Natural Resources
Adelaide and Mt Lofty Ranges

Environmental flow trials in the Western Mount Lofty Ranges

Year 1 environmental outcomes report

Report N13/7474 November 2013

Government of South Australia
Adelaide and Mount Lofty Ranges Natural Resources Management Board

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Government of South Australia
Department of Environment, Water and Natural Resources

SA Water

Contents

EXECUTIVE SUMMARY

The Minister for Environment and Conservation prescribed the surface water, watercourses and underground water of the western Mount Lofty Ranges (WMLR) on 20 October 2005. In so doing, the requirement for a Water Allocation Plan (WAP) that balances the allocation of the water's resources was triggered. The WAP must take into account the needs of all water users, including the environment. Therefore, the environmental water needs of the WMLR, once determined in the WAP, must be provided for. One mechanism for providing environmental water is the delivery of environmental flows from storages. This environmental flows trial has been developed to test the effectiveness of delivering environmental water from storages in four WMLR reaches:

- South Para River – Barossa Diversion Weir to Gawler
- Onkaparinga River – Clarendon Weir to Old Noarlunga
- River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir
- River Torrens – Gorge Weir to Torrens Lake.

The environmental flows trial began in June 2006 but had to be postponed until December 2011 due to drought conditions in the WMLR. It is intended that the trial will run for three years, until December 2014. This report presents the evaluation of the Year 1 results (19 December 2011 to 31 December 2012) against the project objectives and the predictions of how different flows would affect different physical, chemical and biological indicators.

The six planned environmental flow events were achieved in the **South Para River environmental flows trial reach** on a monthly basis. However, the daily peaks were significantly lower than planned (in all but the November 2011 fresh) and the events were delayed. Key objectives for pool maintenance over summer, improved water quality in autumn and riffle establishment were all achieved, suggesting the environmental flows supported the physical habitat and water quality needs of the biological indicators. However, it is unclear what role the high flows in the spring preceding the trial had.

Riffle-dependent macroinvertebrates generally increased in abundance and diversity when the environmental flows were delivered, and stillwater taxa generally decreased, as expected. The strongest response was at the Barossa Diversion Weir suggesting that the greatest environmental flow benefits occurred at the site that had been the driest. Native fish appear to have also benefitted from environmental flows in this reach. The biological responses were not as strong or as consistent as predicted, which may be in part explained by the daily flow peaks not having been as great and/or as early as the planned environmental flows.

The environmental flows observed in the **Onkaparinga River environmental flow trial reach** were generally greater than planned, except for in November and December 2011 during the low flow period. This resulted in strongly-flowing riffle habitats, water quality improvements and longitudinal connectivity as, or greater than, expected. Macroinvertebrates rapidly responded to the flows but were disrupted when the 'riffle' habitats converted to faster and deeper flowing 'run' habitats.

The Onkaparinga River had the highest diversity of fish species in the study, which is likely a result of its habitat diversity as well as its relatively intact connection to the ocean. The environmental flows supported movement along the river and breeding for a range of native fish species. Importantly, native fish species that need to move between the river and the ocean to complete their life cycles (diadromous fish) were observed migrating upstream.

Significantly, a pouched lamprey was caught in the 2012 spring survey at Old Noarlunga, being the first formal reporting of the species in over 100 years. Whilst it is not possible to determine whether the find was a direct response to the environmental flows trial, the occurrence of pouched lamprey in the lower Onkaparinga River underscores the potential importance of an appropriate flow regime that facilitates access to suitable spawning habitat for the lamprey.

The hydrological, physical and water quality predictions were generally supported in the **River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir reach** except for an increase in salinity at the Gumeracha Weir site. Importantly, the environmental flows temporarily increased dissolved oxygen levels, which was a very positive outcome for fish and other fauna. Riffle-dependent macroinvertebrates increased in abundance and diversity, with more rapid and complete responses at Cudlee Creek than at Gumeracha Weir. Very few fish were caught in the trial reach, although, there was positive response by native flathead gudgeon, which were breeding and increasing in abundance.

Water that was transferred between reservoirs along the lower part of the reach (below the junction with Millbrook Creek) confounded some aspects of the environmental flows trial. Regardless, key environmental flow outcomes were achieved in these wetter areas (e.g. flowing riffles, macroinvertebrate communities shifts), which show that the ecosystem will respond to provision of environmental water in the River Torrens.

Environmental flows greatly exceed the planned environmental flows in terms of frequency of flow, monthly volumes and daily peaks in the **River Torrens – Gorge Weir to Torrens Lake reach**, due to natural catchment inflows (rainfall related) above Gorge Weir, stormwater inflows, flows into Gorge Weir exceeding storage capacity and/or other weir related operations. Key hydrological, physical and water quality outcomes were achieved (e.g. improved water quality in pools) but the flows were much 'wetter' than planned. Riffle-dependent macroinvertebrate communities showed little response to the environmental flows in this reach, suggesting that the flows were not ideal for riffle-dependent macroinvertebrates and further investigation is required to determine why, especially given that strong responses to environmental flows observed in other trial reaches. The responses of native fish were mixed. Positive outcomes were seen in terms of breeding and dispersal in mountain and common galaxias populations and in the control of alien fish.

Many of the environmental outcomes observed in the **four trial reaches** in Year 1 were greater than expected. These strong environmental responses demonstrate the high resilience of the WMLR ecosystems and provide evidence that the ecosystems will respond when watered appropriately. Other responses were not as predicted (e.g. presence of predatory macroinvertebrates early in the succession sequence), providing opportunities for improving our understanding and our capacity to deliver environmental flows.
The results from Year 1 suggest that there are a range of critical flow functions, for which specific thresholds could be determined for each trial reach (e.g. maintaining refuge pools over summer). The first year has also highlighted the impacts of rainfall triggers on

environmental flow delivery. While every effort may be made to ensure delivery as close to these rainfall triggers as possible, actual delivery will remain dependent on when (or if) the rainfall events occur.

The knowledge being gained in this trial is highly significant because the trial is being undertaken under 'real world' conditions (e.g. operational constraints, low water availability) and not in controlled laboratory conditions. The development and testing of specific predictions provides a highly robust way of evaluating the trial. As such this environmental flows trial constitutes a real contribution to the science of environmental flow delivery, as well as providing direct and highly relevant evidence for the effects of environmental flows in the trial reaches.

1 INTRODUCTION

On 20 October 2005, the Minister for Environment and Conservation prescribed the surface water, watercourses and underground water of the western Mount Lofty Ranges (WMLR). The area includes the South Para, Torrens and Onkaparinga River catchments, which supply water to Greater Adelaide as well as to the three rivers that flow into the Gulf St Vincent. Figure 1 shows the location of the South Para, Kangaroo Creek and Mount Bold Reservoirs located within these catchments and the boundary of the Adelaide and Mount Lofty Ranges Natural Resources Management (NRM) Board.

The Barossa, Millbrook, Hope Valley and Happy Valley reservoirs are also shown in Figure 1, which are the receiving bodies for raw consumptive water regulated by the diversion weirs. Under the *Natural Resources Management Act 2004*, once a resource has been prescribed a water allocation plan (WAP) must be prepared. The water allocation plan must balance the allocation of the area's water resources, taking into account the needs of all water users, including the environment. The WAP sets out the "rules" for the allocation and transfer of water, and is the basis for the issuing of water licences to users of the resource within the region.

As part of implementing the WMLR WAP, water must be provided for environmental flows. Under the WAP, SA Water becomes a licensed water user, and as part of licensing is required to provide environmental flows downstream its metropolitan water supply reservoirs. Significant investment has been made in estimating the environmental water requirements (EWRs) of the South Para, Torrens and Onkaparinga rivers downstream of SA Water metropolitan water supply reservoirs over the last 15 years (EPA 1999, SKM 2003, VanLaarhoven and van der Wielen 2009, VanLaarhoven 2010). These EWRs have been used as the basis of determining environmental water provisions for the South Para, Torrens and Onkaparinga rivers downstream of those reservoirs. The term "environmental flows" is sometimes used interchangeably with the term environmental water provisions (EWPs). "Environmental flows" is preferentially used in this document for consistency and ease of understanding.

The western Mount Lofty Ranges Water Allocation Plan was adopted on 17 September 2013 and a water licence issued to SA Water on 14 June 2013 with a condition requiring SAW to participate in the environmental flows trial. The environmental flows trial includes the following four reaches (Figure 1; AMLRNRMB 2011):

- South Para River – Barossa Diversion Weir to Gawler
- Onkaparinga River – Clarendon Weir to Old Noarlunga
- River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir
- River Torrens – Gorge Weir to Torrens Lake.

This trial commenced in late June 2006 but had to be postponed in October 2006 with the declaration of drought conditions in the Mount Lofty Ranges. It recommenced in December 2011, in the Gorge Weir reach, and it is intended that it will operate for three years until December 2014 when it is expected the licence conditions will be in place and longer-term delivery of environmental water provisions will be required. The first environmental flows in other WMLR reaches were released from SA Water reservoirs in March 2012, in accordance with the planned environmental flows regime.

This report presents the evaluation of the first year of the environmental flows trial (December 19 2011 to December 31 2012). The focus is on whether the outcomes predicted to result from delivery of environmental flows were achieved, with consideration of how the *actual* environmental flows compared to the *planned* environmental flows for each reach.

Recommendations for refining the environmental flows trial for 2013 and 2014 are also included in relation to:

- optimising the environmental benefits from environmental flows
- improving our conceptual understanding
- improving methods for collecting evidence
- standardising monitoring activities for environmental flows at a state scale.

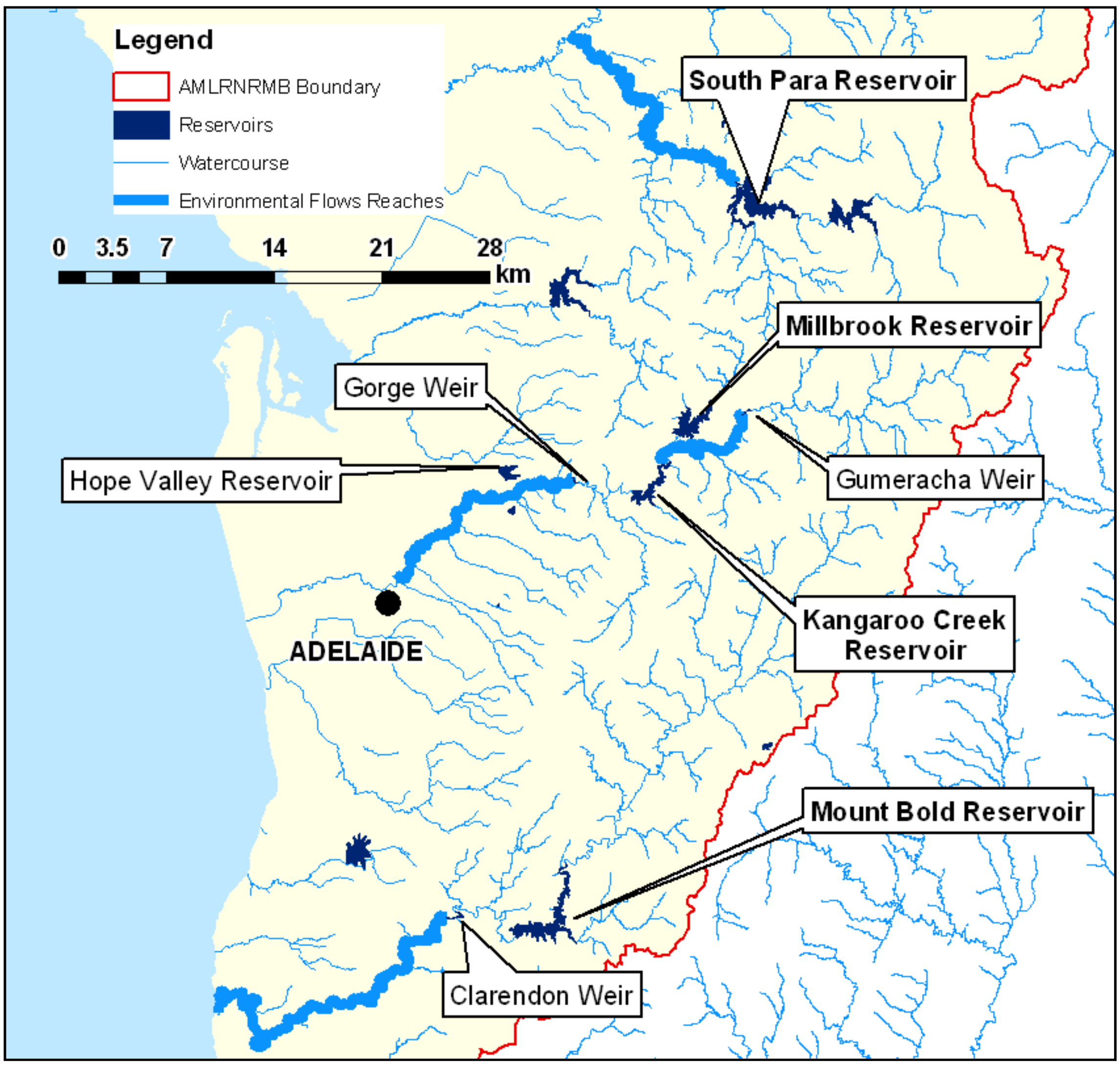

Figure 1: SA Water Reservoirs and river reaches involved in the environmental flows trial

2 REACH DESCRIPTIONS

2.1 South Para River – Barossa Diversion Weir to Gawler

The environmental flows trial reach on the South Para River extends from the Barossa Diversion Weir, located several hundred metres downstream of the South Para Reservoir wall, to the township of Gawler, at the junction of the South and North Para rivers (Figure 2). Hydrologically, the reach can be divided into two sections, that is, upstream and downstream of the main tributary, Tenefeate Creek.

Between the Barossa Diversion Weir and its junction with Tenefeate Creek, the river mainly flows through largely intact and indigenous riparian vegetation within the Para Wirra Recreation Park. The streambed is dominated by bedrock and cobbles with relatively shallow pools (< 2.5 m deep when full) separated by steep cascades through boulders and cobbles.

In the Tenefeate Creek catchment, and from the junction with this tributary along the river to Gawler, the land use is predominantly cleared and grazed farmland. Riparian vegetation, where present, consists of large remnant redgums with reeds and sedges fringing the channel. The streambed in pools is predominantly bedrock and cobble, but it is estimated that since European settlement total sediment deposition, and the relative proportion of fine silts, have increased. Some frequently watered riffle areas of gravels and cobbles can be found separating the pools.

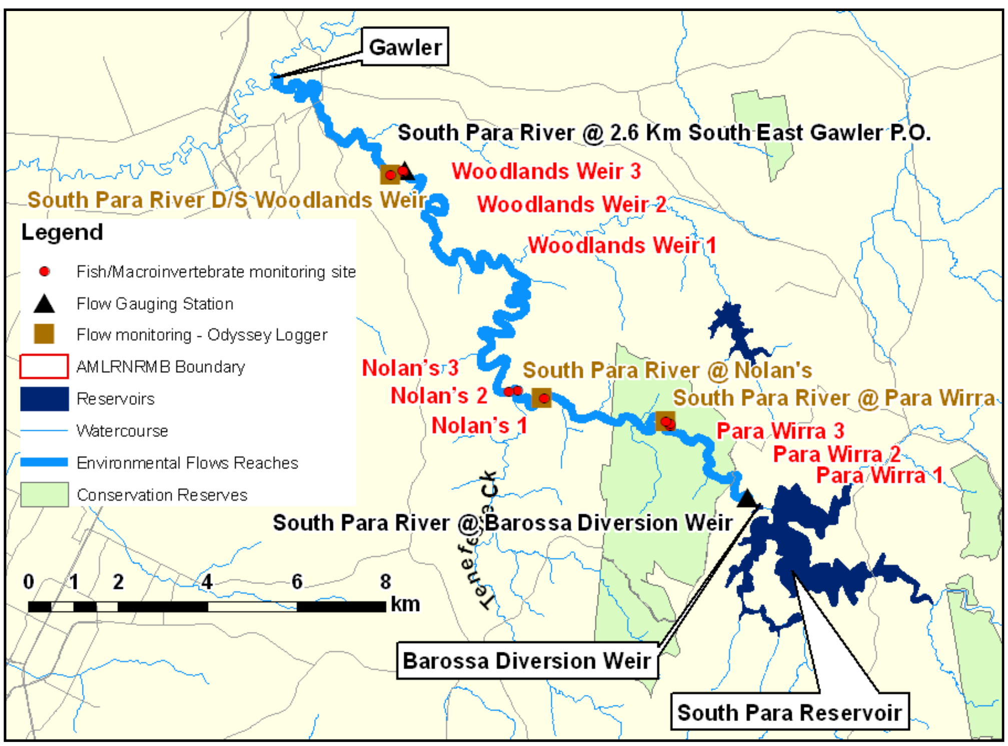

Figure 2: Location of the trial reach in the South Para River between the Barossa Diversion Weir and Gawler

2.2 Onkaparinga River – Clarendon Weir to Old Noarlunga

The trial reach on the Onkaparinga River extends from the Clarendon Weir downstream to Old Noarlunga where the estuary begins (Figure 3). The river runs through an incised gorge from Clarendon Oval (immediately downstream of Clarendon Weir) to below the confluence with Kangarilla Creek (also known as Baker Gully or Peter Creeks). Kangarilla Creek is the major tributary within the trial reach, and minor inflows are also delivered in winter from Angel Gully Creek and another small tributary immediately below the weir. The gorges become steeper as the river descends between rocky outcrops towards the coastal plain. Within the river channel, there are a series of pools of variable depths (deepest pool is at Old Noarlunga approx. 2m deep) with predominately bedrock and cobble substrates. Cascades of cobbles and boulders separate these pools. There is at least one large natural barrier to fish movement located in the gorge between Old Noarlunga and Brooks Road. At Old Noarlunga, the river widens as it reaches the coastal plain and links to floodplain areas. Tidal influences are apparent downstream of the lower boundary of the trial reach.

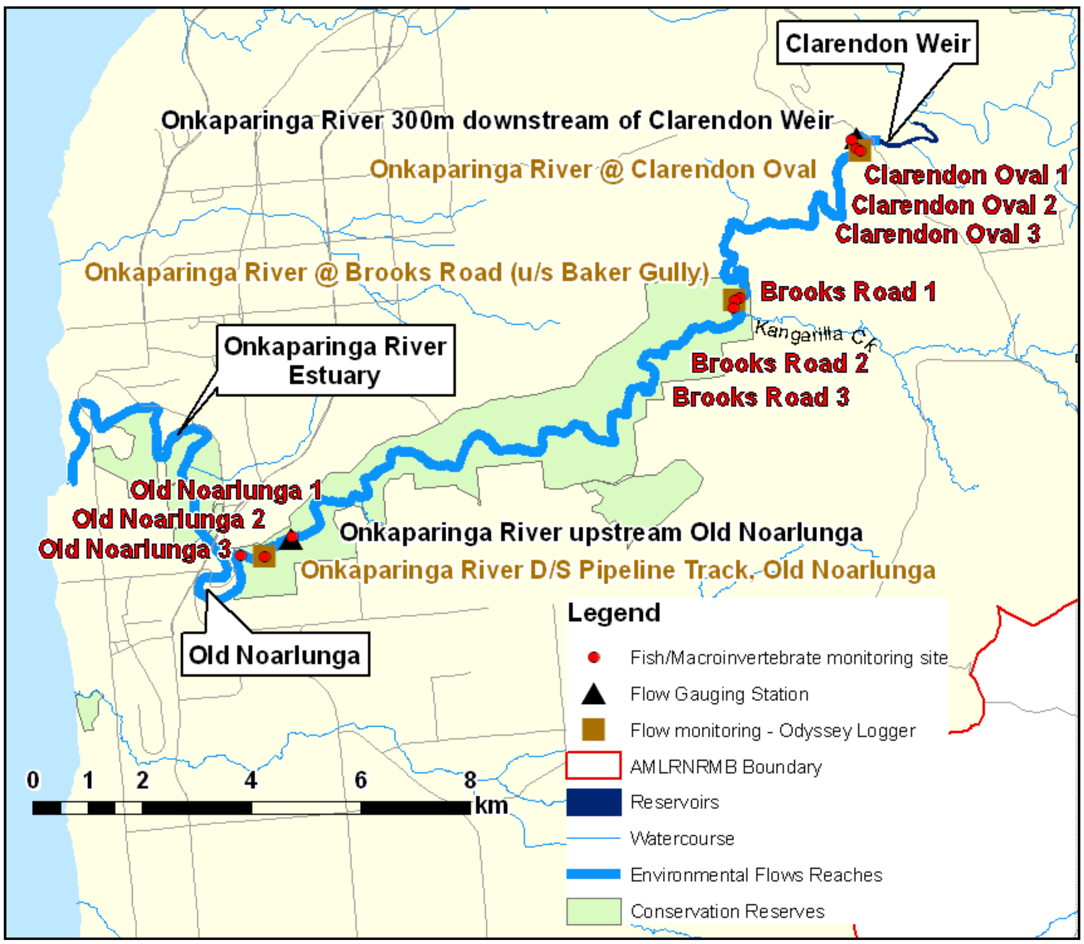

Figure 3: Location of the trial reach in the Onkaparinga River between Clarendon Weir and Old Noarlunga

Most of the trial reach is located within the Onkaparinga River National Park. The catchment vegetation has been substantially modified from its pre-colonisation state through a history of grazing and weed infestation, and is undergoing broad scale revegetation with native shrubs and trees. Modifications to the flow regime since river regulation have led to vegetation encroachment of the channel, particularly the shallower zones between the pools, which in turn has reduced the channel width and created 'pseudo-floodplain' pockets within the channel that are dominated by terrestrial vegetation, particularly the noxious African Needle Grass. However, native vegetation of appreciable ecological value is also present in the form of shrubs from the genera *Callistemon*, *Leptospermum* and *Melaleuca* in the channel and riparian zones. Within these 'pseudo-floodplain' pockets, small wetlands have been formed by groundwater discharge from springs.

2.3 River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir

The first of the two trial reaches on the River Torrens extends from Gumeracha Weir to the upstream end of Kangaroo Creek Reservoir (Figure 4). The reach is divided above and below the junction of River Torrens and Millbrook Creek in terms of land-use, stream structure and hydrology.

From the Gumeracha Weir to Millbrook Creek confluence, the streambed has deep pools (to 2 m deep) with bedrock and cobble to boulder sediments. The riparian zone has a predominately native overstorey of river red gums, wattle and *Callistemon* sp. Reeds and rushes (mostly *Typha domingensis* and *Phragmites australis*) are present around the pools and have also become established in the inter-joining runs and riffles. Part of this reach runs through Cudlee Creek Conservation Park, which is well vegetated. Below the Millbrook Creek confluence, the River Torrens receives more flow than the upper section due to it being occasionally used as a conduit for transfers between Millbrook Reservoir and Kangaroo Creek Reservoir.

2.4 River Torrens – Gorge Weir to Torrens Lake

The second of the two trial reaches on the River Torrens extends from Gorge Weir to the upstream end of Torrens Lake (Figure 5). For the majority of the reach, the river flows through linear parklands in the suburbs before entering the centre of Adelaide where it opens up to become Torrens Lake, which is regulated by the Torrens Weir at its downstream end. The channel has been extensively modified and partially excavated to function as a more efficient conduit within the urban stormwater system (many stormwater networks discharge to the river – directly, or following retention in constructed wetlands). The riparian strip is zoned as the River Torrens Linear Park and is landscaped and actively managed. The vegetation is typical of urban parklands and "open space", with mature trees as overstorey and groundcover largely composed of exotic and grasses. There are many significant remnant river red gums along the riverbanks and areas of high-quality, in-stream habitat containing cobbles in many locations. A threat to the persistence of rocky habitats and to the effective passage of native fish through the reach are extensive 'choking' stands of Reeds and rushes (*Phragmites australis* and *Typha domingensis*) that are extremely resistant and resilient to their potential removal by scouring during floods (McEvoy and Hicks 2011).

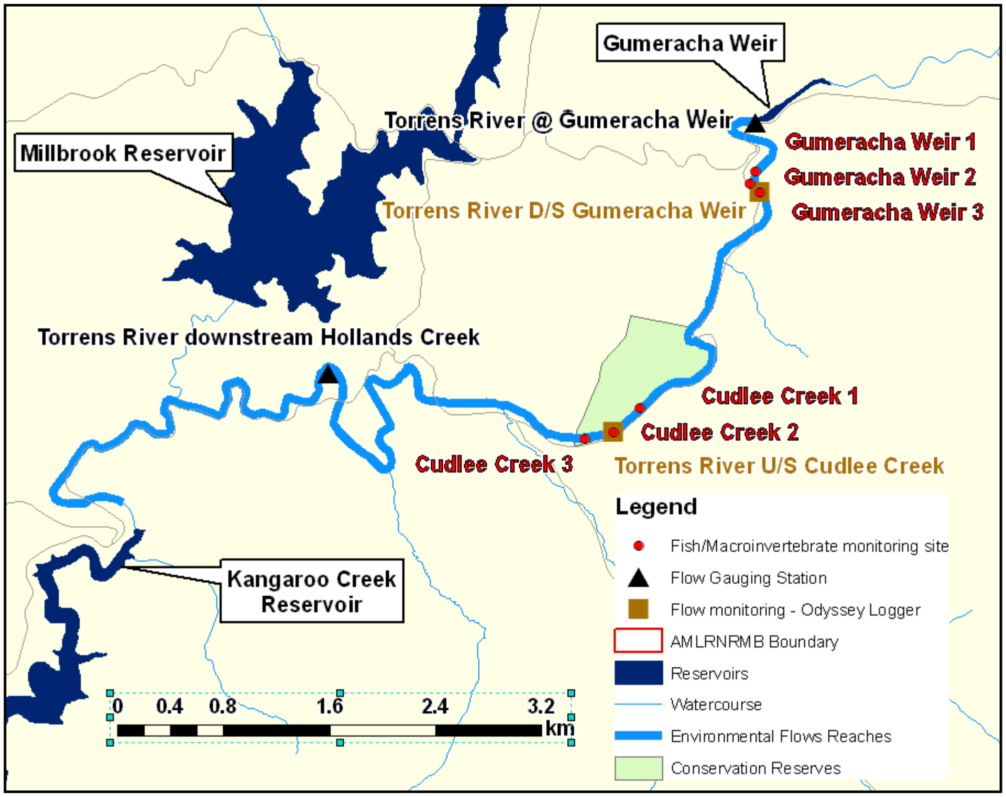

Figure 4: Location of the upper trial reach on the River Torrens between Gumeracha Weir and Kangaroo Creek Reservoir

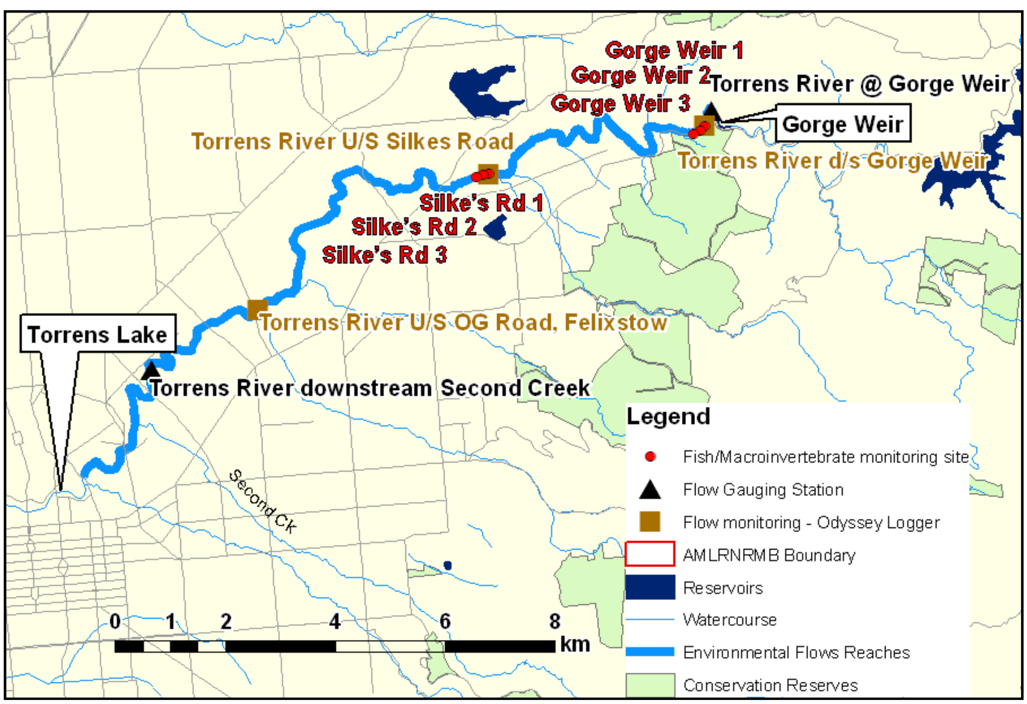

Figure 5: Location of the lower trial reach on the River Torrens – Gorge Weir to Torrens Lake

3 OBJECTIVES OF THE TRIAL

3.1 Overarching environmental objective

A workshop was held in June 2011 to review the ecological objectives of the environmental flows trial (originally planned for 2006) and adjust the original trial release patterns and monitoring protocols, where necessary. This review (Doeg 2011) used the following overarching objectives, which have been retained for the trial:

> *… to deliver an EWP flow regime that maximises the probability of achieving self-sustaining populations of biota that currently exist within the area. This involves improving environmental assets where they are in poor condition, and maintaining assets where they are in good condition. Where possible, the EWP will promote conditions for the support of environmental assets that have been lost (i.e. they are currently absent, but are predicted to have been present prior to water resource development).*
>
> *The EWP flow regime will reduce the likelihood of future degradation of assets, and increase their resilience to future drought conditions (including any temporary reduction in the EWP).*
>
> *…to determine local environmental objectives and release patterns.*

The trial environmental flow regimes presented in Doeg (2011) describe the timing, frequency and duration of 16.74 GL/yr of environmental water releases across the four reaches. Revisions since then have seen the total environmental flow volume change to 16.81 GL/y distributed as follows:

- South Para River, Barossa Diversion Weir to Gawler – 2,015ML/y
- Onkaparinga River, Clarendon Weir to Old Noarlunga – 9,400ML/y
- River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir – 4,510ML/y
- River Torrens – Gorge Weir to Torrens Lake – 890ML/y

3.2 Reach-specific environmental objectives

In addition to the overarching environmental objective, the 2011 flows workshop defined local environmental objectives for each of the reaches (Doeg, 2011); these reach-specific objectives have since been revised, are presented below:

South Para – Barossa Diversion Weir to Gawler:

- maintain water quality in isolated, persistent pools at levels suitable for aquatic life over the cease-to-flow periods
- avoid degradation of in-stream habitat conditions (e.g. infilling of pools, sedimentation of riffles, channel contraction)
- detect reference condition macroinvertebrate communities (typical of ephemeral streams in this habitat type), including an abundance of diverse riffle-dependent taxa

- promote self sustaining populations of Flathead gudgeon with higher abundances than present in 2011 (observe regular recruitment)
- expand the Mountain galaxias distribution, with regular recruitment in the main channel of the South Para River
- reduce the redfin perch population in the upper part of the reach
- avoid expansion of the distribution of gambusia
- sustain in-stream vegetation communities
- provide a water source for riparian red gum communities in the lower part of the reach.

These objectives were based on Environmental Water Requirements (EWRs) for the South Para River determined by Philpott *et al*. (1999) using a Scientific Panel Habitat Assessment Method (SPHAM).

Onkaparinga River – Clarendon Weir to Old Noarlunga:

- maintain water quality in isolated, persistent pools at levels suitable for aquatic life over the cease-to-flow periods
- avoid degradation of in-stream habitat conditions (e.g. infilling of pools, sedimentation of riffles, channel contraction)
- detect reference condition macroinvertebrate communities (typical of ephemeral streams in this habitat type), including an abundance of diverse riffle-dependent taxa
- promote regular recruitment of diadromous[1] fish and increase distribution such that individuals are collected as far upstream as Clarendon Weir
- observe regular recruitment of mountain galaxias, dwarf flathead gudgeon and flathead gudgeon
- promote increased stability in native fish populations (prevent large swings in abundance and reduce risk of localised extinction)
- observe no increases in abundance and/or distribution of alien fish species
- sustain in-stream vegetation communities
- maintain native terrestrial plant species near the channel
- reduce terrestrial plant species within the channel (especially African fountain grass).

River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir:

- maintain water quality in isolated, persistent pools at levels suitable for aquatic life over the low flow periods
- avoid degradation of in-stream habitat conditions (e.g. infilling of pools, sedimentation of riffles, channel contraction)
- reduce reed cover and distribution in riffles and runs
- promote self-sustaining populations of climbing galaxias, with regular breeding and recruitment
- promote self-sustaining populations of flathead gudgeon, dwarf flathead gudgeon and mountain galaxias, with higher abundance than present (regular breeding and recruitment observed in 2011)
- detect reference condition macroinvertebrate communities (typical of permanent streams in this habitat type)

[1] Diadromous fish are those fish species that migrate between freshwater and seawater habitats to complete their life cycles.

- reduce gambusia populations
- observe no increase in abundance or distribution of other alien fish
- sustain in-stream vegetation communities.

River Torrens – Gorge Weir to Torrens Lake trial:

- improve water quality in isolated, persistent pools to levels suitable for aquatic life during the year
- prevent further degradation of in-stream habitat conditions (e.g. infilling of pools, sedimentation of riffles, channel contraction)
- increased representation of riffle-dependent taxa in macroinvertebrate communities
- promote self-sustaining populations of climbing galaxias, with regular recruitment
- increase survival of adult native fish
- reduce gambusia populations
- observe no increase in abundance or distribution of other alien fish
- sustain in-stream vegetation communities.

4 MONITORING APPROACH

4.1 Monitoring logic and hypotheses

The monitoring program was based on measuring the responses of environmental indicators within each reach, and doing this at sites that best show whether the reach-specific objectives were met by the environmental flows provided during Year 1 of the trial.

The selected environmental indicators were nested under five themes (hydrology, physical habitat, vegetation, macroinvertebrates and fish) and were anticipated to respond to environmental flows in a predictable and hierarchical manner.

Following the logic in Figure 6, it is seen that the fundamental objectives are for releases of environmental flows to ameliorate some of the adverse impacts of river regulation in keeping with the National Water Initiative. This will, by default, dampen the effects of climate variability as well. Delivery of environmental flows will be reflected in a "wetter" flow regime (less intermittent) that will, in turn, drive positive changes in water quality and the physical habitats occupied by the biotic indicators (vegetation, macroinvertebrates and fish). Provision of 'wetter' habitats with improved water quality will alter the type (diversity), number (abundance) and/or population structure (recruitment) of the selected biotic indicators – the nature and extent of which it is the aim of this trial to determine. The hypotheses that sit beneath the overarching objectives are testable statements about the predicted environmental outcomes at the indicator level. That is, they are specific statements about how environmental water delivery will affect the indicator species or group that can be monitored and evaluated to improve our understanding of environmental flow delivery over time.

A simple food web is depicted in the biotic components box in Figure 6 to show that whilst the trial focuses on measuring changes in the biotic indicators, it is expected that delivery of environmental water will have much wider ranging ecological outcomes. For example, frogs and waterbirds are likely to benefit from delivery of environmental flows that support vegetation, macroinvertebrates and fish (as well as receiving other direct benefits). If an effect is not demonstrated by the indicators then it could be because the delivered environmental flows were not sufficient or timed incorrectly to achieve the environmental objectives for that reach. An alternative explanation is that our conceptual understanding is flawed and thus we did not monitor the correct indicators and/or at the correct timing.

In order to articulate, develop and test our conceptual understanding, a series of detailed conceptual models and hypotheses were developed. The conceptual models are diagrams that we used to describe and deconstruct our knowledge. The hypotheses are statements about what we predict will happen to a certain indicator under certain flow conditions. These models and hypotheses identify opportunities to test our knowledge with the use of data and statistics. The first level of testing is happening through this three-year trial, after which, it is expected that environmental flow delivery will become a licence condition and require on-going monitoring and evaluation.

Vegetation conceptual models based on water regime and functional groups of aquatic flora – developed by Casanova (2011) and Nicol *et al.* (2010) - were used to predict floral responses to the environmental flows.

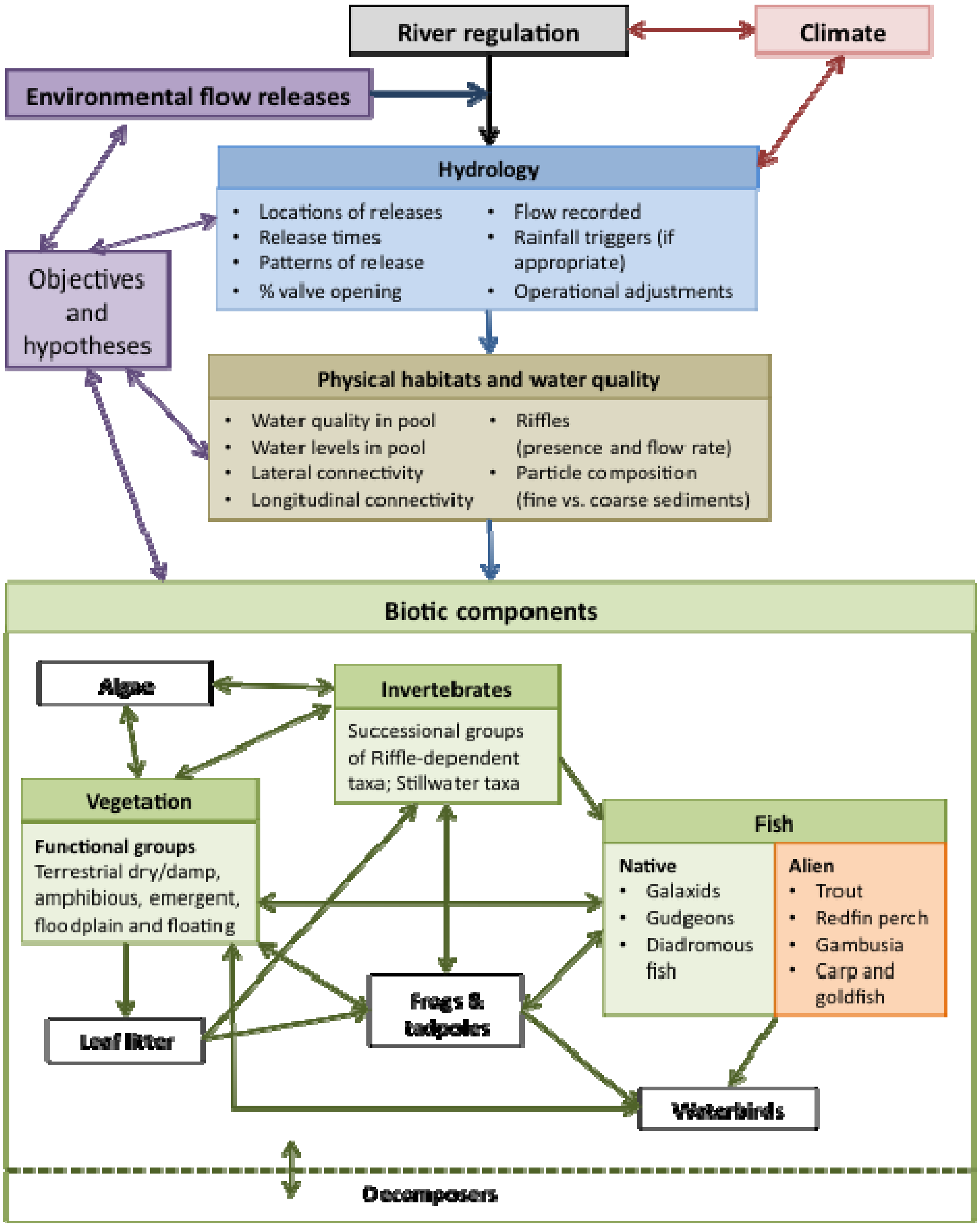

Figure 6: Conceptual model of the logic and environmental indicators used for monitoring the environmental flows trial

Indicators for the five monitoring themes are shown in bullet point lists under the theme headings. The indicators that are shaded green were used to indicate positive change and the indicators shaded orange (alien fish) were used to indicate adverse impacts. Green arrows in the biotic components box indicate interactions between the indicators and other biological components (e.g. waterbird consume vegetation, vegetation use birds for dispersal). Taken from Muller (in prep.).

For macroinvertebrates, a detailed conceptual model was developed specifically for the WMLR and this trial to describe the likely successions that could be expected during a shift from more simple, stillwater communities to more complex, pool-riffle communities with relatively high redundancy across the trophic levels (AWQC 2013, Muller in prep.). For the fish, conceptual models and species-specific information derived from the scientific literature were used to prepare detailed hypotheses for the likely effects of each environmental flow band (Muller in prep.).

Some hypotheses can be tested now (Year 1) but most will require the accumulation and evaluation of data from more than one year of the trial. Vegetation responses, in particular, are not evaluated here because it is expected that a detectable response will not be apparent for several years and thus the hypotheses relate to evaluation of Year 1 and Year 3 data and will appear in the overall trial report in 2015.

4.2 Monitoring locations and data collection

Monitoring locations for flow, fish, vegetation, macroinvertebrates and physical habitat are summarised below and shown in Figure 8 to Figure 11. Additional details on monitoring locations are provided in Muller (in prep.).

The sampling sites within each reach were chosen at increasing distances from the environmental flow delivery point (i.e. the dedicated valve, or crest of the weir at the head of the trial reach) because it was expected that the impacts of regulation (and, inversely, the benefits from environmental flows) would be greatest near the release point and would be expressed in other ways at more distant points in the reach. The aim was to locate the first site immediately downstream of the weir, the second site as close to half-way along the reach as possible and the third near the end of the trial reach. Inflows from tributaries and/or operational uses of the river channels complicated, challenged or confounded this monitoring design in some reaches (e.g. use of the lower portion of the River Torrens – Gumeracha weir to Kangaroo Creek Reservoir to transfer water). Accessibility to sites was also a consideration, with some more permanent or suitable sites overlooked due to inaccessibility.

Within a single monitoring site, the aim was to have three persistent pools for fish sampling interconnected by three riffles for macroinvertebrates sampling (Figure 7).

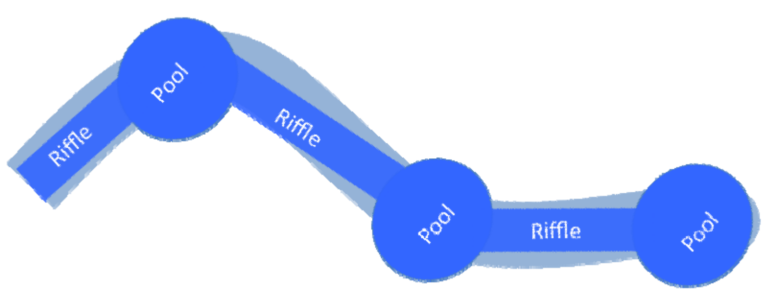

Figure 7: Schema of the ideal sequence of three pools (fish sampling) interconnected by three riffles (macroinvertebrates sampling)

In reality, there were no sites that conformed with the desired layout, and sampling was undertaken at a variable number of sites with variable numbers of pools and riffles within each reach as follows:

South Para River: Four sites with varying numbers of pools (0-3) and riffles (0-2); fish and macroinvertebrates were sampled together at two of the four sites. The sites were located immediately below the Barossa Diversion Weir, within Para Wirra Recreation Park, just above the junction with Tenefeate Creek, and at Woodlands Weir (refer to Figure 8).

Onkaparinga River: Four sites with varying numbers of pools (0-3) and riffles (0-2); fish and macroinvertebrates were sampled together at two of the four sites. The sites were located in the vicinity of Clarendon Oval, immediately upstream of the Kangarilla Creek junction (Brooks Road) and at two sites within the National Park – at about the middle of the gorge (Sundews Track) and at Old Noarlunga, where the coastal plain commences and estuarine conditions are a frequent feature of the river (refer to Figure 9).

River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir: Two sites with three pools for fish sampling and one riffle for macroinvertebrate sampling at each. The sites were located near the townships of Gumeracha and Cudlee Creek, respectively (refer to Figure 10).

River Torrens – Gorge Weir to Torrens Lake: Four sites with varying numbers of pools (1-3) and riffles (0-3) such that fish and macroinvertebrates were only sampled together at two of the four sites. The sites were located below the Gorge Weir, in the Athlestone Reserve, at Silke's Road and in the suburb of Felixstow (refer to Figure 11). For more details about the monitoring program see Muller (in prep.).

4.3 Data Collection

Data for the hydrological indicators were taken from at least two flow gauging stations within each reach. Vegetation was sampled at the beginning of the trial and will be sampled again at the end of the three-year trial.

While consistency was maintained wherever practicable, in some instances, the testing of tailored hypotheses for each reach mandated that some indicators were sampled at different times and in different habitats. Macroinvertebrates were sampled before and after planned flow events in riffle habitats and fish were sampled in spring and autumn in pools. Both the macroinvertebrate and fish sampling teams sampled physical habitat indicators at each site and sampling event.

5 ENVIRONMENTAL FLOW OUTCOMES

5.1 South Para River - Barossa Diversion Weir to Gawler

Hydrology

Over the period of evaluation, November 1 2011 to December 31 2012, there were six planned flow events for the South Para River environmental flows trial reach (Figure 8). These comprised of freshes in March, May and November and flushes in June and September, and a low flow period from June to November, which left a planned cease-to-flow period from December to May (aside from the three day freshes in March and May). The measured flows show that the low flows, freshes and flushes occurred but were generally delayed. The measured peaks of most of the freshes and flushes were significantly lower than the planned peaks, except for the November 2011 fresh, even though actual monthly totals exceeded the planned volumes by 110 to 140 % between July and September 2012 (WDS 2013).

Physical habitats and water quality

It was expected that the planned flows in spring would be great enough to sustain the persistent pools over the summer cease-to-flow period (Table 1). Although the depth loggers installed for the trial failed, data from the water quality sampling rounds indicates that the measured environmental flows did sustain the pools over the summer of 2011/12. However, the preceding spring flows were significantly higher in volume than the planned environmental flows so these data do not confirm that the planned environmental flows would be sufficient to achieve this objective.

Water quality in the persistent pools generally improved in response to environmental flow delivery. Specifically, dissolved oxygen increased from 2-6 mg/L at the end of the cease-to-flow period (April/May) to around 9 mg/L after each flow event and conductivities decreased from >1000 µS/cm in April/May to 600-800 µS/cm after flows.

The freshes in March and May gave temporary connectivity along the reach, which we assume became permanent under the low flows, as predicted. This gave rise to significant riffle habitats being observed in June, August and November at all sites after being dry or reduced to a trickle the previous March, April and May, which was also as predicted. There was, however, no evidence of sediment transport through the riffles.

Biotic components

Macroinvertebrates
Riffle-dependent macroinvertebrates showed a strong positive response to the environmental flows at the Barossa Diversion Weir site, increasing markedly in abundance and richness between mid-June and November, as expected (Table 1).

A similar pattern was observed at the Para Wirra site, although the response was not as strong. The well-established riffles near the Tenefeate Creek junction supported a modest increase in riffle macroinvertebrate abundance and diversity until November, after which diversity of all taxa declined, with the most marked decrease in the stillwater taxa. This evidence supports the hypothesis that stillwater taxa will decrease and riffle-dependent species will increase in abundance and diversity over time when environmental flows are delivered.

Table 1: Comparison of planned flows and predicted responses against actual observations in the South Para River trial reach (Nov. 1 2011 to Dec. 31 2012)

Indicator	Planned flows and predicted responses	Observations	Comments on achievement of objectives
Hydrology			
Freshes and flushes	Six events: freshes in March, May and November (2) and flushes.	Freshes and flushes were delivered but delayed.	Planned flows achieved as monthly flows but daily peaks were significantly lower than planned, except Nov. 2011.
Low flows	Low flows from June to November.	Delivered but delayed start.	Planned flows partially achieved.
Physical habitats and water quality			
Pool depth and persistence	Spring flows would sustain pools; Increased pool levels in autumn and winter.	Depth loggers failed but it appears pools were sustained over cease-to-flow period.	Objective achieved but preceding spring flows were very high compared to planned flows.
Water quality in pools	Improved quality from autumn to spring.	Increased dissolved oxygen and decreased salinity.	Objective achieved.
Riffle habitats	Flowing riffles from autumn to spring.	Significant riffle habitats obs. June, Aug. & Nov.	Objective achieved for winter and spring.
Sediment transport	Redistribution of silt from riffles to pools.	No evidence of silt transport through riffles.	Objective to avoid degradation achieved even though predicted silt transport not observed.
Biotic components			
Macro-macroinvertebrates	Increased relative abundance and diversity of riffle-dependent taxa.	Overall decrease in stillwater and increase in riffle-dependent taxa.	Objective achieved. Strongest response below South Para Weir.
Mountain galaxias	Dispersal within reach.	Caught at new site (Para Wirra) and baseline site (Tenefeate Creek).	Objective achieved. Unclear which flow bands were critical.
Flathead gudgeon	No effect on distribution; facilitate breeding.	No evidence of dispersal but no strong evidence of a new cohort either.	Requires further substantiation in 2013 and 2014.
Diadromous fish	Increased distribution.	Common galaxias and congolli caught below Woodlands Weir.	Unclear. May be remnants of previous translocations and not evidence of connectivity along reach.
Redfin perch	No net effect.	No evidence of breeding or dispersal.	Objective achieved although adults in spawning conditions were captured in spring 2012.
Gambusia	Decreased abundance and distribution due to fatal displacement.	Evidence of dispersal and breeding; net increase.	Objective not achieved.

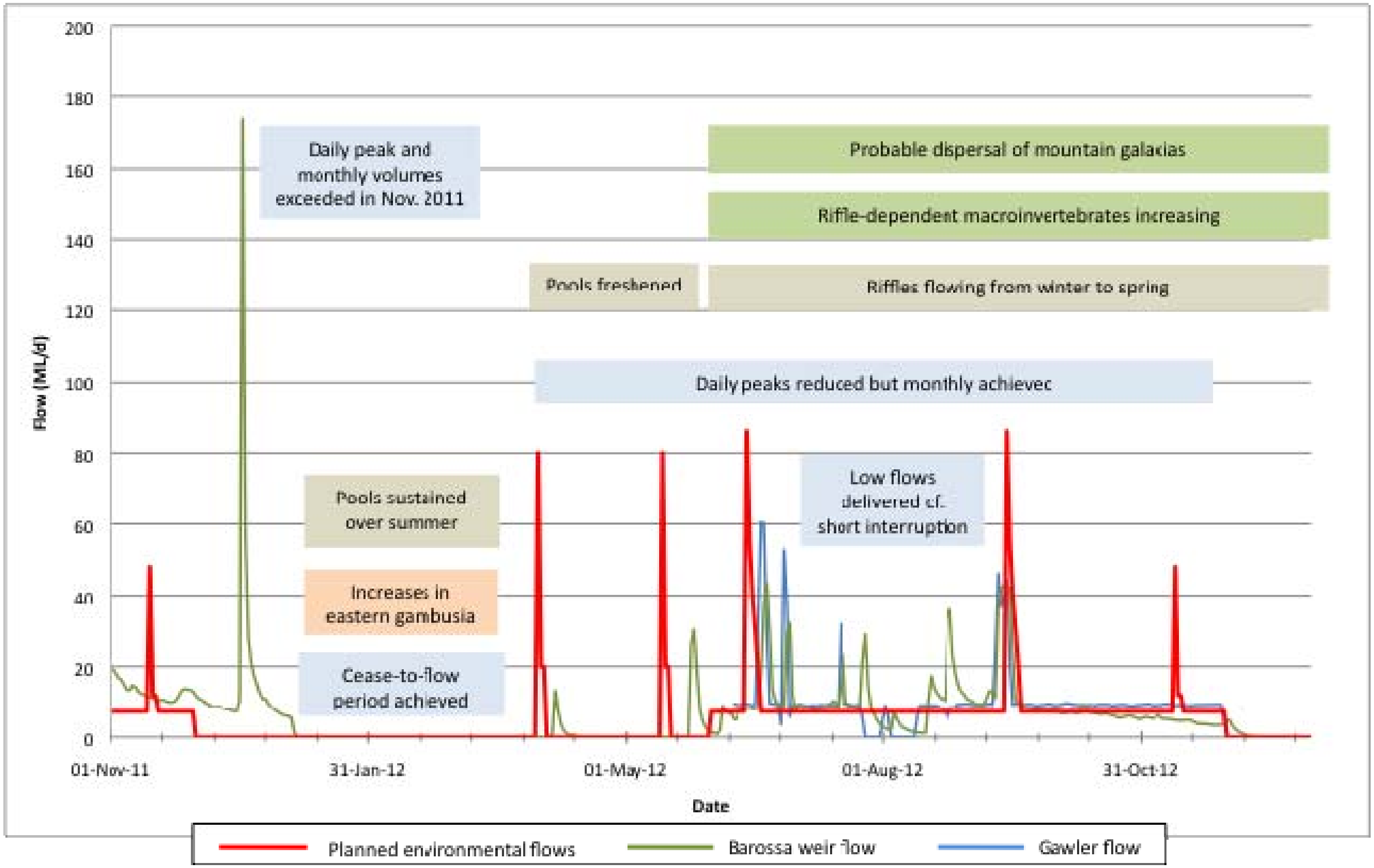

Figure 8: South Para River trial reach hydrology, as measured at the weir and upstream of Gawler, showing key flow events and environmental outcomes for Year 1, November 2011 to December 2012

Native fish

The native fish populations along the South Para trial reach also appear to have benefitted from the environmental flows (Table 1). Prior to the trial (McNeil *et al.* 2011), mountain galaxias had only been caught at the site just above the junction with Tenefeate Creek, suggesting that the population may have originated in the tributary rather than being resident in strong populations in the main channel. In spring 2012 after the fresh and flushes, mountain galaxias were caught at Para Wirra as well as at the Tenefeate Creek junction. This may be evidence that the environmental flows facilitated dispersal and colonisation, as predicted, but at this stage it is unclear which flow bands were critical (if any) and why mountain galaxias did not establish downstream at Woodlands Weir, which was more strongly predicted than establishment at Para Wirra. The data may reflect a preference for these fish to migrate upstream during flushing flows. If the hypothesis that environmental flows facilitate dispersal and colonisation of new habitats continues to hold, then it is expected that the 2013 and 2014 data will show further expansion in distribution and increased abundance and breeding of subpopulations at Para Wirra and in other newly established locations.

It was expected that the environmental flows would have no effect on the distribution of flathead gudgeon but would facilitate breeding and thus alter the population demographics. At this stage, the effects of environmental flows on flathead gudgeon populations are unclear. Abundance increased in the autumn 2012 sampling compared with spring 2011 at both Para Wirra and the Tenefeate Creek junction site but not at Woodlands Weir. However, there was no evidence of breeding or dispersal so this may indicate that the flathead gudgeon retreated to the pools when the riffles dried (i.e. data may show increased density or catchability rather than increased population size). Abundance decreased at Para Wirra and Tenefeate Creek junction with the subsequent fresh and flushes but no changes were apparent at Woodlands Weir. Therefore hypothesis appears to be only partially supported, in that, there was no evidence for dispersal but the evidence for changes in demographics was not strong and will require further evaluation over the next two years.

Two native diadromous species, common galaxias and congolli, were caught at Woodlands Weir but it is uncertain whether this is indicative of functional connectivity having being established between the river and the ocean or if these are remnants of translocations that occurred in 2006 (SARDI 2013). Analysis of 2013 and 2014 demographics will be required to determine population status.

Alien fish

There was no evidence of breeding and or dispersal of redfin perch over the evaluation period, as predicted, which is considered beneficial for the small native fish upon which redfin perch prey. Movement of redfin perch was only apparent during the higher natural flow events that occurred prior to the environmental trial (McNeil *et al*. 2011). However, adult redfin perch in spawning condition were captured in spring 2012, which suggests that breeding may have occurred over the summer of 2012/13 and a cohort of juveniles may appear in the autumn 2013 or spring 2013 data.

Gambusia maintained strong populations and at times constituted up to 92% of all fish caught within the South Para River trial reach (SARDI 2013). This included the uppermost site Para Wirra where this species was not identified during the 2006-8 presurvey (McNeil *et al.* 2011) but has since become established. High numbers of gambusia were also observed at all sites along the South Para River reach after the cease-to-flow period, presumably indicating that breeding was promoted by the stable conditions over summer. Densities dropped by an order of magnitude across the autumn and spring 2012 sampling events, due to high mortality, but abundance in spring 2012 was higher than spring 2011 and that recorded prior to the trial, suggesting a net increase in gambusia in Year 1. The order of magnitude changes in population size between autumn and spring samples had been observed in pre-trial data but the seasonality has been reversed. It appears that gambusia are able to survive the prescribed environmental flow regime and that over time the gambusia populations may become more widespread and of higher density than currently seen. This will have adverse impacts on native fish populations.

Conclusions

The six planned environmental flow events were achieved in the South Para River environmental flows trial reach on a monthly basis. However, the daily peaks were significantly lower than planned (in all but the November 2011 fresh) and the events were delayed. It may be that some predicted responses associated with higher flows (e.g. silt transportation through riffles, fatal displacement of gambusia) would have been observed if the planned daily peaks had been achieved.

The objectives for pool maintenance over summer, improved water quality in autumn and riffle establishment were all achieved, which suggests the environmental flows in the South Para River trial reach were sufficient to support the physical habitat and water quality needs of the biotic indicators. However, it is unclear what role the high flows in the spring preceding the trial had in terms of sustaining the pools over the cease-to-flow period and pre-wetting the channel to support riffle formation. The flow thresholds for maintaining pool depth over the cease-to-flow period and riffles from autumn to spring will need to be defined by analysing several years of variable flow regimes against the objectives and hypotheses, in order to verify the effectiveness of the planned environmental flow regime.

Riffle-dependent macroinvertebrates generally increased in abundance and diversity between June and November when the environmental flows were delivered, as expected. The exception was the site near the junction of Tenefeate Creek where both abundance and diversity declined over this period although riffle dependent macroinvertebrates were still more abundant than stillwater taxa. Abundance of riffle-depedent macroinvertebrates was highest at the Barossa Diversion weir site, which had received the least flow in the years and decades prior to the trial due to its location immediately below the reservoir wall. Overall, these data suggest that the environmental flows had a strong effect on macroinvertebrate community structure, favouring riffle-dependent taxa over stillwater taxa, as predicted. Furthermore, the stronger response at the Barossa Diversion Weir suggests that the greatest environmental flow benefits occurred at the site that had been the driest (i.e. the site where the flows had been most affected by water resource development).

Native fish appear to have benefitted from environmental flows, in general, although the evidence from Year 1 requires substantiation. The strongest response was seen in the mountain galaxias data, which show upstream dispersal from their original location near the Tenefeate Creek junction to Para Wirra.

The alien fish, gambusia, also responded to the environmental flows by dispersing to new sites and increasing in abundance. This is contrary to the prediction that the planned freshes and flushes would mortally displace gambusia downstream leading to reduced distribution and abundance. The unpredicted response may be attributable to the reduced daily flow peaks in the delivered environmental flows compared to the planned peaks. Or the hypothesis may be incorrect. It is important that freshes and flushes of the planned daily volumes are delivered in future years of the trial to test the hypotheses relating to high flows, such as gambusia control and silt transportation.

Overall, the environmental flows in the South Para River trial reach benefitted the ecosystem. Refuge pools were maintained over summer and freshened in autumn. Riffle habitats were sustained long enough for dependent macroinvertebrate communities to establish and to support the dispersal of fish. In general, the biological responses were not as strong or consistent as predicted, which may be in part explained by the daily flow peaks not having been as great and/or as early as the planned environmental flows.

It should be noted that the high volumes of water had been released prior to and at the beginning of the trial. Therefore, the effects of those high flows may have still been apparent and in some ways driving the environmental outcomes seen during this first year of the trial. The effects of the environmental flows themselves will become more apparent over successive years of the trial and beyond.

The Year 1 evaluation generated the following key questions for 2013 and 2014 in the South Para River trial reach:

- Would delivery of higher daily peaks, as planned, achieve more of the high flow objectives?
- Are the planned environmental flows sufficient to maintain pool depth over summer and sustain riffles from autumn to spring?
- What tolerances are there with the timing of the onset of flows in autumn? Can triggers be developed?
- Is our sampling regime appropriate for detecting sediment movements?
- Will gambusia continue to increase in abundance and distribution unless flows high enough to mortally displace them occur?
- Did the pre-trial high flows have any effect on gambusia distribution and/or abundance?
- What factors (e.g. connectivity, water quality) limit mountain galaxias dispersal to and/or survival at Woodlands Weir?
- Can flow thresholds for meeting the objectives and predictions along the reach be determined?
- Is there evidence of further expansion of mountain galaxias in 2013 and 2014?

5.2 Onkaparinga River – Clarendon Weir to Old Noarlunga

Hydrology

The planned environmental flows for the Onkaparinga River trial reach comprised: a fresh in March/April, flushes in both June and September, low flows from April to December and a cease-to-flow period from January until the March/April fresh (Figure 9). The autumnal fresh was delivered in April and was close to the planned rate and volume (WDS 2013). The June flush was also delivered in close approximation of the planned environmental flows but the September flush was 4 weeks later than planned and did not reach the planned peak of 400 ML/d.

Low flows were delivered as per the schedule except for November and December 2011. On a monthly total basis, the environmental flows were generally equal to or greater than the planned environmental flows until November 2012. Flows ceased from January to March, as planned, at Old Noarlunga. Very low flows of 2.2 to 5.1 ML/d during January, February and March were recorded below the Clarendon Weir but it is not known how far downstream the flows reached. It is assumed that most of the reach experienced very little or no flow during these months and thus the cease-to-flow period was achieved.

Physical habitats and water quality

It was expected that the environmental flows would maintain connectivity from April to December throughout the trial reach, after which the riffle habitats would dry during the cease-to-flow period and the river would contract to a series of isolated pools (Table 2). This was broadly supported by the data (AWQC 2013), which showed isolated pools with very weak interconnecting riffles at Clarendon and Brooks Rd. in March, April and May 2012. Longitudinal connectivity was re-established after the autumnal fresh and strong flowing habitats were observed in June, August, September and late October. The water quality data for the trial reach show that the environmental flows broadly supported the predicted changes in water quality over the flow year. That is, dissolved oxygen was at its lowest in March/April before the fresh (~1-5 mg/L) and peaked near saturation (> 7 mg/L) during flow events. Similarly, conductivities were highest (> 1000 μS/cm) in March before the fresh and dropped as low as 500 μS/cm during the flow events. Logger failure meant that the hypotheses relating to maintenance of pool depth from April to December could not be tested in a robust manner.

There was no evidence of significant sediment transport with the environmental flows, although the measured flows were strong enough to generate 'runs' at some sites, which are flowing habitats that are faster and deeper than riffles. Runs function differently in the ecosystem than riffles do, in that, they allow large fish to move along the channel and thus access new riffle and pool habitats. This may lead to a shift in predators for macroinvertebrates from small native fish (e.g. galaxiids) in riffles to larger, typically alien fish (e.g. trout, redfin perch) in runs and flowing pools. It may also lead to displacement of macroinvertebrates and small native fish into different habitats (e.g. lateral fringes rather than riffles), all of which may mean the environmental flow objectives may not be achieved or the trophic and habitat effects may confound the data and hinder comparative analysis. However, these higher flows drive a range of other environmental processes such as sediment transportation, erosion, nutrient cycling and migration, and thus are likely to provide additional environmental benefits at an ecosystem scale to that predicted for the planned environmental flows even though the trial objectives may not be supported.

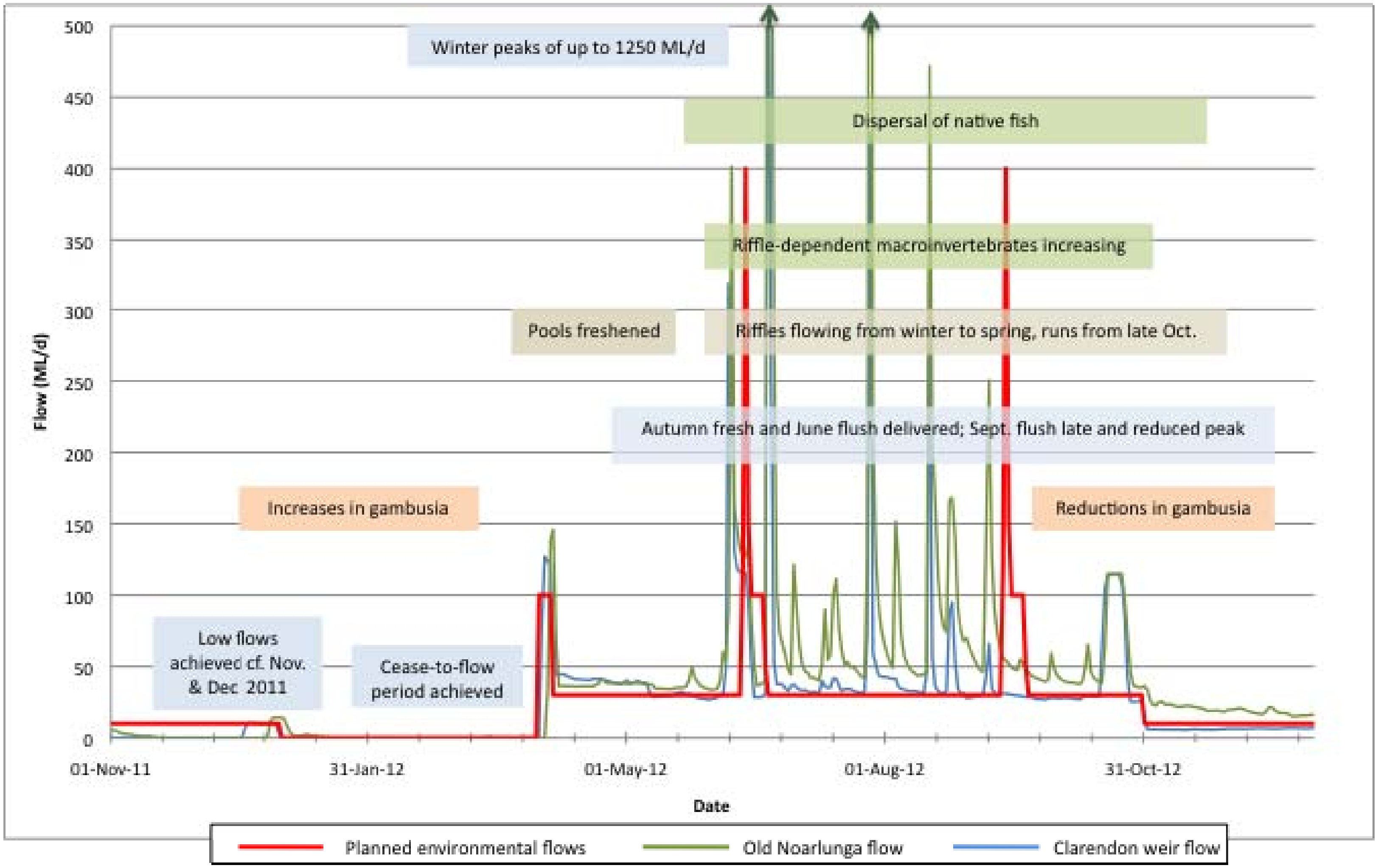

Figure 9: Onkaparinga River trial reach hydrology, as measured downstream of the Clarendon Weir and downstream at Old Noarlunga, showing key flow events and environmental outcomes for Year 1, November 2011 to December 2012

Table 2: Comparison of planned flows and predicted responses against actual observations in the Onkaparinga River trial reach (Nov. 1 2011 to Dec. 31 2012)

Indicator	Planned flows and predicted responses	Observations	Comments on achievement of objectives
Hydrology			
Freshes and flushes	Three events: fresh in March/April and flushes in June and September.	Autumn fresh and June flush were delivered but September flush was late and reduced peak.	Planned flows achieved as monthly flows until Nov. 2012.
Low flows	Low flows from April to December.	Delivered except for Nov. and Dec. 2011.	Planned flows partially achieved.
Physical habitats and water quality			
Pool depth and persistence	Maintain pool depth from April to Jan.; lower levels Jan. to April.	Loggers failed so no direct observations made.	Unknown.
Water quality in pools	Improved quality from autumn to spring.	Increased dissolved oxygen and decreased salinity.	Objective achieved.
Connectivity and riffle habitats	Connectivity and flowing riffles from April to Dec.	Connectivity re-established after autumnal fresh; flowing riffles observed June to late Oct.	Objective achieved from at least June to late Oct.
Sediment transport	Redistribution of silt from riffles to pools.	No evidence of silt transport through riffles.	Reconsider relevant objective and hypothesis.
Biotic components			
Macro-invertebrates	Increased relative abundance and diversity of riffle-dependent taxa; diversity changes will follow a set succession	Overall decrease in stillwater and increase in riffle-dependent taxa; predators appeared earlier in the succession than expected.	Objective achieved. Faster runs displaced riffle-dependent macroinvertebrates at Clarendon and Brooks Rd. after Aug.; early appearance of predators does not support staged succession model.
Galaxiids	Increased abundance.	Dispersal and increased abundance of mountain galaxias; increased abundance of climbing galaxias; common galaxias decreased probably due to predation.	Objective exceeded for mountain and climbing galaxias (both dispersal and increased abundance were observed); likely predation effects confounded results for common galaxias.
Flathead and dwarf flathead gudgeon	Minimal effect.	Variable abundance; no evidence of dispersal.	Objective achieved; longer term trends may need to be evaluated for gudgeon.
Diadromous fish	Dispersal throughout reach and recruitment.	Congolli and a pouched lamprey found moving upstream.	Dispersal objective partially achieved; breeding may become apparent in Year 2 and 3 data.
Redfin perch	No net effect.	No net effect although breeding was observed at Clarendon and Brooks Rd.	Objective achieved although breeding was evident.
Gambusia	Decreased abundance and distribution due to fatal displacement.	Decline at Brooks Rd.; no effect at Clarendon or Old Noarlunga; juveniles caught at Brooks Rd.	Objective partially achieved at Brooks Rd; lack of response at Clarendon suggests may not be due to fatal displacement.

Biotic components

Macroinvertebrates

The abundance and diversity of riffle-dependent macroinvertebrates at Clarendon and Brooks Road increased as expected after the autumnal fresh and the re-establishment of riffle habitat (AWQC 2013; Table 2). Peak abundance and diversity was observed in June 2012, however, both metrics decreased markedly in the August sampling period. This may indicate that the environmental flows exceeded the threshold where riffles transformed into runs, at which point the riffle-dependent macroinvertebrates are displaced and/or consumed, effectively 'resetting' the macroinvertebrate assemblages and succession sequence and thus there was not a gradual transformation from 'stillwater' to 'riffle' communities. It may be that an incremental benefit at the population scale for riffle taxa will be seen over longer time periods due to recharging of egg banks and other reproductive processes occurring while the riffles were present even though the short-term effect of the flows during the evaluation period was adverse for riffle taxa.

Although the hypotheses for Clarendon and Brooks Road were not supported the logic used to explain the changes in macroinvertebrate communities observed is consistent with the conceptual models and the observed macroinvertebrate response at Sundews. If it is assumed that the environmental flow peaks had been attenuated by the time the flows reached Sundews, then the riffles would have been maintained and not converted to runs and consequently the disturbance to the macroinvertebrate communities would have been lower (which is consistent with the data). Under these conditions the 'stillwater' and 'riffle' macroinvertebrate groups both increased in abundance and diversity over the evaluation period, with the riffle taxa succession approximating the predicted sequence. This suggests that the lower flows provided riffles that supported community successions as well as supporting habitats for a range of stillwater taxa during the flow period. Diversity peaked in October 2012 when the community was dominated by 'stillwater' taxa.

The presence of predatory macroinvertebrates at Sundews from the beginning of the trial was not consistent with the conceptual model of macroinvertebrate succession, which predicts that predators would appear late in the succession sequence once prey populations had established in the riffles. The observations suggest that predators moved in early in the flow succession sequence, when riffle populations were most likely just establishing. This again may have confounded the results, especially given that predatory preferences are largely unknown and thus predation early in the succession may skew community composition and mislead the hypothesis evaluation.

Native fish

The variability of the environmental flow regime measured in the Onkaparinga River was predicted to be great enough to decrease habitat stability, and thus increase habitat variability, for fish communities. This was predicted to alter the distribution and abundance of most native (and alien) fish species (Table 2).

The three galaxias species were predicted to increase in distribution due to increased habitat availability and opportunities for dispersal during flushes. At the beginning of the environmental flow trial, mountain galaxias were present at Clarendon but not at Brooks

Road. Over the evaluation period, mountain galaxias appeared at Brooks Rd. and increased in abundance at both sites, which was evidence that the environmental flows were sufficient to support downstream dispersal.

Climbing galaxias increased in abundance at Brooks Road. where a strong population of juveniles were also detected in spring 2012, suggesting that breeding had been successful after the autumn fresh. Common galaxias decreased at both sites over the evaluation period, which was more likely to be an effect of predation by redfin perch rather than indicative of any environmental flow effects *per se*. Indeed, presence of redfin perch throughout the reach is thought to have significantly reduced potential for recruitment, growth and dispersal of all galaxias species. Overall, the galaxias data support the prediction that environmental flows provide connectivity for dispersal and conditions suitable for breeding.

The abundance of flathead gudgeon and dwarf flathead gudgeon varied during the evaluation period but distribution remained unchanged. Flathead gudgeon increased during the cease-to-flow period but then declined during the fresh and flushes such that there was little overall effect on abundance. Dwarf flathead gudgeon showed the opposite pattern of decreasing during the cease-to-flow period and increasing during the higher flows but again there was little overall change, which was predicted (Table 2).

Diadromous fish are those that require access to both the ocean and freshwater habitats to complete their life cycles. As such, they are strong indicators of longitudinal connectivity. It was predicted that the environmental flows would facilitate diadromous fish to migrate during the autumn fresh, disperse during the flushes and breed during the lower flow periods. There is support for the migration component of the hypothesis. Congolli and common galaxias and a single pouched lamprey adult were caught at Old Noarlunga migrating upstream. This is a very rare record and only two other records are known for pouched lamprey in the Onkaparinga River, which are from 1879 and 1901. This importantly suggests that spawning cues were established which in turn suggests that ammnocoetes (young larvae) are likely to be present in the upper catchment somewhere (SARDI 2013).

Smelt were unexpectedly captured at Clarendon. This species is not thought to be endemic to the WMLR and they are only known in the Onkaparinga River from a single 2001 study. The origin of the Onkaparinga smelt is unknown. It may be that they were introduced from the River Murray via inter-basin transfers or that the environmental flows supported their transmission from refuge habitats within the Onkaparinga. Data from 2013 and 2014 may provide evidence of a flow-related response in this unexpected smelt population.

Alien fish

It was expected that the planned flushes would fatally displace the alien fish, gambusia (Table 2). There was a sharp decline in abundance at Brooks Road. after the autumn fresh. No decline was observed at Clarendon, which should have exhibited a stronger effect from stronger displacement flows, if the hypothesis held given that it is immediately downstream of the release point. There was no displacement effect evident at Old Noarlunga either, suggesting that there may be an alternate explanation for the decline at Brooks Road than it being an effect of the environmental flow provisions.

Gambusia were unexpectedly caught at Brooks Road but not at Clarendon. This suggests that the environmental flows supported recruitment at Brooks Road but do not necessarily indicate that breeding did not occur at Clarendon. Other factors such as predation by the large numbers of breeding redfin perch at Clarendon may have removed the juvenile gambusia and thus there was no evidence of recruitment. Despite a tenfold increase in gambusia numbers at Brooks Road in autumn 2012 the net effect of flows was that all sites displayed low abundance during autumn 2012. There were insufficient data to determine whether the environmental flows had an effect on the alien tench.

Conclusions

The environmental flows observed in the Onkaparinga River environmental flow trial reach were generally greater than the planned environmental flows over the reporting period, except for in November and December 2011 during the low flow period. This resulted in strongly-flowing riffle habitats, water quality improvements and longitudinal connectivity as, or greater than, expected.

The evidence for macroinvertebrate succession under the planned environmental flows was confounded by the transition of the riffle habitats to faster and deeper run habitats, which function differently as habitats. In order to refine the management of environmental flows for macroinvertebrates, it is important to determine the flow threshold at which riffle habitats transform into run habitats. It is acknowledged that the high flows that create runs would benefit the system if delivered at an appropriate frequency (e.g. 1 in 5 years), especially if environmental flows sustained persistent pools and provided riffle habitats in the interim. If differential objectives and targets for planned environmental flow events (e.g. expansion of riffle-dependent macroinvertebrates) and occasional higher flow events (e.g. facilitate dispersal of diadromous fish) were developed, it would test our conceptual knowledge of the role of higher and lower flows and improve our management of highly variable 'real world' flow regimes over successive years.

The Onkaparinga River had the highest diversity of fish species in the study, which is likely a result of its hydrological and habitat diversity as well as its relatively intact connection to the ocean. The environmental flows were sufficient to support longitudinal dispersal and breeding for a range of native fish species, even though the effects were variable or indistinct within the different populations based upon the first year's data.

Overall, the environmental flows in the Onkaparinga River trial reach benefitted the ecosystem. Although it is not known whether all the refuge pools were maintained over summer, water quality was improved by the autumn freshes. Riffle habitats were sustained long enough for dependent macroinvertebrate communities to establish and for fish to disperse, including diadromous species. Importantly, diadromous fish were observed migrating upstream, suggesting that a timely and functional connection had been established between Port Noarlunga and the ocean.

The Year 1 evaluation generated the following key questions for 2013 and 2014 in the Onkaparinga River trial reach:

- What is the flow threshold for establishment of riffles after the cease-to-flow period?

- What impact does a delay in the onset of flows that generate flowing riffles after the cease-to-flow period have on macroinvertebrate communities and successions?
- How long are riffles expected to persist into summer under the planned environmental flow regime?
- What were the climatic conditions in the catchment when the riffles converted to runs? How often are those conditions expected to return and can that be used to determine an ideal return period for higher flows that induce runs?
- What are the risks and benefits associated with converting riffles to runs (under higher than planned environmental flow conditions) for the full range of biotic indicators?
- Has the macroinvertebrate succession sequence been 'reset' by the runs during late 2012 displacing the riffle-dependent taxa or will there be a lasting effect of the riffle-generating flows from autumn to August 2012?
- What is the flow threshold for establishing and maintaining longitudinal connectivity with the ocean?

5.3 River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir

Hydrology

The planned environmental flow releases for the first River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir trial reach included three flushes (May, July and September) with low flows all year (2.5 to 9 ML/d; Figure 10). As there is no significant storage upstream of Gumeracha Weir the flushes are subject to the timing of rainfall events. Rainfall events in July provided the July flush in two peaks approximately 10 days apart. The September flush occurred early (August 2012) with daily peaks and total volumes that greatly exceeded the planned environmental flow. However, due to lack of rain the May flush did not occur, which extended the cease-to-flow period at Gumeracha by two months (WDS 2013). Small flows were recorded below Millbrook Creek in late summer and autumn that may have been sufficient to top-up pools and improve water quality.

Flows measured at the Gumeracha Weir gauging station were below the planned flows for 8 out of the 14 months being evaluated, showing the actual flow regime was drier than planned (WDS 2013). By contrast, flows in the reach below Millbrook Creek were below the planned volumes for only 3 out of 14 months and experienced a peak of > 6000 ML in the month of August 2012 which was greater than the annual planned volume. This clearly indicates the large contribution made by the natural catchment between Gumeracha and the gauging site below Millbrook Creek.

Physical habitats and water quality

The depths of the persistent pools at Cudlee Creek and below Gumeracha Weir were maintained by environmental flows as expected (Table 3). These pools lie below the junction with Millbrook Creek and thus received water from transfers between the two reservoirs as well as releases over Gumeracha Weir. During 2012, dissolved oxygen in these pools was observed to increase from < 10 mg/L in April/May to 10-12 mg/L from June-September, as predicted, before dropping to < 10 mg/L again in November 2012. This pattern is most likely to have resulted from turbulence-induced aeration of the water during higher flow periods. It probably temporarily reduced any oxygen stress experienced by resident flora and fauna, which otherwise live in pools that are sub-saturated with oxygen. Thus, the prediction for environmental flows increasing dissolved oxygen levels in pools held, although the water quality was not improved overall due to observed increases in salinity at Cudlee Creek.

Salinity increased from approximately 500 to 1700 μS/cm between April/May and December, contrary to predictions and remains unexplained. The most likely sources are groundwater or River Murray inputs. Although salinities of this level are readily tolerated by adult forms of most Australian flora and fauna that occupy these types of rivers, life cycle processes such as recruitment may be interrupted due to lower tolerances of eggs and/or juvenile life stages (e.g. 5000 μS/cm threshold for juvenile native fish in Ye *et al.* 2010).

One key prediction for the effects of the environmental flows on physical habitat that was not upheld was in regard to siltation. It was expected that without environmental flows, silt from natural erosion would accumulate in the reach over time and that the planned environmental flows would potentially be strong enough to clear these accumulated silts from riffles and redistribute them downstream into deeper pools. As it was observed, there was some evidence of silt transport through riffles. However, there was more silt at the Gumeracha site than there was downstream at Cudlee Creek and the silt levels at Cudlee Creek reduced over time, which was contrary to predictions (Table 3).

It may be that the transfer of water between reservoirs along the lower reaches clears out the silt at the Cudlee Creek site and thus interrupts the continuum of silt deposition that would be expected if releases over Gumeracha Weir were the dominant driver of silt transport. Regardless of whether there was evidence for lateral transport or not, these results show that the environmental flows between December 2011 and December 2012 were insufficient to clear accumulated silts from the Gumeracha Weir site. They also suggest that higher flows keep the lower reach (below Millbrook Creek) clear of silts, which supports the hypothesis.

A major positive outcome of the environmental flows was the maintenance of lateral connectivity between pools by the low flows until at least early November at Cudlee Creek. This resulted in significant riffle habitat being present during the monitoring period (May to November 2012). Connectivity between the pools and riffles was maintained at the Gumeracha Weir site throughout the monitoring period (AWQC 2013). At the Cudlee Creek site, water levels were low in April and in September; at other surveys, normal water levels were maintained (AWQC 2013). It was expected that maintenance of riffles would result in a shift from dominance by 'stillwater' species of macroinvertebrates to a more mixed community showing a progression through a predicted sequence of four stages of development from opportunists to riffle specialists or riffle-dependent species. Some of these riffle dependent species are also predators and thus require their riffle-dependent food species to have previously populated the site (AWQC 2013). It was also predicted that abundance and diversity would markedly increase from the low baseline detected before the trial.

Table 3: Comparison of planned flows and predicted responses against actual observations in the River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir trial reach (Nov. 1 2011 to Dec. 31 2012)

Indicator	Planned flows and predicted responses	Observations	Comments on achievement of objectives
Hydrology			
Flushes	Three events: flushes in May, July and September.	July and Sept. flushes were delivered but the May flush was not.	Planned flows partially achieved. Upper reach (Gumeracha weir) was significantly drier than lower reach (below Millbrook Creek).
Low flows	Low flows all year.	Low flows were below planned for 8 out of 14 months at Gumeracha weir and 3 out of 14 months below Millbrook Creek.	Planned flows not achieved in upper reach; Objective mostly achieved below Millbrook Creek.
Physical habitats and water quality			
Pool depth and persistence	No loss of refuge pools.	Maintenance (no depth change) observed at Cudlee Creek.	Objective achieved below Millbrook Creek and below Gumeracha weir.
Water quality in pools	Improved quality from autumn to spring.	Increased dissolved oxygen; Increased salinity.	Objective achieved for dissolved oxygen but not for water quality overall because of increased salinity.
Connectivity and riffle habitats	Riffles wet and connected all year.	Connectivity and flowing riffles until at least November 2012 at Cudlee Creek.	Objective not achieved in upper section of reach; objective achieved at Cudlee Creek.
Sediment transport	Redistribution of silt from riffles to pools.	Accumulation of silt at Gumeracha weir; Reduction in silt below Cudlee Creek.	Objective not achieved in upper section of reach; objective achieved at Cudlee Creek.
Biotic components			
Macro-invertebrates	Increased relative abundance and diversity of riffle-dependent taxa; diversity changes will follow a set succession	Increase in riffle-dependent taxa at Cudlee Creek; insects recruiting earlier in the succession than expected; minor response at Gumeracha Weir.	Objective achieved; response much stronger at Cudlee Creek than Gumeracha Weir.
Flathead gudgeon	Minimal effect.	Increased abundance and breeding in autumn 2012; spring 2012 abundance higher than spring 2011.	Objective achieved; longer term population trends need to be evaluated to determine effects of environmental flows.
Galaxiids	Increased abundance by using riffle habitats.	Two common galaxias; low numbers of climbing and mountain galaxias at Cudlee Creek.	Objective not achieved; very low numbers of galaxiids caught.
Redfin perch	No net effect.	Unexplained decline at both sites between spring 2011 and 2012.	Objective achieved although no evidence that it was a result of the environmental flows.
Gambusia	Decreased abundance & distribution due to fatal displacement.	Only six caught in total.	Objective achieved although no evidence that it was a result of the environmental flows.
Trout	Increased distribution through flowing riffles. (counter to objective)	No trout caught.	Objective achieved although no evidence that it was a result of the environmental flows.
Common carp	Increased spawning in spring/summer but fatal displacement by flows.	Only one caught at Gumeracha.	Objective achieved although no evidence that it was a result of the environmental flows.

Biotic components

Macroinvertebrates

The data show that abundance and diversity of macroinvertebrates did increase throughout the monitoring period as predicted, especially at Cudlee Creek, where there was a shift to a predominately riffle-dependent macroinvertebrate community by November 2012 (Table 3). Changes in macroinvertebrate communities were less pronounced at Gumeracha with variable abundance of riffle taxa observed against a decrease of approximately one third in stillwater taxa. What was not expected was the observance of insects recruiting in each stage of the succession sequence, apparently independent of progression beyond Stage 1 as had been predicted (AWQC 2013). This suggests that the macroinvertebrate succession is less linear and/or more rapid than predicted.

It is not known whether the riffles dried after the November sampling round or if connectivity was temporarily lost over the low flow period in summer at one or both sites. Evaluation of macroinvertebrate data from Year 2 may provide some further information, particularly if the macroinvertebrate succession sequence appears to have been 'reset' over summer 2012/13 rather than continuing its progression from spring 2012, which could be considered indicative of temporary drying. Drying of riffles may also lead to increased desiccation or predation of macroinvertebrates because all obligate aquatic fauna will be confined to disconnected pools that contain fish. If this has occurred it should be detectable in altered assemblages of macroinvertebrates between the 2012 and 2013 data.

Native fish

The fish communities were not observed to respond to flows according to predictions, although very low numbers of fish were caught and thus the results should be interpreted with caution (SARDI 2013). The available data suggests that the native flathead gudgeon benefited from the environmental flows more than predicted (Table 3). Abundance was low at both sites in spring 2011 but numbers were higher in autumn 2012 and there was evidence of breeding at both sites. Abundance declined again by spring 2012 but remained higher than that observed in spring 2011. It is too early to tell whether the environmental flows have supported a significant inter-annual increase in population size but this may be a profitable line of inquiry as the trial progresses.

Sampling detected two common galaxias at Cudlee Creek, This is the first record of this species at this site, since sampling commenced in 2006. Mountain galaxias were in similarly low numbers and only present at Cudlee Creek. It was expected that flow provision would increase distribution and abundance of climbing and mountain galaxias through improved access to riffle habitats. To date insufficient evidence has been collected to confidently support this hypothesis. While this suggests that environmental flows were not suitable for dispersal and breeding of galaxiids this may or may not be confirmed in 2013 and 2014.

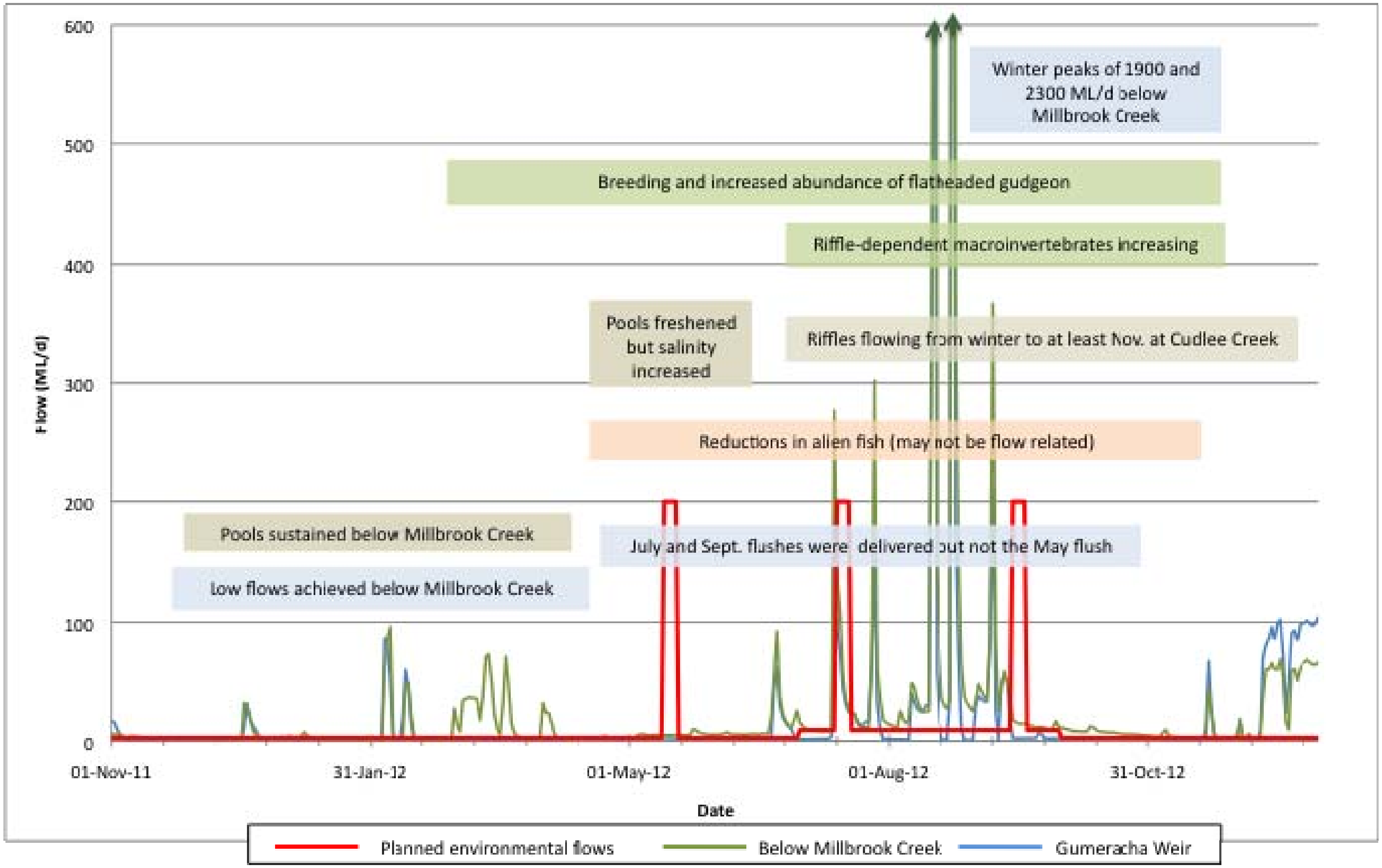

Figure 10: River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir trial reach hydrology, as measured at the weir and below the Millbrook Creek junction, showing key flow events and environmental outcomes for Year 1, November 2011 to December 2012

Alien fish

Alien fish were also caught in low numbers during most of the evaluation period. Redfin perch were initially present in high numbers at both sites (spring 2011) but then decreased markedly, which was not predicted (Table 3). The reason for this decline is currently unknown although it does not appear to be downstream displacement by the flushes as predicted in the hypotheses (OMER PLAN 2013) because the fish were not detected at any downstream site during the study. Only one common carp and six gambusia were caught during the study period and no trout, therefore the hypotheses regarding effects of environmental flows on these alien species cannot be tested at this stage.

Conclusions

The hydrological, physical and water quality predictions were generally supported in the River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir reach except for the increase in salinity (conductivity) and the lack of evidence of silt transportation away from the Gumeracha Weir site. Importantly, the data show that environmental flows temporarily increased dissolved oxygen levels, which was a very positive outcome because it should have significantly reduced the risk of fauna perishing in refuge pools during low flow periods.

Riffle-dependent macroinvertebrate communities also responded positively to environmental flows by increasing in abundance and diversity. The effects were more rapid and a more diverse assemblage established than was expected at Cudlee Creek. The response at Gumeracha Weir was less than expected, which suggests that the lower than planned environmental flows limited the development of riffle-dependent macroinvertebrate communities at Gumeracha. These data could be used to develop a flow threshold above which responses in riffle-dependent macroinvertebrates could be expected.

Very few fish were caught in the trial reach and thus there was little evidence by which to test the hypotheses after Year 1. The breeding and increased abundance of flathead gudgeon was a positive outcome. Further investigation over years 2 and 3 is required.

Across all the data sets it is evident that the transfer flows in the lower part of the reach are confounding the longitudinal aspects of the environmental flows trial in the River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir trial reach. That is, the lower part of the reach is wetter than the upper part, which is counter to the assumption in the trial design that environmental flows would be attenuated downstream of the release point (in this case Gumeracha Weir). Regardless, key environmental flow hypotheses (e.g. flowing riffles, macroinvertebrate communities shifts) were supported in the wetter reach (below the junction with Millbrook Creek), which shows that the indicators will respond to provision of environmental water. The lower portion of the reach should perhaps be treated as a separate trial reach for which different objectives and hypotheses are developed rather than a continuation of the trial from the upper portion of the reach.

The Year 1 evaluation generated the following key questions for 2013 and 2014 in the River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir trial reach:

- What flows are required over Gumeracha Weir to maintain pools and support lateral connectivity and flowing riffles in the upper portion of the reach all year?

- What are the effects of the Millbrook to Kangaroo Creek Reservoir transfers below Millbrook Creek relative to planned releases from Gumeracha weir?
- What are the sources of salinity? How much of the reach is affected by high salinities and for how long?
- What flows are required to transport silts that have accumulated at the Gumeracha Weir site? Once mobilised, what is the fate of these silts?
- Is there a minimal response by riffle-dependent macroinvertebrates (abundance and/or diversity) that needs to occur in order to satisfy the objective or is detection of riffle-dependent taxa sufficient?
- Was the macroinvertebrate succession 'reset' over summer 2012/2013 indicating that the riffles dried out at some time?
- Is there evidence of increased fish numbers, overall, from the very low numbers caught in 2011 and 2012?
- Is there accumulative evidence for fish hypotheses given that Year 1 data did not provide strong evidence of a flow response?
- What factors are limiting galaxiids from increasing in abundance and distribution?
- Will alien fish numbers remain low throughout the trial period? If so, can this be attributed to provision of environmental flows or alternate factors?

5.4 River Torrens – Gorge Weir to Torrens Lake

Hydrology

The planned environmental flow releases for the second River Torrens – Gorge Weir to Torrens Lake trial reach included one flush in November and low flows all year (Figure 11). A short flow event was observed at the time of the November 2011 fresh downstream of Second Creek but it was related to a parallel River Torrens water quality improvement trial. Thus the same event was not recorded at the weir (WDS 2013). Flows equivalent to the planned freshes were recorded at both gauging stations (Gorge Weir and downstream of Second Creek) in November 2012, approximately 2 weeks after the schedule. Low flows past Gorge Weir were equal to or greater than the planned monthly volumes throughout the evaluation period. These flows result from natural catchment inflows (rainfall related), stormwater flows from the urban catchment, flows into Gorge Weir exceeding storage capacity and or other weir related operations, and do not represent a specific over allocation to the environmental flows trial. It should be noted that some base flows have been delivered in this reach since 2006 and that the environmental flows can become confounded with the aesthetic flows delivered to Torrens Lake, however, this report does not seek to attribute benefits to flows from 2006.

Physical habitats and water quality

It was expected that the planned flows in spring would be great enough to sustain the persistent pools over the summer cease-to-flow period (Table 4). Although the depth loggers failed, data from the water quality sampling rounds suggests that the measured environmental flows may have sustained the pools over the summer of 2011-12 but the results are inconclusive.

Water quality in these pools improved in response to environmental flow delivery. Dissolved oxygen increased by 2-8 mg/L before and after the November 2011 and 2012 flows. Some low dissolved oxygen was recorded at depth in the pools during the fish sampling (SARDI 2013) but the water was stratified at the time and therefore the majority of the pool remained habitable. Salinities also decreased during the November 2011 flush from ~2000 μS/cm before the flows to 480 – 1200 μS/cm after the flow event (bug report 2013).

The planned November flush was designed to temporarily connect pools by building up water levels to greater than the sill height and thereby establishing interconnecting riffles or joining strings of small pools into one larger pool. In November 2011 some longitudinal connectivity was observed at all sites, although no surface flow was observed at Athelstone Reserve where pools were lower than expected. The environmental flows in winter 2012 established pool-riffle sequences that were flowing until at least late October 2012 but actual flows greatly exceeded the planned environmental flows and thus this does not confirm that the planned environmental flows would have been sufficient. The hydrological data from 2013 should provide evidence of how long the pool-riffle sequences were sustained by the 2012 environmental flows, from which thresholds could be determined. The 2013 physical habitat data and the 2014 vegetation data should also provide evidence of whether the actual flows in 2012 were great enough to thin reed beds and redistribute sediments, although there is no evidence of either as yet.

Biotic components

Macroinvertebrates

As for the other trial reaches, it was expected that riffle-dependent macroinvertebrates would increase in abundance and diversity and that the macroinvertebrate community would shift through a predictable succession sequence. The data show little or no change in the macroinvertebrate assemblages and the changes that did occur were subtle and difficult to interpret (Table 4). The response at Felixstow was the most consistent with the hypotheses but this was not repeated at other sites across the reach.

Native fish

Numbers of flathead, dwarf flathead and carp gudgeon varied but remained relatively stable throughout Year 1, which was expected (Table 4). There was evidence of dispersal of carp gudgeon, which appeared in low abundance at Silke’s Road and high abundance at Felixstow. There was also evidence of dwarf flathead gudgeon moving through the reach because they were present at Gorge Weir as well as downstream at Felixstow. This movement may be a function of the higher than planned environmental flows during 2012 and may not have occurred if flows of the planned magnitude and timing were delivered instead.

Prior to the trial, mountain galaxias had been in low numbers with a variety of age classes at Silke’s Road prior to the trial. New cohorts were observed in spring 2011 and 2012, although no adults were detected in autumn 2011, suggesting the population perished or shifted locations. Juvenile common galaxias were caught at Gorge Weir in spring 2012 for the first time since sampling began in 2006, which shows that flows immediately below the weir were sufficient to facilitate dispersal and trigger breeding in these fish. Overall, the abundance of galaxiids did not increase and thus the hypothesis was not supported but the results suggest that positive responses to environmental flows may occur over consecutive years.

Alien fish

Redfin perch were present in low numbers at Gorge Weir and Silkes Road prior to the trial. During the trial, numbers at both sites declined with the population at Silkes Road apparently lost (Table 4). It is unclear if redfin perch numbers dropped due to dispersal or mortality, although it is noted that a similar trend was observed in the upper River Torrens trial reach (Section 2.3), and thus may be attributable to catchment activities or processes.

Very high numbers of juvenile gambusia were caught at Silkes Road in autumn 2012 but there was a sharp decline in abundance by spring 2012. This decline does not appear to have been due to downstream displacement given that the population at Felixstow was stable. No dispersal of gambusia upstream to Gorge Weir was detected, as predicted. This is a positive outcome for the predominately native fish communities at Gorge Weir.

Although an objective for the River Torrens – Gorge Weir to Torrens Lake reach was for no increase in alien fish populations (Section 3.2), it was expected that the planned environmental flows would lead to an increase in habitat availability, and thus abundance and distribution for trout. This prediction was not upheld, in that, trout abundance was stable (after an initial increase) at Gorge Weir and no trout were caught at Silkes Road, suggesting a decline there. This is a significant positive result, given that trout are voracious predators of native fish. It may not be attributable to the environmental flows, however, because there was no evidence of downstream displacement to Felixstow. The other main alien fish, goldfish, were observed to be breeding and a small population established at Silkes Road. This is not consistent with the objectives or desirable given that goldfish will impact strongly on native fish, especially over the summer months.

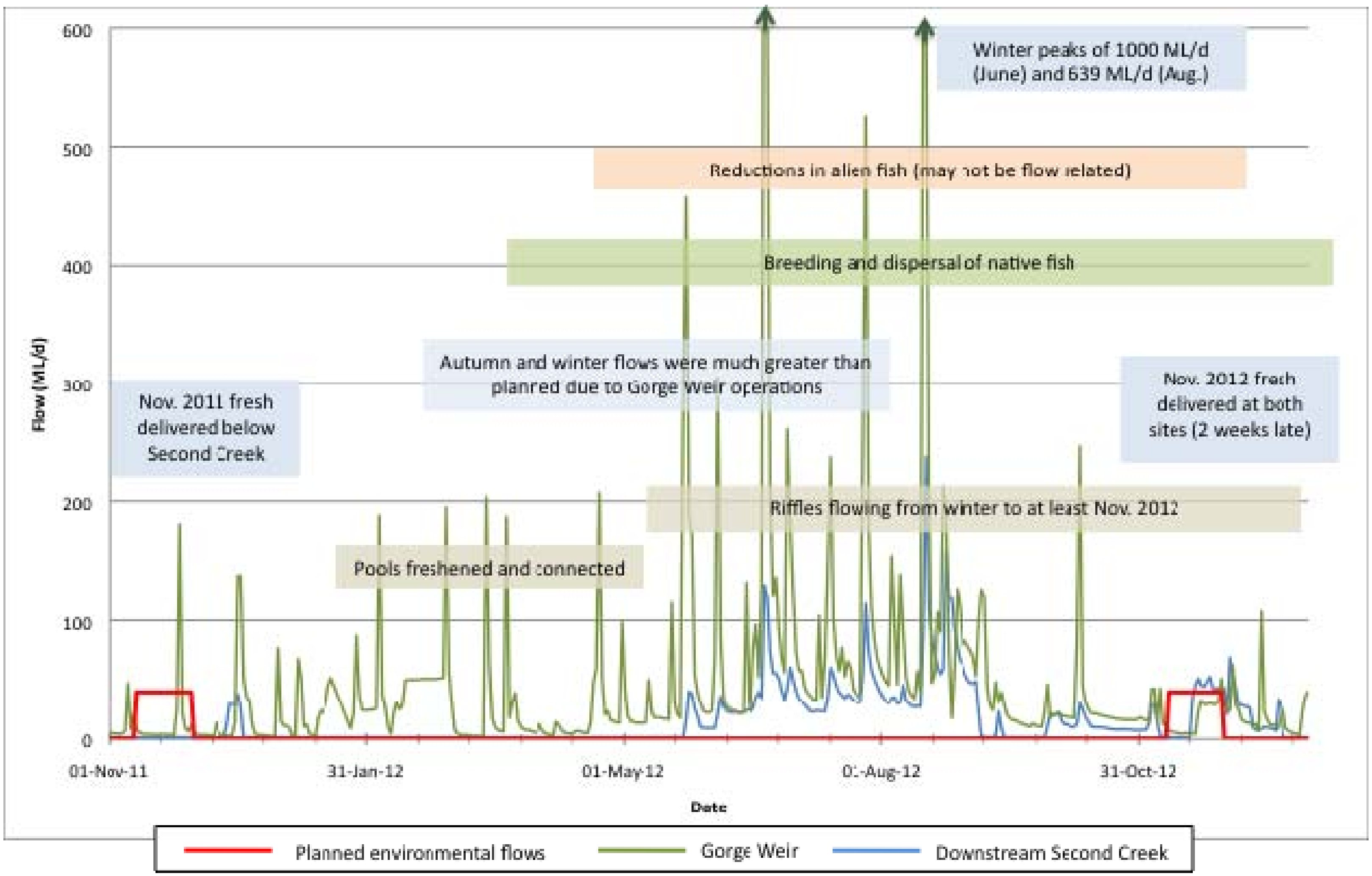

Figure 11: River Torrens – Gorge Weir to Torrens Lake trial reach hydrology, as measured at the weir and below the Second Creek junction, showing key flow events and environmental outcomes for Year 1, November 2011 to December 2012

Table 4: Comparison of planned flows and predicted responses against actual observations in the River Torrens – Gorge Weir to Torrens Lake trial reach (1 Nov. 2011 to 31 Dec. 2012)

Indicator	**Planned flows and predicted responses**	**Observations**	**Comments on achievement of objectives**
Hydrology			
Freshes	Two events: November 2011 and 2012.	Nov. 2011 observed below Second Creek but not at weir; Nov. 2012 observed both sites (2 weeks late).	Planned flows achieved in lower reach (below Second Creek); objective partially achieved in upper reach.
Low flows	Low flows all year.	Low flows equal to or greater than planned at both sites.	Planned flows achieved.
Physical habitats and water quality			
Pool depth and persistence	Increased water levels in autumn and winter; no loss over summer.	Loggers failed.	Unknown.
Water quality in pools	Improved quality from delivery of spring flush.	Increased dissolved oxygen and decreased salinity after the Nov. 2011 flush and over winter 2012.	Objective achieved; actual flows were significantly greater than planned environmental flows.
Connectivity and riffle habitats	Riffles wet and pools connected during and after November high flow.	Connectivity and flowing riffles obs. July, Sept. and Oct. 2012 at all sites	Objective achieved; actual flows were significantly greater than planned environmental flows.
Sediment transport	Redistribution of silt from riffles to pools.	Between 10-35 % cover of accumulated silt; no evidence of silt transportation.	Objective not achieved; revise hypotheses for planned flows given that higher actual flows did not redistribute sediments.
Biotic components			
Macro-invertebrates	Increased relative abundance and diversity of riffle-dependent taxa; diversity changes will follow a set succession	Little or no change in riffle-dependent taxa; succession model not supported.	Objective not achieved; data patterns not as predicted and difficult to interpret.
Gudgeon	Minimal effect.	Relatively stable populations with limited dispersal.	Objective achieved; higher than planned environmental flows may have facilitated dispersal.
Galaxiids	Increased abundance by using riffle habitats.	Low abundance; juvenile mountain and common galaxias suggest breeding occurred.	Objective partially achieved; breeding observed but very low numbers of adults therefore no increase in abundance.
Redfin perch	No net effect.	Unexplained decline at Gorge Weir and lost from Silkes Rd.	Objective achieved although no evidence that it was a result of the environmental flows.
Gambusia	Decreased abundance and distribution due to fatal displacement.	No overall increase in abundance or distribution.	Objective partially achieved; there was no decrease in abundance and distribution but there was no increase either.
Trout	Increased distribution through flowing riffles (counter to objective).	Stable abundance and reduced distribution.	Prediction not upheld so the objective of no observable increase was achieved.
Goldfish	Increased spawning in spring/summer but fatal displacement by flows.	Breeding and establishment of population at Silkes Rd.	Objective not achieved.

Conclusions

The hydrological, physical and water quality predictions were generally supported in the River Torrens – Gorge Weir to Torrens Lake reach, although the actual environmental flows greatly exceed the planned environmental flows in terms of frequency of flow, monthly volumes and daily peaks. Therefore, any observed responses were to environmental flows that were much 'wetter' than planned.

Flows in excess of planned environmental flows are the result of natural catchment inflows (rainfall related) above Gorge Weir, stormwater flows direct to the River Torrens from the urban catchment, flows into Gorge Weir exceeding storage capacity and/or other weir related operations. With limited ability (or desire) to intercept such flows, it is expected that flows during the low flow period (outside of November) will continue to exceed planned environmental flows on a regular basis. This "natural" flow regime now represents the new hydrological regime for this urban River Torrens reach, and so will need to be accommodated by the planned environmental flows.

It is difficult to determine which of the observed outcomes would occur if only the planned environmental flows were delivered. It is reasonable to assume, however, that if a predicted response was not observed in 2012 then it is unlikely that the lower planned environmental flows will achieve it. For example, the lack of evidence for silt transport through the reach at the higher flows during 2012 suggests that the planned environmental flows will also not redistribute sediments and thus the relevant hypotheses need to be revised.

Riffle-dependent macroinvertebrate communities showed little response to the environmental flows and there was little evidence for the hypotheses, other than a minor increase at Felixstow. This suggests that the delivered flows were not ideal for riffle-dependent macroinvertebrates and further investigation is required to determine why, especially given that strong responses to environmental flows observed in other trial reaches (Sections 5.1 to 5.4).

The responses of native and alien fish to the environmental flows were mixed. Positive outcomes were seen in terms of breeding and dispersal in mountain and common galaxias populations. There were also positive outcomes for controlling alien fish, although it is not clear whether the declines in alien fish can be attributed to the environmental flows or some other factor(s), especially given that a similar trend was seen in the upper River Torrens trial reach (Gumeracha Weir to Kangaroo Creek Reservoir).

Overall, the environmental flows in the lower River Torrens reach benefitted the ecosystem. Water quality in pools was freshened in autumn and connected riffle habitats were flowing over winter and until at least November 2012, which facilitated riffle-dependent macroinvertebrate communities to establish and limited dispersal of fish. In general, the biological responses were not as strong or consistent as predicted even though the actual flows were greater than planned, which may indicate that there were other barriers in place (e.g. limited dispersal into the reach; poor baseline condition).

The Year 1 evaluation generated the following key questions for 2013 and 2014 in the River Torrens – Gorge Weir to Torrens Lake trial reach:

- Were the 2012 flows sufficient to sustain riffles over the 2012-13 summer period?
- Are the planned environmental flows sufficient to sustain persistent pools over summer? Would a reduction in the November fresh daily flow rate adversely impact on the persistence of pools over summer?
- Can the hydrological data be interrogated to determine the periodicity of flowing riffle habitats before and during the trial? And perhaps flow thresholds?
- What flows are required to transport silts that have accumulated? Once mobilised, what is the fate of these silts?
- Why was the response by riffle-dependent macroinvertebrates so minimal given that actual flows were greater and more frequent than the planned environmental flows and riffle habitats were established and maintained?
- Is there evidence for accumulative benefits for macroinvertebrates and fish over several years of environmental flow provision in this reach?
- What factors are limiting galaxiids from increasing in abundance and distribution?
- Will alien fish numbers remain stable throughout the trial period?

6 DISCUSSION

All four environmental flow trial reaches showed positive responses to the delivery of environmental flows. The responses were strongest at sites that had previously been the driest (macroinvertebrates at Barossa Diversion Weir) or where environmental flows provided connectivity along the whole reach (fish moving along the Onkaparinga River trial reach). Furthermore, the responses were generally lower at sites that did not receive the full volumes of planned environmental flows and higher at sites that received more than the planned volumes (e.g. Gumeracha weir site vs. sites below Millbrook Creek on the River Torrens – Gumeracha Weir to Kangaroo Creek Reservoir). The exception was the Gorge Weir site that received a lot more water for a longer period than planned but had only a minor response. These observations suggest that the ecosystems respond positively to environmental flows and that there will be a threshold below which environmental flows will add to achievement of the stated objectives.

It is likely that there will be flow thresholds for key environmental outcomes specific to each reach. The results from Year 1 suggest that the critical flow functions, for which thresholds need to be determined, are:

- maintaining permanent refuge pools over summer
- freshening persistent pools in autumn before low water quality triggers are met
- establishing longitudinal connectivity early enough in the flow season to prevent 'resetting' of the riffle communities and enable population expansion into 'new' riffle habitats
- maintaining longitudinal connectivity for long enough to facilitate development of complex riffle-dependent macroinvertebrate communities
- maintaining longitudinal connectivity for long enough or frequently enough to enable dispersal of fish along the full length of the reach.

If the reaches are considered individually, a continuum from 'wetter' to 'drier' conditions may be constructed around which these thresholds (e.g. daily peak, monthly volumes, ML x days) could be determined. For example, the flows in the Onkaparinga River trial reach in 2012 were greater than planned and consequently the riffles were converted to runs, which adversely affected the riffle-dependent macroinvertebrate communities but facilitated fish dispersal. Whereas, the flows along the upper River Torrens – Gumeracha Weir to Millbrook Creek were too low to stimulate environmental outcomes that were readily observed in other reaches. Further separation of the trial reaches into sub-reaches may help to overcome confounding factors, including the very strong effects of tributary inflows or water transfers on longitudinal processes such as sediment transport.

In refining the planned environmental flow regimes it needs to be recognised, that many of the environmental water releases are triggered by rainfall events. While every effort may be made to ensure delivery as close to these rainfall triggers as possible, actual delivery will remain dependent on when (or if) the rainfall events occur, which will fail to account for what else was happening in the catchment and the magnitude of the rainfall event.

The knowledge being gained in this trial is highly significant because the trial is being undertaken under 'real world' conditions (e.g. operational constraints, low water availability) and not in controlled laboratory conditions. The development and testing of specific hypotheses and conceptual models provides a highly robust system for evaluating multiple lines of evidence and capturing changes in knowledge over time. As such this environmental flows trial constitutes a real contribution to the science of environmental flow delivery, as well as providing direct and highly relevant evidence for the effects of environmental flows in the trial reaches.

Many of the environmental outcomes were greater than expected. For example, the presence of pupae, predators and key indicator species in the macroinvertebrate communities at Humbug Scrub Road or the capture of pouched lamprey in the Onkaparinga River. These strong environmental responses demonstrate the high resilience of these ecosystems and provide evidence that the ecosystems will respond when watered appropriately. The equally strong response by alien fish, such as gambusia in the South Para River trial reach, to provision of environmental flows may be an unavoidable risk of providing water to native species and alternate mechanisms for control may be required if high flows do not produce the predicted fatal displacement.

The responses of some environmental indicators to the provision of environmental flows were not as predicted. This was particularly evident in the macroinvertebrate response, especially in the Onkaparinga and Torrens rivers, which did not follow the expected succession model. This does not mean that the logic is flawed or that the objectives for macroinvertebrates were not achieved but rather indicates that the response was more rapid and less linear than expected and that our knowledge of succession processes needs refining. Similarly, evaluation of more than one year of environmental flow trial data may indicate that some environmental responses are accumulative over successive years. For example, the responses by flathead gudgeon were positive but not as strong as predicted in the South Para and Onkaparinga rivers. It may be hat flathead gudgeon require 3-5 years of environmental flow provision before strong population responses will be evident.

There is a need to investigate some aspects of the environmental flows delivery more closely. In particular, persistence of pools and riffle habitats over summer needs to be tracked because it is a key objective of all reaches. Failure to maintain refuge pools and/or riffles over summer is one of the highest risks to achievement of the environmental flow objectives for the four reaches. The results from Year 1 clearly indicated that the provision of suitable hydrological habitats is fundamental to the achievement of other environmental outcomes.

Although it is recognised that the most powerful statistical analysis would come from co-locating the monitoring sites for all indicators and having similar site placement across reaches, it became apparent that the available habitats for collecting fish and macroinvertebrate samples were not at the same sites in every reach and that flow gauging stations were fixed at locations that did not necessarily provide information about those habitats. Data loggers for monitoring pool depth and water quality have been re-instated at key sites to improve the spatio-temporal correlation between data collection points. The monitoring program design achieves the maximum level of replication possible within the physical and operational constraints of the sites within each reach. Evaluation of the data from the three years will take into account the inter-site differences by focussing on testing conceptual models for indicator responses and reach-specific hypotheses as well as formally analysing population statistics.

Overall, the results from Year 1 of the environmental flows trial show that environmental indicators will respond to environmental flow delivery and that provision of environmental flows leads to positive environmental outcomes. Further evaluation of the trial data will yield information that can be used to develop specific, measureable, attainable, relevant and time-bound (SMART) targets for different magnitudes of flow in the specific reaches. This will close the adaptive management cycle and establish a sound basis for on-going environmental flow delivery and evaluation.

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