs, finding clear linkages between physical responses, primary and secondary productivity and higher order effects on vegetation and fish. These results combine to create a powerful message concerning the environmental benefits that accrued from environmental water in these systems.

8.2 Conceptual model of outcome linkages

We have attempted to link many of the observations from the different monitoring programs into a single conceptual model for the lower Goulburn River (Figure 8-1). The environmental flows program in the lower Goulburn River in 2013/14 was based around improved baseflows and the two major spring freshes.

Increased discharge during the spring freshes appears to have mobilized sediments from the river banks and from inputs from unregulated tributaries (the environmental water itself is almost devoid of sediments as it comes from a dam). This was not directly measured, but turbidity increased during the freshes and fine sediments were mobilized during these events. These effects were strongest at McCoy's bridge, further downstream, lending more weight to the argument that these sediments are being mobilized within the lower Goulburn River itself.

Increased water column turbidity was associated with increased nutrient availability, to the extent that nutrient levels exceeded ANZECC water quality guidelines during peak flow events. Nutrients are often associated with sediments, tightly bound to colloidal surfaces. However, in this case, bioavailable nutrient levels also increased during the freshes. These nutrients would have stimulated primary productivity in the system, leading to the observed increase in water column primary productivity and an increase in benthic algae. This algae (as a food source), along with sediments scoured clean of fine sediments by the later freshes, could partly explain the increase in macroinvertebrate abundance observed, although we note that these were not benthic invertebrates, and so the link is relatively weak. An alternative explanation for the increase in macroinvertebrate abundance with the freshes is an increase in water column drift.

The freshes and higher base flows increased the availability of both pool and slackwater habitat in the system. Importantly, the spring freshes were not so high that they led to a reduction in slackwater habitat. Rather, the inundation of low-lying benches created large amounts of temporary slackwater. These areas would probably have experienced deposition of seeds and nutrient-rich sediments from further upstream. This would explain the rapid growth of native vegetation on low-lying benches after they emerged from the water.

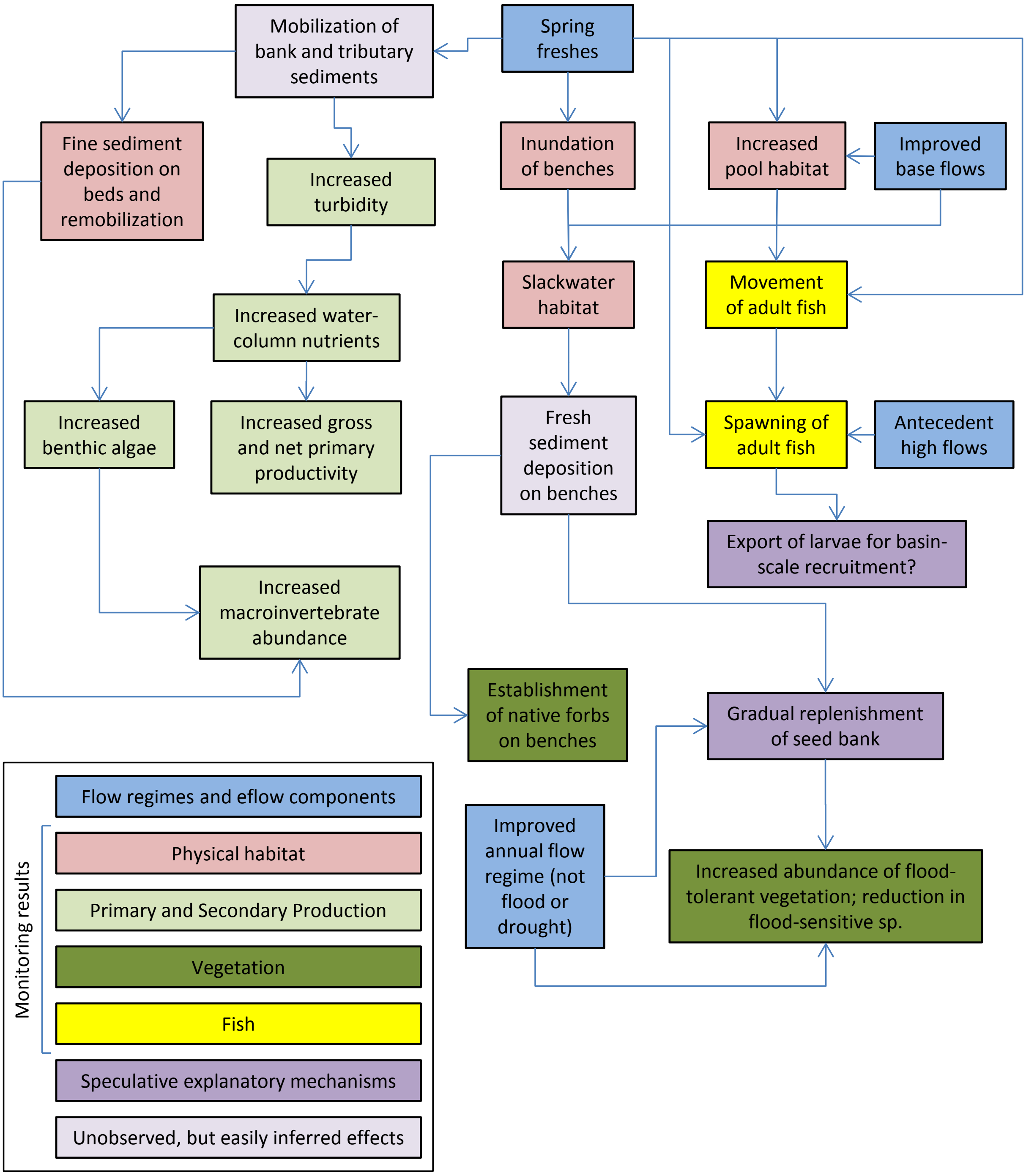

Figure 8-1. Synthesis of results across monitoring programs. Flow drivers, results from the different parts of the monitoring program, and inferred and hypothesized effects and mechanisms are colour-coded according to the inset key.

Inundation of benches and bars by environmental flows may also be slowly replenishing river bank seed banks following 10 years of drought and subsequent floods. Together with generally improved annual-scale flow regimes, this may be facilitating the establishment of more flood-tolerant vegetation on the river banks while also reducing the abundance of terrestrial vegetation species.

The high flow events were associated with the movement of golden perch adults, many moving to the area where eggs and larvae were observed during the first spring fresh. However, we note that the spawning success observed in 2013/14 occurred at discharge levels similar to previous unsuccessful spring freshes. We believe that the antecedent high-flow conditions prior to the spring fresh may have been an important precursor to successful spawning during the November fresh. The failure to identify any recruits from this spawning event was disappointing, but may point to the larvae being exported from the Goulburn River by the high flows, with recruitment subsequently occurring further downstream. Whether any such recruits will return to the Goulburn River is unknown, but the capture of a single 1-year old golden perch (98mm in length) with an otolith chemical signature from the Murrumbidgee river demonstrates that even small fish of this species move long distances, and that adults in the Goulburn River may have recruited elsewhere before migrating into the system.

We have not attempted to create a separate conceptual diagram for the fish movement results from Broken Creek, but note that they largely agree with the observations from the Goulburn River. Movements of acoustic-tagged golden perch in Broken Creek were mostly associated with the slight rises in discharge observed in that system, although in the absence of large flow events, it is difficult to be certain. Movement of pit-tagged fish through the Broken Creek fishways also occurred in response to rising flows. In both the Goulburn and Broken systems, movements of tagged fish were not ubiquitous; approximately half of acoustic-tagged fish undertook substantial migrations in both systems. The proportion of pit-tagged fish moving was higher, but it must be noted that these fish were only ever tagged after first being trapped while moving through a fishway. Thus the tagging program is biased towards those individual already inclined to move.

8.3 Conclusion – effects of environmental flows in the lower Goulburn River and lower Broken Creek in 2013/14

The individual results presented in greater detail in the preceding chapters, and in exhaustive detail in the attached appendices, together with the complementary narrative outlined above, are indicative of major environmental benefits arising from environmental flows delivered in the lower Goulburn River and lower Broken Creek in 2013/14.

The environmental benefits of water delivered to lower Broken Creek were already known in detail from the 2012/13 short-term intervention monitoring program, and from earlier research. Put bluntly that system relies on Commonwealth and other environmental water to maintain dissolved oxygen levels and prevent Azolla blooms. Without these, major fish kills of the important populations of native fish in the Broken Creek weir pools are virtually assured. The 2013/14 monitoring highlights the importance of environmental flows for promoting movements of native fish through the system, which is also important for maintaining these populations.

Benefits of environmental flows in the Goulburn River were less well known, and the 2012/13 short-term intervention monitoring program was not able to strongly demonstrate beneficial effects (Stewardson *et al.* 2013). Results in 2013/14 have greatly improved upon this starting point. We can now point to the importance of spring freshes for mobilizing sediments and nutrients, driving increases in primary and secondary productivity in the system, creating slackwater habitat for the germination and growth of native vegetation and for larval fish and microinvertebrates. The freshes promoted movement of native fish and resulted in the largest spawning event for golden perch in the Goulburn River since the 2010 floods. There were no areas within the program that were not able to detect beneficial effects of environmental flows.

Looking forward, the Goulburn River has been selected as one of 7 Selected Areas to be monitored under the Commonwealth Environmental Water Office long-term intervention monitoring program. We are building upon the lessons learned during two seasons of short-term intervention monitoring programs to further improve our abilities to detect beneficial effects of environmental watering in the lower Goulburn River. Such innovations include:

- 2-dimensional habitat modelling to provide better indications of how different classes of hydraulic habitat (e.g. slackwater) change in response to different flows;
- direct monitoring of bank erosion to assess the degree to which environmental flows mobilize bank sediments and whether they are having any negative effects upon channel structure;
- a new approach to monitoring macroinvertebrates that will focus upon biomass accumulation of benthic species, and will also monitor emergence responses to individual flow events;
- improved vegetation sampling techniques that can produce more accurate estimates of vegetation abundance;
- more intensive adult fish sampling, including sampling of otoliths to age fish; and
- basin scale monitoring of adult fish movement, with compatible tags to be used by several selected area monitoring programs, allowing us to better determine the scale over which species such as golden perch move.

All of these programs will be able to employ the data and results generated by the 2012/13 and 2013/14 short-term monitoring programs, improving their inferential strength and ability to determine the achievement of Basin Plan objectives and other benefits of environmental flows.

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11 Appendix A – Detailed site locations

Table 11-1. Detailed site locations that appear in Figure 1-5. X indicates the activities taking place at each site. All Eastings and Northings are in Map zone 55.

Name	Easting	Northing	Electro-fishing	Acoustic tracking	Fish larvae	Fish-ways	Vegetation	Physical habitat	Ecosystem processes	Flow gauge
Murchison (Cable Hole)	341868	5938056	X	X	X					
Moss Road	337452	5936179					X			
Cemetery Bend	349750	5957507	X	X	X					
Darcy Track	351770	5965722					X	X	X	
Pyke Road	352716	5967435	X	X						
Mooroopna	353726	5971336	X	X						
Shepparton	355948	5972594	X							X
Shepparton Weir	352219	5975527	X	X						
Loch Garry	346077	5987849	X	X			X			X
Pogues Road Undera	344292	5992145	X							
Kotupna	340077	5996396	X	X						
McCoys Bridge	331200	5994786	X	X			X	X	X	X
Murrumbidgee Road Pederick	323238	5996959	X							
Yambuna	320302	5999674	X	X	X					
Junction 1	305518	6002610		X						
Junction 2	305888	6002094		X						
Kanyapella	313197	6003521	X	X						
Rice’s Weir	316200	6017600				X	X			X
D/S RicesW2	315783	6018256		X						
D/S RicesW1	316101	6017931		X						
Downstream junction	304115	6002554		X						
Upstream junction	305235	6002922		X						
0.2 km	316375	6017604		X						
0.4 km	316483	6017437		X						
6.6 km	318655	6013329		X						
7.0 km	318939	6012990		X						
0.6 km	316572	6017297		X						
0.8 km	316735	6017204		X						
1.0 km	316918	6017194		X						
1.2 km	316950	6017010		X						
1.4 km	316857	6016889		X						
1.6 km	316948	6016750		X						
1.8 km	317085	6016583		X						
2.0 km	317253	6016683		X						

Name	Easting	Northing	Electro-fishing	Acoustic tracking	Fish larvae	Fish-ways	Vegetation	Physical habitat	Ecosystem processes	Flow gauge
2.2 km	317384	6016578		X						
2.4 km	317295	6016416		X						
2.6 km	317415	6016301		X						
2.8 km	317522	6016213		X						
3.0 km	317622	6016037		X						
3.2 km	317651	6015852		X						
3.4 km	317815	6015778		X						
3.6 km	317901	6015573		X						
3.8 km	263957	6014198		X						
4.0 km	318133	6015290		X						
4.2 km	318139	6015111		X						
4.4 km	318291	6014974		X						
4.6 km	318172	6014814		X						
4.8 km	318083	6014632		X						
5.0 km	317964	6014447		X						
5.2 km	317936	6014246		X						
5.4 km	318035	6014159		X						
5.6 km	318208	6014073		X						
5.8 km	318313	6013928		X						
6.0 km	318484	6013853		X						
6.2 km	318628	6013702		X						
6.4 km	318615	6013462		X						
6.8 km	318735	6013141		X						
7.2 km	319126	6012909		X						
7.5 km	319246	6012648		X						
Kennedys Weir	320964	6011978		X		X	X			
Harding’s Weir	327173	6009044		X		X				
Schier’s Weir	323384	6012056				X	X			
Lucke’s Weir	331537	6009997				X				
Balls Weir	334530	6010643		X		X	X			
Chainman’s Weir	337350	6009683				X				
Nathalia Town Weir	338806	6006804				X				
Seven Creeks @ Kialla West	356542	5964189								X
Broke River @ Orvale	361042	5967072								X
Murchison	340787	5946120								X

12 Appendix B – Further physical Habitat results

Table 12-1. Results of the influence of hydrologic metrics on sediment smothering: slope and significance. These results are based on normalized data (using square root of sediment data) to produce linear models.

Variable Assessed	Coefficient	P-Value	Significance
Days of greater than 2k flows in preceding month	-0.018012	4.47e-12	Yes
Days of greater than 3k flows in preceding month	-0.010641	0.0023	Yes
Days of greater than 4k flows in preceding month	-0.012038	0.00203	Yes
Days of greater than 5k flows in preceding month	-0.014981	0.000305	Yes
Days of greater than 6k flows in preceding month	-0.016753	0.000326	Yes
Days of greater than 7k flows in preceding month	-0.02770	0.00189	Yes
Days since flows greater than 5k	0.001500	5.02e-05	Yes
Days since flows greater than 10k	0.0006690	0.0158	No. Inadequate occurrences.
Days of flows less than 1500 in preceding month	0.015409	6.39e-11	Yes

Volume of flow in preceding month	-3.023e-06	7.22e-07	Yes. But small change.
No Eflow days in preceding month	-0.009232	1.6e-06	Yes
Days of Baseflow in preceding month (0<flows<700)	0.014981	1.01e-13	Yes
Days of Fresh flow in preceding month (flow>700)	-0.006595	0.0103	Slightly.

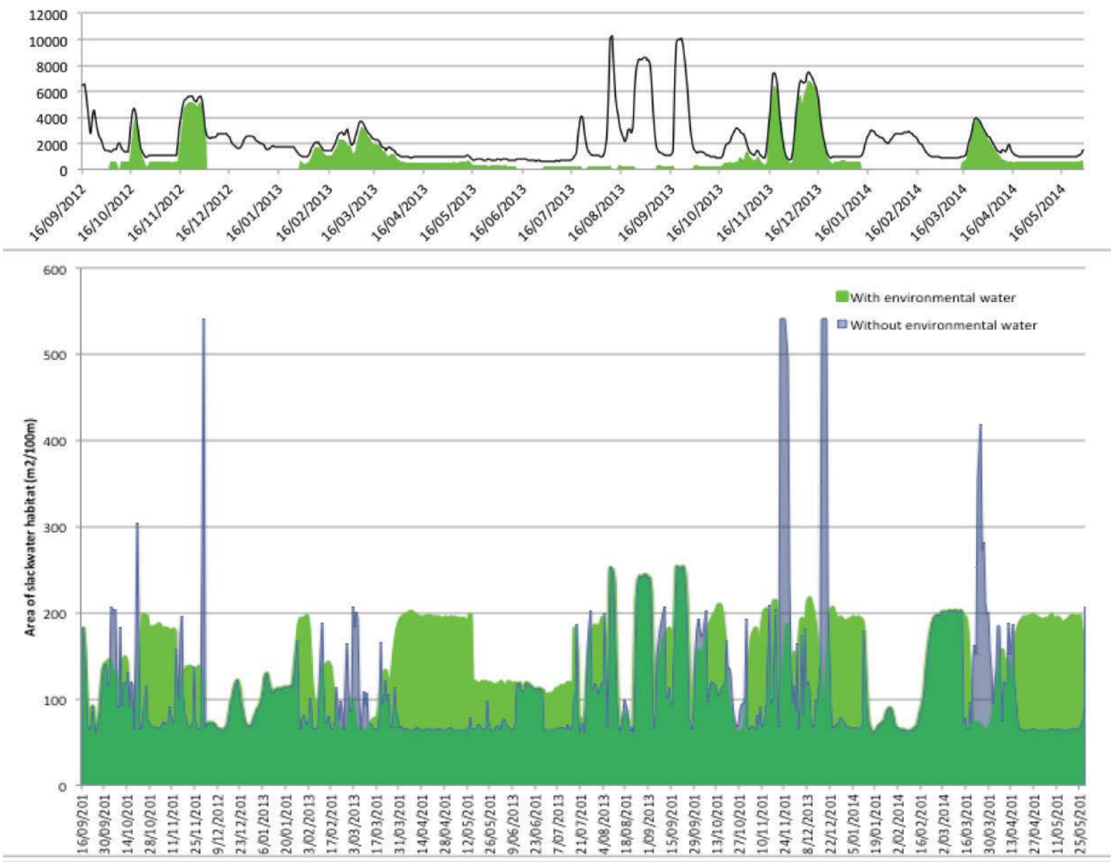

Figure 12-1. Slackwater habitat available with environmental water (green) and without (blue) for the Darcy's Track site.

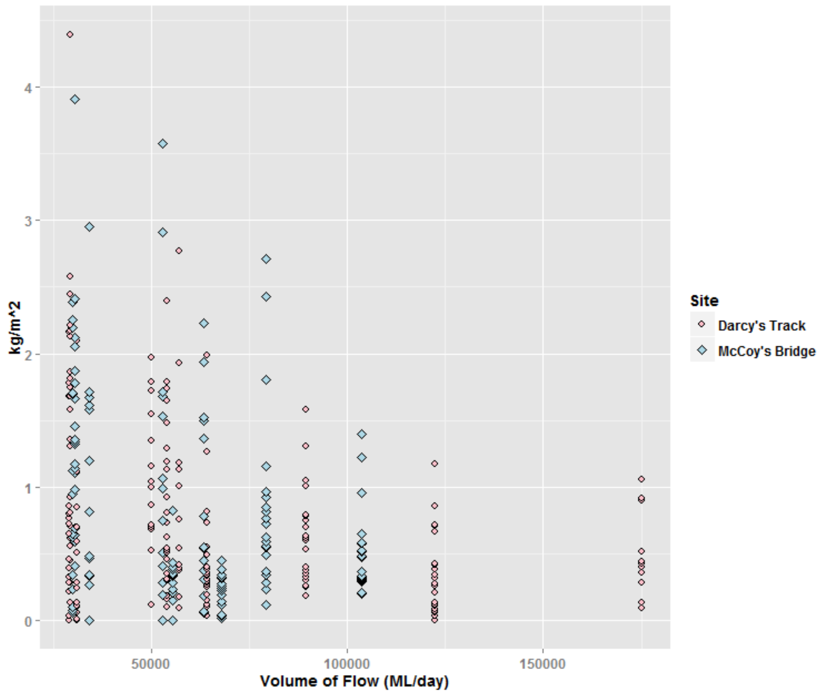

Figure 12-2. Sediment smothering (kg/m2) relative to volume of flow in the proceeding 30 days.

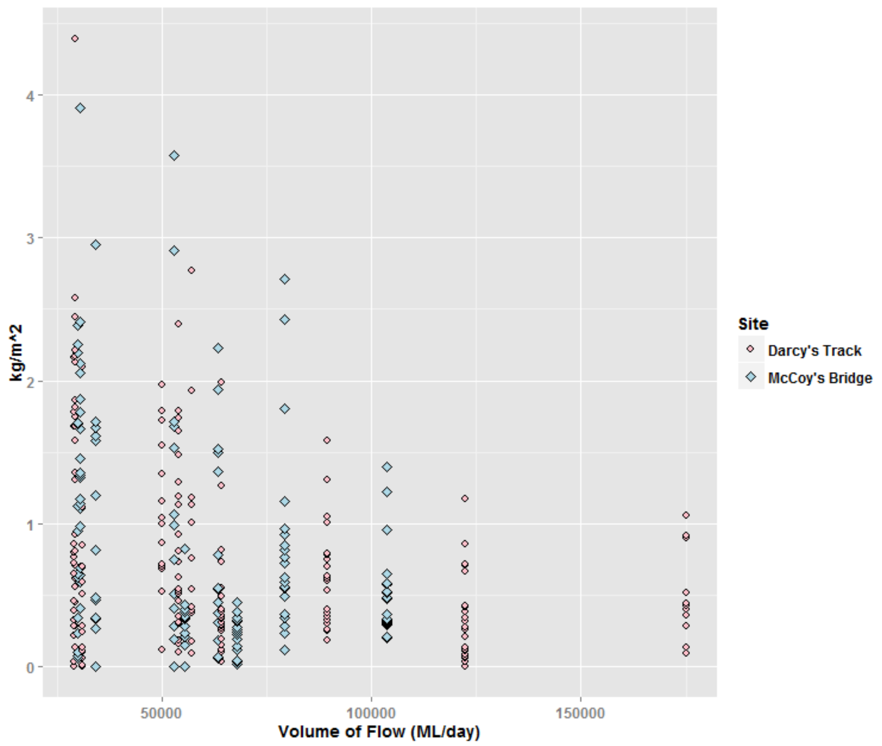

Figure 12-3. Sediment smothering (kg/m2) relative to number of days of baseflow in the proceeding 30 days, where base flow is defined by flows < 1,500 ML/day.

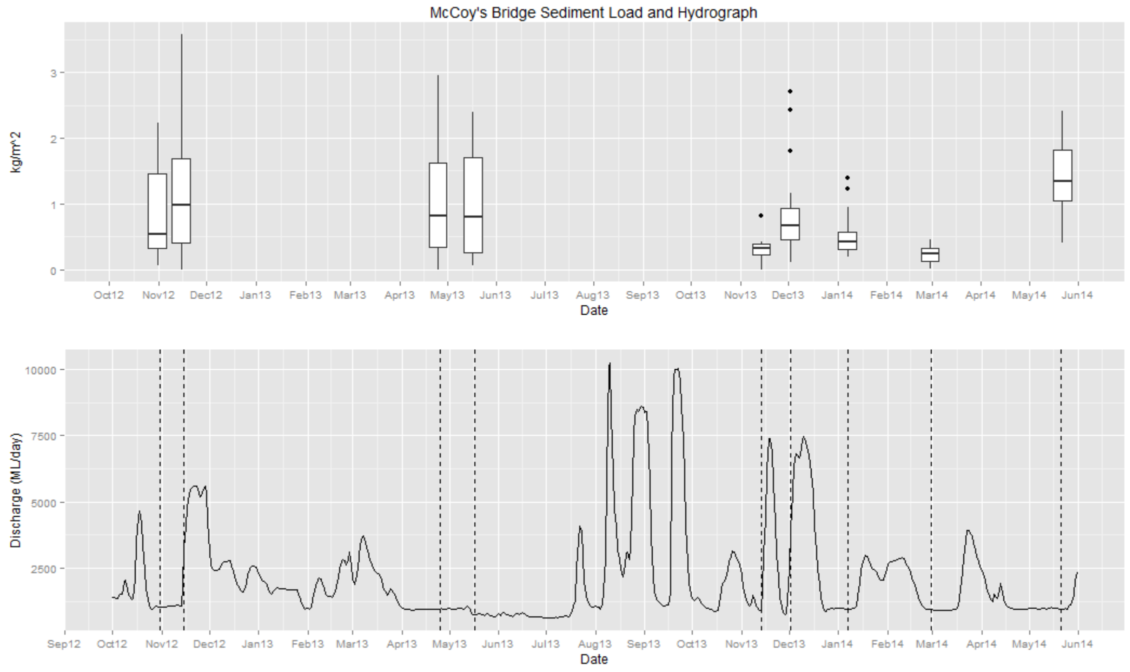

Figure 12-4. Sediment smothering per event sampled relative to discharge for the 2012/13 and 2013/14 seasons for McCoy's Bridge.

13 Appendix B – Further ecosystem productivity results

13.1 Nutrient concentrations

Nutrient concentrations were measured in terms of nitrate/nitrite (here after NOx), ammonia (NH_3), total phosphorus (TP), total nitrogen (TN) and dissolved reactive phosphorus (FRP). Results show that TP and NOx levels were periodically higher than the water quality guidelines for lowland rivers in this area (TP trigger value is 0.05 mg/L, TN is 0.5 mg/L, NOx is 0.04 mg/L, FRP is 0.02 mg/L and NH_3 is 0.02 mg/L) (ANZECC 2000) (Figure 13-1). Other nutrient concentrations measured were within the recommended guidelines. These high levels seem to coincide with the peaks of the spring freshes (TP, TN, NOx), intervalley transfers (TP, TN, NOx) and autumn freshes (TN and NOx).

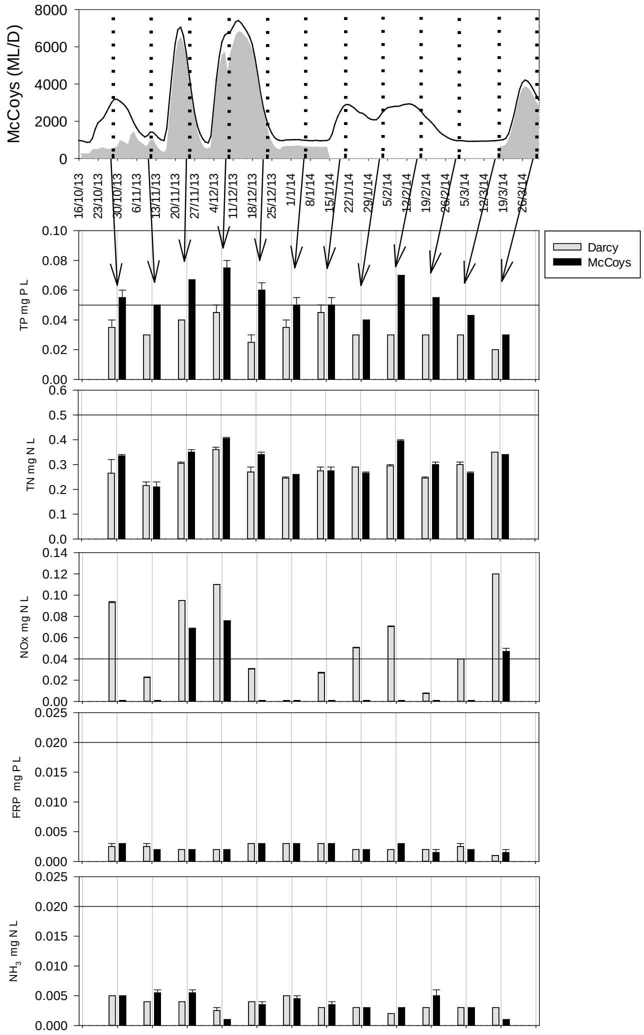

Figure 13-1. Nutrient concentrations (in mg/L) in the water column for duplicate samples (shown as means with standard error bars). Lines on nutrient graphs represent ANZECC trigger values. Top panel displays hydrology during the sampling period indicating environmental flow contributions (grey shading) based on Goulburn Murray Water data (McCoy's Bridge gauge).

13.2 In-stream productivity and respiration

Gross primary production (GPP) appeared to increase in relation to the spring freshes and environmental water supplemented baseflows this was most evident at the McCoys site (Figure 13-2). There also appeared to be an increase in GPP in relation to the intervalley transfers at McCoys. No marked response was evident in relation to the autumn fresh at the Darcy site, whereas there was some evidence of an increase in the Gross primary production :Ecosystem ratio (GPP: ER ratio) with the rising limb of the fresh at the McCoys site. GPP was also observed to increase similarly during low flow periods (mid-November 2013, early January 2014, Darcy only). Respiration was high at McCoys during low flows in early November 2013. The GPP: ER ratio which indicates the balance between primary production rates and ecosystem respiration rates, with a value <1 reveals that more organic carbon is being consumed in the study reach than is being produced by photosynthesis. The reach at McCoys revealed several occasions to have values greater than 1, during the spring and autumn freshes, intervalley transfers and also during an environmental water supplemented base flow in late December 2013/ early January 2014. This suggests that GPP was particularly high and exceeded rates of ER. In contrast Darcy generally had values less than 1 for the GPP:ER ratio therefore organic carbon was being consumed within the river reach and was predominately heterotrophic (dominated by carbon entering the reach from outside, rather than by photosynthesis).

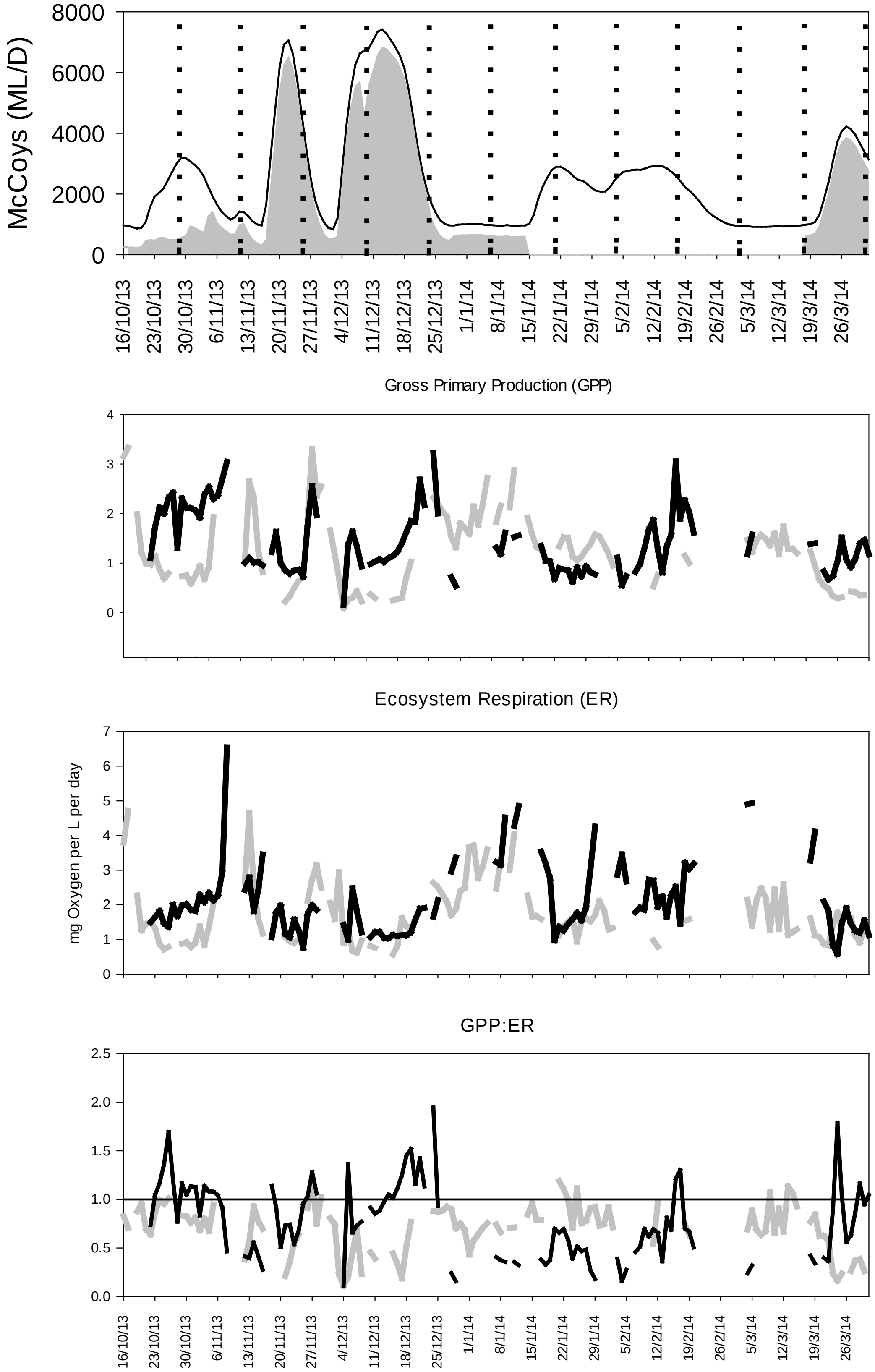

Figure 13-2. Rates of gross primary production, ecosystem respiration and the ratio between them taken at two reaches (Darcy [grey line] and McCoys [black line]) from the lower Goulburn River at different rivers levels (top panel). Line denotes ratio = 1 on the GPP:ER ratio figure.

13.3 Benthic algae

At both sites there was less benthic algal biofilm in deeper waters compared to the shallower waters. This pattern was evident for both chlorophyll a (Figure 13-3) and organic matter (Figure 13-4). High flows which occurred during spring fresh 1 and the intervalley transfers appeared to reduce algae levels as they were higher during the low flow period of early January 2014.

In terms of taxonomic algae composition the algal communities were dominated primary by diatoms, followed by green algae and filamentous algae to a lesser extent (Table 13-1). These patterns did not change through time or in response to flows (Figure 13-5). Blue green algae was also present but in very low amounts. Analysis of similarities found no clear patterns of biofilm taxonomic composition with water depth or through time (Global R = 0, p=0.49).

Table 13-1. Dominant biofilm taxa from scrubbings of wooden blocks from two reaches on the Goulburn River sampled at three depths between October 2013 and March 2014.

Chlorophyta (green algae)	**Cyanophyta (blue-green algae)**	**Filamentous green**	**Bacillariophyta (diatoms)**
Bulbochaete spp.	*Anabaena* spp.	*Mougoutia* spp.	*Achnanthes* spp.
Closterium spp.	*Lyngbya* spp.	*Oedogonium* spp.	*Amphora* spp.
Coelastrum spp.	*Nodularia* spp.	*Pediastrum* spp.	*Fragillaria* spp.
Cosmarium spp.	*Oscillatoria* spp.	*Pleurotaenium* spp.	*Melosira* spp.
Draparnaldia spp.	*Phormidium* spp.	*Scenedesmus* spp.	*Navicula* spp.
	Schizomeris spp.	*Spirogyra* spp.	*Nitzschia* spp.
			Pinnularia spp.

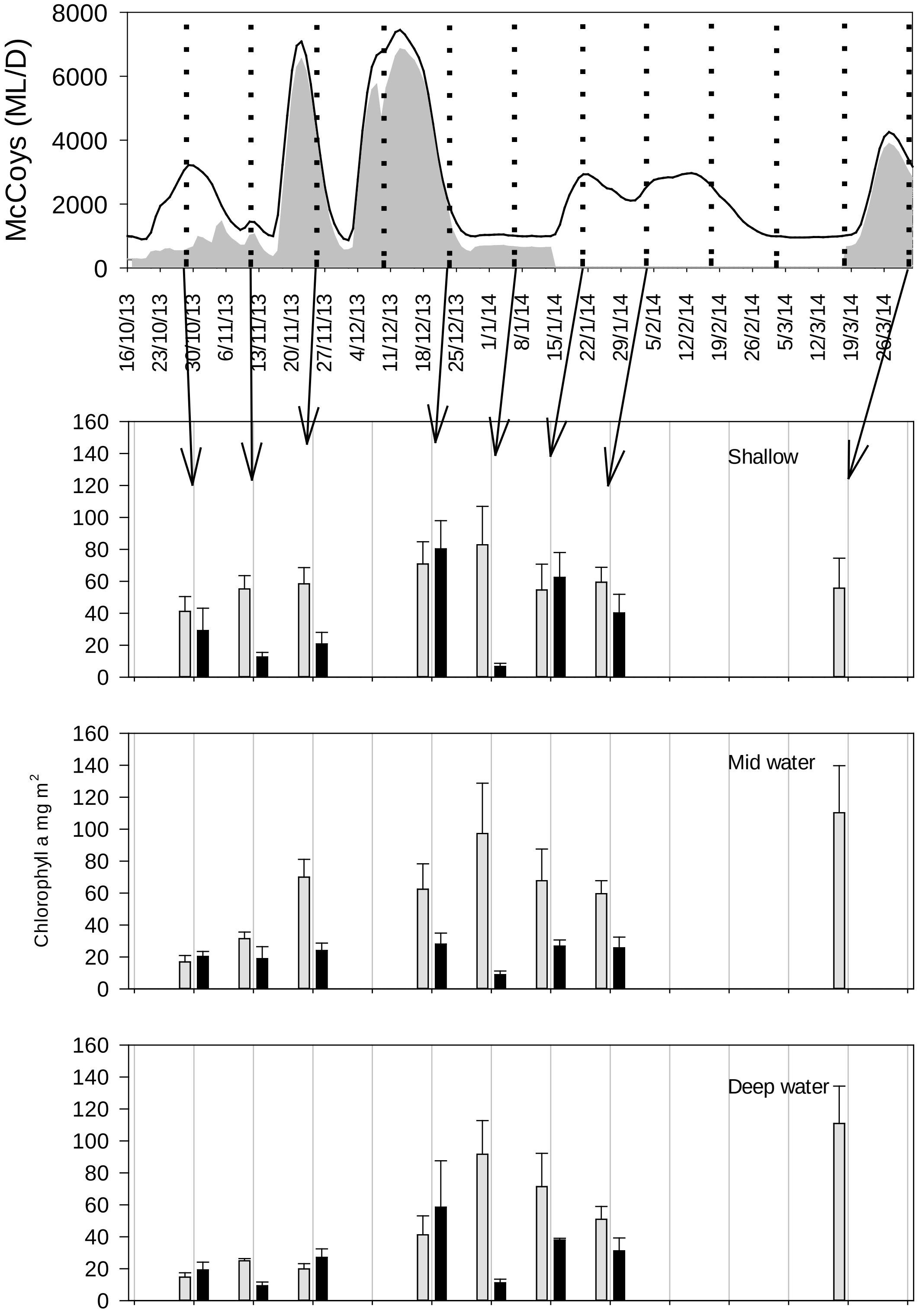

Figure 13-3. Response of benthic algae (measured as chlorophyll-a) grown on colonization blocks to flow (top panel) in the lower Goulburn River at two reaches (Darcy [grey bars] and McCoys [black bars]). Dotted lines indicate dates of sampling. Results are shown for blocks placed in shallow, medium and deep water (see Methods). Values are means for two locations in each reach with standard errors.

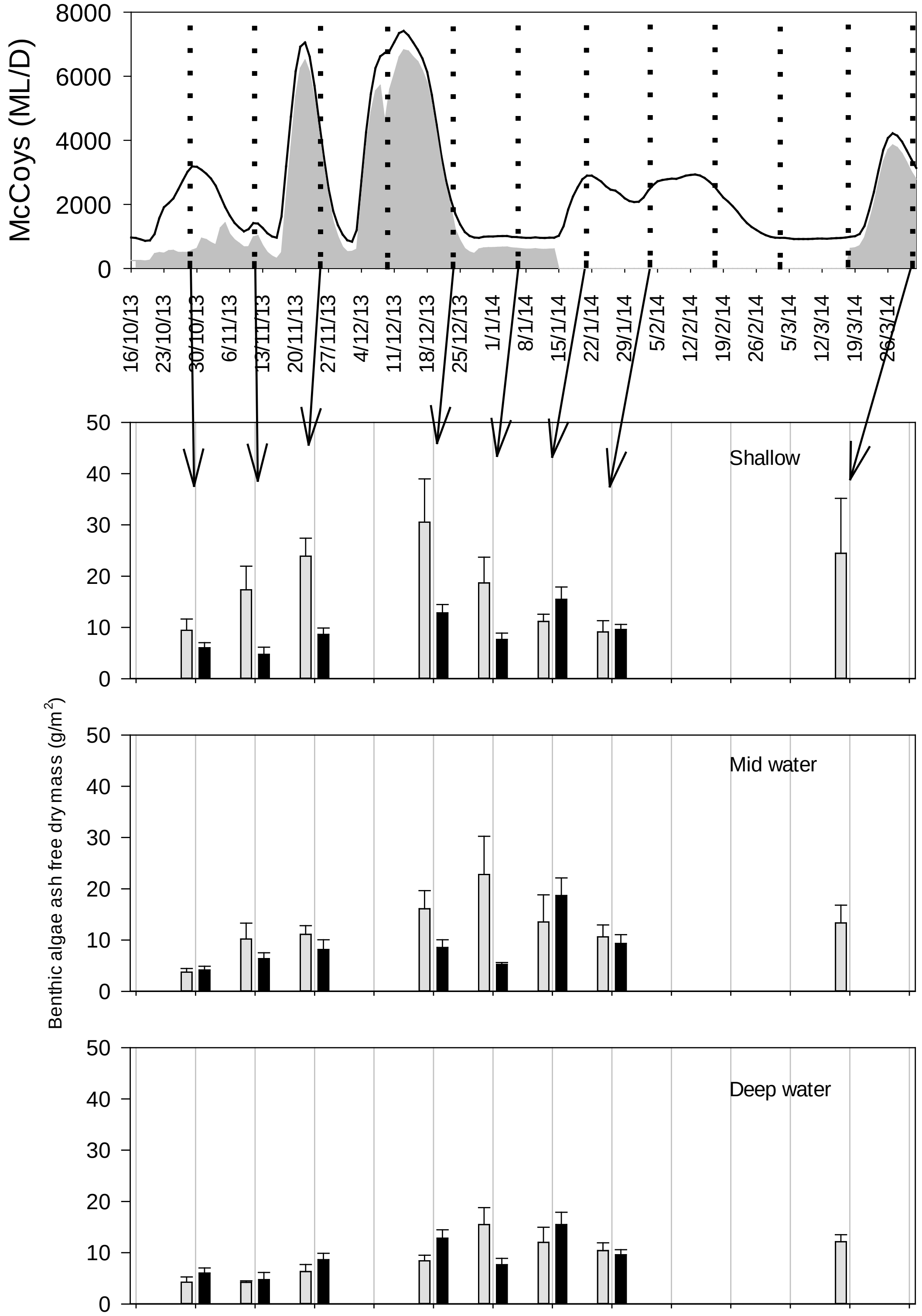

Figure 13-4. Responses of benthic algae (measured as ash free dry weight of biomass) grown on colonisation blocks to flow (top panel) in the lower Goulburn River at two reaches (Darcy [grey bars] and McCoys [black bars]). Dotted lines and dates indicate dates of sampling. Results are shown for blocks placed in shallow, medium and deep water (see Methods). Values are means for two locations in each reach with standard errors.

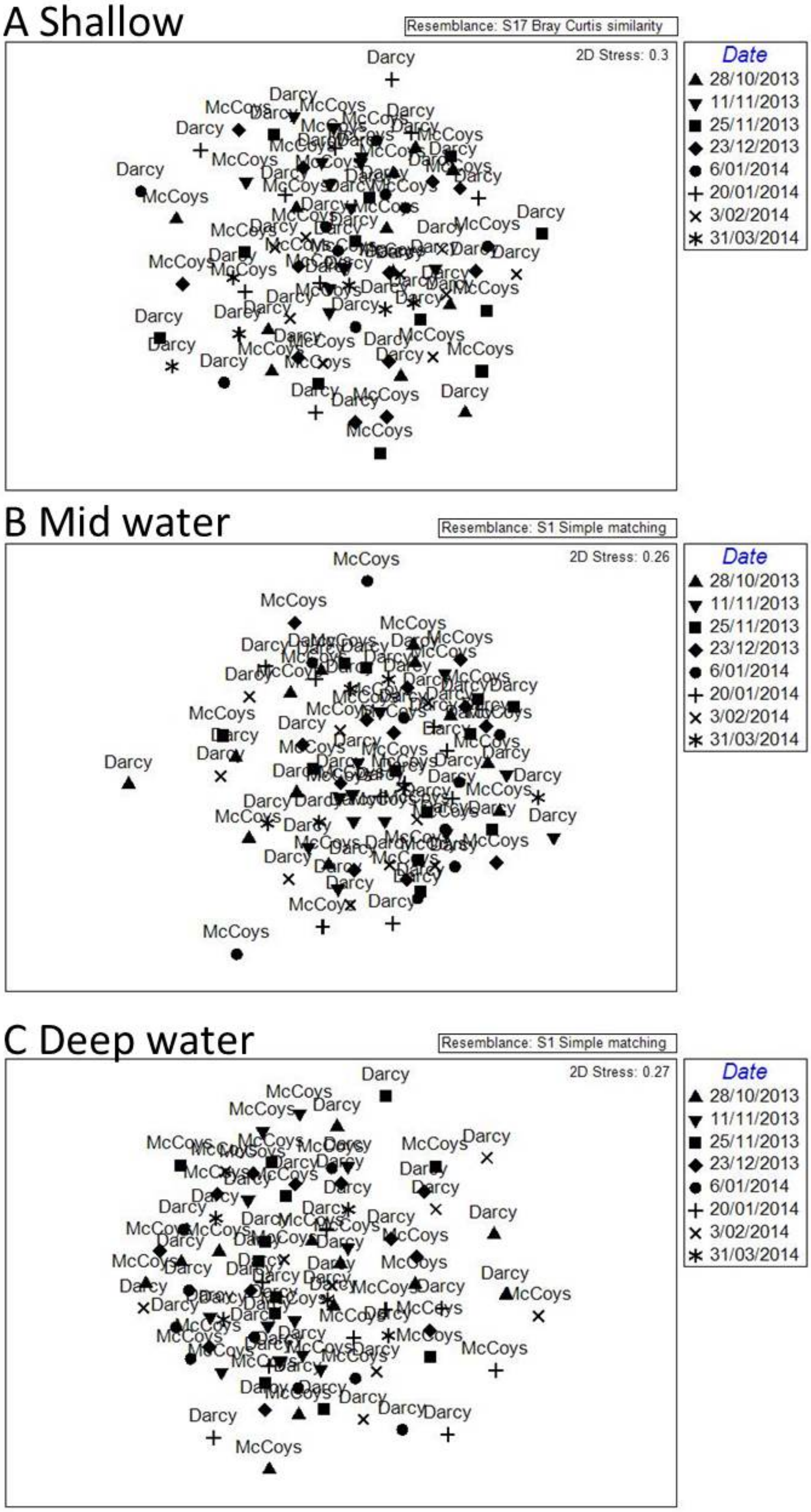

Figure 13-5. Responses of algae taxonomic species in response to flow, showing multi-dimensional scaling ordinations of similarities in communities between sites and sampling dates (top panel; A algae communities from shallow water blocks, B algae communities from mid water blocks and C algae communities from deep water blocks.

13.4 Phytoplankton

There was no clear patterns with phytoplankton in relation to flows for either ash free dry mass or chlorophyll a (Figure 13-6). There was some evidence to suggest that ash free dry mass at McCoys was greater after the second spring fresh and the intervalley transfers. This may suggest re-suspension of suspended sediments in the water column is caused by flow events.

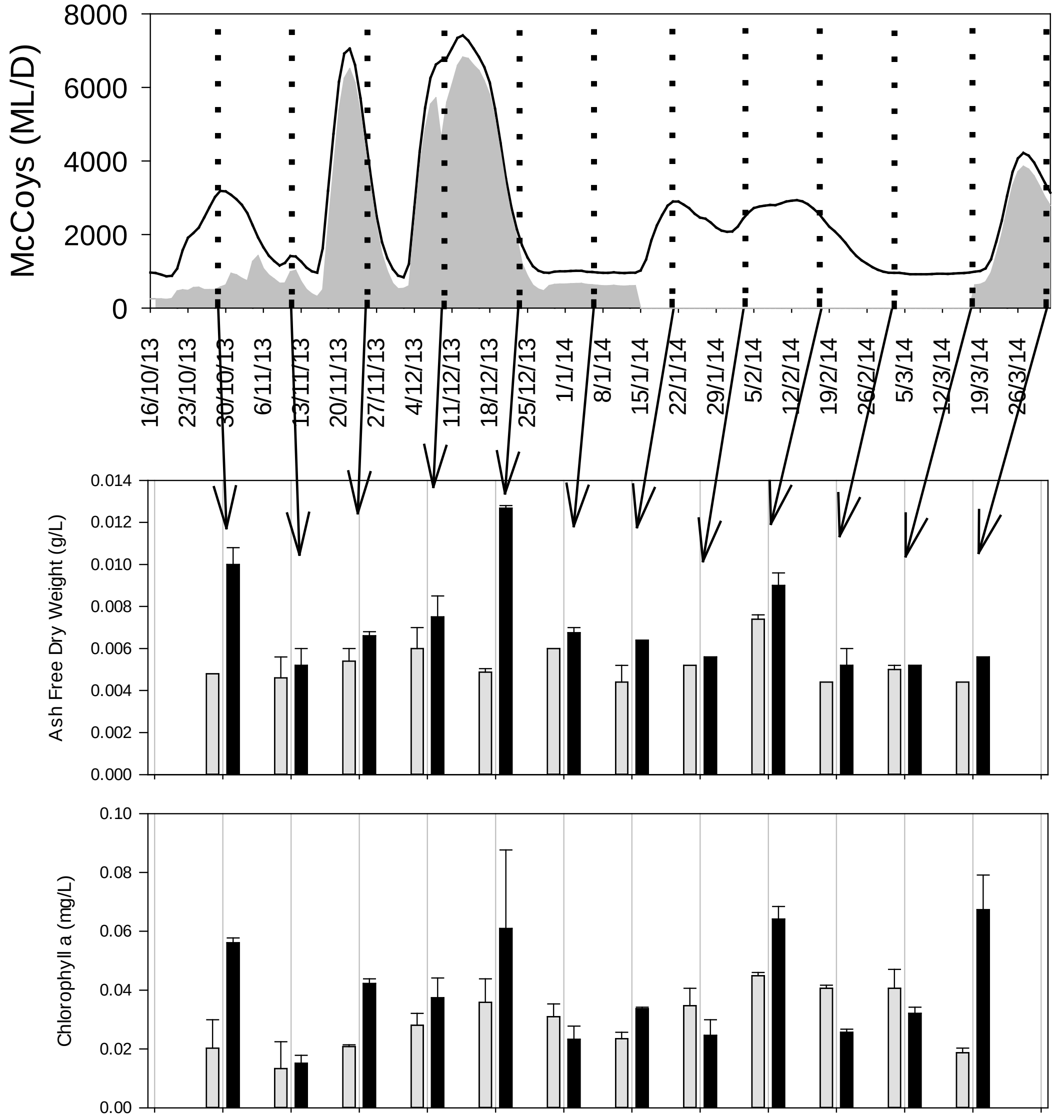

Figure 13-6. Responses of phytoplankton to flow (top panel), measured as ash free dry weight of biomass (includes seston and phytoplankton (middle panel) and chlorophyll-a (bottom panel) collected from the water column in the lower Goulburn River at two reaches (Darcy [grey bars] and McCoys [black bars]). Values are means of two samples per reach with standard errors. Dotted lines and dates indicate dates of sampling.

13.5 Benthic invertebrate communities

There was some evidence at the Darcy site that benthic invertebrate communities were responding to the higher magnitude spring freshes. There was higher invertebrate abundances after the spring freshes (Figure 13-7). No macroinvertebrate response was evident for the lower magnitude freshes (autumn fresh and intervalley transfers). The water bug that was driving this response was *Micronecta sp.* Taxonomic richness did not change in response to flows. Calculated SIGNAL scores were always below 4 during the study period, which suggests a very tolerant macroinvertebrate community. There was no marked changes in SIGNAL scores with changes in flow conditions (Figure 13-7).

Benthic invertebrate communities were dominated by the corixid bug *Micronecta*, dipteran larval chironomidae and two water bugs Velliidae and Gerridae (Table 13-1). Sampling through time did not show any clear relationships between flow and community structure across the sites with similar taxa been dominant through time (Table 13-2; Figure 13-8). Analysis of similarities found an effect of date of sampling (Global R = 0.438, p = 0.01) but this was not related to flow events. These changes may be related to seasonal changes in invertebrate communities.

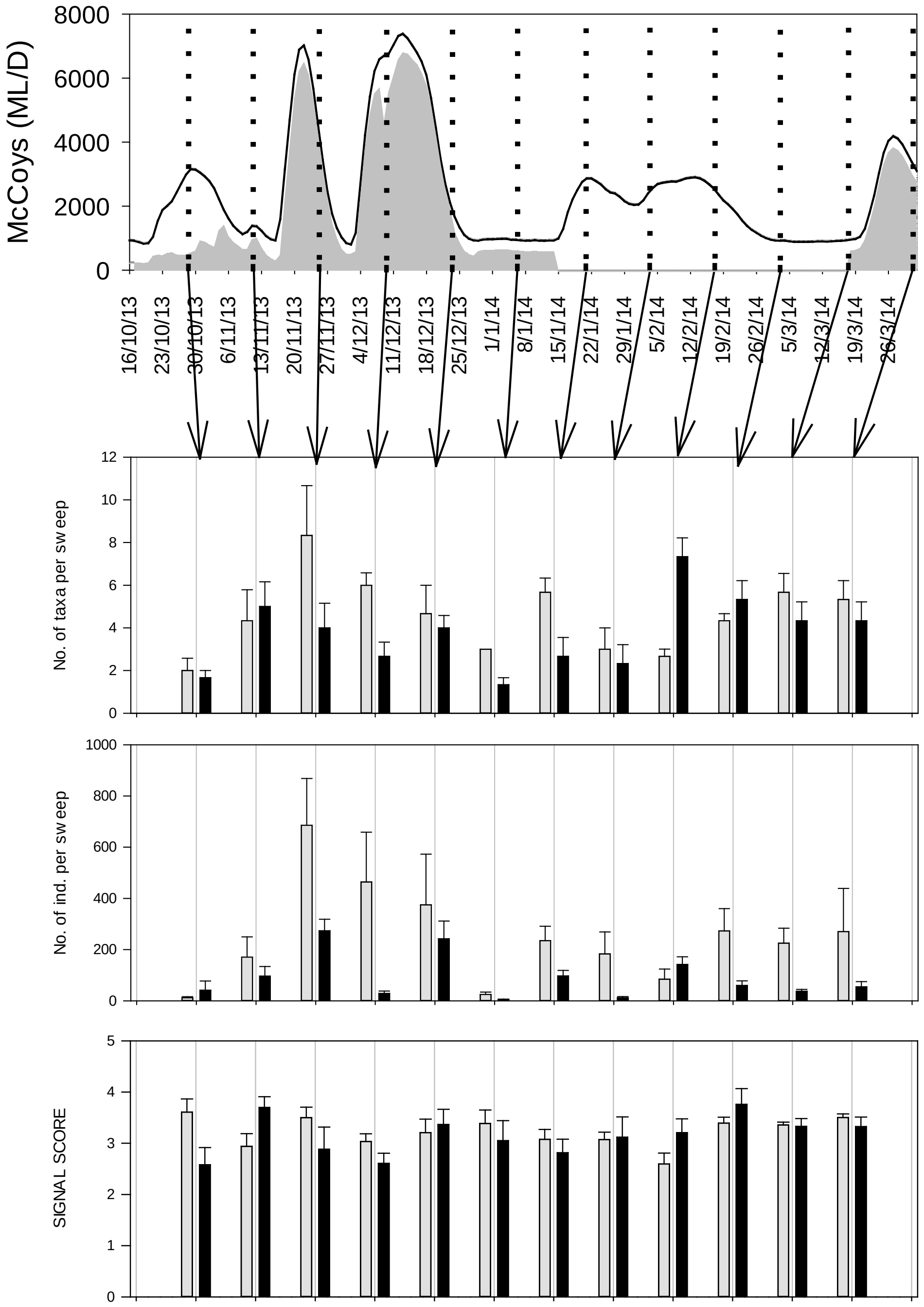

Figure 13-7. Responses of macroinvertebrates taxa richness (middle panel 1), abundance (middle panel 2) and SIGNAL score (bottom panel) to flow (top panel), measured as means of three sweep samples with standard errors from the lower Goulburn River at two reaches (Darcy [grey bars] and McCoys [black bars]). Dotted lines and dates indicate dates of sampling. Lines on figures represent average values over the study period.

Table 13-2. Major species contributing to the dissimilarities between sampling periods as determined by similarity percentages analysis (SIMPER) based on log (x+1) transformed relative abundances.

Date Symbol on MDS	Date	Characteristic taxa
▲	28/10/13	Micronecta, Chironomidae
▼	11/11/13	Chironomidae, Micronecta, Paratya, Tasmanocoenis sp.
■	25/11/13	Micronecta, Chironomidae, Velliidae
◆	9/12/13	Micronecta, Chironomidae, Velliidae
●	23/12/13	Micronecta, Gerridae, Chironomidae
+	6/1/14	Gerridae, Micronecta
×	20/1/14	Micronecta, Velliidae, Gerridae
∗	3/2/14	Micronecta, Gerridae
△	17/2/14	Micronecta, Gerridae, Hydraenidae A, Baetidae
▽	3/3/14	Micronecta, Baetidae, Gerridae
□	17/3/14	Micronecta, Baetidae, Gerridae
◇	31/3/14	Micronecta, Chironomidae, Baetidae

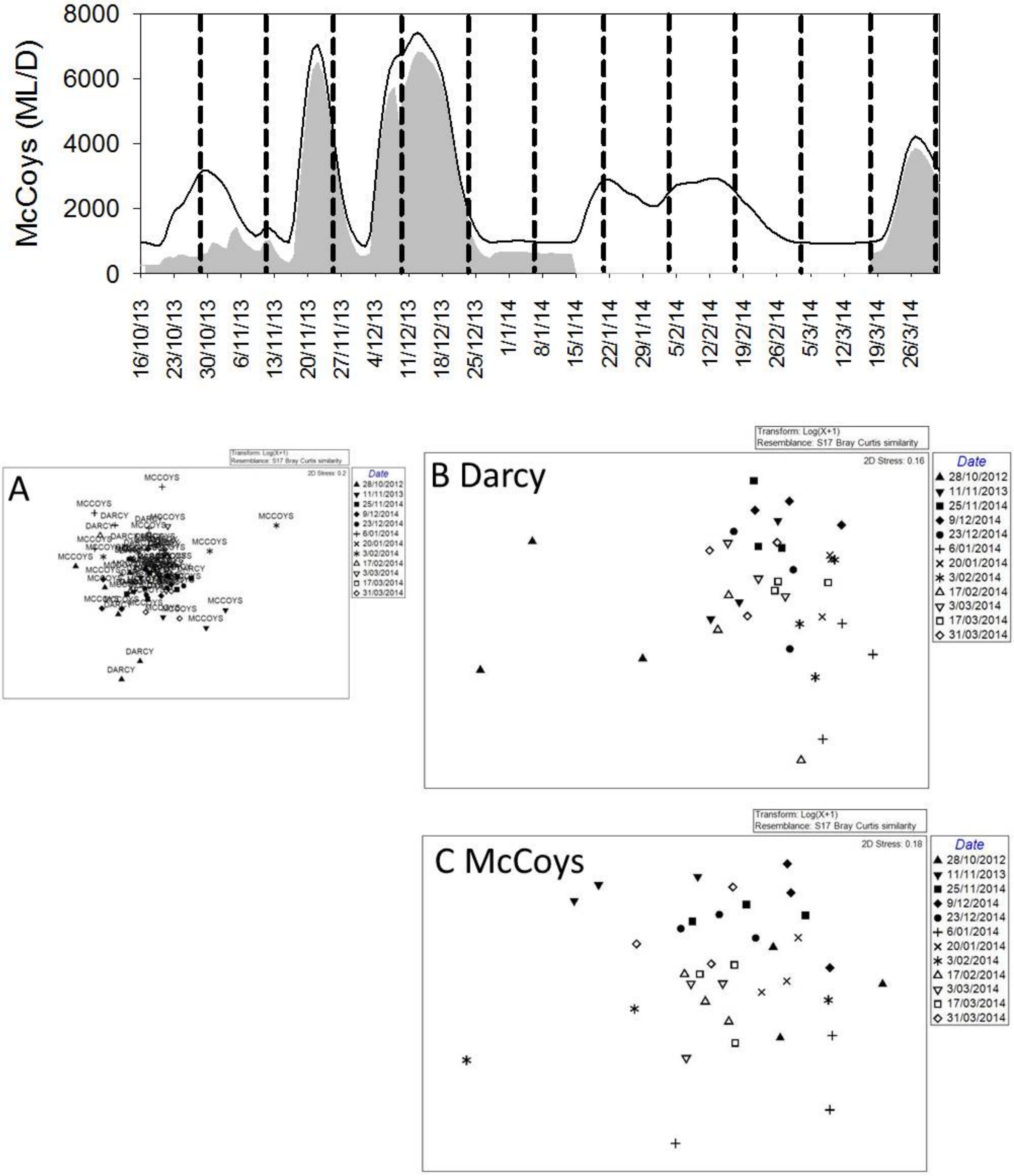

Figure 13-8. Responses of macroinvertebrate abundance in sweep samples to flow (top panel), showing multi-dimensional scaling ordinations of similarities in communities between sites and sampling dates (bottom panel; A with all samples, B Darcy and C McCoys sites.

13.6 Zooplankton

Zooplankton samples were dominated by rotifers and the water flea Bosminidae (Figure 13-9). There was no clear response of zooplankton densities or changes in relative abundance of different taxonomic groups in response to flows (Figure 13-9).

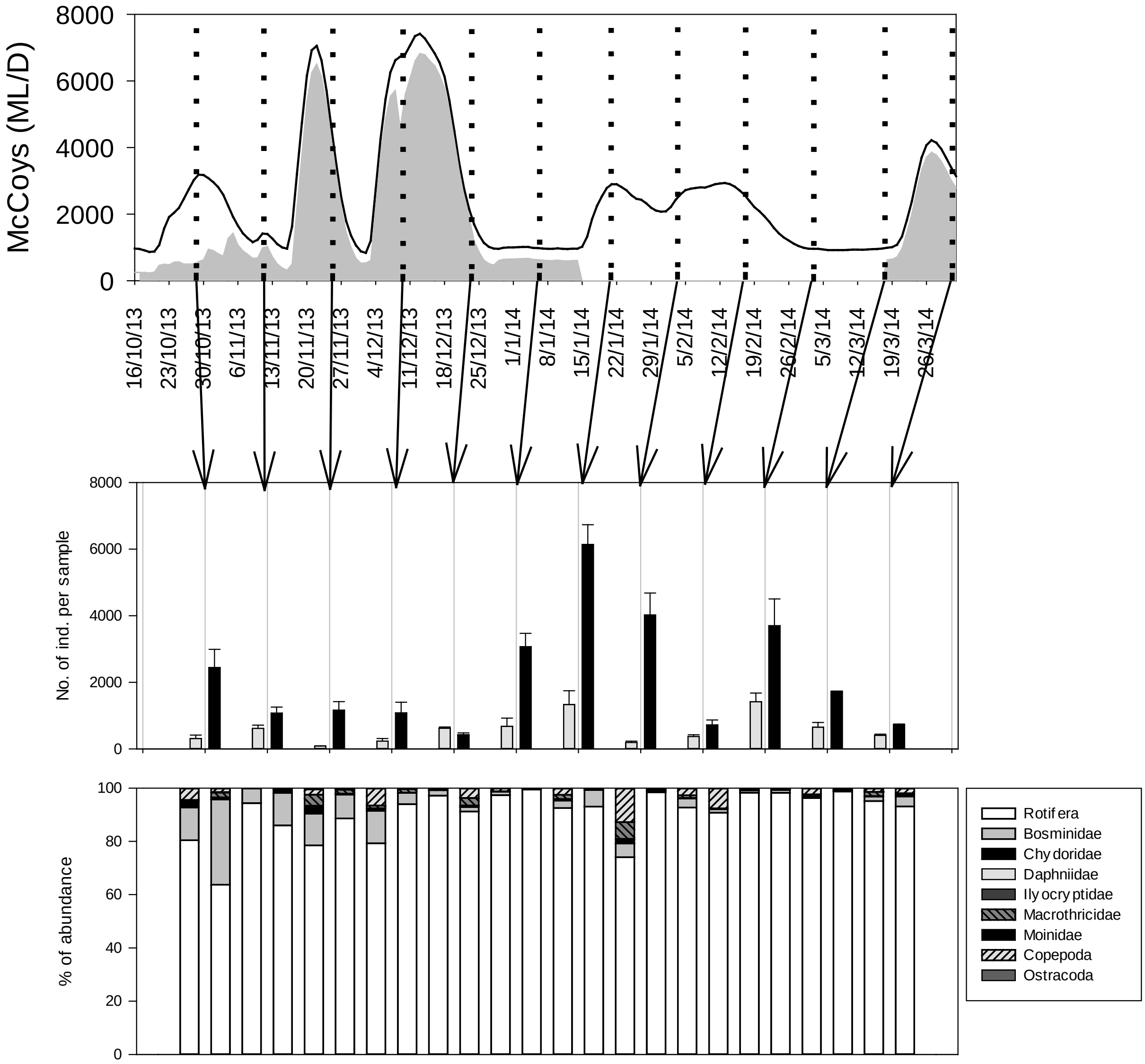

Figure 13-9. Responses of zooplankton abundance (middle panel) and community composition (bottom panel) to flow (top panel), measured as means of three haul samples with standard errors from the lower Goulburn River at two reaches (Darcy [grey bars], McCoys [black bars], taxa richness (middle panel) and abundance (bottom panel) to flow (top panel). Taxa are shown in order from the bottom to the top of the bar as indicated in the legend.

13.7 Organic matter supply

There were small pulses of increased suspended matter with the peaks of spring fresh 2 and intervalley transfers (Figure 13-10). No marked response in suspended organic matter was found for spring fresh 1 or the autumn fresh. These increases in suspended matter coincided with the flow peaks. Other monitoring dates were after flow peaks and so may have missed the initial increases in suspended matter, as sediment is usually picked up and suspended in the water column in the initial stages of increasing flows, post peak, sediments start to settle out on river benches (G. Vietz, per. comm.). These results suggest that flow events can potentially increase suspended matter in the water column.

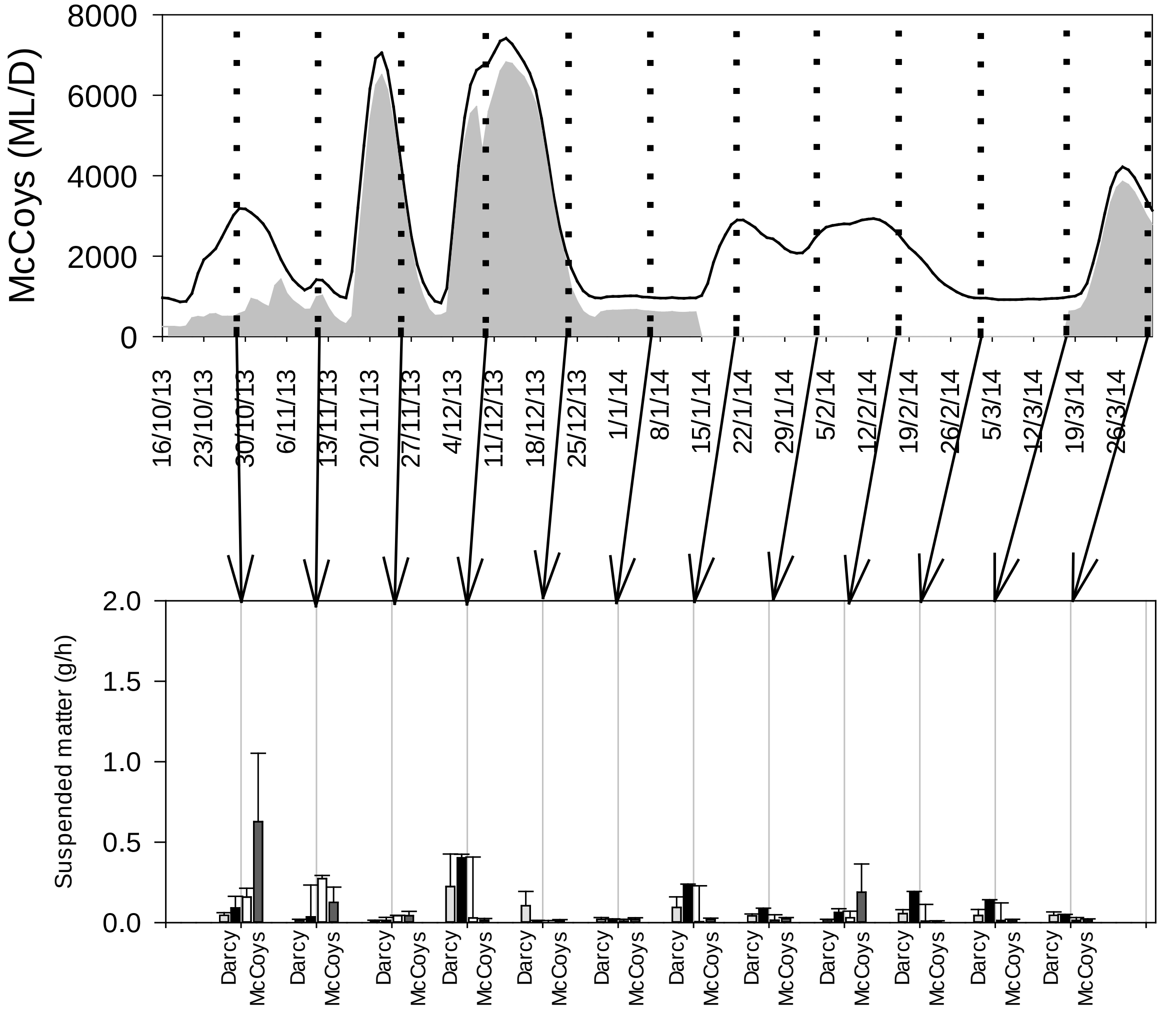

Figure 13-10. Patterns in suspended material in the flow captured using drift nets collected from the lower Goulburn River at two reaches (Darcy [Light grey bar indicate organic material and black bar indicates inorganic material] and McCoys [White bar indicates organic material and dark grey indicates inorganic material] as flow varies (top panel). Dotted lines and dates indicate dates of sampling.

13.8 Organic matter retention

The spring, autumn freshes and intervalley transfers influenced organic matter dynamics through mobilization of woody debris within the river channel (Figure 13-11). The higher magnitude spring freshes were able to mobilize greater amounts and larger sizes classes of woody debris than the lower magnitude smaller freshes (autumn fresh and intervalley transfers).

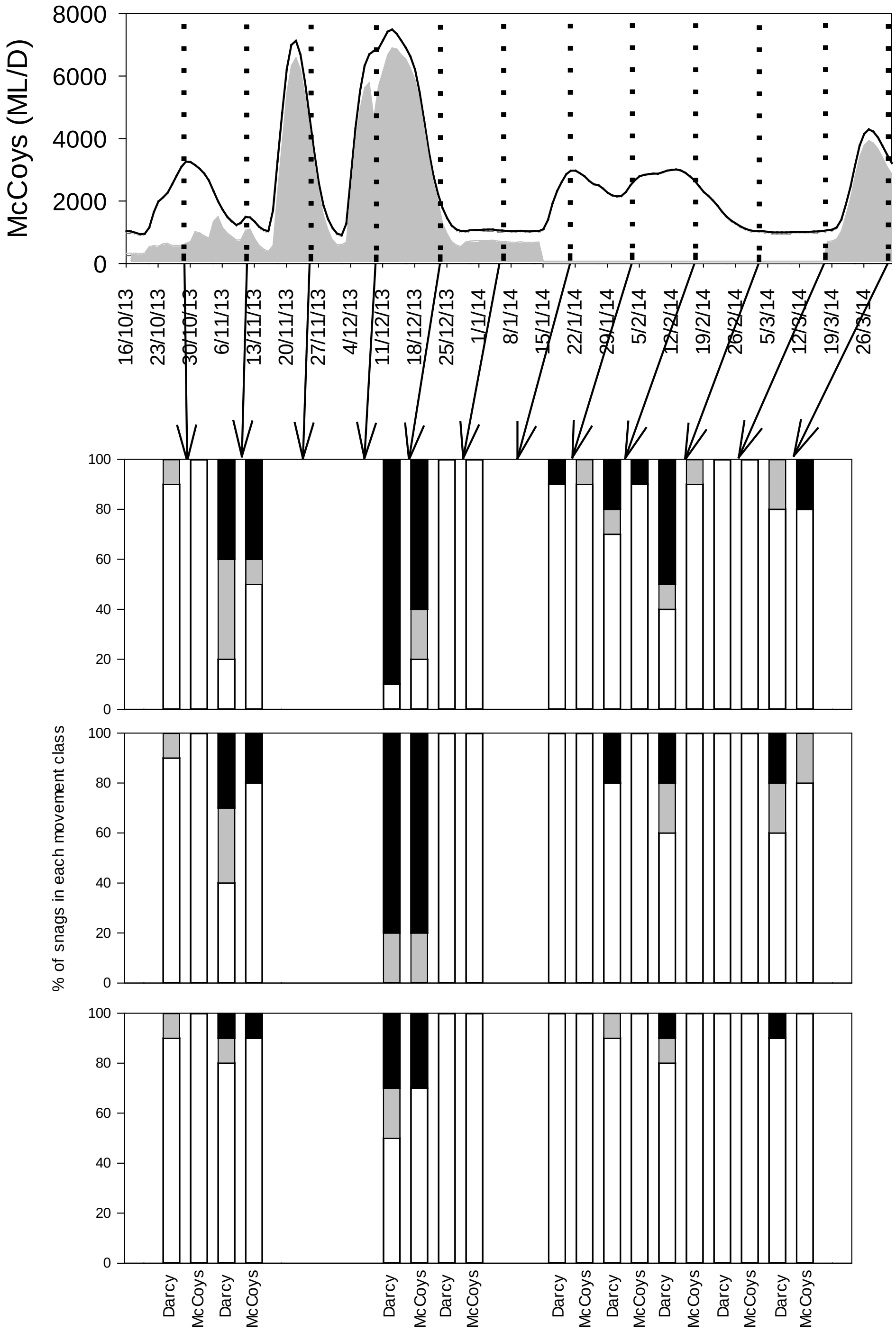

Figure 13-11. Percentage of snags of different sizes that moved with different flows (top panel) in the lower Goulburn River at two reaches (Darcy and McCoys). A) snags <1m long, B) 1-2m long, C) 2-5m long. White bar denotes % unmoved snags, grey bar % moved snags and black bar % lost snags.

13.9 Turbidity

During the monitoring period the Darcy site expressed lower turbidity levels than the McCoys site. There were marked increases in turbidity levels with the spring freshes and this was most noticeable at the McCoys site (Figure 13-12). No response was detected with the autumn fresh. Intervalley transfer 1 had a similar effect as the spring freshes, whereas no response was evident with intervalley transfer 2.

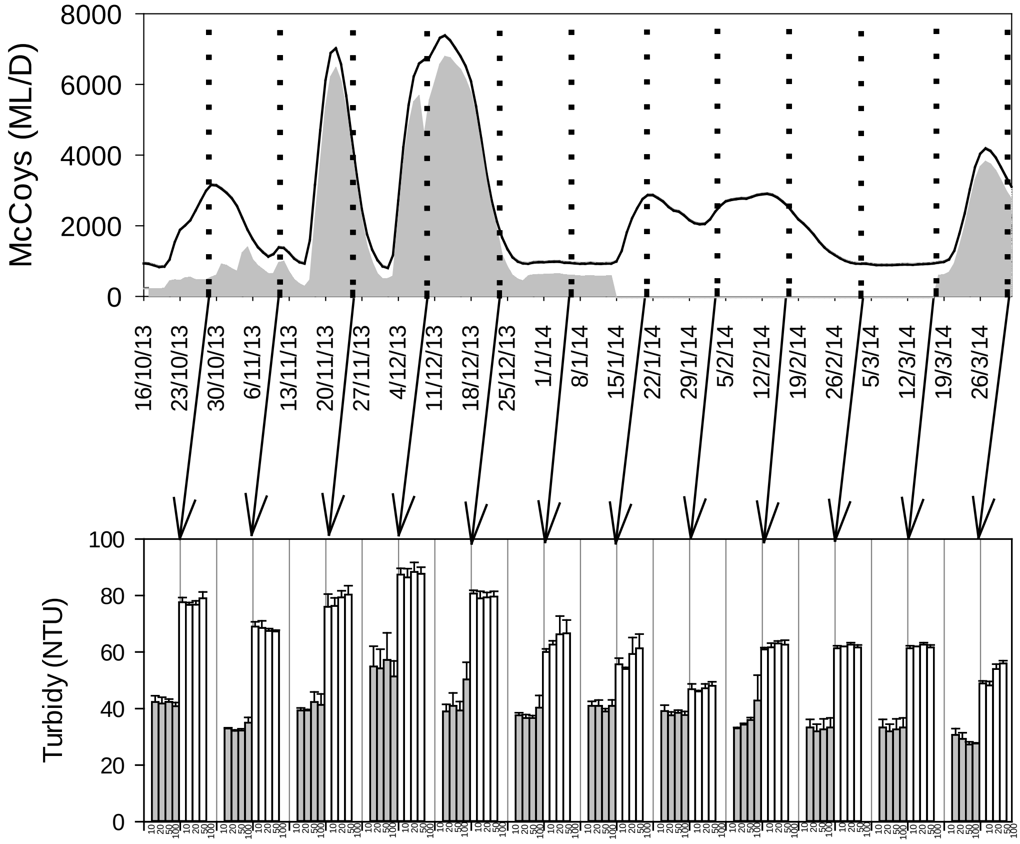

Figure 13-12. Patterns in water turbidity at different depths from the lower Goulburn River at two reaches (Darcy and McCoys) as flow varies (top panel). Dotted lines and dates indicate dates of sampling. Light grey bars indicate measurements from the Darcy reach, while white bars indicates measurements from the McCoys reach. Values are averages of three measurements from each depth with standard errors.

13.10 Light

The light levels recorded from the different depths of the river showed that there was rapid attenuation of light in the first meter of water depth. Light levels decreased with increasing water depth over the river bottom and light levels decreased with both small and large flows (spring and autumn freshes, intervalley transfers) (Figure 13-13).

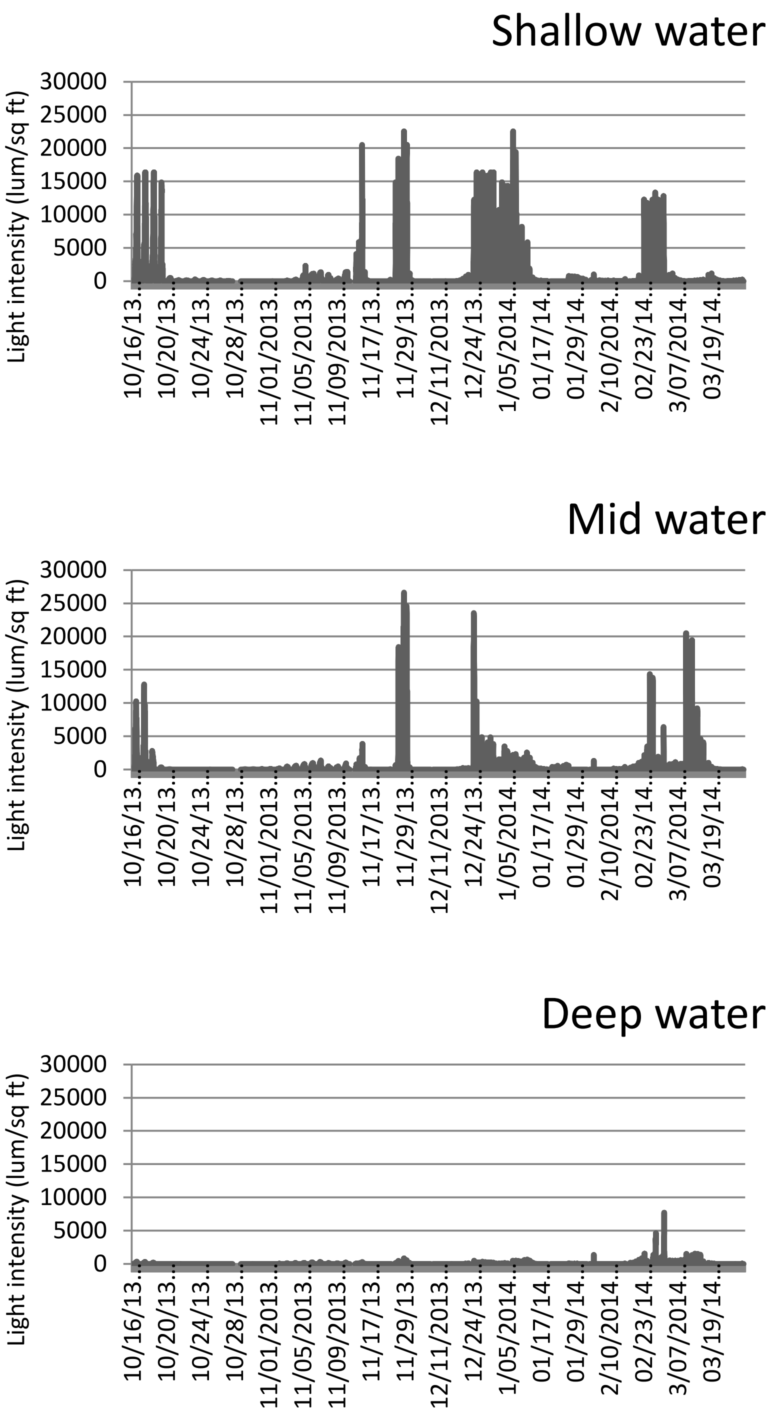

Figure 13-13. Light intensity reaching the stream bed at three fixed locations as water levels vary in the lower Goulburn River. Shallow indicates a sensor at a 2m gauge height on the McCoys Bridge gauge, mid is 1.5m and deep 1m.

14 Appendix C – Details of vegetation statistical analysis and results

14.1 Details of statistical analysis

14.1.1 Effects of relative elevation in channel

These analyses employed data collected from the Goulburn River and Broken Creek in 2012/13 and 2013/14. Each vegetation data point (y_i) – with different transformations as described below – was analyzed as a linear function of relative elevation ($elev_i$) in the channel (Equation 14-1). The models included random effects of the transect upon which the quadrat lay (δ_l) and the repeated measures of the quadrat itself (φ_m) to avoid pseudoreplication in the analysis. The regression parameters α and β were modelled separately for each year of data (k). The site-level (j) estimates for α and β were modelled hierarchically, being assumed to be drawn from a normal (N) river-level distribution of possible parameter values (means A and B), and with common variance parameters ($\sigma^2{}_\alpha$, $\sigma^2{}_\beta$) across both years. Minimally informative priors – $N(0,10)$ for mean values, and uniform $U(0,10)$ on standard deviations – were used for all hyperparameters.

Equation 14-1

$$
\begin{aligned}
y_i &= \alpha_{jk} + \beta_{jk} \cdot elev_i + \delta_l + \varphi_m \\
\alpha_{jk} &\sim N\left(\mathrm{A}_{nk}, \sigma_\alpha^2\right) \\
\beta_{jk} &\sim N\left(\mathrm{B}_{nk}, \sigma_\beta^2\right) \\
\delta_l &\sim N\left(0, \sigma_\delta^2\right) \\
\varphi_l &\sim N\left(0, \sigma_\varphi^2\right)
\end{aligned}
$$

Presence/absence data (Hypothesis 1 – test of survival) were modelled as a logistic regression, with the presence/absence data being assumed to be drawn from a Bernoulli distribution, with the probability for each data point (p_i)being logit-transformed to make the linear model applicable (Equation 14-2).

Equation 14-2

$$
\begin{aligned}
y_i &\sim Bernoulli\left(p_i\right) \\
\operatorname{logit}\left(p_i\right) &= \alpha_{jk} + \beta_{jk} \cdot elev_i + \delta_l + \varphi_m
\end{aligned}
$$

When vegetation was present, cover data (Hypothesis 2 – test of growth) were modelled as a standard linear regression following square-root transformation of the data to account for the uneven spacing of Braun-Blanquet cover classes and also to improve the homogeneity of unexplained variation around the regression line (Equation 14-3). The residual uncertainty (σ^2) was assumed equal for all years and sites, and modelled the same as the hyperparameter uncertainties – with a minimally-informative uniform prior distribution on standard deviation.

Equation 14-3

$$\sqrt{y_i} \sim N\left(\mu_i, \sigma^2\right)$$
$$\mu_i = \alpha_{jk} + \beta_{jk} \cdot elev_i + \delta_l + \varphi_m$$

Species richness within quadrats (Hypothesis 3 – test of diversity) was modelled using a log-Poisson regression. This is the generally accepted form for analyzing count data (i.e. count of taxa). The species counts were assumed to be drawn from a Poisson distribution, the mean of which (λ) was log-transformed to make the linear model applicable (Equation 14-4).

Equation 14-4

$$y_i \sim Poisson\left(\lambda_i\right)$$
$$\log\left(\lambda_i\right) = \alpha_{jk} + \beta_{jk} \cdot elev_i + \delta_l + \varphi_m$$

14.1.2 Effects of inundation duration and frequency

These analyses employed data collected from the Goulburn River only across four years of sampling (2008/09, 2010/11, 2012/13, 2013/14), with data for the first three years being drawn from the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP). The basic model structure was a quadratic regression, with log-transformation of the inundation variable. This allows the model to describe a peaked response (i.e. best vegetation performance at intermediate levels of inundation), and the log-transformation means that the curve does not need to be symmetrical.

Equation 14-5

$$y_i = \alpha_j + \beta_{jk} \cdot \log\left(inund_i\right) + \gamma \cdot \log\left(inund_i\right)^2 + \kappa_k \cdot seas_i + \delta_l + \varphi_m$$
$$inund_i = T_i \cdot e^{\left(-f_i \cdot \phi\right)}$$

Similar to the analysis of relative elevation effects, the regression parameters α, β, γ were modelled hierarchically. There was one difference, with α being modelled as the same across all four sites, but drawn from a distribution of possible values each year. This was to give the model an overall intercept that was common among sites, but could vary from year to year with climatic conditions. In addition, there was a separate linear effect of the season of inundation (*seas*) upon vegetation. This was modelled as a linear effect (κ) modelled separately (not hierarchically) with a N(0,10) prior distribution for each year. *seas* was quantified as the proportion of inundation time during the environmental flows 'summer' (November – April), centred on zero, such that 100% of inundation occurring in summer takes a value of 0.5, 100% of inundation occurring in winter takes a value of -0.5, etc. The inundation variable (*inund*) for each data point was calculated from total duration of inundation (T) and number of inundation events (f). Its construction means that multiple inundation events are expected to have less effect upon vegetation than a single event of the same total duration (see Discussion in Chapter 4). The parameter ϕ weights the effect of f so that multiple inundation events can either have a small effect compared to total inundation duration (ϕ approaches 0) or a large effect (ϕ approaches 1), which will substantially downweight the effect of inundation relative to T. This parameter was fitted as part of the analysis and was assigned a U(0,1) prior distribution.

The three data types were modelled using the same transformations and link functions as for the analysis of the effects of relative elevation: presence/absence – logistic regression, cover when present – linear regression of square-root transformed data, species richness – log-Poisson regression. This maintained comparability among the different analysis types.

14.1.3 Implementation and presentation of results

All models were coded in the OpenBUGS software (version 3.2.2). Multiple Markov chains were used to monitor convergence of the models. Most models had converged by 10,000 iterations, but occasionally longer burn-ins (20,000 and 30,000) were required. All models were monitored for 30,000 iterations for parameter estimation. The models were run predictively to provide results for plotting. Presenting results as predictive plots makes much more intuitive sense than presenting posterior probability distributions for model parameters.

For the analysis of effects of elevation, I modelled predicted cover at different elevations and included average uncertainty introduced by the random effects of transects and quadrats (Figures in 14.2).

For the analysis of the effects of inundation, I modelled the effect of different inundation durations (*T*), holding number of inundation events constant at 1, assuming inundation was equally spread over summer and winter, and also including the uncertainty introduced by transects and quadrats (Figures in 14.3).

For the analyses of the effect of environmental flows, the parameterized models for 2013/14 data only from 14.1.2 were used to predict vegetation performance for 63 quadrats for which we could model inundation both with and without environmental flows in the hydrograph (Table 14-1). This included specific modelled quantities for *T*, *f*, and *seas* for all quadrats under the two inundation scenarios. Results for these analyses were presented as relative change in the median vegetation result (probability of presence, cover, number of species) moving from the environmental flows to the no environmental flows scenario (Figures in 14.4).

14.2 Effects of quadrat elevation on the presence, cover and species richness of vegetation

The plots below are the full results for the models of the effect of relative elevation within the stream channel on the presence/absence and on cover of the four different functional groups, plus on species richness. See Chapter 4 for summaries of results and interpretations.

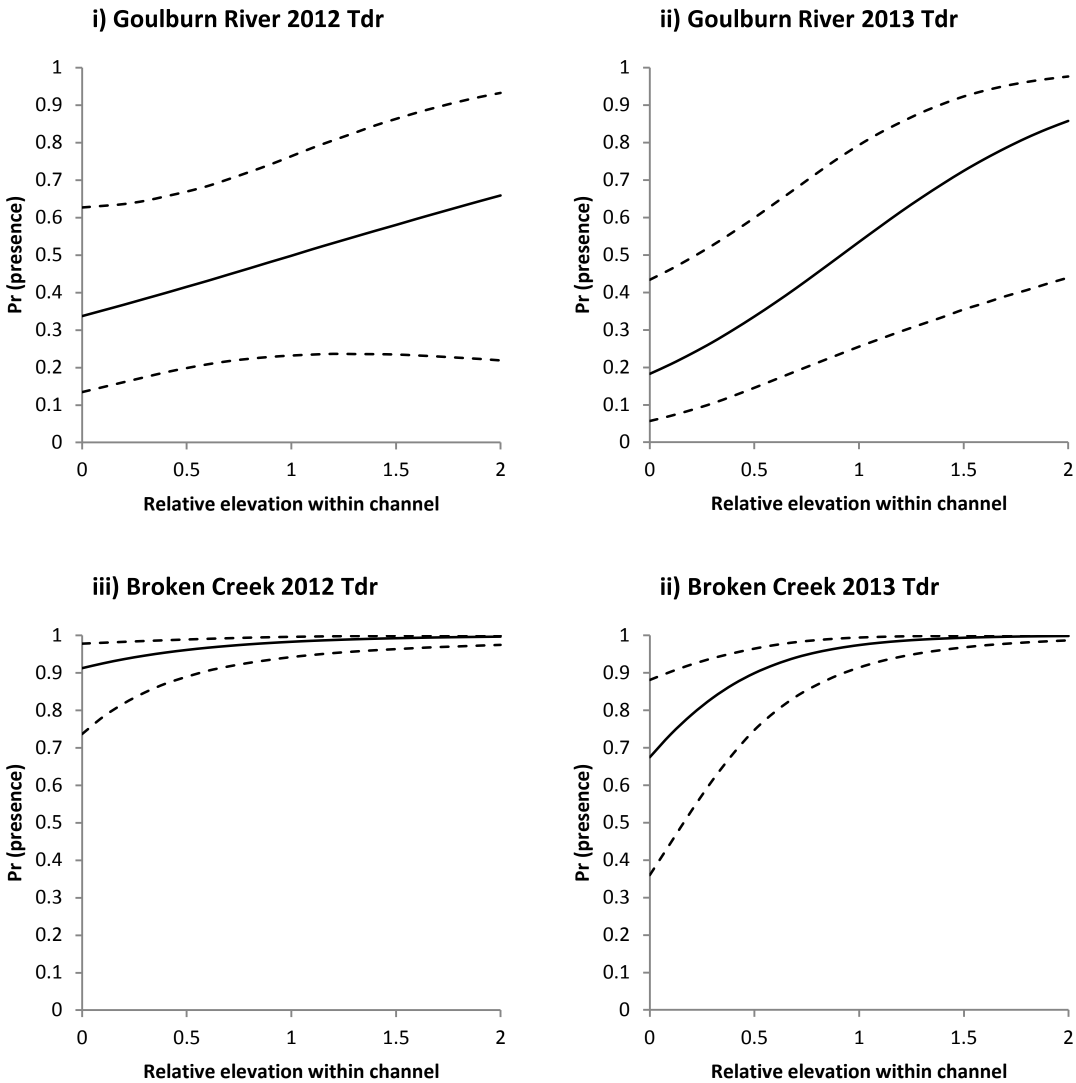

Figure 14-1. Effect of elevation on the presence/absence of Terrestrial Dry (Tdr) taxa. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

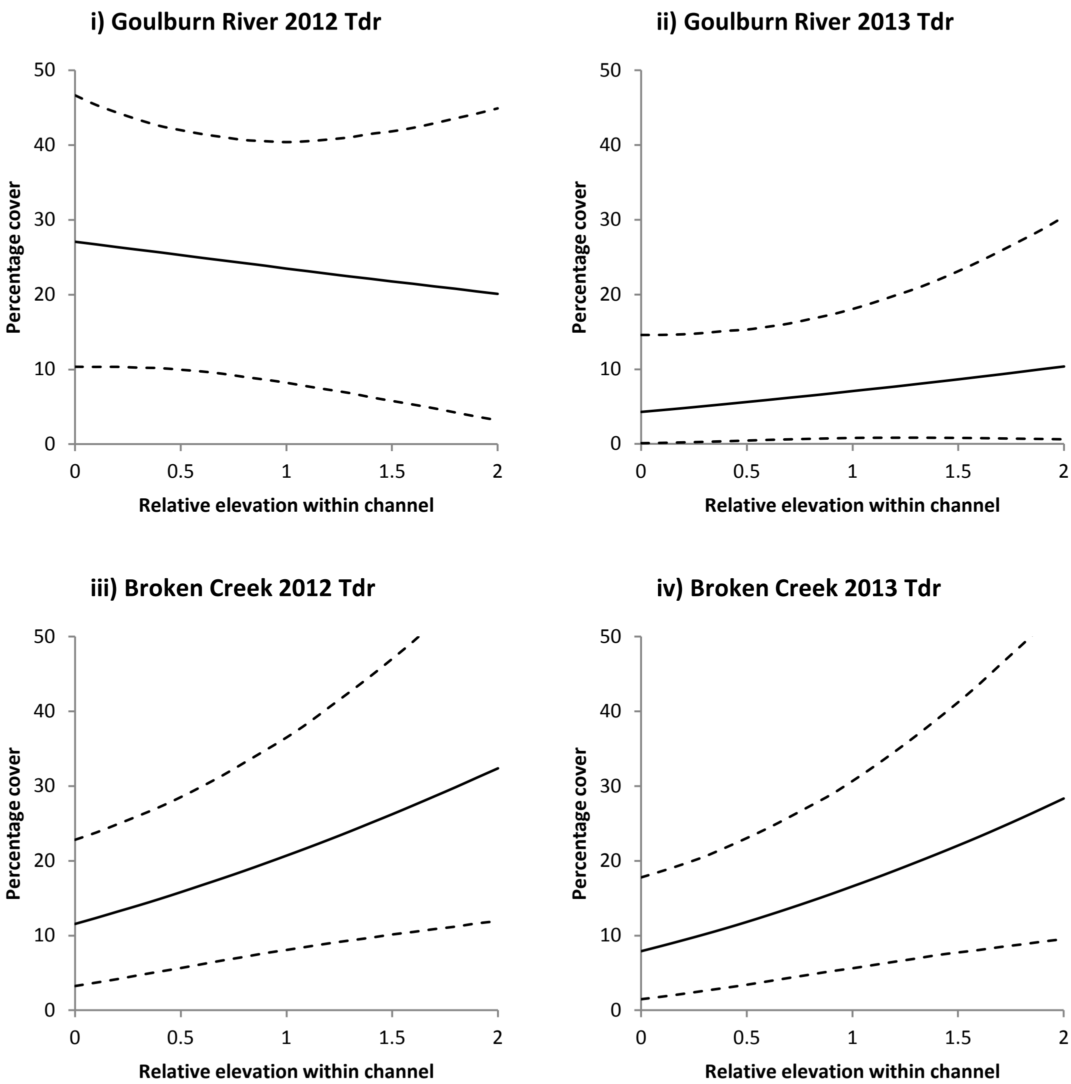

Figure 14-2. Effect of elevation on the cover of Terrestrial Dry (Tdr) taxa. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

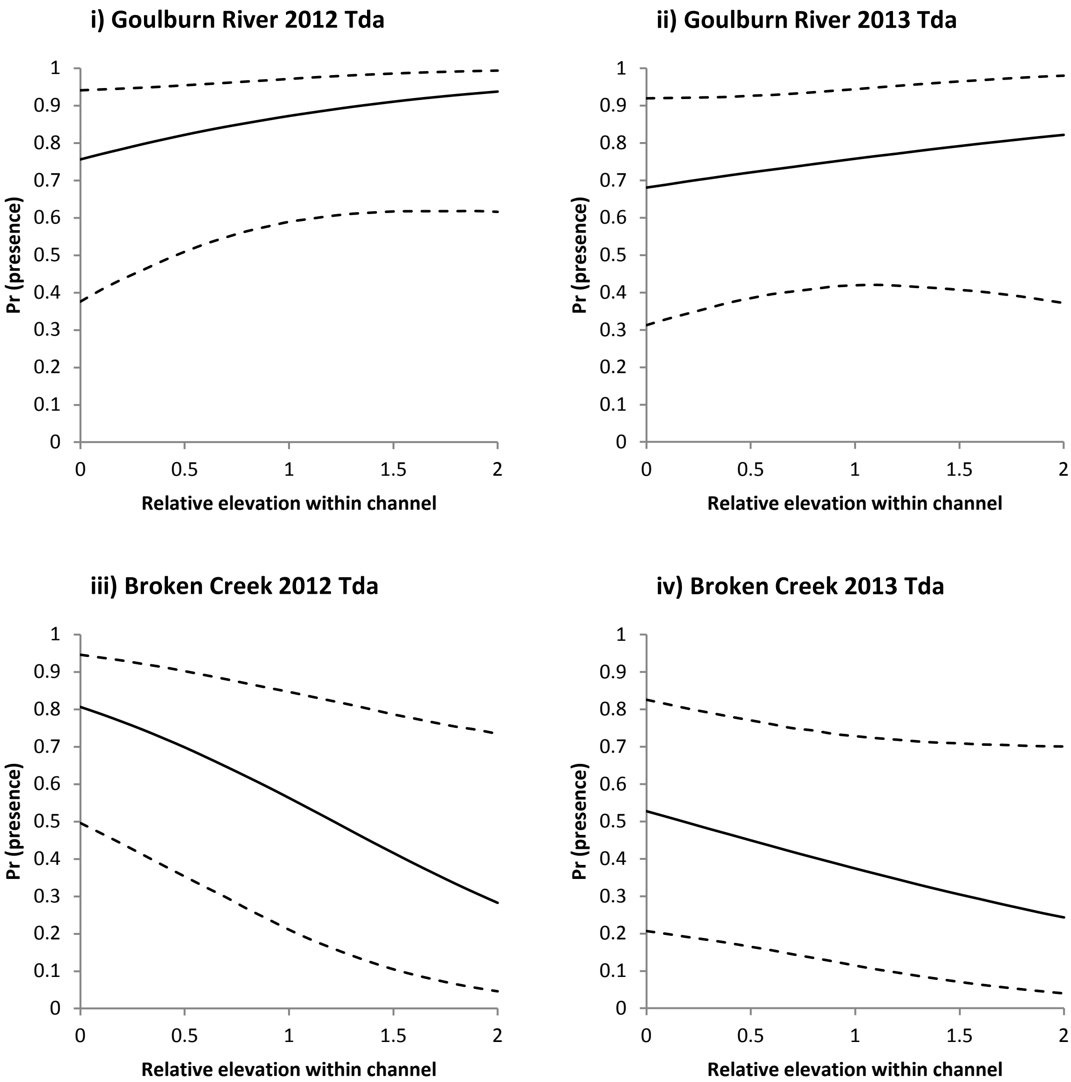

Figure 14-3. Effect of elevation on the presence/absence of Terrestrial Damp (Tda) taxa. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

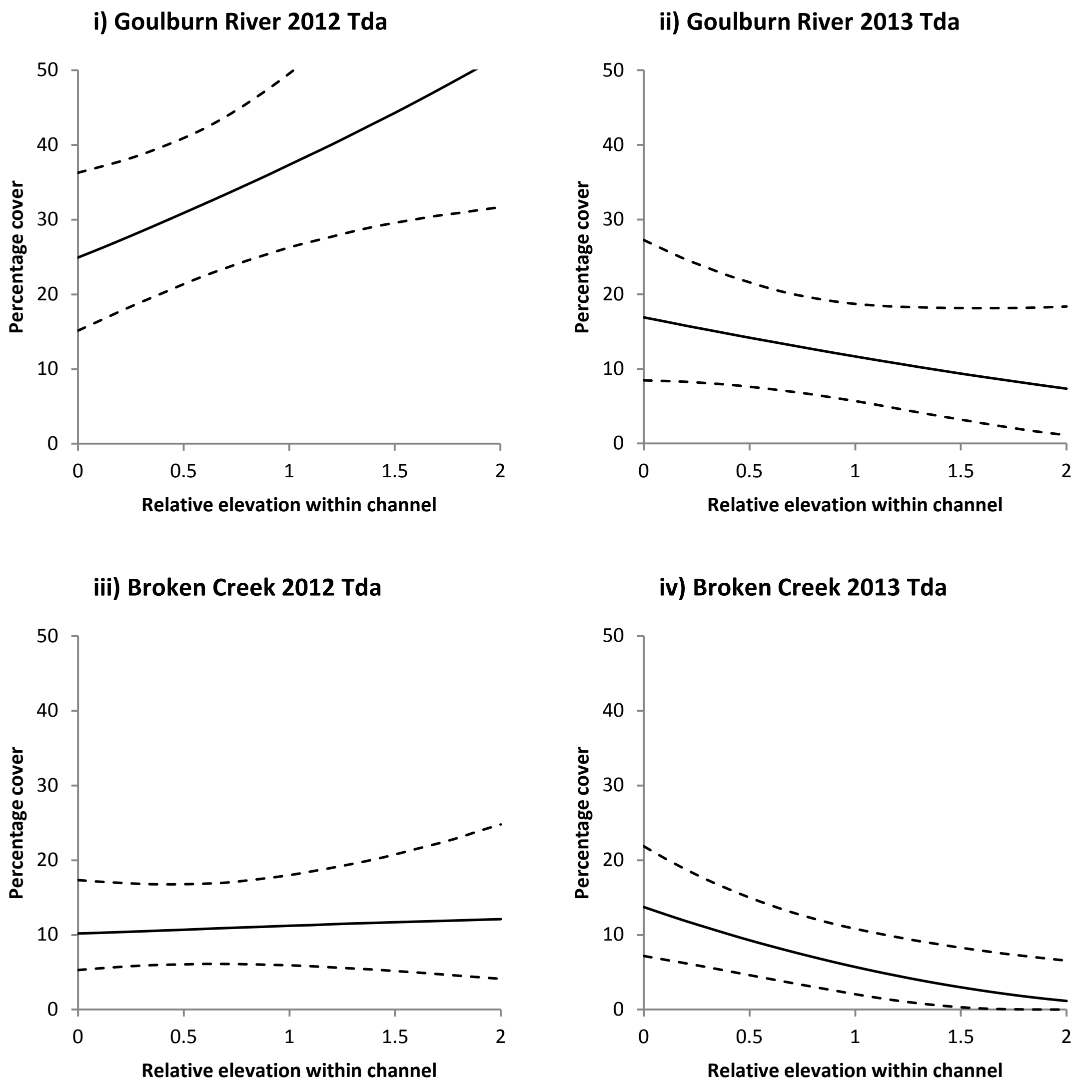

Figure 14-4. Effect of elevation on the cover of Terrestrial Damp (Tda) taxa. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

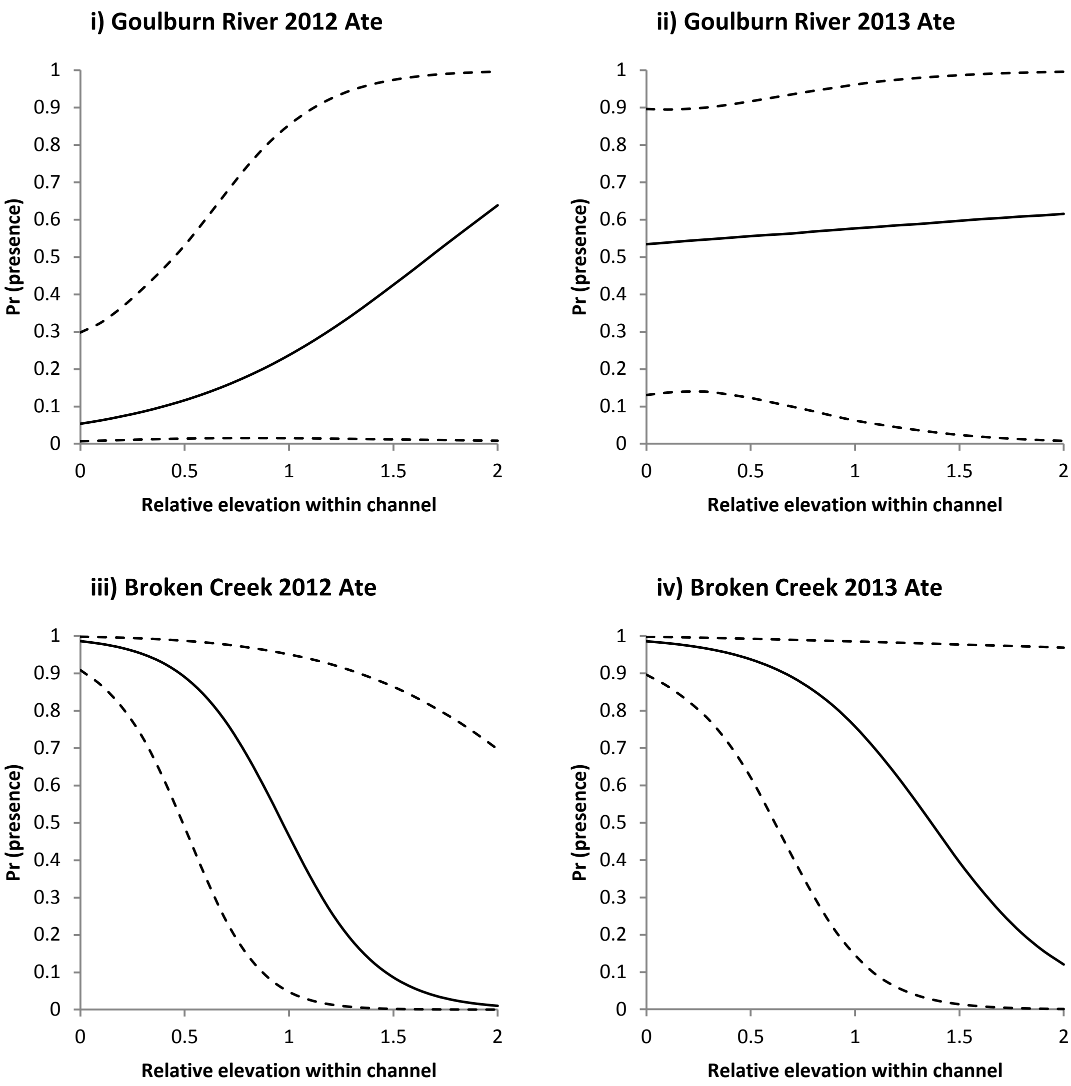

Figure 14-5. Effect of elevation on the presence/absence of Amphibious Fluctuation Tolerator - Emergent (Ate) taxa. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

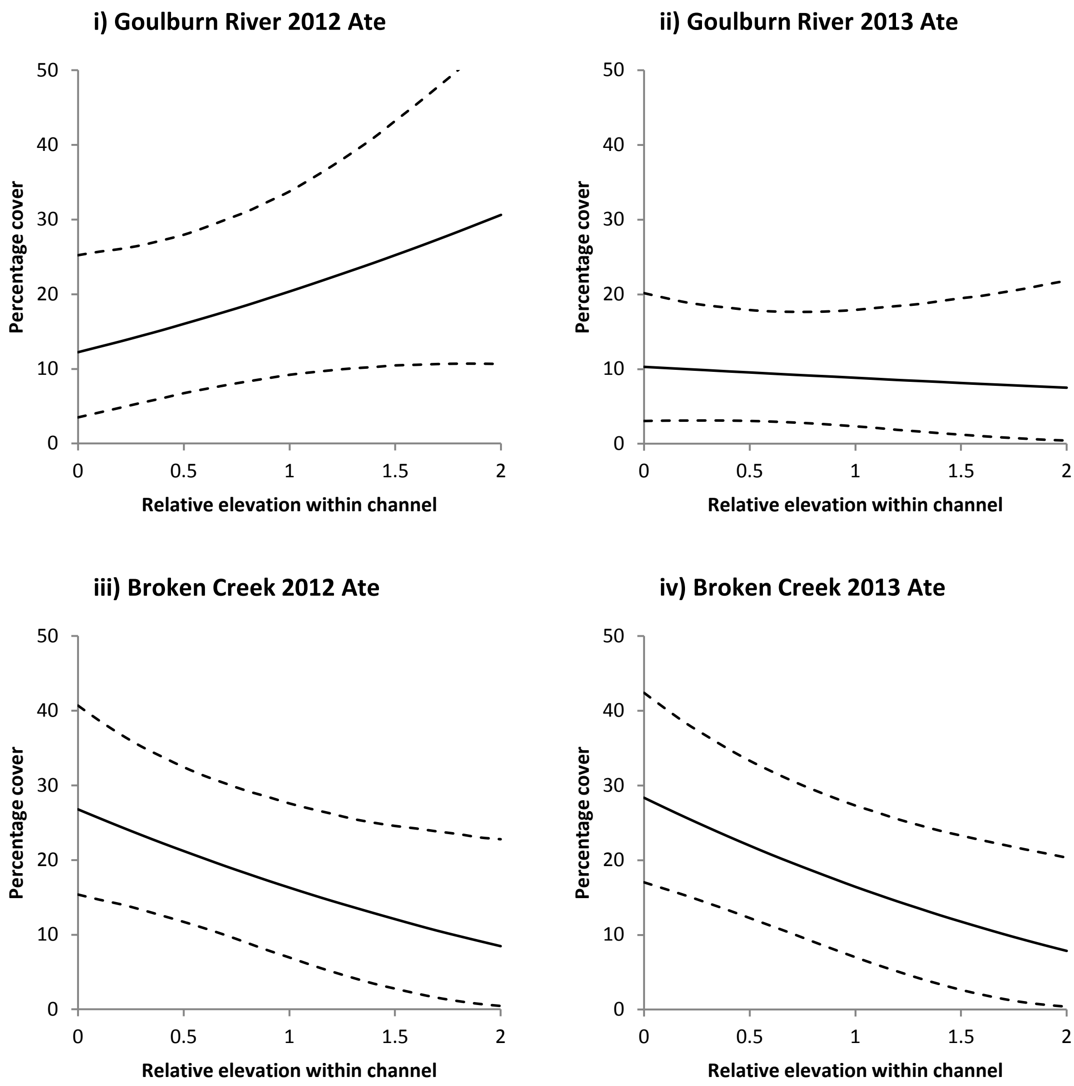

Figure 14-6. Effect of elevation on the cover of Amphibious Fluctuation Tolerator - Emergent (Ate) taxa. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

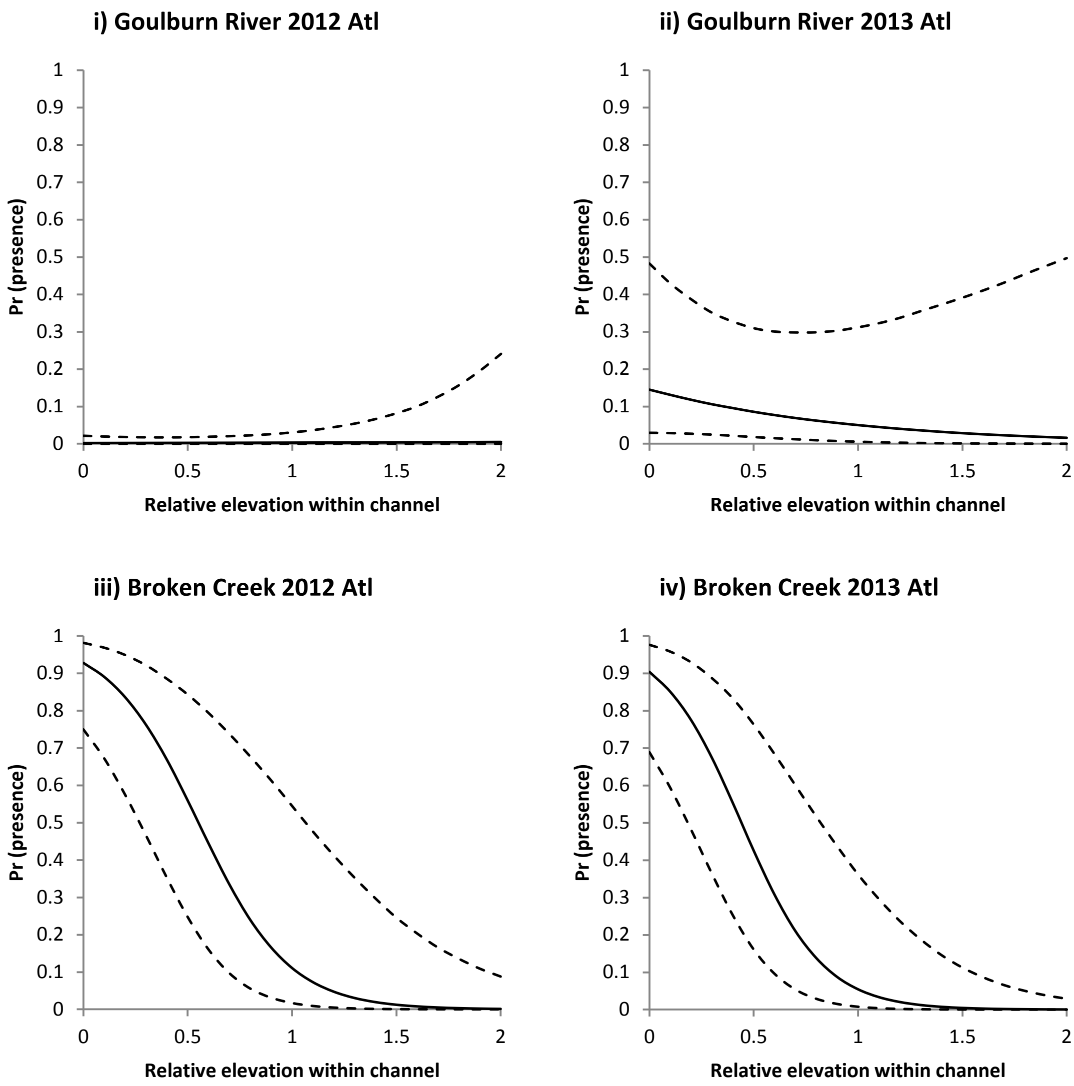

Figure 14-7. Effect of elevation on the presence/absence of Amphibious Fluctuation Tolerator – Low-Growing (Atl) taxa. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

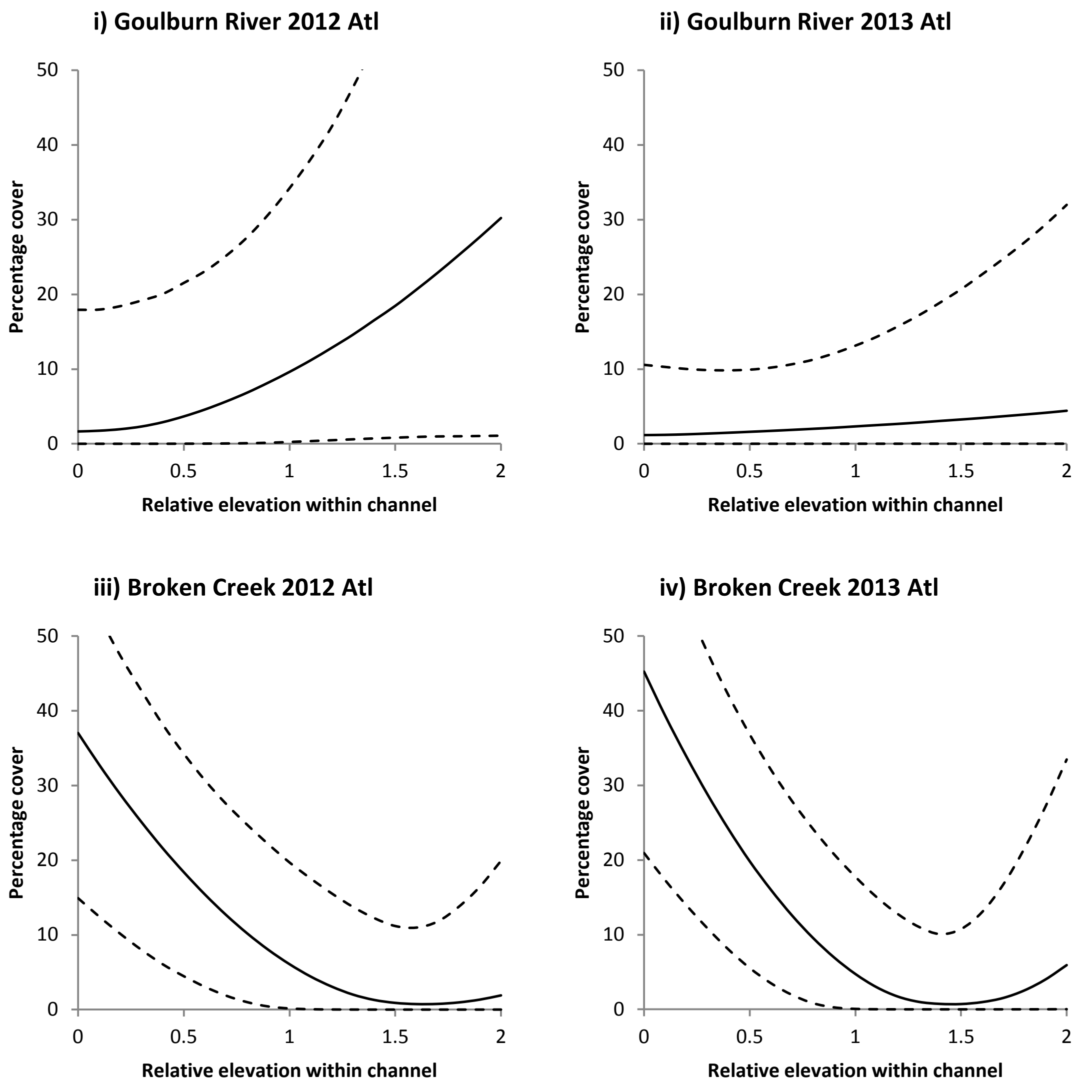

Figure 14-8. Effect of elevation on the cover of Amphibious Fluctuation Tolerator – Low-Growing (Atl) taxa. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

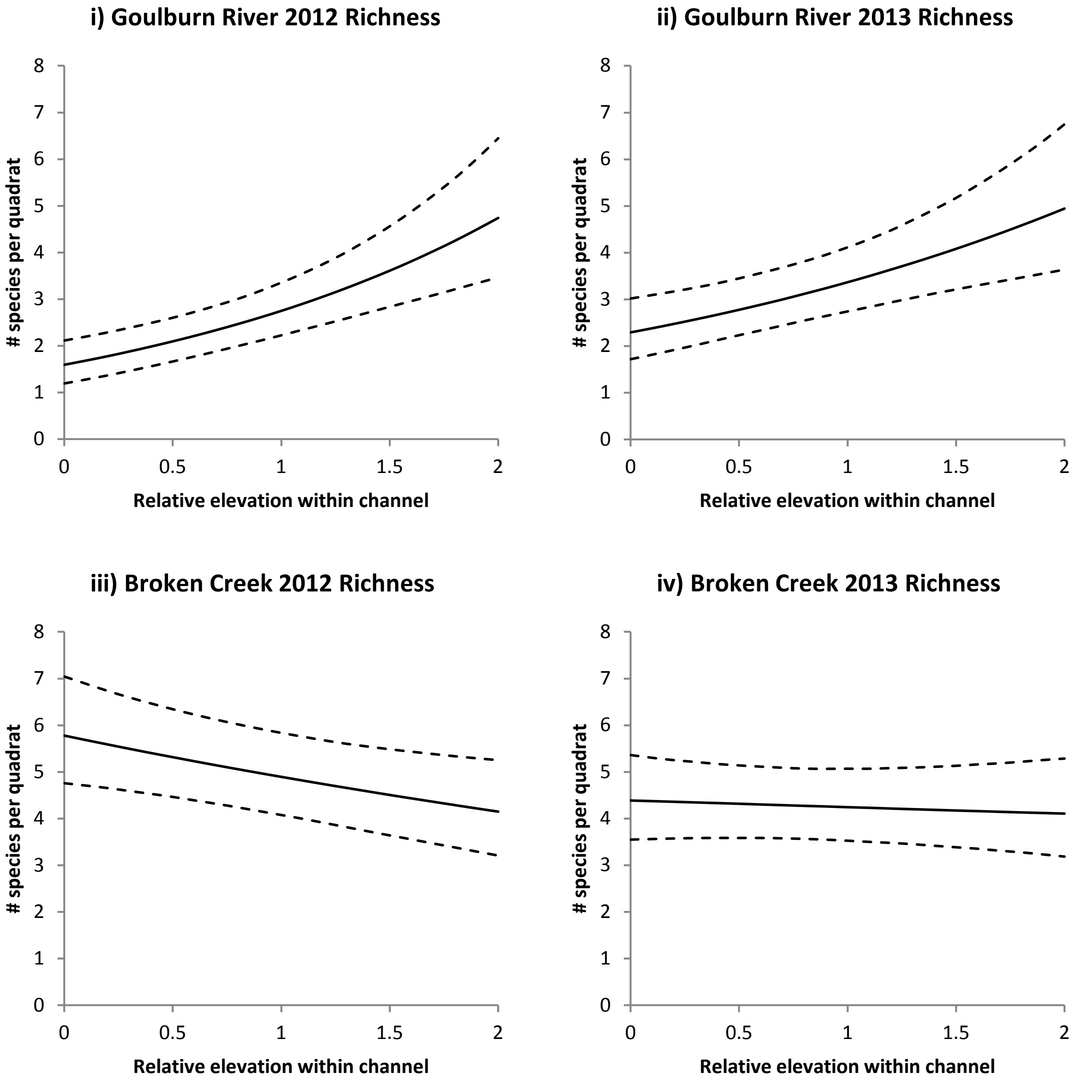

Figure 14-9. Effect of elevation on species richness within quadrats. The four panels are for the Goulburn River and Broken Creek, and 2013/14 and 2012/13 respectively. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

14.3 Effects of inundation duration on the presence, cover and species richness of vegetation

The plots below are the full results for the models of the effect of duration in the Goulburn River on the presence/absence and on cover of the four different functional groups, plus on species richness. See Chapter 4 for summaries of results and interpretations.

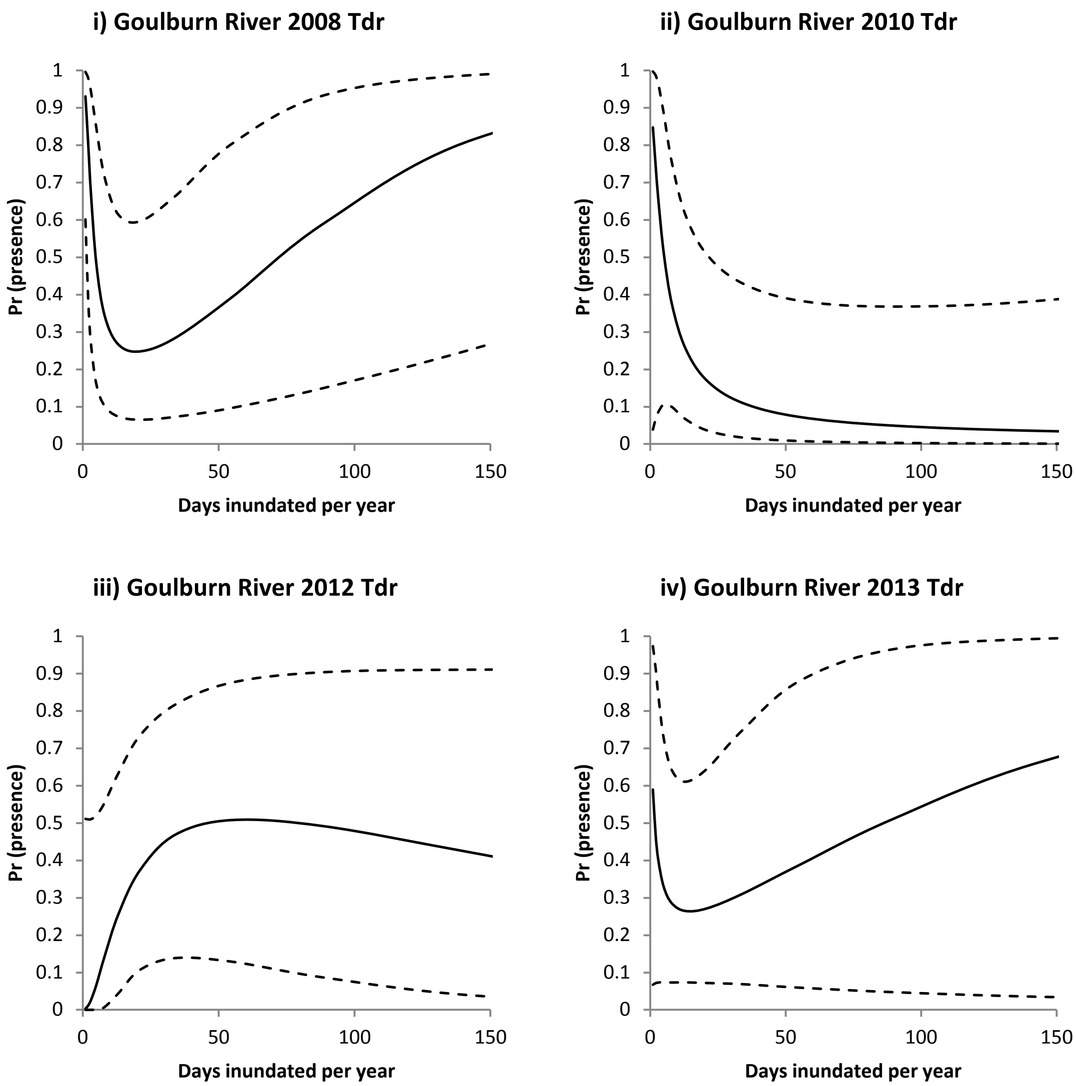

Figure 14-10. Effect of inundation duration on presence/absence of Terrestrial Dry (Tdr) taxa. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

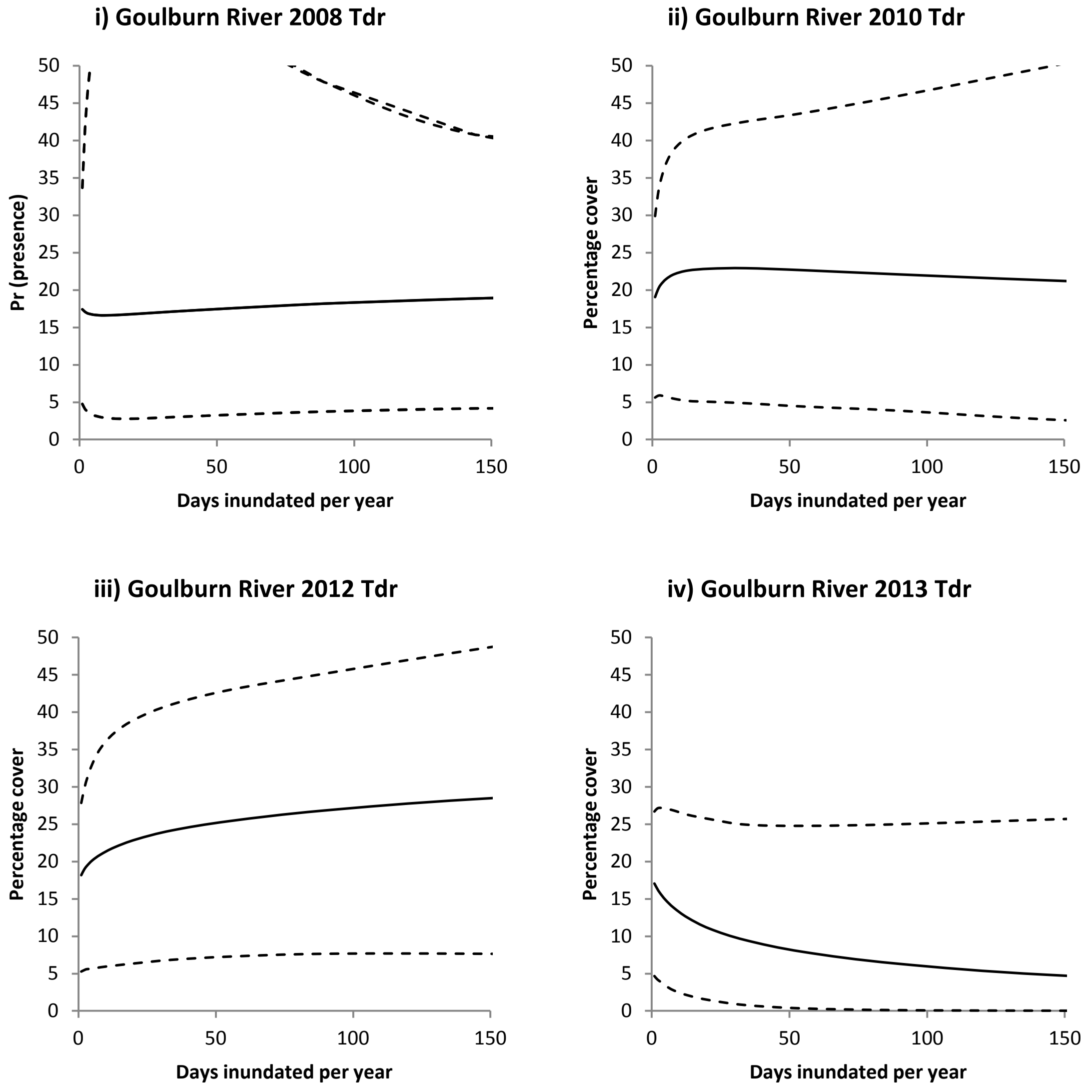

Figure 14-11. Effect of inundation duration on cover of Terrestrial Dry (Tdr) taxa. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

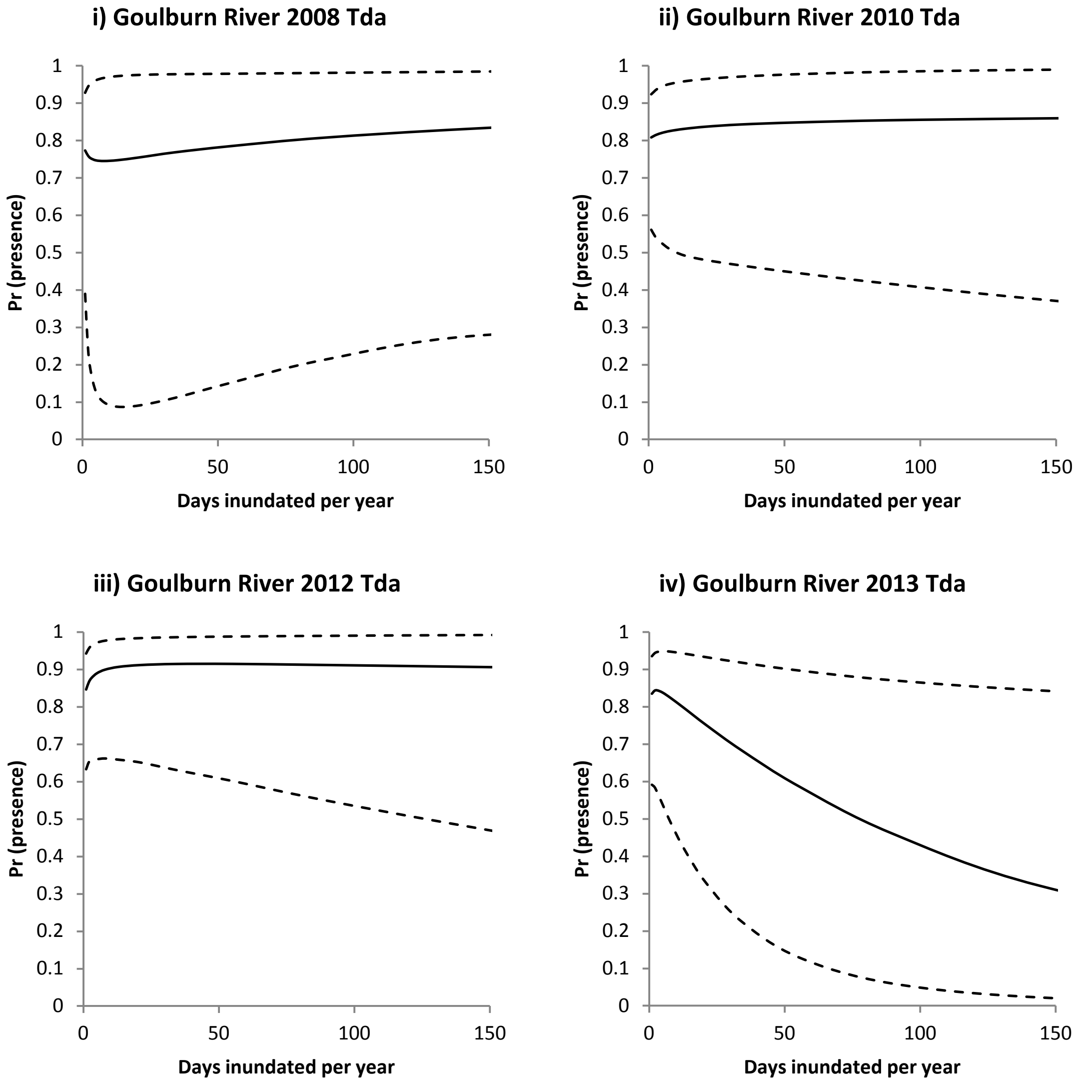

Figure 14-12. Effect of inundation duration on presence/absence of Terrestrial Damp (Tda) taxa. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

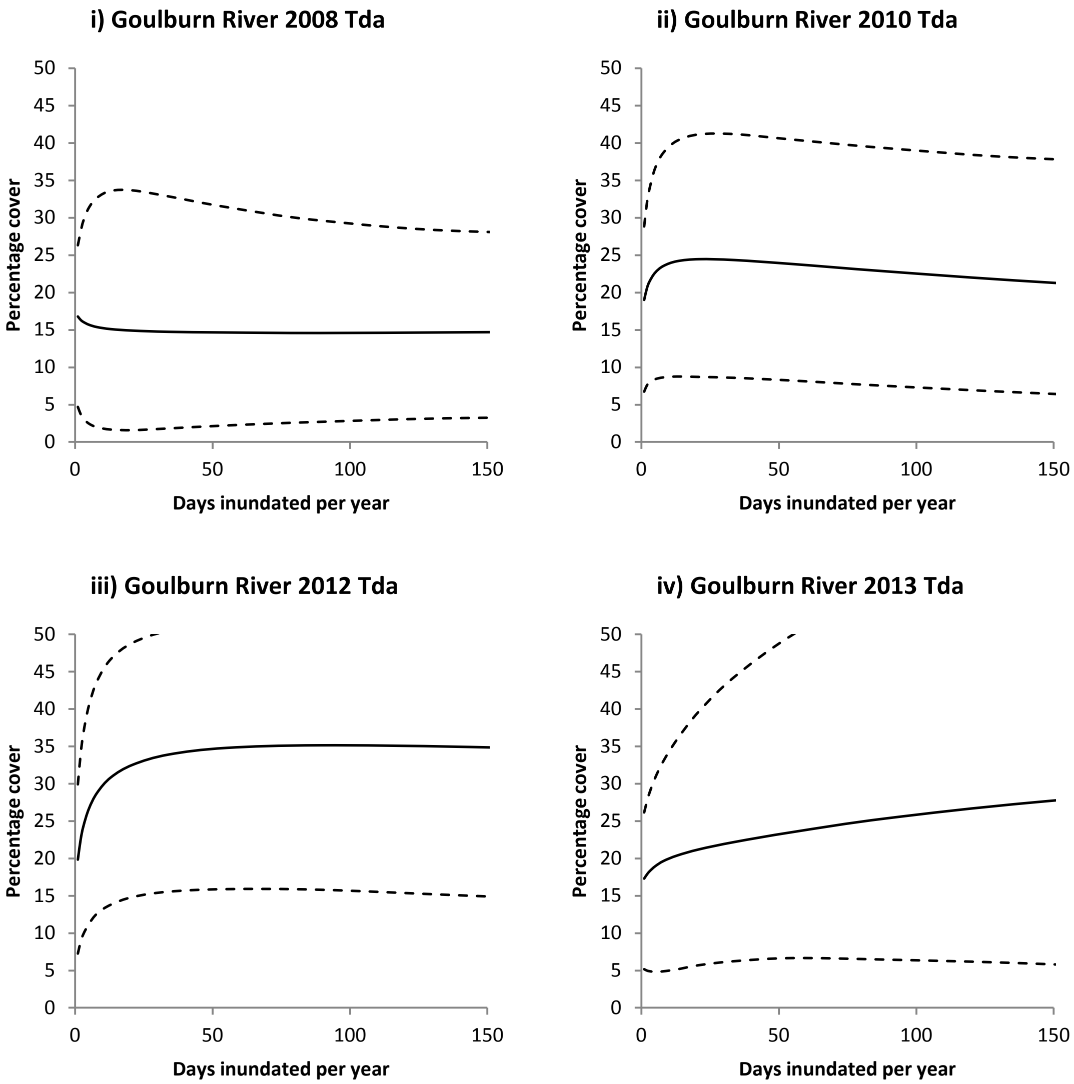

Figure 14-13. Effect of inundation duration on cover of Terrestrial Damp (Tda) taxa. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

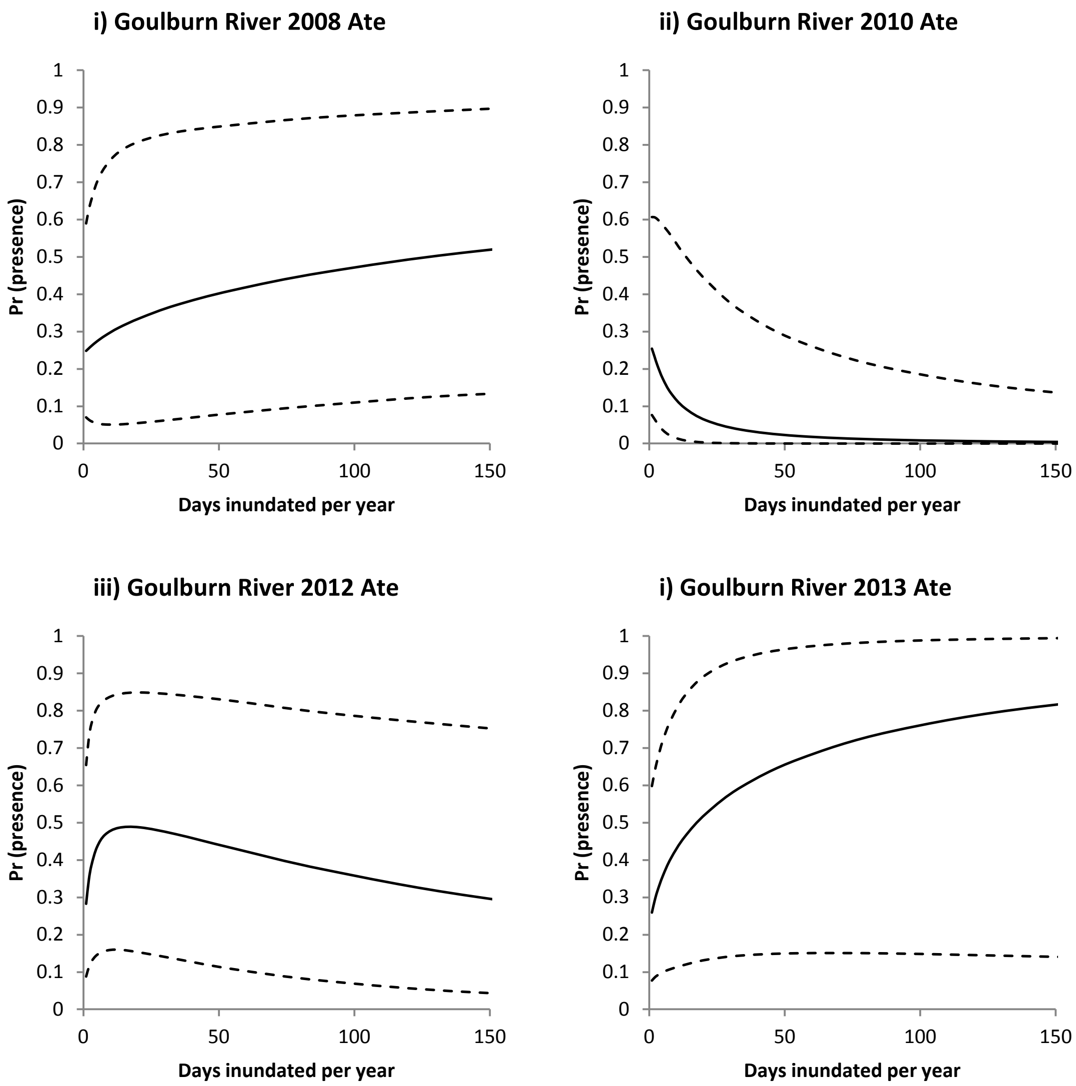

Figure 14-14. Effect of inundation duration on presence/absence of Amphibious Fluctuation Tolerator – Emergent (Ate) taxa. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

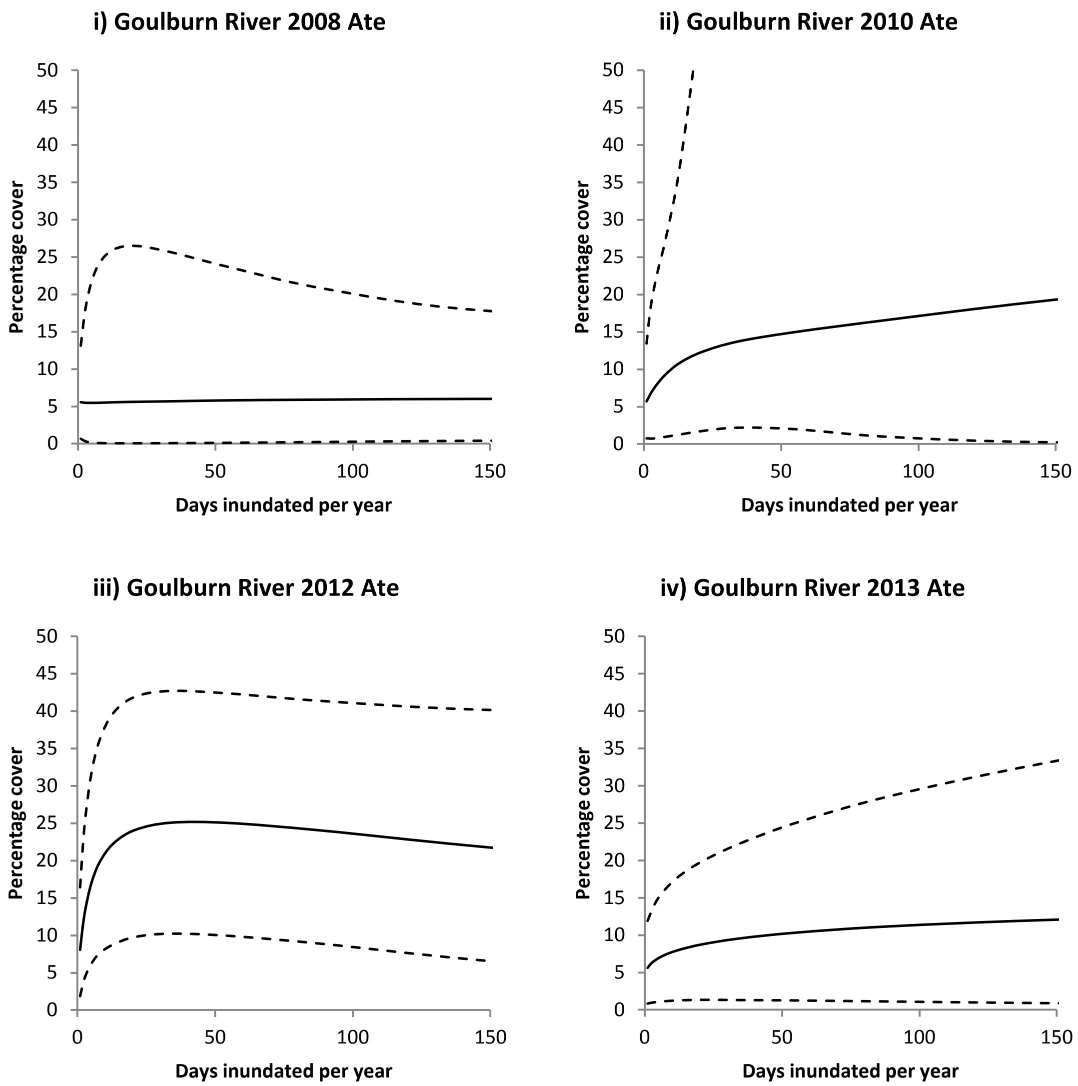

Figure 14-15. Effect of inundation duration on cover of Amphibious Fluctuation Tolerator – Emergent (Ate) taxa. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

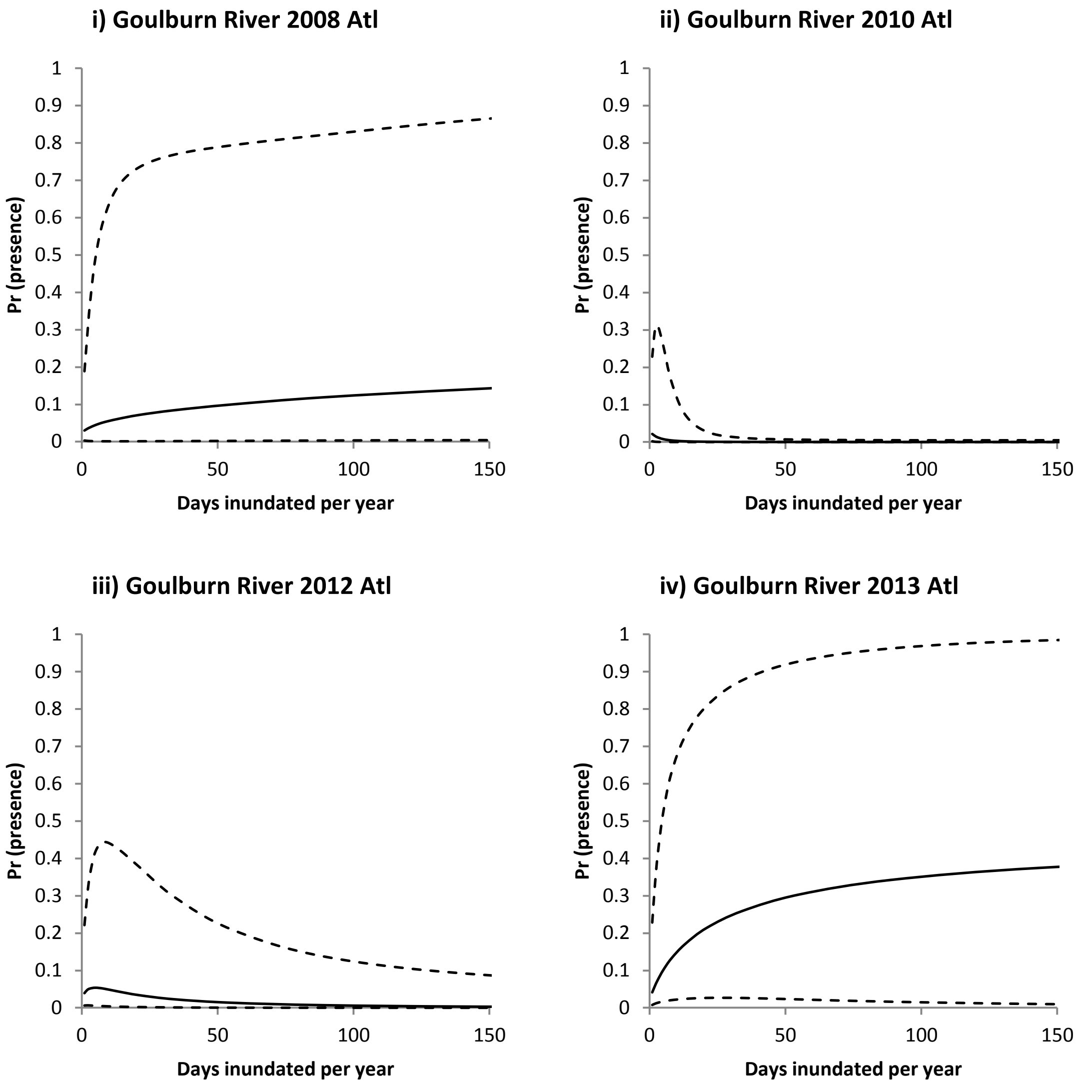

Figure 14-16. Effect of inundation duration on presence/absence of Amphibious Fluctuation Tolerator – Low-Growing (Atl) taxa. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

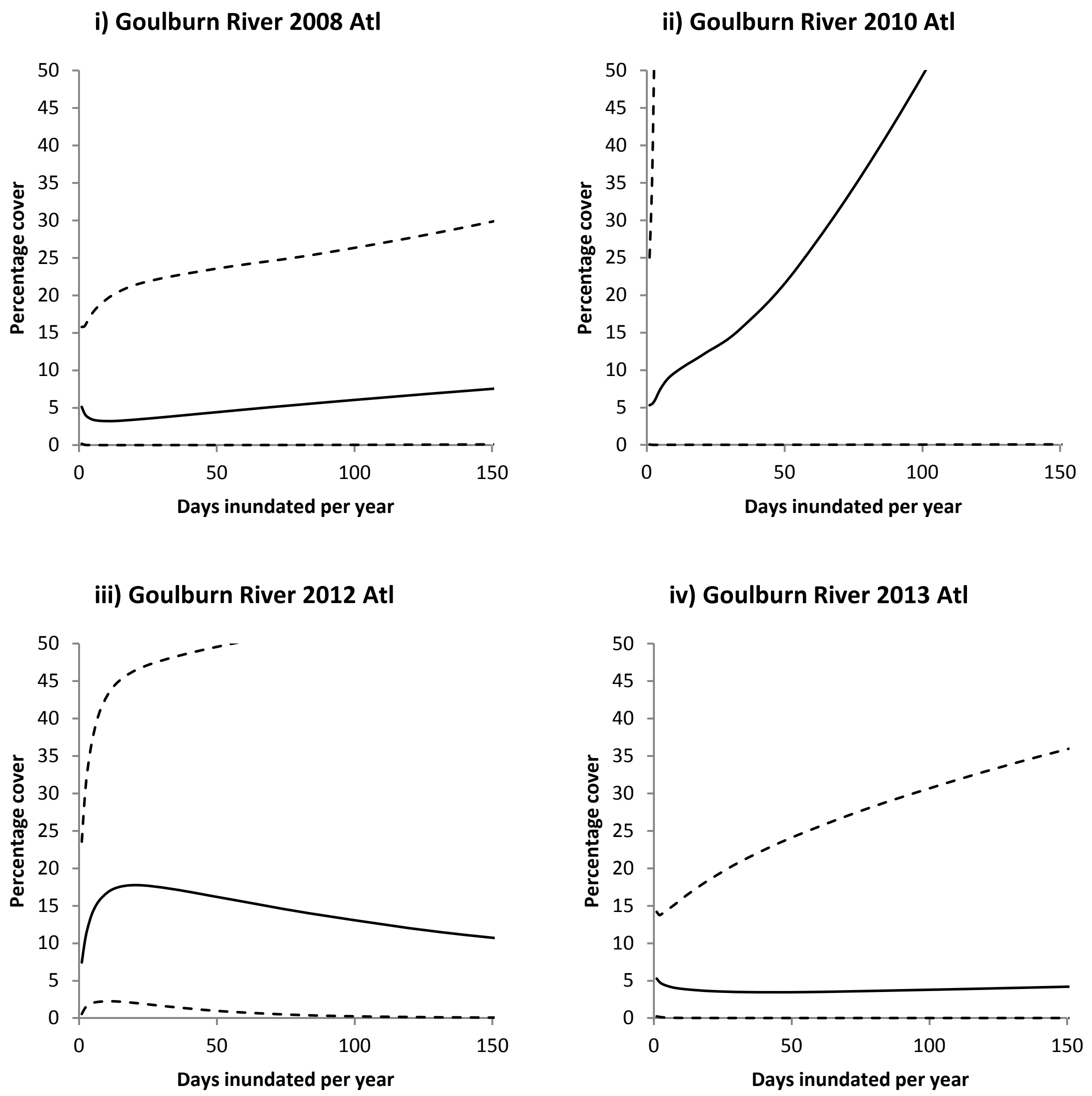

Figure 14-17. Effect of inundation duration on cover of Amphibious Fluctuation Tolerator – Low-Growing (Atl) taxa. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

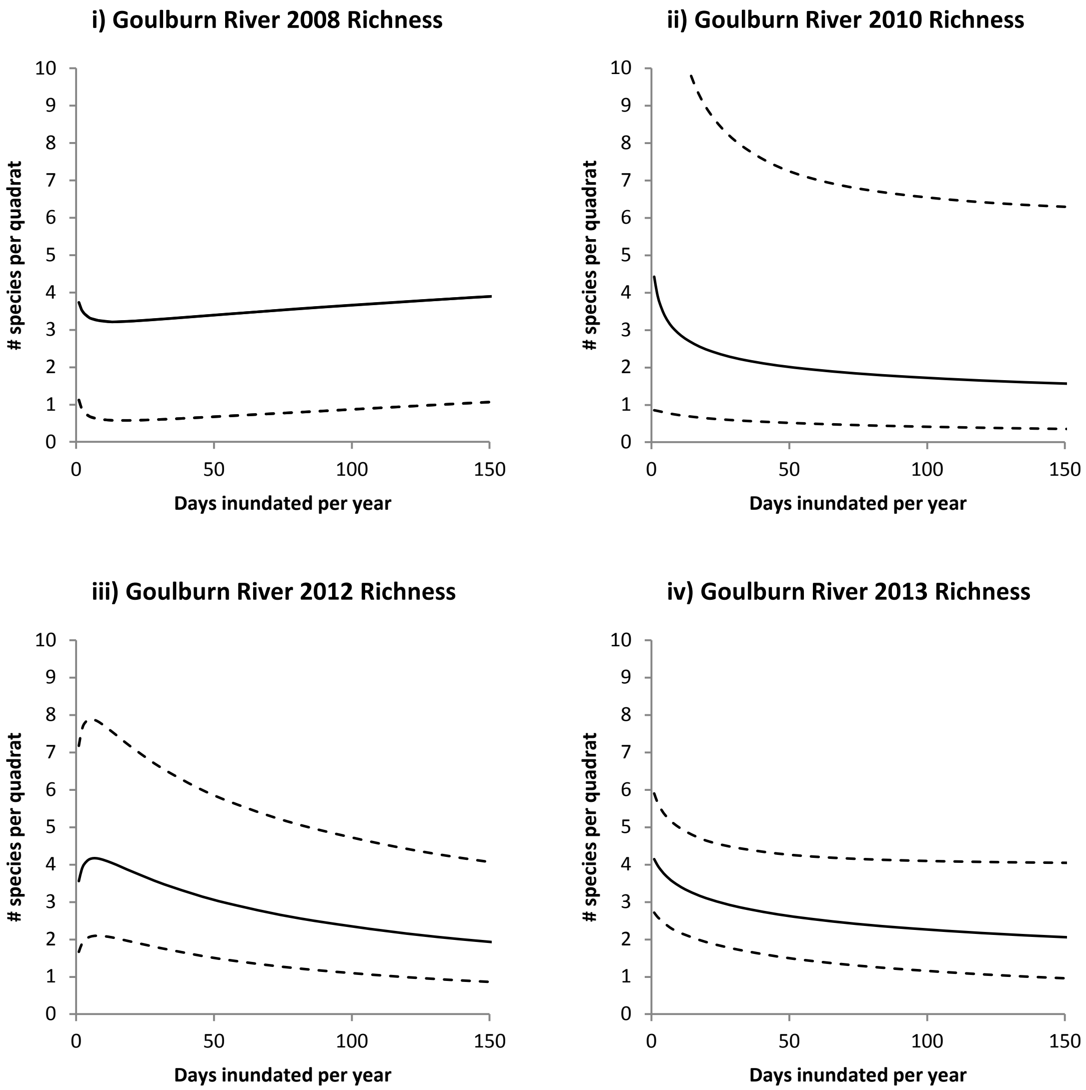

Figure 14-18. Effect of inundation duration on species richness within quadrats. The four panels are for the four years of sampling in Goulburn River. Solid line is the median prediction from the statistical model, with the dotted lines encompassing the 95% credible interval of the estimate.

14.4 Effect of environmental flows on the presence, cover and species richness of vegetation

The plots below are the full results for the assessment of the effect of environmental flows, using the model of the effect of inundation, fitted to the 2013/14 data only. See Chapter 4 for summaries of results and interpretations.

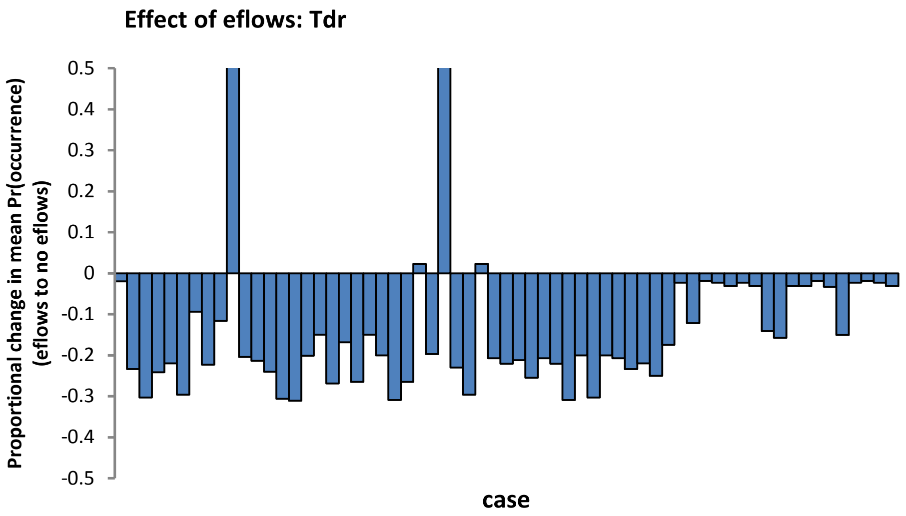

Figure 14-19. The effect of environmental flows upon presence/absence of Terrestrial Dry (Tdr) taxa. Bars are proportional change in the predicted probability of occurrence when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

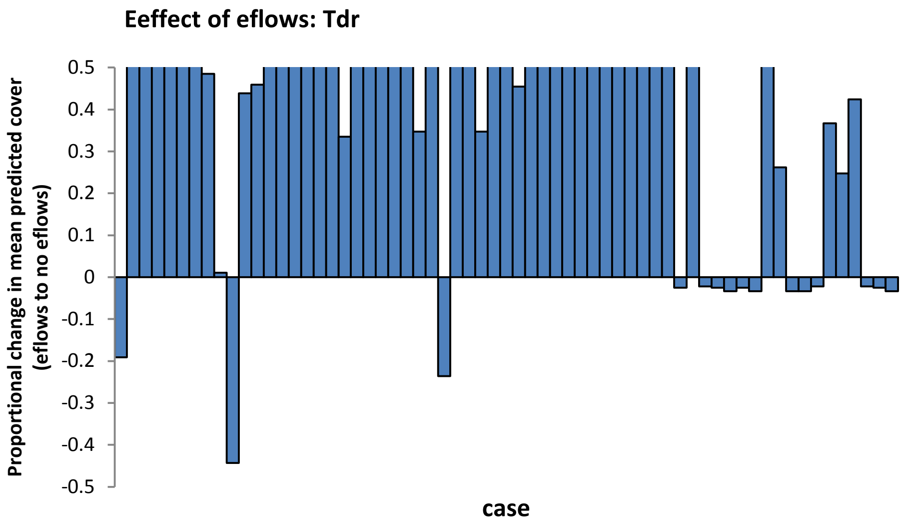

Figure 14-20. The effect of environmental flows upon cover of Terrestrial Dry (Tdr) taxa. Bars are proportional change in the predicted cover when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

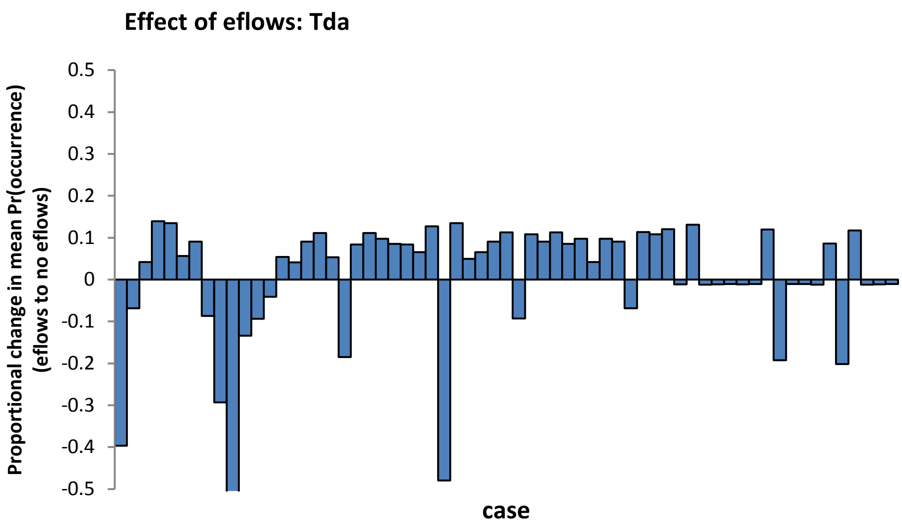

Figure 14-21. The effect of environmental flows upon presence/absence of Terrestrial Damp (Tda) taxa. Bars are proportional change in the predicted probability of occurrence when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

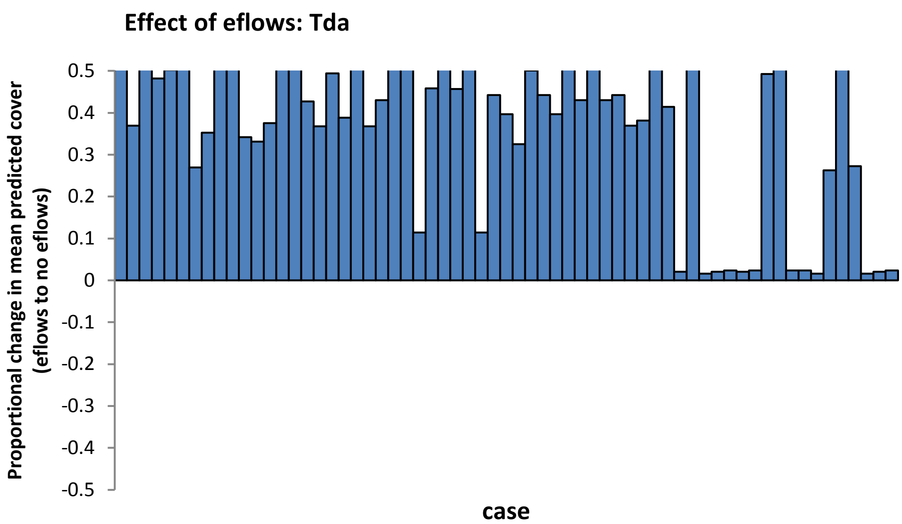

Figure 14-22. The effect of environmental flows upon cover of Terrestrial Damp (Tda) taxa. Bars are proportional change in the predicted cover when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

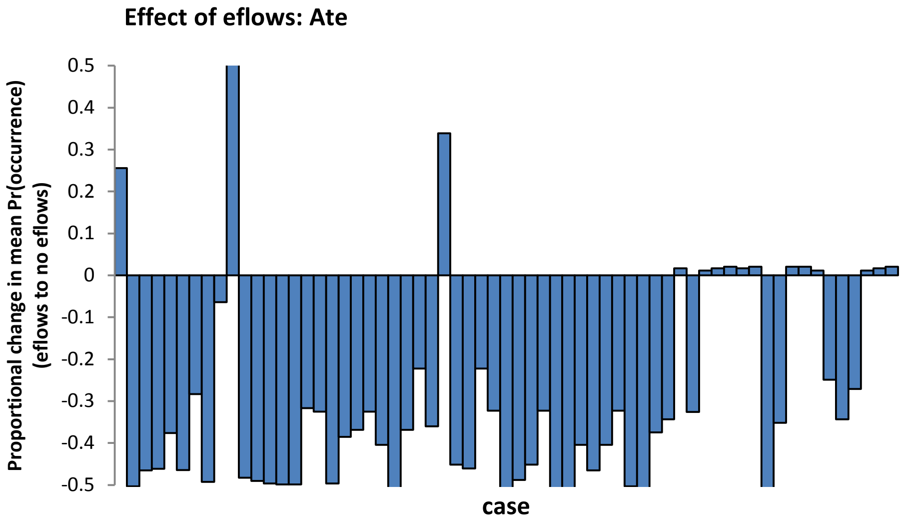

Figure 14-23. The effect of environmental flows upon presence/absence of Amphibious Fluctuation Tolerator - Emergent (Ate) taxa. Bars are proportional change in the predicted probability of occurrence when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

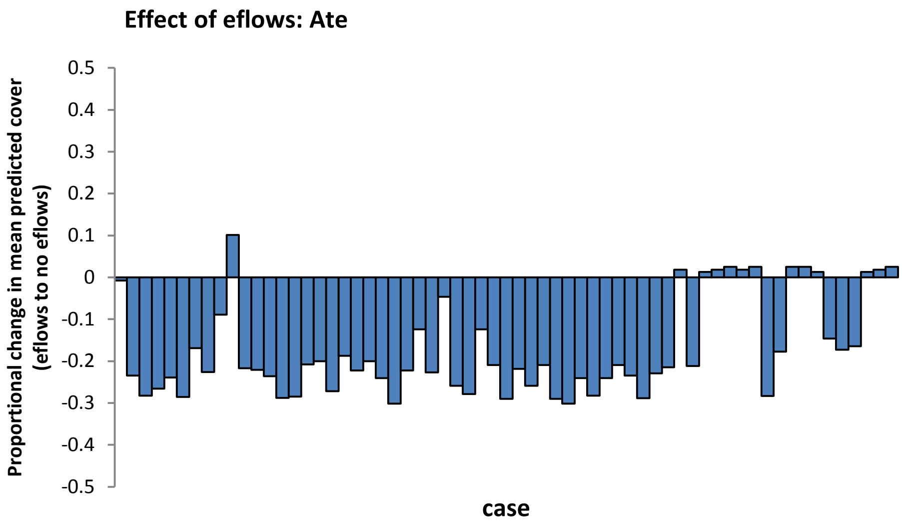

Figure 14-24. The effect of environmental flows upon cover of Amphibious Fluctuation Tolerator - Emergent (Ate) taxa. Bars are proportional change in the predicted cover when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

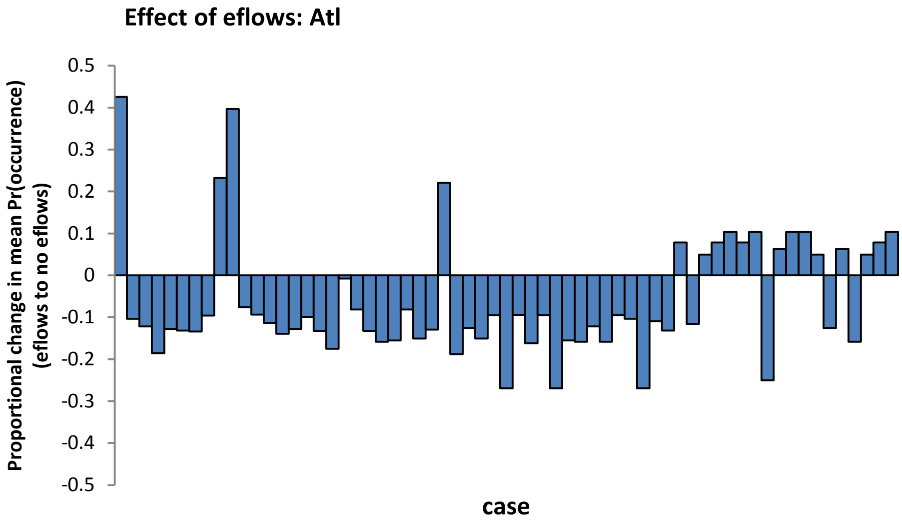

Figure 14-25. The effect of environmental flows upon presence/absence of Amphibious Fluctuation Tolerator – Low-Growing (Atl) taxa. Bars are proportional change in the predicted probability of occurrence when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

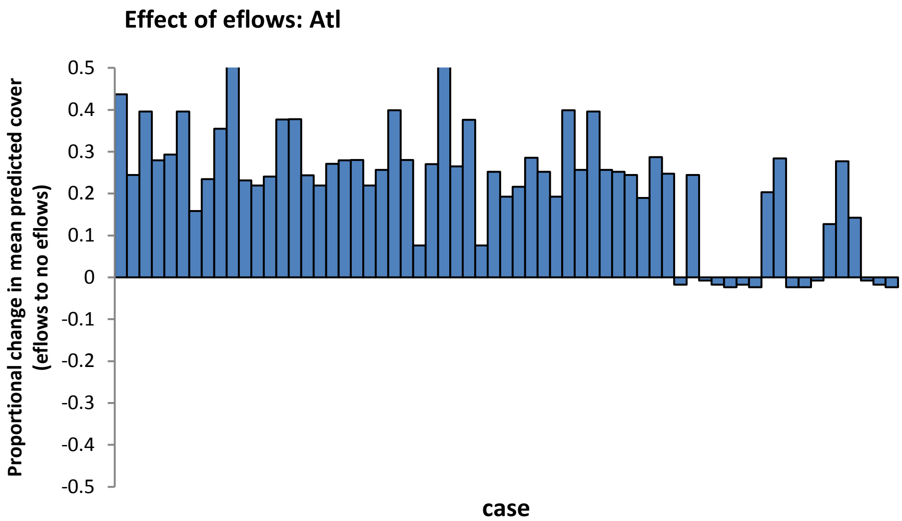

Figure 14-26. The effect of environmental flows upon cover of Amphibious Fluctuation Tolerator – Low-Growing (Atl) taxa. Bars are proportional change in the predicted cover when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

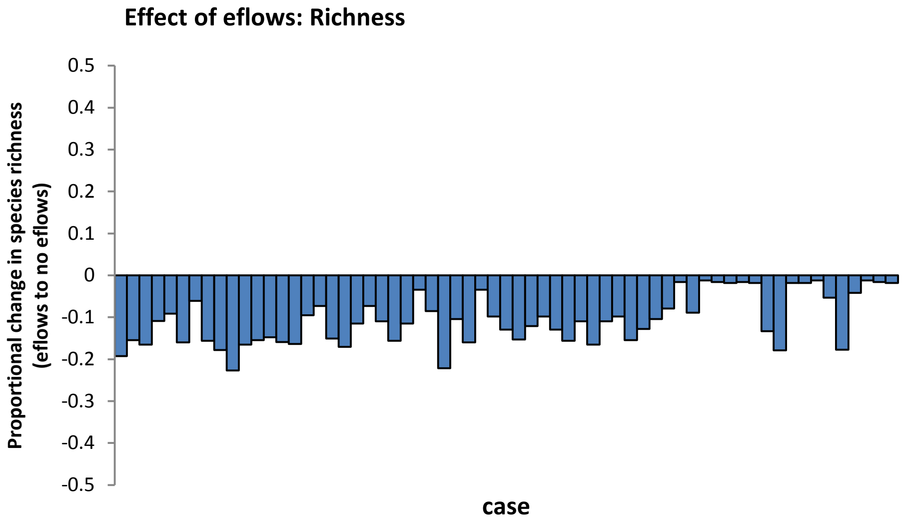

Figure 14-27. The effect of environmental flows upon species richness within quadrats. Bars are proportional change in the predicted number of taxa when environmental flows are removed from the hydrograph. Bars below zero indicate a reduction; bars above zero indicate an increase.

14.5 Effect of environmental flows on inundation duration and frequency

The table below illustrates that for the majority of quadrats for which we were able to predict the effect of eflows, the removal of eflows from the hydrograph decreased the number of separate inundation events. This goes some way to explaining some of the counter-intuitive results of these analyses, as discussed in Chapter 4.

Table 14-1. Table shows inundation duration (*T*) and frequency (*f*) for modelled quadrats for hydrographs with environmental flows and without, and the difference in both quantities caused by having environmental flows in the lower Goulburn River. Rows are ordered in decreasing order of the change in inundation duration caused by environmental flows. Table continues on the next page.

with eflows		without eflows		difference	
T	*f*	*T*	*f*	*T*	*f*
365	1	170	9	195	-8
329	3	143	7	186	-4
221	6	100	9	121	-3
203	7	95	8	108	-1
191	9	85	8	106	1
191	8	87	6	104	2
187	9	83	8	104	1
182	9	83	6	99	3
165	9	79	6	86	3
162	9	77	6	85	3
164	9	79	6	85	3
157	9	75	6	82	3
157	9	75	6	82	3
146	9	72	6	74	3
125	8	59	5	66	3
125	8	59	5	66	3
120	8	55	5	65	3
115	8	51	5	64	3
104	7	45	4	59	3
107	7	48	4	59	3
104	7	45	4	59	3
99	7	44	4	55	3
84	8	37	4	47	4
77	9	37	4	40	5
76	9	37	4	39	5
69	9	33	4	36	5
69	9	33	4	36	5
63	7	33	4	30	3
57	7	32	4	25	3
52	6	28	4	24	2
52	6	28	4	24	2
56	7	32	4	24	3
50	6	27	3	23	3
50	6	27	3	23	3

with eflows		without eflows		difference	
T	*f*	*T*	*f*	*T*	*f*
50	6	27	3	23	3
52	6	30	4	22	2
44	5	26	3	18	2
43	5	25	3	18	2
43	5	25	3	18	2
43	5	25	3	18	2
42	5	26	3	16	2
35	5	21	3	14	2
34	5	21	3	13	2
33	5	21	3	12	2
32	5	21	3	11	2
32	5	21	3	11	2
30	5	21	3	9	2
29	5	21	3	8	2
27	5	21	3	6	2
25	5	20	3	5	2
25	5	20	3	5	2
8	3	7	3	1	0
11	3	10	3	1	0
8	3	7	3	1	0
6	2	5	2	1	0
8	3	7	3	1	0
6	2	5	2	1	0
6	2	5	2	1	0
6	2	5	2	1	0
11	3	10	3	1	0
11	3	10	3	1	0
8	3	7	3	1	0
6	2	5	2	1	0

15 Appendix D – Details of fish movement analysis.

The best supported model (in terms of both AIC and BIC) explaining the probability of fish moving (any direction) was model 6 (Table 15-1). In this model, four variables were significant ($p < 0.05$): current flow, time step, day of the year, and zone. The probability of fish moving increased with increasing flow. Fish were also less likely to move with time, less likely to move in winter/more likely to move in summer, and less likely to move in the middle reaches.

The best supported model (in terms of both AIC and BIC) explaining the probability of fish moving downstream was model 4 (Table 15-1). In this model, four variables were significant ($p < 0.05$): current flow, current water temperature, time step and spawning season. There was a non-linear or dome-shaped relationship between the probability of fish moving downstream and current flow and water temperature. The probability of fish moving downstream peaked when current flow and current water temperature increased to about 12000 ML day and 18-19 °C, respectively. Fish were more likely to move downstream in the spawning season, and less likely to move downstream with time.

The best supported model explaining the probability of fish moving upstream was model 5 (Table 15-1). In this model, four variables were significant ($p < 0.05$): previous flow, previous water temperature, flow difference and day of the year. Fish were more likely to move upstream if flow difference and previous flow increased, and more likely to move upstream in spring. There was a non-linear or dome-shaped relationship between the probability of fish moving upstream and previous water temperature. The probability of fish moving upstream peaked previous water temperature increased to about 22 °C .

The best supported model explaining the probability of fish moving downstream (versus upstream) was model 4 (Table 15-1). In this model, three variables were significant ($p < 0.05$): current flow, fish length and zone. There was a non-linear or dome-shaped relationship between the probability of fish moving downstream and current flow. The probability of fish moving downstream (versus upstream) peaked when current flow increased to about 6500 ML day. The likelihood of fish moving downstream decreased with fish length/the likelihood of fish moving upstream increased with fish length, although the average size of fish moving upstream (422 mm TL) and downstream (410 mm TL) were similar. Fish in the upstream reaches were less likely to move downstream.

Table 15-1. Akaike's Information Criterion and Bayesian Information Criterion for each of the models. Best models are in bold.

	AIC				BIC			
	Moving vs. NM	DS vs. NM or US	US vs. NM or DS	DS vs. US	Moving vs. NM	DS vs. NM or US	US vs. NM or DS	DS vs. US
Model 1	920.5	645.2	547.5	205.3	830	618.8	514.9	211.1
Model 2	919.7	629.5	559.9	197.5	835.9	617.5	522.5	209.3
Model 3	957.6	647.4	550.4	203.3	843.6	613.8	512.9	206.5
Model 4	931.5	**625.6**	560.8	**195.5**	844.6	**609.7**	517.4	**204.6**
Model 5	919.6	647.6	**546.2**	204.2	**823.6**	614.4	**508.4**	209.1
Model 6	**919.4**	628.3	558.7	196.1	829.5	612.1	515.9	207.5

NM – not moving, DS- downstream movement, US upstream movement

16 Appendix E – fishway movement results

16.1 Bayesian Analysis Results

16.1.1 Murray Cod

Murray cod were caught in low numbers (i.e. presence/absence) and as such, binomial (logistic) models were used for the analysis. The information criteria used for each model is shown below (Table 16-1), with the model with flow and Day after 1st Sept providing the lowest DIC i.e. most evidence. This model fits the data relatively well as the posterior predictive Bayesian p-value of 0.315 and only one observation with Pearson residuals greater than 4. The parameter estimates and 95% high density intervals (HDI) for the best model is given in Table 16-2. All of the HDI exclude zero, there is evidence to claim that Murray cod use of the fishways is increased by increased flow and fewer days past September 1st

Table 16-1. The information criteria for each of the binomial models used for Murray Cod capture numbers.

Model	DIC	ΔDIC
Flow + Day after 1st Sept	67.6	
Flow + Day after 1st Sept + Weir (Random)	69.1	1.5
Flow + Temperature	69.5	1.9
Day after 1st Sept + Temperature + Weir (Random)	70.9	3.3
Flow + Day after 1st Sept + Weir (Fixed)	72.7	5.1
Flow + Temperature + Weir (Fixed)	74.5	6.9

Table 16-2. Parameter estimates (logit scale) and 95% high density intervals (HDI) for the binomial model for the number of Murray Cod given the number of days after 1st Sept and the flow.

Variable	Estimate	95% HDI	
		Lower	Upper
Intercept	-2.35	-3.202	-1.493
zFlow	0.903	0.274	1.605
z Day after 1st Sept	-1.022	-1.852	-0.201

16.1.2 Golden Perch

The number of golden perch caught during each trip follows a Poisson distribution. Therefore, Poisson models were fitted for golden perch (Figure 16-1). It was noted that the smoother for flow was linear and therefore was replaced by a linear term in the modelling. The information criteria for each golden perch model is given in Table 16-2. The model with flow and smoother temperature and weir as a random factor provided the lowest DIC, however only slightly (0.4 difference). This model fits the data relatively well with a posterior predictive Bayesian p-value of 0.220, and no Pearson residuals greater than 4.

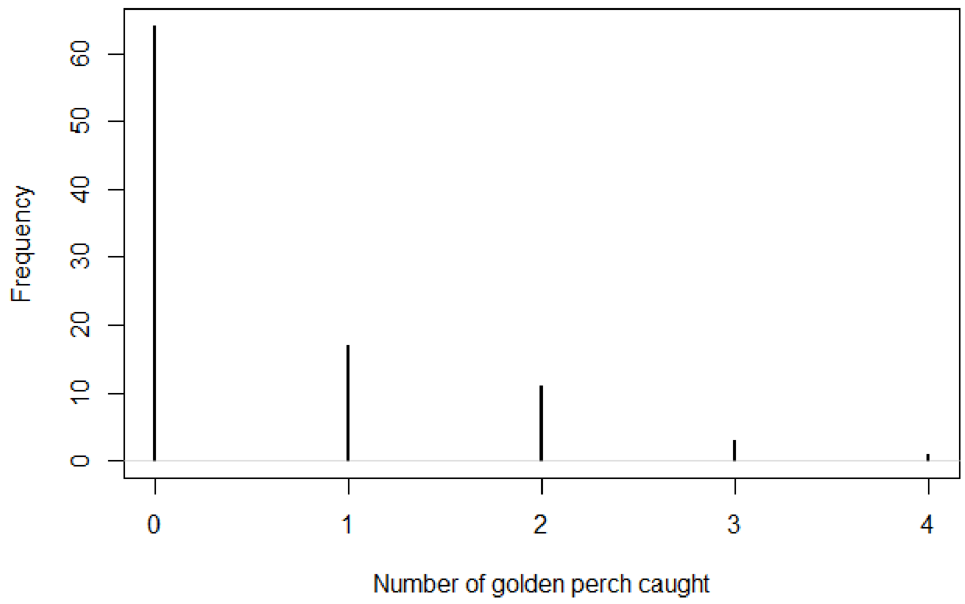

Figure 16-1. Plot of the frequency of the number of golden perch caught per weir for each trip.

Table 16-2. The information criteria for each of the Poisson models used for Golden Perch capture numbers.

Model	DIC	ΔDIC
Flow + s(Temperature) + Weir (Random)	193.0	
Flow + s(Temperature)	193.4	0.4
Flow + s(Temperature) + Weir (Fixed)	193.4	0.4

The parameter estimates and 95% high density intervals (HDI) are shown in Table 16-3. This indicates that weir is producing an effect, with Chinaman's weir having the highest abundances, while Nathalia was the lowest (Table 16-4).

Table 16-3. Parameter estimates (log scale) and 95% high density intervals (HDI) for the Poisson model for the number of Golden Perch given the trip number and the flow.

Variable	Estimate	95% HDI	
		Lower	Upper
Intercept	-1.319	-5.012	1.440
zFlow	0.140	-0.168	0.434
Weir	0.457	0.049	1.254

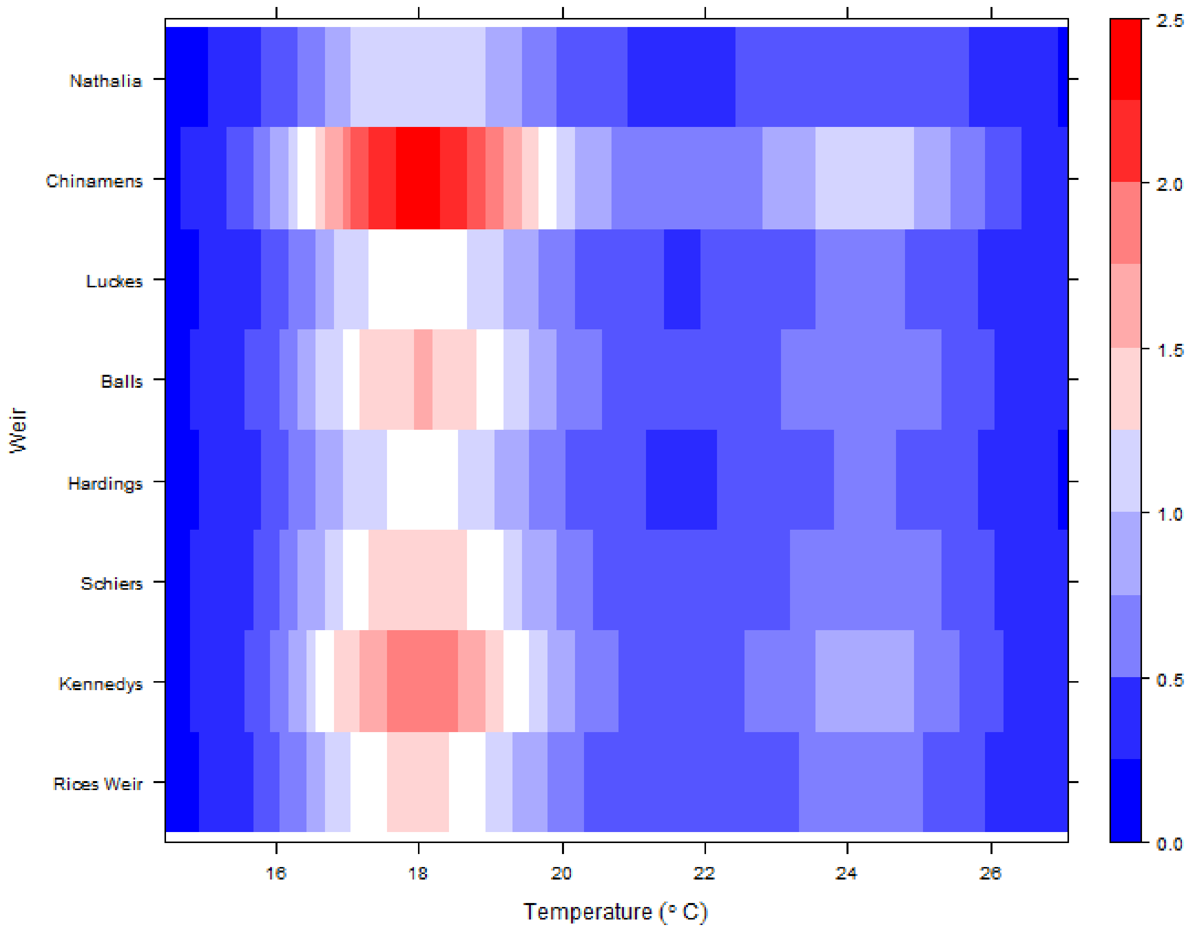

Table 16-4. The expected catch of golden perch (per day) given the weir and water temperature.

16.1.3 Silver Perch

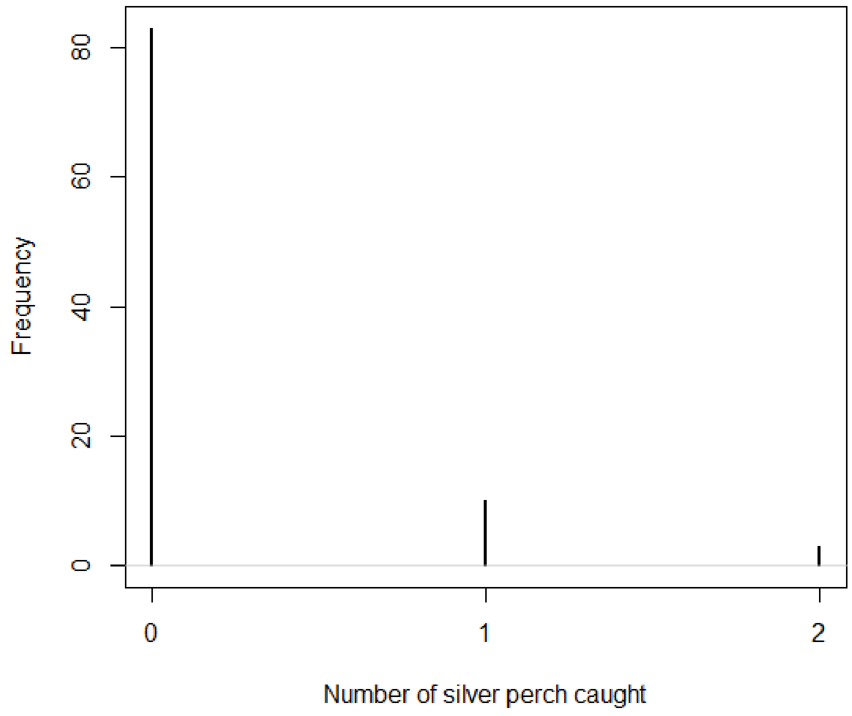

Table 16-5. Plot of the frequency of the number of silver perch caught per Weir per trip.

16.1.4 Carp

The number of common carp caught were highly variable with too many zeroes and ones, and as such, negative binomial models were fitted (Figure 16-6). The smoother for temperature was linear and was therefore replaced with a linear term in the modelling. The model with flow and water temperature provided the lowest deviance information criterion (DIC) and therefore, the most evidence (Table 16-7). This model fits the data relatively well, with the posterior predictive Bayesian p-value of 0.271, and only two Pearson residual is marginally greater than 4.

The parameter estimates and 95% high density intervals (HDI) are shown below (Table 16-8). As none of the HDI exclude zero, there is evidence that higher temperatures are associated with higher carp numbers, and some evidence that higher flows are also associated with carp numbers up until 550 ML/d, where the numbers decrease (Figure 16-9).

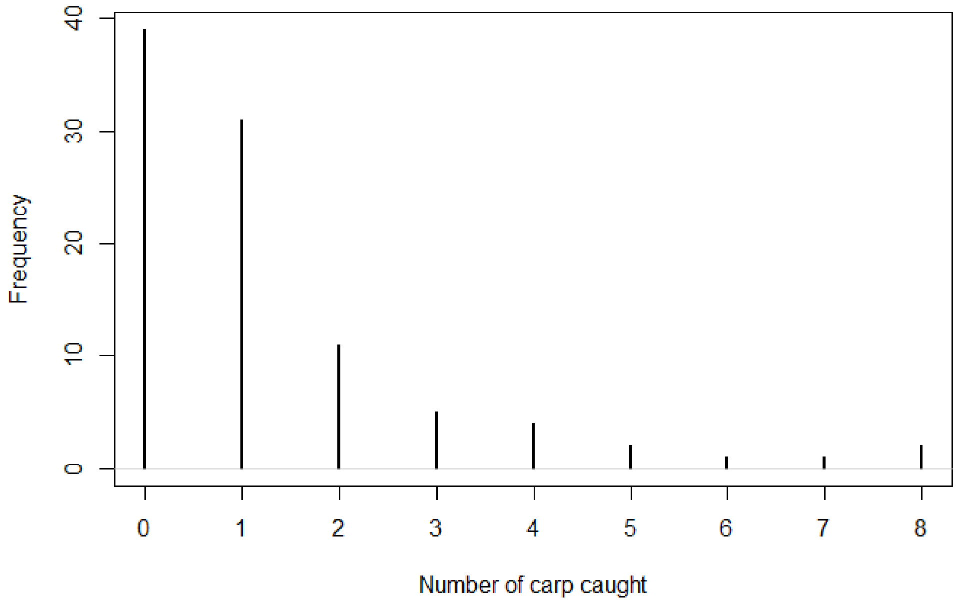

Figure 16-6. Plot of the frequency of the number of common carp caught per weir for each trip.

Table 16-7. The information criteria for each of the negative binomial models used for common carp capture numbers.

Model	DIC	ΔDIC
s(Flow) + Temperature	297.1	
s(Flow) + Temperature + Weir (Random)	300.2	3.1
s(Flow) + Temperature + Weir (Fixed)	301.7	4.6

Table 16-8. Parameter estimates (log scale, except for Size) and 95% high density intervals (HDI) for the negative binomial model for the number of common carp given the trip number and the flow.

Parameter	Estimate	95% HDI	
		Lower	Upper
Intercept	0.055	-0.457	0.468
Temperature	0.412	0.111	0.713
Size	1.514	0.772	3.776

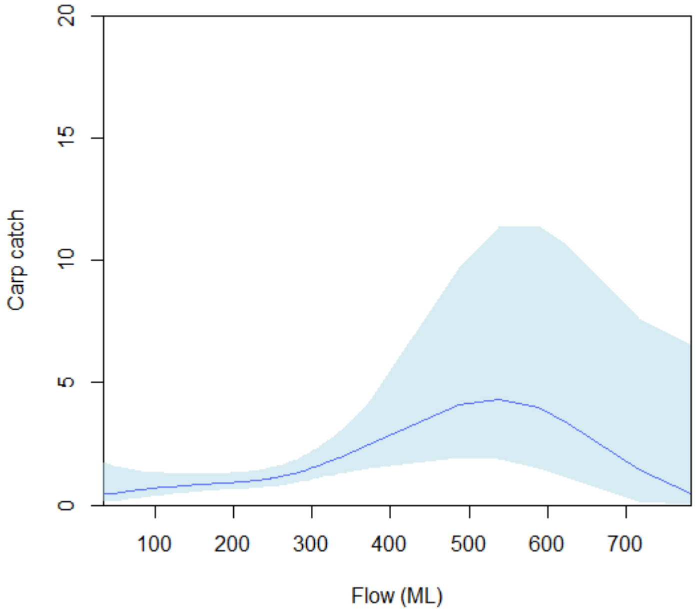

Figure 16-9. Expected number of carp per weir at recorded flows given average temperature.