When to break the habit: Adapting the FLOWS method for use in the highly modified Lower Broken Creek

Lisa Duncan[1], Simon Treadwell[2], Daniel Lovell[3]

1 Jacobs, 33 Kerferd St Tatura, 3616. Email: lisa.duncan@jacobs.com

2. Jacobs, 452 Flinders St Melbourne, 3000. Email: simon.treadwell@jacobs.com

3. Goulburn Broken CMA, 168 Welsford St Shepparton, 3630. Email: daniell@gbcma.vic.gov.au

Key Points

- A full environmental flows study was undertaken on the Lower Broken and Nine Mile Creeks to replace interim flow recommendations developed in 2008.
- Developing ecological objectives and recommendations in a system that has been highly regulated over a long time period is challenging given the operational constraints, reversal of the natural seasonal flow pattern and a series of slow-flowing weir pools maintained at a near-constant level
- A flexible approach was taken to address the specific issues within the system including the approach to hydraulic modelling and developing complementary actions to provide physical habitat

Abstract

The Broken Creek in Northern Victoria is a distributary system that extends from a breakout point on the Broken River near Benalla to its confluence with the Murray River in Barmah Forest. The system was historically intermittent, receiving seasonal flood flows from the larger Broken River and some within catchment runoff in non-flood years. Over 100 years of modification has seen the creek largely disconnected from the Broken River and changed into an irrigation and water supply network with 11 weirs constructed over the creek's lower section. More than 100 kilometres of the creek are now a series of slow-flowing weir pools maintained at a near-constant level. The operation of the creek has reversed the natural flow regime so that it now flows at its highest in summer and lowest in winter. Although a highly modified environment, good native fish populations exist within the Broken Creek, supported by fish passage on weirs. However, slow moving water, high nutrients, low dissolved oxygen and azolla outbreaks are all management challenges. The Goulburn Broken Catchment Management Authority (Goulburn Broken CMA) developed interim environmental flow recommendations in 2008, mainly focused around these key challenges. A full environmental flow study using the FLOWS methodology expanded on the interim flow recommendations and developed a full complement of environmental flow objectives and recommendations. A degree of flexibility is built in to the FLOWS method when determining environmental water requirements for Victoria's waterways. This flexibility proved invaluable during the Broken Creek study to address questions such as:

- How do we define and prepare ecological objectives and flow recommendations in such a modified system?
- Which modelling method is most suitable for static weir pools?
- Can manipulation of weir pool levels provide habitat variability?
- Are there reaches within the system where flow is not the main constraint to achieving good ecological health and a greater focus on complementary works is required?

This project exemplifies the importance of adopting a flexible approach and explores the unique adaptations utilised when employing the FLOWS method in highly modified creek environment.

Keywords
Broken Creek, Nine Mile Creek, environmental flows, FLOWS method, weir pools, flow regulation

Introduction
This project updates environmental objectives and flow recommendations for the Lower Broken and Nine Mile Creeks using the revised FLOWS method (DEPI 2013). Interim flow recommendations were first developed by the Goulburn Broken CMA in 2008 (GBCMA 2008) to provide habitat and connectivity for native fish, improving water quality and preventing large build-ups of azolla in weir pools. However, there were several limitations in the development of the interim flow recommendations. No field inspections were undertaken, no hydraulic models were used, there was a limit to the available hydrological data available for the study and an expert panel was not used during the development of the environmental flow objectives and recommendations. Recent operational changes to the system provided an opportunity to undertake a full environmental flows study, updating the environmental objectives and providing new environmental flow recommendations for the system. The environmental flow recommendations for the Lower Broken and Nine Mile Creeks were developed to:

- maximise environmental outcomes within the context of the ongoing need to provide regulated flows in summer-autumn to meet irrigation demands;
- consider current and future environmental water availability, and the likely implications for environmental objectives that might be set for the Broken Creek system; and
- Identify complementary actions that may enhance the benefits of environmental water delivery in this system.

While the study followed the FLOWS method, adaptations were made to deal with specific issues within the Lower Broken and Nine Mile Creeks. These centered around the hydraulic modelling, understanding the operational constraints of providing environmental flows or changing the established flow regime, and developing complementary actions to improve ecological values in reaches where flow was not found to be the main limiting factor in improving the health of the system.

Study area
This study applies to the Lower Broken Creek below the confluence with the Boosey Creek and includes the Nine Mile Creek anabranch (Figure 1), which was broken into four reaches:

- Reach 1 - Broken Creek from the Boosey Creek confluence to the Nine Mile Creek confluence (including a short section of the Boosey Creek downstream of the 7/3 Channel outfall in Katamatite)
- Reach 2 - Nine Mile Creek from Katandra Weir to its confluence with the Broken Creek downstream of Numurkah
- Reach 3 - Broken Creek from the Nine Mile Creek confluence to the Nathalia Weir
- Reach 4 - Broken Creek at Nathalia Weir to the Murray River confluence

Reaches 1 and 2 are largely flowing aside from relatively small weir pools created by the Katandra and Numurkah town weirs. Reach 3 is influenced by the Nathalia town weir, which restricts flow most of the way through the reach. Reach 4 is almost entirely a continuous series of weir pools (8 weirs in total occur along Reach 4) with the exception of the very bottom of the system for a few hundred meters between Rices Weir and the Murray River. In total there are 11 weirs along the lower Broken Creek, all of which have fish ladders providing (when they are operating correctly) fish passage the entire length of the system from the Murray River to the Boosey Creek confluence.

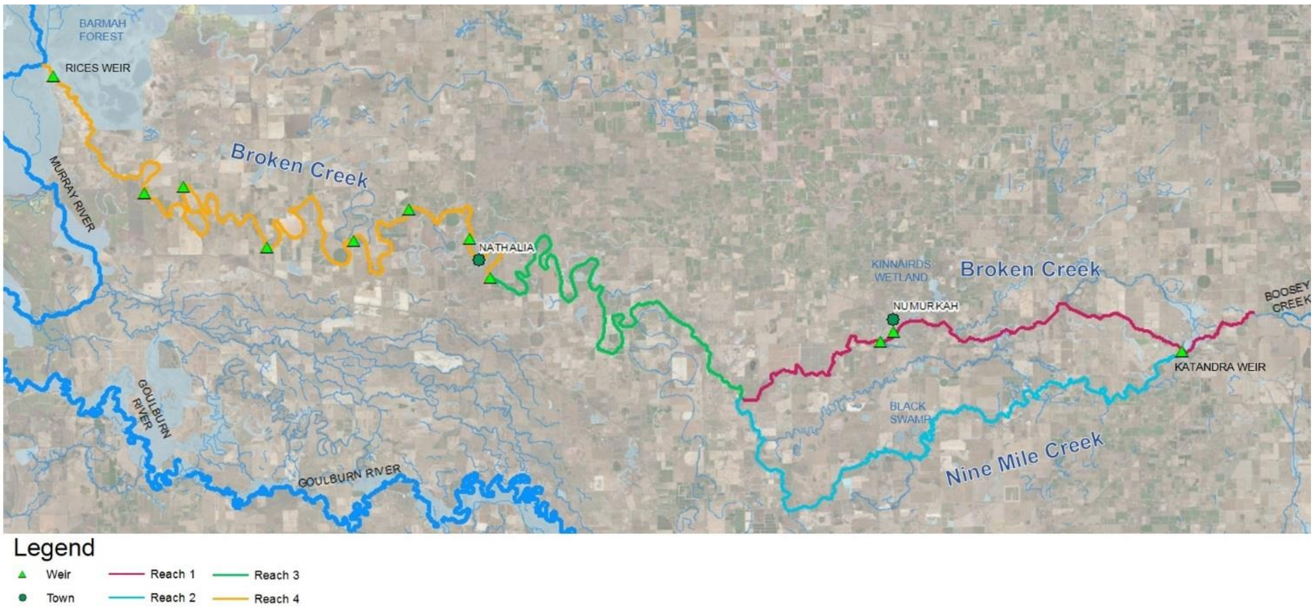

Figure 1 – Locality map of Lower Broken and Nine Mile Creeks

A brief history of the Lower Broken and Nine Mile Creeks

The Lower Broken Creek system has been regulated for over 100 years. Naturally the main sources of water for the Lower Broken Creek were flood flows via the Broken River and Upper Broken Creek and catchment run off from the Boosey Creek. However, regulation of flow from the Broken River to the Upper Broken Creek, construction of weirs and extractions for irrigation in the upper catchment have largely disconnected the Upper and Lower Broken Creeks, except during very large flood events. The Lower Broken Creek now gets the majority of its inflow via the 7/3 Main Channel from the Murray River and the East Goulburn Main (EGM) Channel from the Goulburn River. It also receives unregulated catchment run off in wet years.

Under natural conditions, the creeks would have ceased to flow and contracted to a series of permanent pools during summer and autumn and would have received high flows during winter and spring. Now the creek is operated at a high level throughout much of the irrigation season (mid-August to mid-May) and is at its lowest during winter. The weirs throughout the system now means there are a series of connected weir pools that are maintained at almost a constant level throughout the year. The weirs and associated fish ladders are typically shut off completely outside of the irrigation season to maintain water levels until the beginning of the next season. The presence of year-round water in weir pools and extensive fish stocking means that large-bodied native fish permanently inhabit the continuous weir pool reaches of the system. However, channelisation, levees and removal of snags means overall habitat condition for fish is poor.

Irrigation practices have also changed significantly over the period that the Lower Broken Creek has been regulated. There is evidence of old block banks within the channel and informal weirs which have since been removed, existing weirs have also been upgraded, including the addition of automatic gates and fishways. Prior to the millennium drought and the introduction of on-farm efficiency upgrades the system would have been wetter outside of the irrigation season and received a greater volume of high nutrient drainage water during the irrigation season. Increases in nutrient levels from farm runoff and a lack of flushing flows through the system often cause widespread azolla blooms which carpet the surface of the creek within weir pools, taking months to clear. Blackwater and fish kills have also occurred in the system when dissolved oxygen levels reach critically low levels in weir pools.

All of these changes have brought about a significant shift in the creek ecosystem and the resident biota, making it virtually unrecognizable from its natural condition. As such the natural paradigm is not applicable for developing environmental flow objectives and recommendations Broken Creek.

Recent improvements

There have been multiple efforts to improve the ecological health of the Lower Broken Creek in the last 20 years. From the late 1990s fish ladders were fitted to all weirs along the creek - although operations have historically been limited to the irrigation season when sufficient flow is available. Re-snagging has occurred in some areas, with over 700 snags installed to date (Jones and O'Connor, 2015). However, anecdotal evidence suggests that native fish populations throughout the creek are still relatively poor, suggesting that despite recent improvements challenges remain in providing conditions to support a healthy native fish community.

Environmental flows have been provided to the Lower Broken Creek since about 2008 when the interim flow recommendations were developed (GBCMA, 2008). The Goulburn Broken CMA, in conjunction with the system operators, Goulburn-Murray Water has recently made significant progress in further improving the flow regime of the Lower Broken Creek system. In 2017 the fish ladders were kept operational outside of the irrigation season (with the use of environmental water) to provide opportunities for fish movement and dispersal during winter. This is a significant achievement in improving the hydrology of the creek despite it being a highly regulated system. Increases in operation flexibility and an increase in availability of water for environmental purposes means there are still opportunities to further improve the flow regime of the creek through the development of a full suite of environmental objectives and flow recommendations.

Key challenges in developing flow recommendations for the Lower Broken and Nine Mile Creeks

The Lower Broken and Nine Mile Creeks have been significantly altered from their natural state over the last 100 years. Parts of the system are considered to be backbone channel in the Goulburn-Murray Irrigation District and the creek system is controlled at multiple locations. Most other regulated systems in northern Victoria are controlled at a smaller number of locations. The high level of regulation caused significant challenges in developing ecological objectives and environmental flow recommendations for this system.

Operational constraints

A particular challenge in this system for an environmental flows study is the high degree of operational constraints compared with other regulated system. Delivery of water to the creek is via the irrigation channel outfall points which were designed primarily for overflow from the irrigation areas and delivery of small amounts of irrigation water for creek diverters. Environmental water delivery to the creek could be as high as 500 ML/d if the nine different outlets along the creek system were simultaneously being used at their full capacity. However, the need to share capacity with irrigation demands limits the ability of system operators to deliver environmental water when and where it is needed. Demands at the lower end of the system are often so high that there are often delivery shortfalls for both irrigators and for environmental water orders. Peak irrigation demand generally coincides with peak need for environmental water during hot spells and lack of delivery capacity during this time poses a particularly high risk to declining water quality.

Weirs within the system maintain constant water level with automated gates, which allows a slow build-up followed by then a quick 'dump' of water over the weir meaning the hydrograph is quite peaky and difficult to manipulate using environmental flows. Reliance of downstream irrigators on pumping from these weir pools means that manipulating the weir pool level, even if it was easily achievable from an operational perspective, would not be acceptable to the irrigators.

Outside of the irrigation season the weirs are normally shut off to maintain water levels through to the next season, meaning no flow is passing through those reaches and fishways do not operate. Although there have been recent changes to this, even small operational changes require careful coordination by the system operators to coordinate delivery with maintenance works on the irrigation network that often occur during the winter.

Weir pools

Poor water quality is the major flow related risk in the weir pools during hot weather. Low flow through the weir pools may result in low flow velocity and high water temperatures that reduces mixing and can lead to stratification. High nutrient and organic matter loads, especially from azolla build-up and subsequent collapse, can stimulate biological activity which can result in low dissolved oxygen levels with consequent impacts on ecosystem health, notably fish deaths.

The highest risk location within the system is Rices Weir, which is located at the very end of the Lower Broken Creek system. As it is at the end of the system, historically it received no or little through flow leading to settling of organic matter and sedimentation. Establishing critical flow velocities through the weir pool to maintain mixing is the primary objective for this weir pool.

Lack of access to suitable habitat is also a limiting factor with an opportunity to improve the ecological condition through complementary works such as re-snagging.

Flowing sections

Although there is a significant length of creek influenced by weir pools there are sections in the upper and middle parts of the Broken and Nine Mile Creeks which are flowing and are more reliant on upstream flows to raise creek levels and maintain water depths and access to habitat. These sections are likely to have been most affected by irrigation efficiency improvements in the adjacent irrigation district. Outside of the irrigation season flow ceases in these reaches and water levels are very low, with some sections drying completely. The lack of connecting winter flow in these reaches is considered a significant factor limiting the ability to sustain native fish populations in the creek.

Approach taken to addressing challenges in Lower Broken Creek system

How do we define and prepare ecological objectives and flow recommendations in such a modified system?

A useful starting point for defining ecological objectives during environmental flows studies is looking at how the system would have looked and functioned under natural, unregulated conditions, identifying what environmental assets still remain from this time and developing objectives and flow recommendations around these assets. This approach was not applicable in the case of the Lower Broken Creek because the system has been so significantly altered from its natural state in terms of its hydrology and assets.

The system has changed from a seasonal creek to a perennially flowing system for much of the last century caused by leaky or inefficient irrigation practices and a relatively wet climate compared with what has been experienced over the last 20 years. During the Millennium Drought the volumes of water received by the creeks decreased significantly as irrigation activities were scaled down due to the scarcity of water (DELWP, 2016). This period was also characterised by low rainfall which further decreased the volumes of water entering the creeks. Following the Millennium Drought, the modernisation of the irrigation district and implementation of on-farm irrigation efficiencies meant that the creeks no longer received the same volume of water from the drainage network that they previously would have, this has particularly affected the flowing upper sections of the creek which are now dry for most of the time outside the irrigation season.

Many of the environmental assets associated with the Lower Broken Creek such as instream vegetation and large-bodied native fish are now no longer experiencing favourable conditions in these upper reaches. It is clearly not realistic to consider returning to a leaky and inefficient irrigation system to allow better outcomes for these values, the water is simply not available and in the context of climate change where even drier conditions are expected it would be inappropriate. Conversely, the total absence of flow in the upper reaches of Lower Broken Creek is having a detrimental effect of the creek environment and the environmental assets that have previously flourished here.

The approach taken in the Lower Broken Creek was a 'middle ground' option where environmental water will be used in a targeted way to support some of the values that had established in the system during the long period of regulation over the last 100 years without the need to return to inefficient irrigation practices. In the weir pool reaches flows will continue to be provided to maintain fish ladders and the volumes of environmental water needed to flush azolla from the system have been optimized using hydraulic models. However, it may be unrealistic to expect that self-sustaining populations of large-bodied native fish can be maintained.

Which modelling method is most suitable for static weir pools?

The slow-flowing weir pools in Reaches 3 and 4 posed a challenge to the hydraulic modelling component of the flows study. In most systems, hydraulic modelling is used to determine what flow rates will lead to the desired river height in a system to support functions such as enabling fish passage between pools or inundating low benches to enable growth of in-stream vegetation. In the Lower Broken Creek weir pools the creek levels remain relatively constant with different flow rates, but velocities may change.

Hydraulic modelling is typically used during a FLOWS study to assist in the development of relationships between stream flow and water level for the various assessment sites. The model outputs are then linked with conceptual understanding of ecology-flow relationships and field observations to determine flow recommendations that support the values of the system (DEPI, 2013). This standard approach was not used for Reaches 3 and 4 of the Lower Broken Creek as there was so little opportunity to change creek levels with flow due to the operation of weir pools.

It was decided not to build a hydraulic model for Reach 3 and instead use habitat mapping data produced through an earlier project to make recommendations around improving the physical habitat. Due to the influence of downstream weir pools there was very little scope to improve conditions within the creek through environmental flows and the limiting factor in achieving good ecological condition is more closely related to lack of physical habitat within this reach.

In Reach 4, and specifically Rices Weir, a 2D hydraulic model was developed, using bathymetric survey and Lidar data with the aim of determining how the velocity profile varies across the creek under a range of inflows and outflows. 2D modelling is not an uncommon modelling technique in a FLOWS study. They can be used to understand the influence of overbank flows on the floodplain or in low flows to model the velocity profile across riffles. The way the model was used in the Lower Broken Creek was different to the standard approach.

The model was used to look at flow direction and velocity distribution under various flow conditions to identify specific areas of hydraulic habitat such as slackwater zones, which provide important small bodied fish habitat. This approach was also used to identify areas where azolla could persist and to enable identification of a flow rate that would generate sufficient velocity to mobilise and transport azolla through the system (Figure 2).

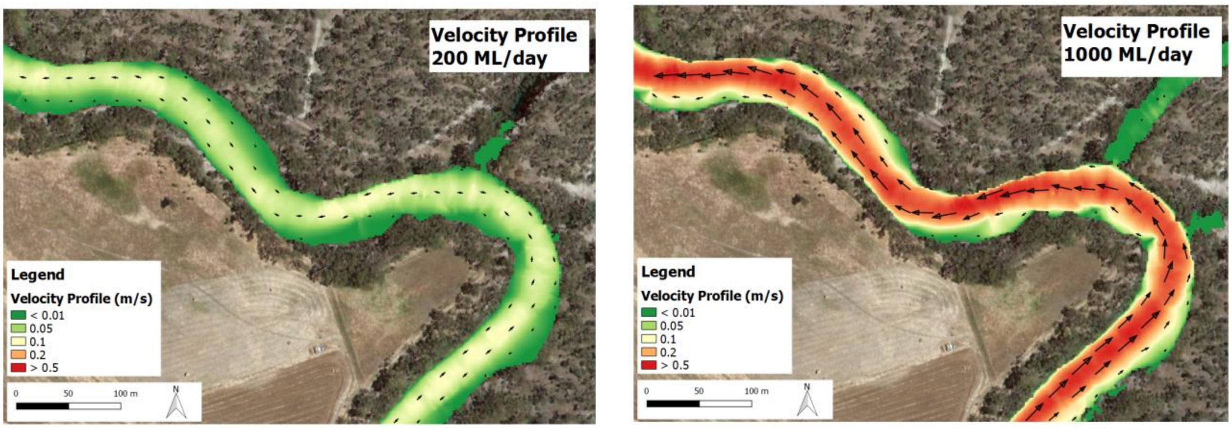

Figure 2 – Velocity profiles generated from the 2D model in Reach 4 of the Lower Broken Creek. The model outputs show that a flow rate of 200 ML/d (left) would be unlikely to generate sufficient velocities to mobilise azolla whereas a flow rate of 1,000 ML/d (right) would be more successful in achieving this objective.

The 2D model was also able to predict the influence of flow on mixing within the water column. Water quality monitoring results have previously indicated a relationship between higher flows and improved dissolved oxygen levels at different depths within the weir pools. The model was used to enable the Environmental Flows Technical Panel (EFTP) to pinpoint flows that achieve adequate mixing within the water column to provide beneficial dissolved oxygen levels. Rices Weir was chosen for this modelling as it is the highest risk weir pool in terms of poor water quality and environmental flow constraints. The bathymetry data was also used to enable to EFTP to visualize the physical habitat available within Rices Weir to inform recommendations around complementary actions which were also relevant to all weir pools.

Are there reaches within the system where flow is not the main constraint to achieving good ecological health and a greater focus on complementary works is required?

Reaches 3 and 4 of the Lower Broken Creek are made up of a connected series of weir pools. These reaches have a permanent water supply as water levels are kept high for irrigation purposes. It was identified during the environmental flows study that flow was not the main constraining factor in achieving good ecological outcomes in these reaches. Although Reach 4 will benefit from environmental flows in maintaining good water quality over summer and in dispersing azolla prior to large blooms occurring, the main opportunity for improving conditions within these reaches to support environmental values was to continue efforts to increase the amount of large woody debris within the system to provide higher quality physical habitat to support native fish and other environmental assets.

Can manipulation of weir pool levels provide habitat variability?

Manipulation of weir pools has been undertaken in other systems to provide environmental benefits, particularly for vegetation outcomes in connected wetlands. This has occurred in the lower Murray River where water levels above Locks have been raised and lowered to influence river banks, creeks and floodplains to encourage a greater diversity of plant growth (DEWNR, 2012). In the Lower Broken Creek, however, the opportunities to do this are limited. Firstly, there are no areas of floodplain that would benefit from raising water levels by surcharging weir pools and the design of the weirs wouldn't allow for this either. Lowering weir pools may provide some benefit however the time of year that it would be beneficial to do so directly conflicts with peak irrigation time when weir pools within the Lower Broken Creek are operated to be as close to full as possible. Additionally, the fish ladders on Broken Creek weirs are manually operated which means that they are set at fixed opening points based on assumed weir levels. Varying upstream and downstream creek levels can affect the efficiency of the ladders for fish passage. Operational changes to the weirs to manipulate water levels could limit the effectiveness of the fish ladders, potentially offsetting any benefit from a varied water level within the pools. This means that there would be very little opportunity of benefit associated with manipulating weir pool levels in the Lower Broken Creek.

Conclusions

The Lower Broken and Nine Mile Creek system is highly complex both in terms of ecology and system operations. The creeks have changed significantly over the last 100 years, making them virtually unrecognisable from their natural condition and presenting considerable management challenges. Although some improvements have been made to the physical habitat and management of the system over the last 20 years there still remain barriers to achieving good ecological condition. This environmental flows study was an opportunity to further build on the improvements that have been made over the last 20 years, and to review and refine the interim flow recommendations implemented by the Goulburn Broken CMA in 2008. The FLOWS method for determining environmental flow requirements in Victoria enables flexibility in the application of the method to take into account the unique needs of various river systems. This flexibility was needed in this environmental flows study to address the unique challenges of the Lower Broken and Nine Mile Creeks. Providing an individualised approach to hydraulic modelling within each reach, involving the system operators as much as possible throughout the process, undertaking additional site visits and considering the health of the system beyond flow related impacts enabled the EFTP to provide the Goulburn Broken CMA with environmental flow recommendations and complementary actions that will help to achieve the best possible ecological outcomes for the whole system within the constraints.

Acknowledgments

Funding for this project was provided by the Victorian State Government through the Department of Environment, Land, Water and Planning.

The Goulburn Broken CMA and Jacobs acknowledge the input and assistance of the Environmental Flows Technical Panel: Peter Sandercock (Jacobs), Ben Mason (Jacobs), Nick Bond (MDFRC), Gavin Rees (MDFRC), Daryl Nielsen (MDFRC), Michael Shackleton (MDFRC) and Melody Serena (APC), members of the Project Steering Committee and the Project Advisory Committee.

References

DELWP (2016) Managing extreme water shortage in Victoria – Lessons from the Millennium Drought. Department of Environment, Land, Water and Planning, East Melbourne, Victoria.

DEPI (2013) FLOWS – a method for determining environmental water requirements in Victoria, Edition 2, Department of Environment and Primary Industries, East Melbourne, Victoria.

DEWNR (2012) Riverine Recovery Monitoring and Evaluation Program: Conceptual understanding of the ecological response to water level manipulation. Department for Environment, Water and Natural Resources, Adelaide, South Australia.

GBCMA (2008) Lower Broken Creek and Nine Mile Creek Interim Environmental Flow Recommendations, Goulburn Broken Catchment Management Authority, Shepparton, Victoria

Jones, M. and O'Connor, J. (2015) Client Report for the Goulburn Broken CMA. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria

O'Connor, J. and Amtstaetter, F. (2008) Monitoring of Native Fish Communities in the Broken Creek and Broken River. Unpublished Client Report for the Goulburn Broken CMA. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria