ACTEW Water

Murrumbidgee Ecological Monitoring Program
Spring 2013

April 2014

Executive summary

The Murrumbidgee Ecological Monitoring Program commenced in 2008. The project is being undertaken by the GHD Water Sciences Group for ACTEW Water to establish information and data regarding relevant biological and water quality information prior to and then following on from the commissioning and initial operation of the Murrumbidgee to Googong (M2G) water transfer project and Murrumbidgee Pump Station. Up until autumn 2013 there were four components to the MEMP; however following the autumn 2013 sampling run, ACTEW Water reviewed the MEMP which resulted in the discontinuation of part 3 (the Murrumbidgee Pump Station component) and part 4 (the Tantangara to Burrinjuck component). This report presents the findings from part 1 (Angle Crossing) and part 2 (Burra Creek), which both relate to the Murrumbidgee to Googong project.

Part 1 – Angle Crossing

ACTEW Water has constructed an intake structure and pipeline to abstract water from the Murrumbidgee River near Angle Crossing (southern border of the ACT). The system is designed to pump up to a nominal 100 ML/d and was completed in August 2012.

Part 2 –Burra Creek

The Burra Creek component of the MEMP has focused on establishing a baseline of water quality and biological characteristics over the three year period between 2009 and 2012. Since the completion of the M2G pumping infrastructure in August 2012, the project has continued to monitor the system to determine what changes, if any, are attributable to the water discharges from the Murrumbidgee River into Burra Creek following the commencement of the operation phase of M2G. Since commissioning, the system has been operating in a standby mode.

The key results from the spring 2013 sampling run are summarised below:

Part 1 – Angle Crossing

The results from the water quality data indicate that water quality generally conformed to guideline ranges. This was reflected in both the readings taken during macroinvertebrate sampling and the in-situ water quality monitoring probes. This finding is in agreement with the results for spring 2012, though dissolved oxygen saturation showed improvement in spring 2013 compared to spring 2012. There were some spikes in turbidity levels, but these were associated with peak flow events and were typical of what would be expected. Total Nitrogen(TN) and Total Phosphorous (TP) levels were once again outside of the guideline range, but were typical of readings historically recorded for the Murrumbidgee River system. The water quality results recorded in spring 2013 were within the 20th percentile and 80th percentile ranges recorded throughout the MEMP study. Moreover, there were no patterns to suggest any significant differences in water quality upstream or downstream of Angle Crossing. Periphyton data results for spring 2013 showed that chlorophyll-a and Ash Free Dry Mass (AFDM) varied substantially between sites, but there were no significant differences in these parameters between locations upstream and downstream of Angle Crossing. Both chlorophyll-a and AFDM were reduced in spring 2013 compared to spring 2012 and this is thought to be attributed to scouring effects associated with the high flow events that preceded the spring 2013 sampling run.

Macroinvertebrate community data results showed that there were no significant differences between locations upstream and downstream of Angle Crossing in terms of taxa richness, EPT richness, SIGNAL-2 scores and O/E 50 scores. This was the case for both riffle and edge habitat. AUSRIVAS results showed a similar pattern to spring 2012, with sites rated mainly Band B (significantly impaired), though site MUR23 achieved a rating of Band A (similar to reference), while two sites recorded a NA (no reliable result) based on high levels of variability being recorded between replicate samples. Multivariate analysis did not detect any significant differences in macroinvertebrate *community composition between locations upstream and downstream of Angle Crossing for either edge habitat or riffle habitat, though this was attributable partly to a relatively high degree of within and between-site variability. All samples were within the 50% similarity band, which means that they shared at least 50% of taxa in common. Sample groups identified at the 65% similarity level contained a mixture of samples from sites upstream and downstream of Angle Crossing,*

There was a decline in the number of taxa present in spring 2013 compared to spring 2012, particularly in the riffle zone. Furthermore, those present in spring 2013 were typical of those that normally occur post flow disturbance events. Hence, it is likely that the spring 2013 macroinvertebrate community status was influenced heavily by the two significant high flow events in spring 2013. This phenomenon has been observed in earlier rounds of MEMP sampling.

Data collected to date suggest that the local macroinvertebrate community is adapted to hydrological disturbance events that occur in the Murrumbidgee River. However, we currently only have limited data in relation to how they cope with reduced flows, which is the potential impact in focus with respect to Angle Crossing. Given this, the fact that the spring sampling round did not coincide with any periods of water abstraction and that we appear to be entering another dry phase, it is recommended that further monitoring be done to characterise the macroinvertebrate community in relation to its status under lower flow conditions. Results from that monitoring could be potentially used to identify tipping points, which in turn, could be used to inform ACTEW with regards to sustainable water abstraction levels.

Part 2 –Burra Creek

We aimed to undertake spring sampling to coincide with a scheduled ACTEW "APPLE" run as part of the M2G infrastructure maintenance program; however this was postponed soon after the sampling had been completed. As it happened, there were no M2G flow releases for the spring period. Sampling occurred approximately four weeks after a 1 in 2.5 year ARI event in mid-September (peak flow of 3,030 ML/d).

The water quality results show indicative seasonal changes and responses to natural runoff events, which were consistent with previous sampling runs. Although several of the water quality parameters were above the recommended national guidelines for ecosystem health, these results are considered "normal" for Burra Creek as they are within the range of values collected over the current duration of the MEMP.

The periphyton results show an increase in mean chlorophyll a concentrations downstream of the discharge point suggesting active uptake of nutrients entering Burra Creek via Holden's Creek, located upstream of the discharge point. Depending on the time of year, nutrient uptake may decline downstream of the discharge point due to increases in flow; therefore, if primary production declines during these periods, nutrient loads could increase in the downstream sections of Burra Creek

AUSRIVAS scores improved at three of the six monitoring sites, so that all of the monitoring sites, except one site (BUR 1c) are now BAND A sites. These improvements are likely due to habitat quality improvements that followed the high flow event in mid – September, through sediment removal from riffle zones, and from higher base flows over the spring period compared to the same period in 2012.

Macroinvertebrate assemblages in Burra Creek appear to respond quickly to natural increases in surface flow from runoff events; and there was some evidence of improvements (albeit small) that were recognised by the brief period of M2G maintenance and trial releases into Burra Creek in spring 2012. Once M2G is fully operational, the releases from the Murrumbidgee River are likely to improve the overall health of Burra Creek inferred from AUSRIVAS and habitat assessments.

Long term analysis is currently underway as part of the MEMP. This follows the recommendations from autumn 2013 and focuses on water quality trends and long term patterns in the macroinvertebrate communities. The Burra Creek *reporting could benefit by undertaking a review of the water quality guideline values such that the trigger levels better reflect values considered to be outside of the normal range for Burra Creek, and assessing environmental thresholds associated with important macroinvertebrate taxa – this would improve our understanding of likely responses to increasing frequency and volumes of water once M2G is used on a regular basis. It is therefore recommended that autumn sampling should occur as soon as possible following any scheduled releases. Ideally this would occur two to three weeks after the next full ramp up/ramp down schedule and would ideally avoid natural high flow events, so that potential benefits from these releases can be identified without being confounded by natural events.*

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List of abbreviations

ACT – Australian Capital Territory

ACTEW – ACTEW Corporation Limited

AFDM – Ash Free Dry Mass (periphyton)

ALS – Australian Laboratory Services

ANOSIM – Analysis of similarities

ANOVA – Analysis of Variance (statistics)

ANZECC –Australian and New Zealand Environment and Conservation Council

APHA – American Public Health Association

APPLE – Angle Crossing Planned Pumped Lubrication Exercise (ACTEW acronym)

ARMCANZ – Agriculture and Resource management Council of Australia and New Zealand

AUSRIVAS – Australian River Assessment System

BACI – Before After Control Impact

EC – Electrical Conductivity

EIS – Environmental Impact Statement

EPA – Environmental Protection Authority

EPT – Ephemeroptera, Plecoptera and Trichoptera taxa

GL/a – Gigalitres per annum

GPS – Global positioning system

M2G – Murrumbidgee to Googong

MEMP – Murrumbidgee Ecological Monitoring Programme

ML/d – Megalitres per day

NATA – National Association of Testing Authorities

NMDS – Non-metric Multidimensional Scaling (statistics)

NSW – New South Wales

NTU – Nephlelometric Turbidity Units

PERMANOVA – PERMutational Multiple Analysis Of Variance

QA – Quality Assurance

QC – Quality Control

SIMPER – Similarity Percentages

TN – Total Nitrogen

TP – Total Phosphorus

1. Introduction

During the 2000-2010 drought in the Australian Capital Territory (ACT) and surrounding regions of New South Wales (NSW), the ACT's dam storage volumes declined to unprecedented levels. ACTEW Corporation, the major water utility company in the ACT, developed a water security programme that involved building additional; and upgrading existing infrastructure to improve the future water supply security for the residents of Canberra and Queanbeyan (see Appendix A for a schematic representation of these projects).

The water security projects include:

1. Murrumbidgee to Googong transfer pipeline (M2G): from Angle Crossing just within the ACT's southern border to Burra Creek in the Googong Dam catchment, at a nominal 100 ML/d;
2. Murrumbidgee Pump Station (MPS): adjacent to the existing Cotter Pump station to increase pump capacity from ~50 ML/d to 150 ML/d (nominally 100 ML/d);
3. Tantangara Reservoir release for run of river flow to the M2G abstraction point at Angle Crossing, and;
4. A new 78 GL Cotter Dam called the Enlarged Cotter Dam (ECD) just downstream of the existing 4 GL Cotter Dam.

The Murrumbidgee Ecological Monitoring Programme (MEMP) was set up by ACTEW Water to evaluate the potential impacts of water abstraction from the Murrumbidgee River. It was designed to address concerns raised by both Government and non-Government stakeholders; and to provide ACTEW Water with relevant information regarding any beneficial and/or detrimental ecological effects of the project. The MEMP was implemented prior to the commencement of the M2G project, allowing ACTEW Water to collect pre-abstraction baseline data to compare against the post-abstraction data once the M2G project is in operation. Sampling has been conducted in spring and autumn each year since 2008.

Between spring 2008 and autumn 2013 there were four component areas being considered as part of the MEMP[1]:

- Part 1: Angle Crossing (M2G);
- Part 2: Burra Creek (M2G);
- Part 3: Murrumbidgee Pump Station (MPS) and;
- Part 4: Tantangara to Burrinjuck (Tantangara Transfer).

However, following the autumn 2013 sampling run, ACTEW Water reviewed the MEMP, which resulted in the discontinuation of part 3 (the Murrumbidgee Pump Station component) and part 4 (the Tantangara to Burrinjuck component).

The M2G ecological monitoring component is consistent with the Operation Environmental Management Plan (ACTEW Corporation, 2012) and associated Ecological Monitoring Sub Plan (ACTEW Corporation, 2010) which responds to commitments made during the EIS and subsequent environmental approvals process.

[1] Note that the MEMP does not include monitoring related to the Enlarged Cotter Dam (point 4 in section 1).

1.1 Background of major projects

1.1.1 Parts 1 and 2 - Murrumbidgee to Googong transfer pipeline (M2G)

The pumping system at Angle Crossing transfers water from the Murrumbidgee River through a 12 km underground pipeline into Burra Creek. The water is then be transported a further 13 km by run of river flows into the Googong Reservoir. Water abstraction from the Angle Crossing pump station will be dictated by the Googong Reservoir's capacity and by the availability of water in the Murrumbidgee River. The system is designed to enable pumping of up to 100 ML/d, and construction was completed in August 2012. Abstraction from the Murrumbidgee River and the subsequent discharges to Burra Creek will be directed by the Operational Environment Management Plan (OEMP).

During periods of low flow (whether climate related or artificially induced), impacts upon aquatic environments can be measured using surrogate indices based on changes to macroinvertebrate communities, such as changes in species richness, abundances and community structure. Such changes can result either directly through invertebrate drift, or indirectly through reductions in habitat diversity or flow conditions which do not suit certain taxa. Dewson*, et al.* (2007) reported that certain macroinvertebrate taxa are especially sensitive to reductions in flow and can be useful indicators in flow restoration assessments and can assist in longer term management of flows in regulated river systems. It is possible that there will be changes to the aquatic ecosystem within the Murrumbidgee River as a result of M2G. Some of these effects include, but are not limited to: changes to water chemistry; and changes to channel morphology, velocity and depth. All of these changes have potential knock-on effects to the biota within the river's ecosystem (see Appendix B for examples). This current monitoring program will form the basis of an Ecological Monitoring Program to satisfy EIS commitments for the M2G Project.

In light of the natural low flow conditions in Burra Creek compared to the maximum pumping rate of 100 ML/d, it is expected that the increased flow due to the discharge from the Murrumbidgee River may have several impacts on water quality, channel and bank geomorphology and the ecology of the system. Some beneficial ecological effects might occur in the reaches of Burra Creek between the discharge point (just upstream of Williamsdale Road) to downstream of the confluence of the Queanbeyan River.
These may include, but are not limited to:

- The main channel being more frequently used by fish species due to increased flow permanence and longitudinal connectivity between pools;
- Increased biodiversity in macroinvertebrate communities; and
- A reduction in the extent of macrophyte encroachment in the Burra Creek main channel.

On the other hand, there is potential for the transfer of Murrumbidgee River water into Burra Creek to adversely affect the natural biodiversity within Burra Creek due to the different physico-chemical characteristics of water in each system (particularly with regards to EC). Furthermore, the inter-basin water transfer also poses a risk of spreading exotic plant and fish species which could displace native biota directly through competition or indirectly through the spread of disease. Other potential impacts are highlighted in Table 1-1.

Table 1-1. Potential impacts to Burra Creek following Murrumbidgee river discharges

Property	Possible impact	Source	Comments based on data collected to date
Water Quality	Increased turbidity from Murrumbidgee water which could decrease light penetration, resulting in lower macrophyte and algal growth.	Martin and Rutlidge (2009)	Turbidity increases with the first initial pulse following flow release. These are short term changes only and there is no evidence to date to support the possible impacts in column one.
	The inter-basin transfers (IBT) of soft Murrumbidgee water into the harder water of Burra Creek may change the natural biodiversity within Burra Creek.	Davis *et. al.* (1992) Martin and Rutlidge (2009)	Based on the data collected following the short term maintenance runs, there have been changes to several physico-chemical water quality parameters. The changes to these parameters are short lived and there has been no evidence of alterations to the macroinvertebrate community composition as a result. It is still unknown if this will be the case for prolonged periods of M2G operation or if there are likely to be cumulative impacts to these periodic changes in water quality.
	Changes in water temperature could be expected from the IBT and increased turbidity. This may affect plant growth, nutrient uptake and dissolved oxygen levels and ultimately compromise the quality of fish habitat.	Martin and Rutlidge (2009)	The changes in the water temperature, turbidity and dissolved oxygen are only short term during the pumping schedule. Compromising fish habitat is not a concern in Burra Creek as the fish community is wholly introduced species.
Ecology	Changes in macroinvertebrate communities and diversity through habitat loss from sedimentation, riparian vegetation and scouring of macrophytes. Changes in macroinvertebrates are also expected with an increase of flow (e.g. increased abundances of flow dependant taxa).	Bunn and Arthington (2002)	The current M2G pumping regime has not continued for durations long enough to, nor at volumes large enough result in significant macrophyte scouring, sediment movement or alter the community composition over and above what occurs naturally within the system.
	Potential risk of exotic species recruitment from IBT, this could displace native species in the catchment and pose a risk of the spread of disease.	Martin and Rutlidge (2009)Davies *et al.* (1992)	No evidence of any new introduced species since the commencement M2G operations.
	Infilling from fine sediment transport could threaten the quality of the hyporheic zone, which provides important habitat for macroinvertebrates in temporary streams.	Brunke and Gonser (1997)	The transport of fine sediment within the creek by the operation of M2G is minor compared to the sediment transport capabilities of the natural high flow events that occur in Burra Creek.
	Increased flow with improved longitudinal connectivity which will potentially provide fish with more breeding opportunities and range expansion, although this will be dependent on the flow regime.	Martin and Rutlidge (2009)	Water transfer has increased the longitudinal connectivity between the pools in Burra Creek. However, the short duration of the releases would be unlikely to facilitate breeding opportunities or range expansion by native fish species.
Bank Geomorphology	Bank failure from the initial construction phase and first releases. This could result in increased sedimentation, loss of riparian vegetation and increased erosion rates from bank instability. Increased sedimentation may also reduce benthic habitat complexity, which may result in a loss of benthic macroinvertebrate diversity and a potential loss of sensitive taxa.		Natural events have a much larger impact potential upon the geomorphology than the pump maintenance releases from M2G. However, if the pumps are run for a prolonged period (greater than 1 week), this may have additional impact due to saturation of the creek embankment from continued elevated water levels. (GHD, 2013_a)
Channel Geomorphology	Scouring of the river bed may result in a loss of emergent and submerged macrophyte species. This would result in a reduction of river bed stability and a change in macroinvertebrate diversity and dynamics.	Harrod (1964)	There has been no evidence of scouring directly related to commissioning flows over and above the scouring which has been recorded following natural high flow events (GHD, 2013_a). Ongoing vegetation monitoring is coinciding with seasonal biological sampling.

1.2 Environmental flows and the 80:90 percentile rule

The environmental flow rules for the Murrumbidgee to Googong project (M2G) have been adopted from the framework outlined in the Environmental Flow Guidelines (ACT Government, 2011).

Under the current licence agreement (ACTEW's Licence to take water, 2012), flows in the Murrumbidgee River at the Cotter Pump Station must be maintained at 20 ML/d during any stage of water restrictions (http://www.actew.com.au). When these restrictions do not apply, flows must be maintained at the 80th or 90th percentile flow, depending on the time of year. The 80:90 rule has been applied to hydrological modelling of the Murrumbidgee River at Angle Crossing for the M2G operational plan; and was based on data collected from the Lobb's Hole gauging station. Specifically the 80th percentile flow applies from November to May and the 90th percentile from June through to October (Figure 1-1).

As can be seen from the Figure 1-1, the lowest flows in the Murrumbidgee River occur in summer and autumn. The 80th percentile flows from November to May are less than the 90th percentile flows except for November. It is during these low flow months that abstraction from the Murrumbidgee River is likely to have the most significant impact, as the proportion of the abstraction rate to the base flow is the greatest.

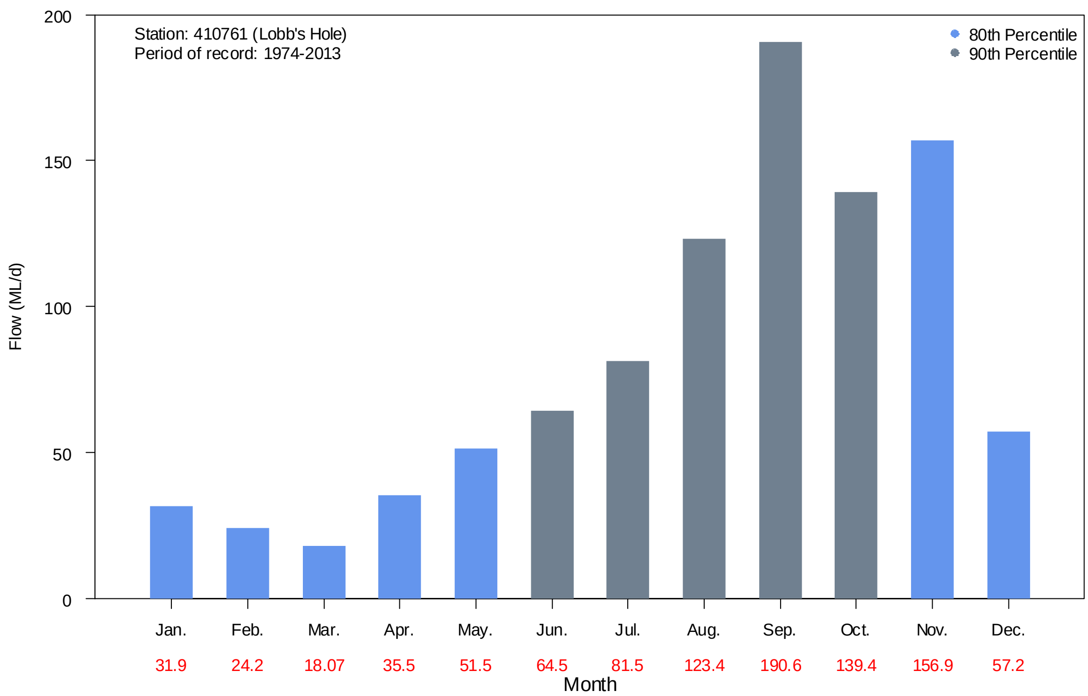

Figure 1-1. Environmental flow values for the operation on the M2G project

Note: Flow data values for data to 30/11/2013. Monthly values in red are megalitres per day (ML/d) and are based on continuous daily flow data from the Lobb's Hole gauging station (410761) since its commencement of operation in 1974.

1.3 The Upper Murrumbidgee River

The Murrumbidgee River flows for 1600 km from its headwaters in the Snowy Mountains to its junction with the Murray River. The catchment area to Angle Crossing is 5096 km^2. As part of the Snowy Mountains Scheme, the headwaters of the Murrumbidgee River were constrained by the 252 GL Tantangara Dam, which was completed in 1961. The reservoir collects water and diverts it outside the Murrumbidgee catchment to Lake Eucumbene. This has reduced base flows and the frequency and duration of floods in the Murrumbidgee River downstream. The Murrumbidgee River is impounded again at Burrinjuck Dam, after the river passes through the ACT. This region above Burrinjuck Dam is generally known as the Upper Murrumbidgee.

Land use varies from National Park in the high country to agriculture and farming in the valley regions. Land use is dominated by urbanisation between Point Hut Crossing and the North Western suburbs of Canberra near the confluence with the Molonglo River. The major contributing urbanised tributary flowing into the Murrumbidgee River is Tuggeranong Creek which enters the Murrumbidgee River downstream of Point Hut crossing. Annual rainfall in the Upper Murrumbidgee River catchment ranges from greater than 1400 mm in the mountains, to 620 mm at Canberra airport (B.O.M, 2013).

Prior to spring 2010, drought was the most significant impact on catchment quality within the upper Murrumbidgee catchments in recent times. During this period, more than 80% of catchments had been drought-affected since late 2002. Some of the effects of this were drought-induced land degradation increased stress on surface and groundwater resources, increased soil erosion and a shift from mixed farming and cropping, to grazing and reduced stock numbers. Since the spring of 2010, the drought broke in the ACT and surrounding NSW regions, with more frequent high flow events occurring throughout that year and an upward trend in the monthly average base flows (Figure 1-2). More recently, during the period between November 2012 and May 2013, there has been a decline in base flows in the Murrumbidgee River following particularly dry summer and autumn. As of 31st May, base flows in the Murrumbidgee River are currently flowing at similar volumes to those seen in early 2010 and mid-2009 (Figure 1-2).

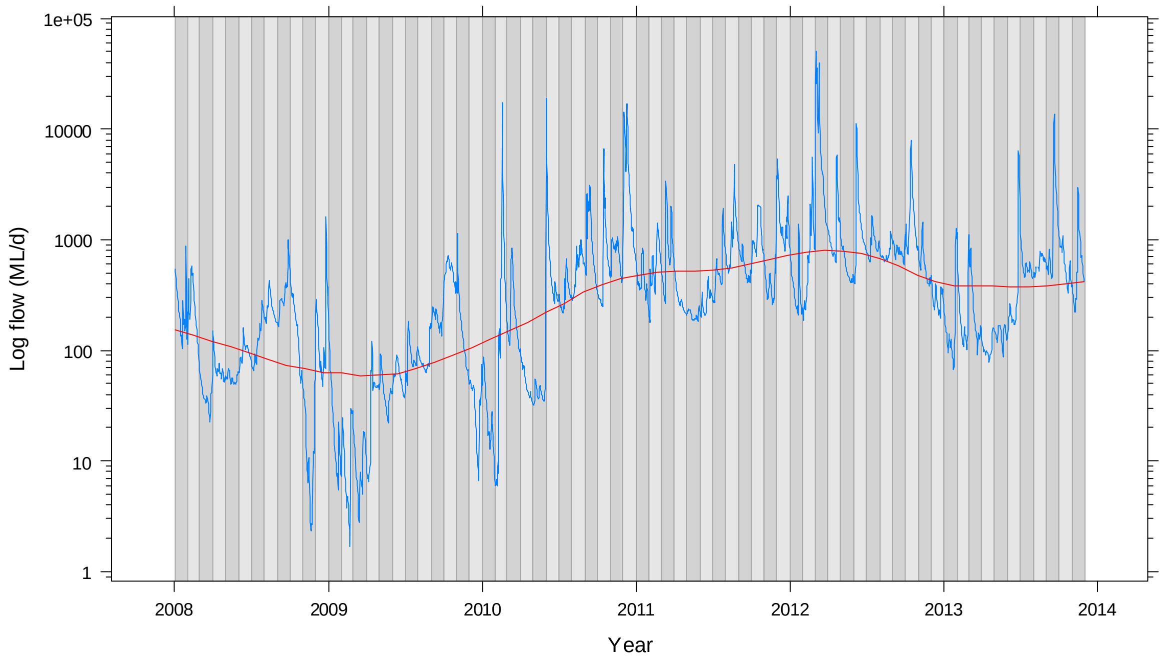

Figure 1-2. Hydrograph of the Murrumbidgee River at Lobb's Hole (410761) from 2008 to November 2013*

**The red line is a locally weighted smoother (LOESS) trend line with a smoothing coefficient of 0.5.*

1.4 Burra Creek

Burra Creek is a small intermittent stream which flows north to north-east along the western edge of the Tinderry Range into Googong Reservoir. The majority of its catchment is pastoral and small rural holdings with the Tinderry Range being natural dry sclerophyll forest. Burra Creek is characterised by emergent and submergent macrophyte beds with limestone bedrock and frequent pool-riffle sequences throughout its length. During low periods the main channel is commonly choked with *Typha sp.* (also known as cumbungi or bull rush) The creek is within a wider eroded channel in the lower section upstream and downstream of the London Bridge (natural limestone arch). When Googong Reservoir is >80% the lower sections of Burra Creek become inundated by the reservoir.

The mean daily flow in Burra Creek (from January 1st 2008 to the 31st May 2013) was 11.8 ML/d - slightly higher from the previous sampling period due to the operation of the M2G pipeline in August and September 2012 and March and May 2013.

Since flow records began in 1985 a mean monthly flow of 100 ML/d has been exceeded 8 times, while flows in excess of 100 ML/d have occurred less than 2 % (1.68%) of the time on a daily basis.

Flow conditions have varied considerably since the inception of the MEMP in late 2008 (Figure 1-3). In 2008 mean daily flow was 0.15 ML/d and this was followed by an equally dry year in 2009 when the mean daily flow was 0.18 ML/d. In early 2010 there were a few rainfall events and this pattern continued throughout most of the year resulting in an upward trend of daily mean flows, which reached 23.4 ML/d. 2011 was a moderately dry year and mean flows fell back to less than 5 ML/d until March 2012 which saw another period of large rainfall events. These rainfall events resulted in another upward trend in average flows until early spring 2012 (Figure 1-3).However, since November 2012 there has been a downward trend in base flows, reflecting the low seasonally reduced rainfall.

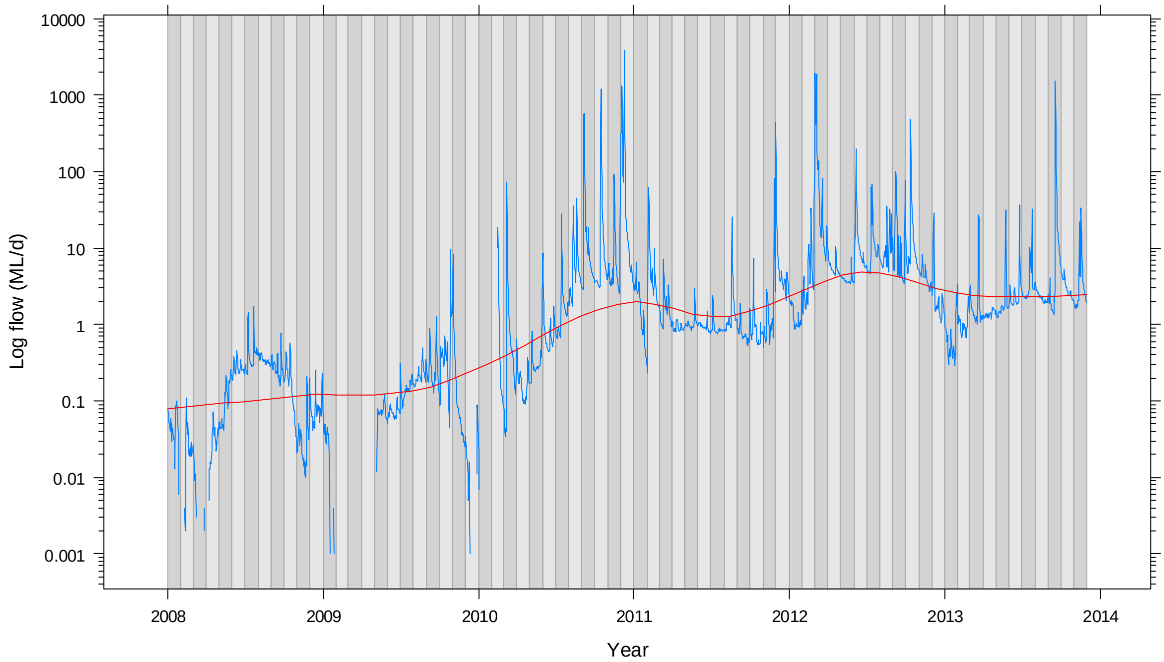

Figure 1-3. Hydrograph of Burra Creek at the Burra Road weir (410774) from 2008 to November 2013*

**The red line is locally weighted smoother (LOESS) trend line with a smoothing function coefficient of 0.5.*

1.5 Project Objectives

The Murrumbidgee Ecological Monitoring Programme (MEMP) was set up by ACTEW Water to evaluate the potential impacts of water abstraction from the Murrumbidgee River and the subsequent changes that might occur in Burra Creek as a result of the M2G project (Parts 1 and 2).

Increasing water abstractions from the Murrumbidgee River could have several impacts on water quality, riparian vegetation, riverine geomorphology and the aquatic ecology of the system. Some beneficial ecological effects could be expected in the reaches downstream of the discharge point in Burra Creek under the proposed flow release regime, including increased habitat availability for native fish species. The increased flow in those locations is also likely to favour flow-dependent macroinvertebrates and improve surface water quality.

The key aims of the MEMP are:

- to determine whether or not, and to what extent, abstraction from Murrumbidgee River is affecting the maintenance of healthy aquatic ecosystems within the river or impacting Burra Creek, in terms of biological communities;
- to determine whether or not, and to what extent, abstraction of water at Angle Crossing is impacting riverine habitat through changes in sediment movement;
- to determine whether or not, and to what extent, abstraction of water at Angle Crossing is impacting riverine habitat through changes in flow;
- to establish baseline and operational information on water quality and stream flow, macroinvertebrate communities, fish, riverine vegetation and geomorphology, relating to aquatic systems impacted by the water abstraction and discharge (M2G), in accordance with the Ecological Monitoring Sub Plan (ACTEW, 2010) of the OEMP (ACTEW, 2012);
- to monitor water quality within Burra Creek, to establish normal annual and seasonal variation so that any changes resulting from the operations of abstraction and release are identified.

These potential impacts have been assessed by the relevant Government authorities through submission of Environmental Impact Statements (EIS) or similar assessments. One of the components of the EIS is to undertake an ecological monitoring programme, on which this programme is based.

This monitoring programme is designed to be adaptive. Through the reporting of data and results, liaison with the client and technical advisory groups, it may be decided that certain monitoring methodologies need to be changed or adapted to enhance the outcomes of the program. However, with these procedures in place, GHD will be able to provide ACTEW Water with appropriate information to further develop knowledge and understanding of environmental flows and ecosystem thresholds. The information derived from this programme will also support ACTEW Waters' adaptive management approach to water abstraction and environmental flow provision in the ACT. Frequent review of the MEMP will ensure that the monitoring has the capacity to adapt to changing environmental, social and economic conditions with regard to ACTEW Water's operational requirements.

1.6 Scope of work

Parts 1-2: Angle Crossing & Burra Creek

The current ecological health of the sites monitored as part of the MEMP was estimated using AUSRIVAS protocols for macroinvertebrate community data, combined with a suite of commonly used biological metrics and descriptors of community composition. The scope of this report is to convey the results from the spring 2013 sampling. Specifically, as outlined in the MEMP proposal to ACTEW Corporation (GHD, 2012) this work includes:

- Sampling conducted in spring 2013;
- Macroinvertebrate communities collected from riffle and edge habitats using AUSRIVAS protocols;
- Macroinvertebrate samples counted and identified to the taxonomic level of genus;
- Riffle and edge samples assessed through the appropriate AUSRIVAS model;
- Periphyton samples collected at each site;
- *In-situ* water quality measurements collected and samples analysed for nutrients in the Australian Laboratory Services (ALS) Canberra NATA accredited laboratory.

1.7 Rationale for using biological indicators

Macroinvertebrates and periphyton are two of the most commonly used biological indicators in river health assessment. Macroinvertebrates are commonly used to characterise ecosystem health because they represent a continuous record of preceding environmental, chemical and physical conditions at a given site. Macroinvertebrates are also very useful indicators in determining specific stressors on freshwater ecosystems because many taxa have known tolerances to heavy metal contamination, sedimentation, and other physical or chemical changes Chessman (2003). Macroinvertebrate community composition, and two indices of community condition: the AUSRIVAS index and the proportions of three common taxa (the Ephemeroptera, Plecoptera, and Trichoptera, or EPT index), were used as part of this study to assess river health.

Periphyton is the matted floral and microbial community that resides on the river bed. The composition of these communities is dominated by algae, but the term periphyton also includes fungal and bacterial matter (Biggs and Kilroy, 2000). Periphyton is important to maintaining healthy freshwater ecosystems as it absorbs nutrients from the water, adds oxygen to the ecosystem via photosynthesis, and provides a food for higher order animals. Periphyton communities respond rapidly to changes in water quality, light penetration of the water column and other disturbances, such as floods or low flow, and this makes them valuable indicators of river health.

Changes in total periphyton biomass and/or the live component of the periphyton (as determined by chlorophyll *a*) can vary with changes in flow volume, so these variables are often used as indicators of river condition in relation to monitoring the effects of flow regulation, environmental flow releases or water abstraction impacts.

Water abstractions from Angle Crossing will not affect the timing or magnitude of higher flows, but could affect conditions during the seasonal low flow period, such as increasing the nutrient availability through increased residence time, reducing scouring impacts on benthic organisms and reducing surface flows over riffle habitats and thus decreasing habitat quality and availability. As changes in flow volume are expected with the proposed changes in the Murrumbidgee River water abstraction regime, periphyton biomass and chlorophyll *a* are included as biological indices.

2. Materials and methods

2.1 Study sites

Prior to sampling, comprehensive site assessments were carried out, including assessments of safety, suitability and access permission from landowners. There are no suitable reference sites in the proximity for the MEMP, so a Before – After / Control – Impact (BACI) design (Downes *et al.*, 2002) was adopted based on sites upstream of the abstraction point serving as 'Control' sites and sites downstream of the abstraction / construction point serving as 'Impacted' sites.

Sites were chosen based on several criteria, which included:

- Safe access and approval from land owners;
- Sites have representative habitats (i.e. riffle / pool sequences). If both habitats were not present then sites with riffle zones took priority as they are the most likely to be affected by abstractions;
- Sites which have historical ecological data sets (e.g. Keen, 2001) took precedence over new sites –allowing for comparisons through time to help assess natural variability through the system. This is especially important in this programme, because there is less emphasis on the reference condition, and more on comparisons between and among sites of similar characteristics in the ACT and surrounds over time.

Potential sites were identified initially from topographic maps, they were visited prior to sampling and their suitability was subsequently considered. The MEMP consists of 12 sites which meet these criteria. Details of these sites are given in Table 2-1 and are shown in Figure 2-1.

Macroinvertebrate community composition, periphyton assemblages and water quality were monitored from sites on the Murrumbidgee River, Burra Creek and the Queanbeyan River with the aim of building a knowledge base on the ecological condition based upon the AUSRIVAS river health framework and following the ANZECC guidelines for ecological monitoring (ANZECC & ARMCANZ, 2000).

Aquatic macroinvertebrates were sampled from two habitats (riffle and pool edges) and organisms identified to genus level (where practical) to characterise each site. Periphyton was sampled in the riffle habitat at each site and analysed for chlorophyll-a and Ash Free Dry Mass (AFDM) to provide estimates of the algal (autotrophic) biomass and total organic mass respectively based on the methods of Biggs and Kilroy (2000).

Table 2-1. Sampling site locations and details

Component of the MEMP	Site Code	Location	Alt. (m)	Landuse	Latitude	Longitude
PART 1 - Angle Crossing	MUR15	Near Colinton - Bumbalong Road	658	Grazing / Recreation	**-35.866300**	**149.135017**
	MUR16	The Willows - Near Michelago	646	Grazing / Recreation	**-35.688033**	**149.136867**
	MUR18	U/S Angle Crossing	608	Grazing	**-35.587542**	**149.109902**
	MUR19	D/S Angle Crossing	608	Grazing / Recreation	**-35.583027**	**149.109486**
	MUR23	Point Hut Crossing	561	Recreation / Residential	**-35.451317**	**149.074400**
	MUR28	U/S Cotter River confluence	468	Grazing	**-35.324382**	**148.950381**
PART 2- Burra Creek	BUR1a	Upper Burra Creek	815	Native	**-35.598461**	**149.228868**
	BUR1c	Upstream Williamsdale Road	762	Grazing / residential	**-35.556511**	**149.221238**
	BUR2a	Downstream Williamsdale Road	760	Grazing	**-35.554345**	**149.224477**
	BUR2b	Downstream Burra Road Bridge	751	Woodland / Grazing	**-35.541985**	**149.230407**
	BUR2c	Approximately 1km u/s London Bridge	730	Recreational / Grazing	**-35.517894**	**149.261452**
	QBYN1	Flynn's Crossing	685	Recreational / Native	**-35.524317**	**149.303300**

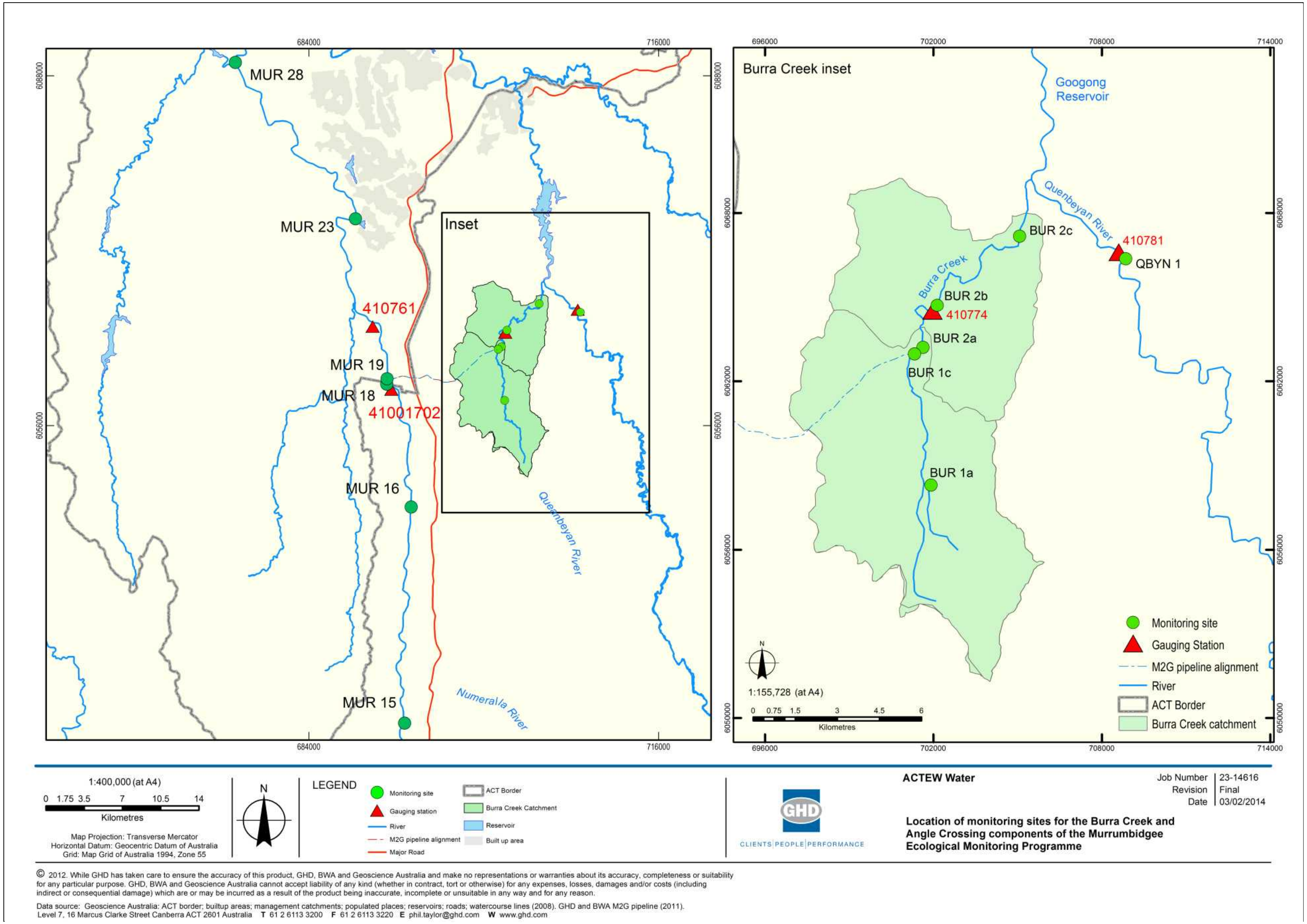

Figure 2-1. Map of site locations on the Murrumbidgee River, Burra Creek and the Queanbeyan River for the MEMP

2.2 Hydrology and rainfall

River flows and rainfall for the sampling period were recorded at ALS operated gauging stations located: upstream of Angle Crossing (41000270); at Lobb's Hole (downstream of Angle Crossing: 410761); Burra Creek (upstream of BUR 2b: 410774) and the Queanbeyan River (upstream of Googong Reservoir: 410781). A list of parameters measured at each station is given in Table 2-2. Stations were calibrated according to ALS protocols and data were downloaded and verified before quality coding and storage in the ALS database. Water level data were manually verified by comparing the logger value to the physical staff gauge value and adjusted if required. Rain gauges were also calibrated and adjusted as required. Records were stored using the HYDSTRA© database management system.

Table 2-2. River flow monitoring locations and parameters

Site Code	Location/Notes	Parameters*	Latitude∞	Longitude	Component of the MEMP
41001702	Murrumbidgee River, U/S of Angle Crossing	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	-35.5914	149.1204	Angle Crossing
410761	Murrumbidgee River @ Lobb's Hole (D/S of Angle Crossing)	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	-35.5398	149.1001	Angle Crossing
410774	Burra Creek D/S road bridge	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	-35.5425	149.2279	Burra Creek
410781	Queanbeyan River U/S of Googong Reservoir	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	-35.5222	149.3005	Burra Creek

** WL = Water Level; Q = Rated Discharge; EC = Electrical Conductivity; DO = Dissolved Oxygen; Temp = Temperature; Turb = Turbidity; Rainfall = Rainfall (mm) D/S = downstream; U/S = upstream.*

∞ Negative value indicates south of equator.

2.3 Water quality

Baseline physico-chemical parameters including temperature, pH, electrical conductivity, turbidity and dissolved oxygen were recorded using a YSI multiprobe unit at sites indicated in Table 2-1. The multiprobe was calibrated following QA procedures and the manufactures requirements prior to sampling. Additionally, grab samples were taken from each site in accordance with the AUSRIVAS protocols (Coysh *et al*., 2000) for multiprobe verification and nutrient analysis. All samples were placed on ice, returned to the ALS Canberra laboratory, and analysed for nitrogen oxides (total NOx), total nitrogen and phosphorus in accordance with the protocols outlined in APHA (2005), with NATA certified results. Collectively, this information on the water quality parameters was used to assist in the interpretation of biological data and provide a basis on which to gauge ecosystem changes potentially linked to flow reductions at these key sites following water abstractions.

2.4 Macroinvertebrate sampling and processing

At each site, macroinvertebrates were sampled in the riffle and edge habitats where available. Both habitats were sampled to provide a more comprehensive assessment of each site (Coysh *et al*., 2000) and potentially allow the programme to isolate flow-related impacts from other disturbances. The reasoning behind this is that each habitat is likely to be affected in different ways by changes in flow conditions. Riffle zones, for example, are likely to be one of the first habitats affected by low flows and water abstractions as water abstraction will result in an immediate reduction in flow velocities and inundation level over riffle zones downstream of the abstraction point. Impacts on edge habitat macroinvertebrate assemblages might be less immediate as it may take some time for the reduced flow conditions to cause loss of macrophyte beds and access to trailing bank vegetation habitat. Therefore, monitoring both habitats will allow the assessment of the short-term and longer-term impacts associated with water abstraction.

Riffle and edge habitats were sampled for macroinvertebrates using the ACT AUSRIVAS (Australian River Assessment System) protocols outlined in Coysh, *et al*. (2000). The sampling nets and all other associated equipment were washed thoroughly between habitats, sites and sampling events to remove any macroinvertebrates retained on them.

Two replicate samples were collected from each of the two habitats (edge and riffle - where available) at most sites in spring. Sampling of the riffle habitat involved using a framed net with 250 µm mesh size. Sampling began at the downstream end of each riffle, with the net held perpendicular to the substrate and the opening facing upstream. The stream bed directly upstream of the net opening was agitated by vigorous kicking, allowing dislodged invertebrates to be carried into the net by the current. The process continued, working upstream over ten metres of riffle habitat.

The edge habitat sample was collected by sweeping the collection n*et al*ong the edge of the creek line at the sampling site, with the operator working systematically over a ten metre section covering all microhabitats such as overhanging vegetation, submerged snags, macrophyte beds, overhanging banks and areas with trailing vegetation.

The bulk samples were placed in separate containers, preserved with 70% ethanol, and clearly labelled inside and out with project information, site code, date, habitat, and sampler details.

Processing of the aquatic macroinvertebrate bulk samples followed the ACT AUSRIVAS protocols. In the laboratory, each preserved macroinvertebrate sample was placed in a sub-sampler, comprising of 100 (10 X 10) cells (Marchant, 1989). The sub-sampler was then agitated to evenly distribute the sample, and the contents of randomly selected cells were removed and examined under a dissecting microscope until a minimum of 200 animals were counted. All animals within the selected cells were identified.

In order to provide additional replication within the experimental design, laboratory processing of each sample was repeated 3 times to total up to 6 samples per habitat per site (2 field replicates x 3 laboratory processed replicates). Macroinvertebrates were identified to genus level (where possible) using taxonomic keys outlined in Hawking (2000) and later publications. Specimens that could not be identified to the specified taxonomic level (i.e. immature or damaged taxa) were removed from the data set prior to analysis.

2.5 Periphyton

Estimates of algal biomass were made using complementary data from both chlorophyll-a (which measures autotrophic biomass) and ash free dry mass (AFDM, which estimates the total organic matter in periphyton samples and includes the biomass of bacteria, fungi, small fauna and detritus in samples) measurements. All periphyton (i.e. adnate and loose forms of periphyton, as well as organic/inorganic detritus in the periphyton matrix) samples were collected using the in situ syringe method similar to Loeb (1981), and as described in Biggs and Kilroy (2000). A one metre wide transect was established across riffles at each site. Along each transect, twelve samples were collected at regular intervals, using a sampling device consisting of two 60 ml syringes and a scrubbing surface of stiff nylon bristles, covering an area of ~637 mm^2.

The samples were divided randomly into two groups of six samples to be analysed for Ash Free Dry Mass (AFDM) and chlorophyll-a. Samples for Ash Free Dry Mass and chlorophyll-a analysis were filtered onto glass filters and frozen. Sample processing followed the methods outlined in APHA (2005). Qualitative assessments of the estimated substrate coverage by periphyton and filamentous green algae were also conducted at each site in accordance with the AUSRIVAS habitat assessment protocols (Nichols *et al*., 2000) to compliment the quantitative samples.

2.6 Macroinvertebrate quality control

A number of Quality Control procedures were undertaken during the identification phase of this program including:

- Organisms that were heavily damaged were not selected during sorting. To overcome losses associated with damage to intact organisms during vial transfer; attempts were made to obtain significantly more than 200 organisms;
- Identification was performed by qualified and experienced aquatic biologists with more than 100 hours of identification experience;
- When required, taxonomic experts confirmed identification. Reference collections were also used when possible;
- ACT AUSRIVAS QA/QC protocols were followed;
- An additional 10% of samples will be re-identified by another senior taxonomist and these QA/QC results are found in Appendix C;
- Very small, immature, damaged animals or pupae that could not be positively identified were not included in the dataset.

All procedures were performed by AUSRIVAS accredited staff.

2.7 Licences and permits

All sampling was carried out with current scientific research permits under section 37 of the Fisheries Management Act 1994 (permit number P01/0081(C)).

All GHD aquatic ecology field staff hold current AUSRIVAS accreditation.

3. Data analysis

Data were analysed using both univariate and multivariate techniques. Analyses were performed in PRIMER V6 (Clarke and Gorley, 2006) and R version 3.0.1 (R Development Core Team, 2013). Descriptive statistics performed on rainfall, hydrology and continuous water quality parameters were organised in the time series data management software - HYDSTRA©.

3.1 Water quality

Water quality parameters were examined for compliance with ANZECC water guidelines for healthy ecosystems in upland streams (ANZECC and ARMCANZ, 2000). This report presents results based on spring 2013 sampling. Summary statistics were determined for the parameters collected at the gauging stations and time series plots were created to assist with the interpretation.

3.2 Macroinvertebrate communities

3.2.1 Univariate analysis

The univariate techniques performed on the macroinvertebrate data include:

- Taxa Richness and EPT taxa index (richness and relative abundance)
- SIGNAL-2 Biotic Index, and:
- ACT AUSRIVAS O/E scores and bandings.

3.2.1.1 Taxarichness

The number of taxa (taxa richness) was counted for each site and other descriptive metrics such as the relative abundances of pollution-sensitive taxa (Ephemeroptera, Plecoptera and Trichoptera - EPT) and, pollution-tolerant taxa, (i.e. Oligochaeta, Chironomids and other Diptera) were examined at family and genus levels. Taxa richness was monitored as a means of assessing macroinvertebrate diversity. In assessing the taxonomic richness of a site, it is important to keep in mind that high taxa richness scores may, though does not always, indicate better ecological condition at a given location. In certain instances high taxa richness may indicate a response to the provision of new habitat or food resources that might not naturally occur as a result of anthropogenic activities.

3.2.1.2 SIGNAL-2

Stream Invertebrate Grade Number – Average Level (SIGNAL) is a biotic index based on pollution sensitivity values (grade numbers) assigned to aquatic macroinvertebrate families that have been derived from published and unpublished information on their tolerance to pollutants, such as sewage and nitrification (Chessman, 2003). Each family in a sample is assigned a grade between 1 (most tolerant) and 10 (most sensitive).to these assigned bandwidths to aid the interpretation of each site assessment. The SIGNAL index is then calculated as the average grade number for all families present in the sample. The resulting index score can then be interpreted by comparison with reference and/or control sites. These grades have been improved and standard errors applied under the SIGNAL-2 model approach developed by Chessman (2003). These changes were introduced to improve the reliability of the SIGNAL index. The variation in the above univariate indices between location ('upstream' versus 'downstream' site groups) and also individual sites was assessed using analysis of variance (ANOVA) methods.

3.2.1.3 AUSRIVAS

In addition to assessing the composition and calculating biometrics from the macroinvertebrate data, riffle and edge samples, river health assessments based on the ACT AUSRIVAS spring riffle and edge models were conducted. AUSRIVAS is a prediction system that uses macroinvertebrate communities to assess the biological health of rivers and streams. Specifically, the model uses site-specific information to predict the macroinvertebrate fauna expected (E) to be present in the absence of environmental stressors. The expected fauna from sites with similar sets of predictor variables (physical and chemical characteristics which cannot be influenced due to human activities, e.g. altitude) are then compared to the observed fauna (O) and the ratio derived is used to indicate the extent of any impact (O/E). The ratio derived from this analysis is compiled into bandwidths (i.e. X, A-D; Table 3-1) which are used to gauge the overall health of particular site (Coysh *et al*., 2000). Data are presented using the AUSRIVAS O/E 50 ratio (Observed/Expected score for taxa with a >50% probability of occurrence) and the previously mentioned rating bands (Table 3-1).

The site assessments are based on the results from both the riffle and edge samples. The overall site assessment was based on the furthest band from reference in a particular habitat at a particular site. For example, a site that had an A assessment in the edge and a B Band in the riffle would be given an overall site assessment of B (Coysh *et al*., 2000). In cases where the bands deviate significant between habitat (e.g. D – A) then an overall site-level assessment was avoided due to the unreliability of the results.

The use of the O/E 50 scores is standard in AUSRIVAS. However it should be noted that this restricts the inclusion of rare taxa and influences the sensitivity of the model. Taxa that are not predicted to occur more than 50% of the time are not included in the O/E scores produced by the model. This could potentially limit the inclusion of rare and sensitive taxa and might also reduce the ability of the model to detect any changes in macroinvertebrate community composition over time (Cao, *et al*., 2001). However, it should be noted that the presence or absence of rare taxa does vary naturally over time and in some circumstances the inclusion of these taxa in the model might indicate false changes in the site classification because the presence or absence of these taxa might be a function of sampling effort or the effects of a recent hydrological disturbance rather than truly reflecting ecological change.

Table 3-1. AUSRIVAS band widths and interpretations for the ACT spring edge and riffle models

BAND	RIFFLE O/E Band width	EDGE O/E band width	Explanation
X	> 1.14	> 1.13	More diverse than expected. Potential enrichment or naturally biologically rich.
A	0.86 – 1.14	0.87 – 1.13	Similar to reference. Water quality and / or habitat in good condition.
B	0.57 – 0.85	0.61 – 0.86	Significantly impaired. Water quality and/ or habitat potentially impacted resulting in loss of taxa.
C	0.28 – 0.56	0.35 – 0.60	Severely impaired. Water quality and/or habitat compromised significantly, resulting in a loss of biodiversity.
D	< 0.28	< 0.35	Extremely impaired. Highly degraded. Water and /or habitat quality is very low and very few of the expected taxa remain.

3.2.1.4 Univariate analysis techniques

Linear mixed effects ANOVA models were conducted separately for the riffle and edge samples to test for location differences in the univariate metrics: SIGNAL-2 scores and AUSRIVAS O/E 50 ratios. The factor, “site” (nested within location) was considered a random effect representing the river condition upstream and downstream of the proposed abstraction point; while location (upstream and downstream) was considered a fixed, constant effect. Data transformations were not necessary, because the model assumptions were met on all accounts. Models were made using lme4 (Bates *et al*., 2013) a statistical package applied in the R environment (R Development Core Team, 2013). For all analyses, the level of significance (alpha) was set to 5%.

3.2.2 Multivariate analysis

The initial step in this process was to calculate a similarity matrix for all pairs of samples based on the Bray-Curtis similarity coefficient (Clarke and Warwick, 2001). For the macroinvertebrate data collected during this survey, the final number of dimensions was reduced to two.

Non-metric multidimensional scaling (NMDS) ordination was performed to reduce dimensionality of the macroinvertebrate data in order to provide a visual representation of the macroinvertebrate relationships between sites and locations. Within the NMDS plot, sites closer together indicate that the macroinvertebrate communities are more similar to one another than sites further apart in the ordination space. In other words, NMDS reduces the dimensionality of the data by describing trends in the joint occurrence of taxa. This procedure was performed on the macroinvertebrate community data following the initial cluster-analysis.

Stress values for each NMDS plot were examined before results were interpreted. The stress level is a measure of the distortion produced by compressing multidimensional data into a reduced set of dimensions and will increase as the number of dimensions is reduced and can be considered a measure of “goodness of fit” to the original data matrix (Kruskal, 1964). Stress values near zero suggest that NMDS patterns are very representative of the multidimensional data, while stress values greater than 0.2 indicate a poor representation and, therefore, the need to interpret NMDS plots with these sorts of stress values with caution (Clarke and Warwick, 2001).

An Analysis Of Similarities test (ANOSIM) was performed on the macroinvertebrate similarity matrix to test whether macroinvertebrate communities were statistically different between upstream and downstream locations. Sites were nested within location for the analysis (Parts 1-3 only). The Similarity percentages (SIMPER) routine was carried out on the datasets only if the initial ANOSIM test was significant (i.e. $P<0.05$), to examine which taxa were responsible for, and explained the most variation among statistically significant groupings (Clarke and Warwick, 2001). This process was also used to determine which taxa characterised particular groups of sites.

3.3 Periphyton

To test whether estimated biomass (AFDM) and live content (chlorophyll-a) were different between sites upstream and downstream of Angle Crossing, a mixed effects, analysis of variance model was fitted to the Log-transformed AFDM and Chlorophyll-a data. The factor “site”, was nested within location (upstream or downstream of the abstraction point). Consequently, site and location were treated as random and fixed effects, respectively in the ANOVA model. Log-transformations were necessary to meet the assumptions of equal variances in the response variable residuals.

Post-hoc tests performed on the periphyton data collected for the Burra Creek component were carried out using the p-values function available in the R package “LMERConvenienceFunctions” (Trembley and Ransijn, 2013).

4. Angle Crossing

4.1 Summary of sampling and river condition

Angle Crossing monitoring sites were sampled on the 28th & 29th of November 2013. During this time the weather conditions were mainly fine with some cloud present on the 29th. Canberra maximum air temperatures recorded during these two days were 31.6°C and 21.8°C respectively (BOM, 2013). Flow conditions at the time of sampling were relatively stable, although the hydrograph was still in recession following a high flow event in mid-November.

Site photographs are shown in Plate 4-1 and full site summaries are shown in Appendix D. General observations from this sampling run indicated an abundance of *Myriophyllum sp.* in the riffle habitat at MUR 15 and 23 compared to the other sampling sites. MUR 23 also had notably more sand in the reach compared to the previous sampling run, while the benthic substrate at MUR 18 was notably more diverse than spring 2012. An unidentified turtle species was recorded at MUR 15.

MUR 15 – looking upstream from the riffle habitat (350 ML/d)

MUR 16 – Looking upstream from the riffle habitat (350 ML/d)

MUR 18 – Looking downstream from the riffle habitat (350 ML/d)

MUR 19 – From the riffle habitat looking upstream across the crossing (440 ML/d)

MUR 23 – Looking downstream and across to the edge habitat (440 ML/d)

MUR 28 – Looking upstream (440 ML/d)

Plate 4-1. Photographs of the Angle Crossing sites during spring 2013 sampling

Note: Flow values from the relevant gauging sites (41001702: sites 15,16 and 18) and (410761: sites 19, 23 and 28)

4.2 Hydrology and rainfall

Flow and rainfall summaries for the upstream Angle Crossing and Lobb's Hole gauging stations are provided in Table 4-1. Total rainfall for the spring period ranged from 210.4mm at Lobb's Hole to 234.8mm at the upstream Angle Crossing rain gauge; which was approximately 20% more than for the same period in 2012. September 2013 was the wettest it has been for 5 years (Figure 4-1) while conversely, October was the driest it has been over the past 5 years (only 12.8 mm fell for that month in 2013).

The hydrology of the Murrumbidgee River for spring 2013 was characterised by two main flow events (Figure 4-2). The first event occurred during mid-September from a rainfall event on the 16th and 17th, which peaked at just over 20,000 ML/d at the Lobb's Hole gauging station (410761) (1:2 yr ARI; Log Pearson III Annual Series analysis). The second event occurred in mid-November and peaked at 3700 ML/d (instantaneous maximum) and delayed spring sampling by ten days. The average flow for spring 2013 (at 410761) was 1,226 ML/d compared to 1,125 ML/d for the same period in 2012 (Figure 4-3). Murrumbidgee River flows during sampling were lower for this sampling run (range: 420-443 ML/d) compared to spring 2013 (range: 639-831 ML/d).

The recession curve from the September event continued through October with some short isolated showers creating some small peaks during this time. The period of lowest flow for the spring occurred during early November when just over 200 ML/d was recorded at both the Lobb's Hole and upstream Angle Crossing gauging stations (41001702). There were no scheduled maintenance flows relating to the Murrumbidgee to Googong project during this period.

On the day of sampling, the Murrumbidgee River flow volume was approximately 60% lower compared to the sampling period in spring 2012 (Plate 4-2).

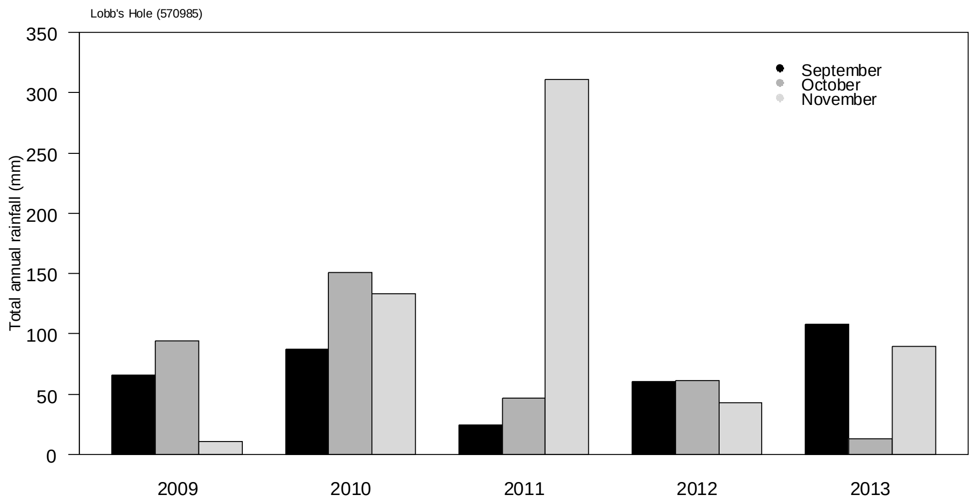

Figure 4-1. Annual comparisons of spring rainfall (mm) recorded at Lobb's Hole (570985)

Table 4-1. Spring rainfall and flow summaries upstream and downstream of Angle Crossing

	Upstream Angle Crossing (41001702)		Lobb's Hole (410761)	
	Rainfall Total (mm)	Mean Flow (ML/d)	Rainfall Total (mm)	Mean Flow (ML/d)
September	121.0	2,100	108.2	2,300
October	15.8	550	12.8	620
November	98.0	620	89.4	720
Spring (mean)	234.8 (78.3)	1,100	210.4 (70.1)	1,200

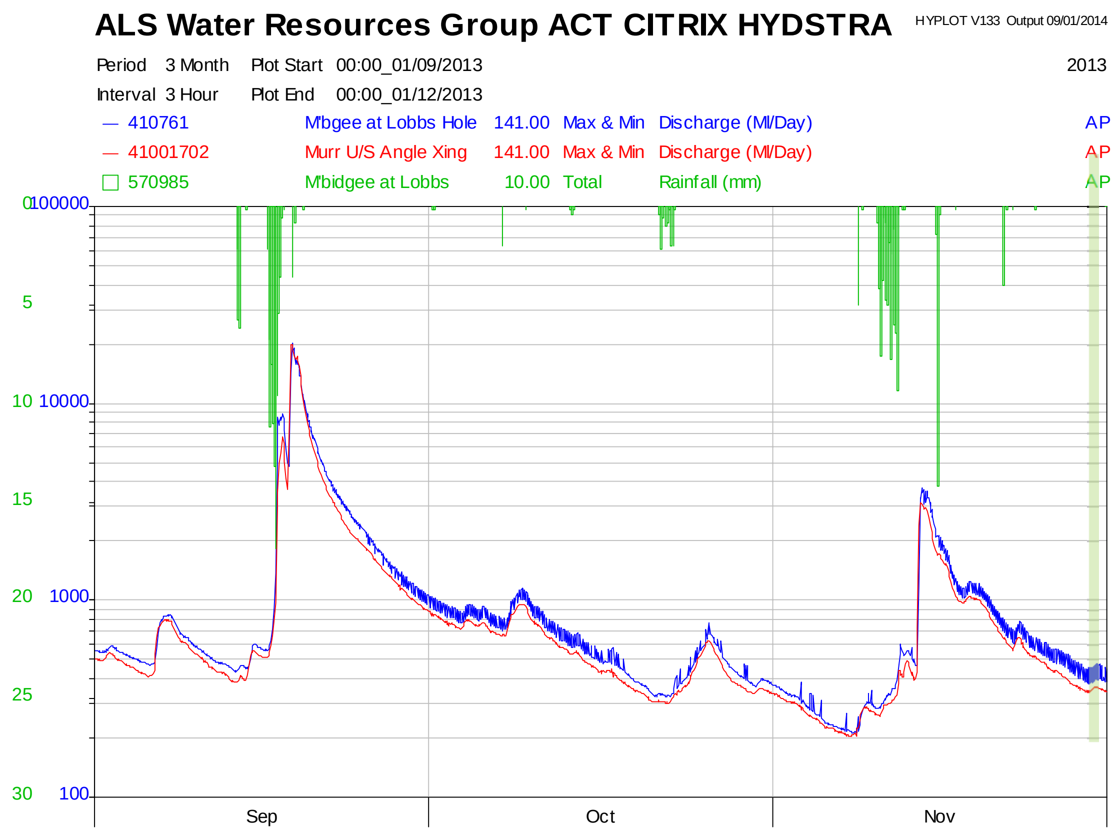

Figure 4-2. Spring hydrograph of the Murrumbidgee River upstream of Angle Crossing (41001702) and downstream of Angle Crossing at Lobb's Hole (410761)

Note: Green shaded area indicates sampling period

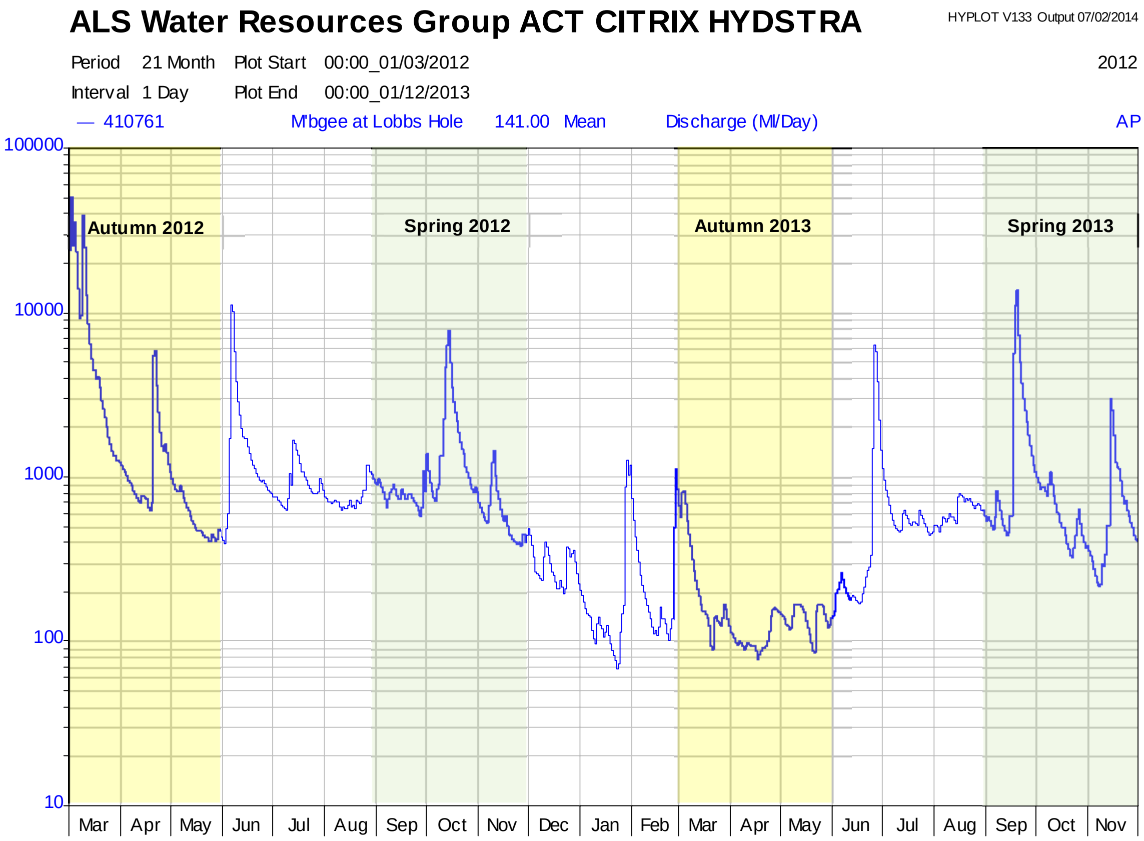

Figure 4-3. Lobb's Hole hydrograph highlighting the past four sampling periods between March 2012 and November 2013

2012: 1200 ML/d (14/11/2012)

2013: 510 ML/d (28/11/2013)

Plate 4-2. Comparative photographs of the Murrumbidgee River looking upstream towards the Cotter River confluence in spring 2012 (top) and in spring 2013

Note: Flow values recorded at Mt. MacDonald (410738)

4.3 Water quality

4.3.1 Grab samples and *in-situ* parameters

Grab samples and *in-situ* water quality results are presented in Table 4-2. The spring 2013 results are comparable to the results presented in the spring 2012 report (GHD, 2012). The main difference between the two sampling periods is in the dissolved oxygen readings. For example, 66% of the readings were below the ANZECC guideline values in spring 2012, compared to 100% compliance with ANZECC guidelines in this sampling run. Three sites were recorded as exceeding the recommended range for pH (MUR 18, 19 & 28), which were also recorded as exceeding the recommended range during spring 2012.

Surface water temperatures ranged from 19.6°C to 23.4°C (MUR 15 & 23 respectively). All sites were within the ANZECC & ARMCANZ (2000) recommended ranges for both electrical conductivity (EC) and turbidity, which is consistent with the spring 2012 results.

Total nitrogen (TN) and total phosphorus (TP) exceeded the ANZECC & ARMCANZ (2000) guidelines at all sampling sites (Table 4-2), which is again consistent with spring 2012, except that MUR 23 in the 2012 run was below the upper limit for total nitrogen. All sites were within the guidelines for NO_x.

4.3.2 Continuous water quality monitoring

The continuous water quality data collected from Lobb's Hole and upstream of Angle Crossing are presented in Figure 4-4 & Figure 4-5 respectively. Summary statistics of these parameters indicate that instances of water quality being outside the ANZECC & ARMCANZ (2000) guidelines ranges were minimal, with the largest exceedances associated with elevated turbidity during September and November, as a result of high flow events that occurred during those months (Table 4-3). Daily means for EC and DO were found to be within guideline recommended ranges for the entire season, while daily means for pH showed some guidelines exceedances from month to month (Table 4-3). Monthly and seasonal values are shown in Table 4-4.

Outside of the recorded guideline exceedances, water quality parameters responded as expected to the periods of high flow with reductions in EC and increases in turbidity. The remainder of the period, the parameters showed consistency across the season with temperature increasing towards summer, while temperature, pH and DO all displayed natural diurnal trends.

There was some fouling and potential damage sustained to the water quality sensor at the upstream Angle Crossing site (41001702) following a high flow event on the 26th of June 2013; resulting in unreliable pH and dissolved oxygen readings leading up to, and including September 2013. Due to ongoing access issues to this site (GHD, $2012_{a,b}$), maintenance and calibration was unable to be carried out until late September. For this reason, the compliance values and summary statistics provided in Table 4-3 and Table 4-4 are presented with and without the September data for the spring period.

Table 4-2. *In-situ* water quality results from Angle Crossing during spring 2013

ANZECC and ARMCANZ (2000) guidelines are in red bold parentheses, yellow cells indicate values outside of the guidelines and orange values are on the cusp of the guideline values.

	Site	Date	Time	Temp. (°C)	EC (µs/cm) (30-350)	Turbidity (NTU) (2-25)	TSS mg/L	pH (6.5-8)	D.O.(% Sat.) (90-110)	D.O. (mg/L)	Alkalinity (mg/L)	NO_x (mg/L) (0.015)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L) (0.02)	TN (mg/L) (0.25)
Upstream	MUR 15	29/11/2013	10:00	19.6	96.5	10.4	9	7.89	100.4	8.42	19	0.005	0.003	< 0.002	0.008	0.038	0.38
	MUR 16	29/11/2013	12:15	20.3	105.6	9.49	19	7.93	103.5	8.54	41	0.004	0.003	< 0.002	0.007	0.040	0.4
	MUR 18	29/11/2013	14:45	21.1	109.1	7.65	8	8.21	104.4	8.49	42	0.002	< 0.002	< 0.002	0.007	0.028	0.36
Downstream	MUR 19	28/11/2013	14:00	21.9	108.3	6.52	10	8.06	103.4	8.25	42	< 0.002	< 0.002	< 0.002	0.004	0.030	0.37
	MUR 23	28/11/2013	11:40	23.4	112.5	9.71	11	7.94	101.5	7.88	44	< 0.002	< 0.002	< 0.002	0.005	0.032	0.38
	MUR 28	28/11/2013	9:30	21	116.8	7.3	12	8.04	102.5	8.42	45	< 0.002	< 0.002	< 0.002	0.007	0.030	0.41

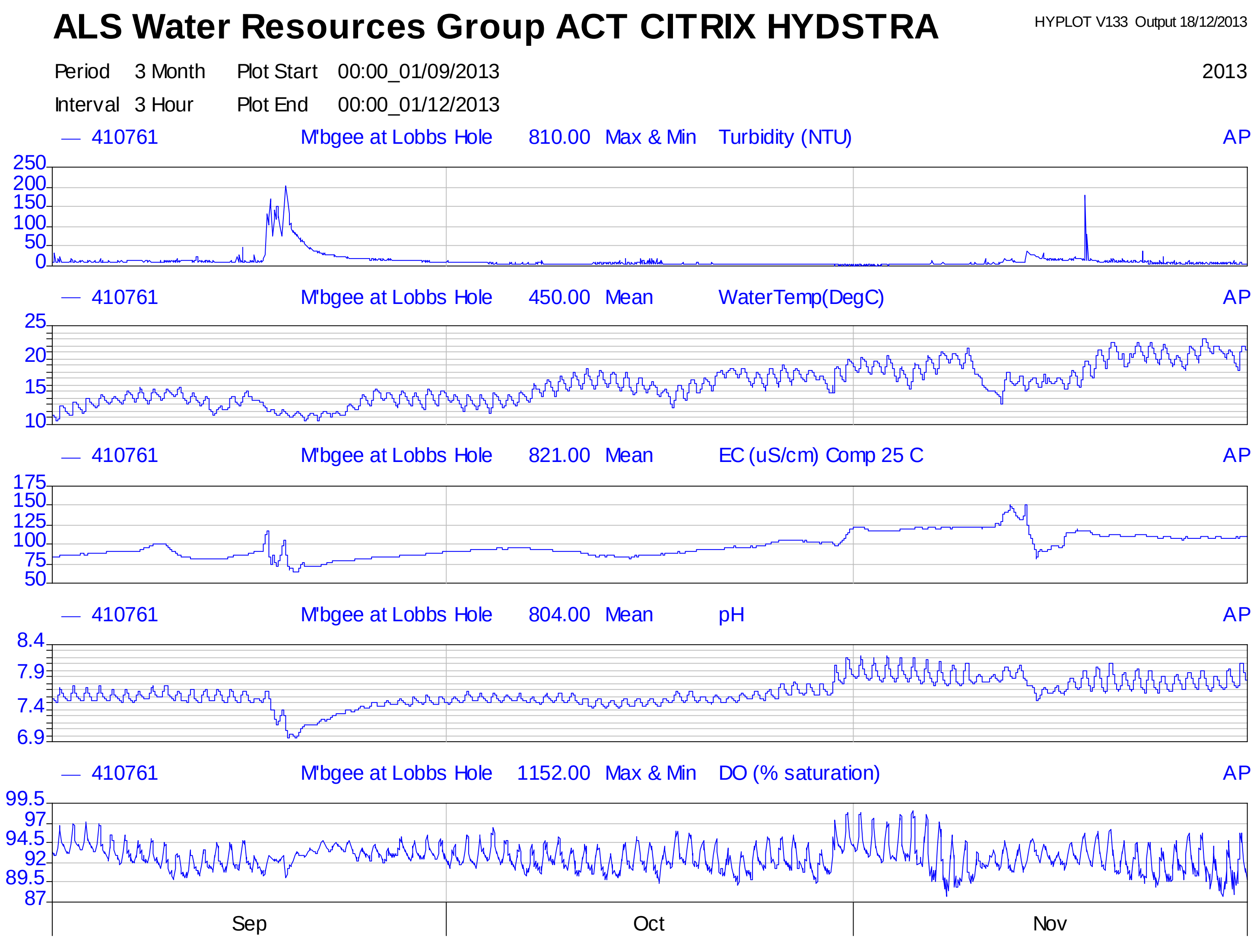

Figure 4-4. Continuous water quality records from Lobb's Hole (410761) for spring 2013

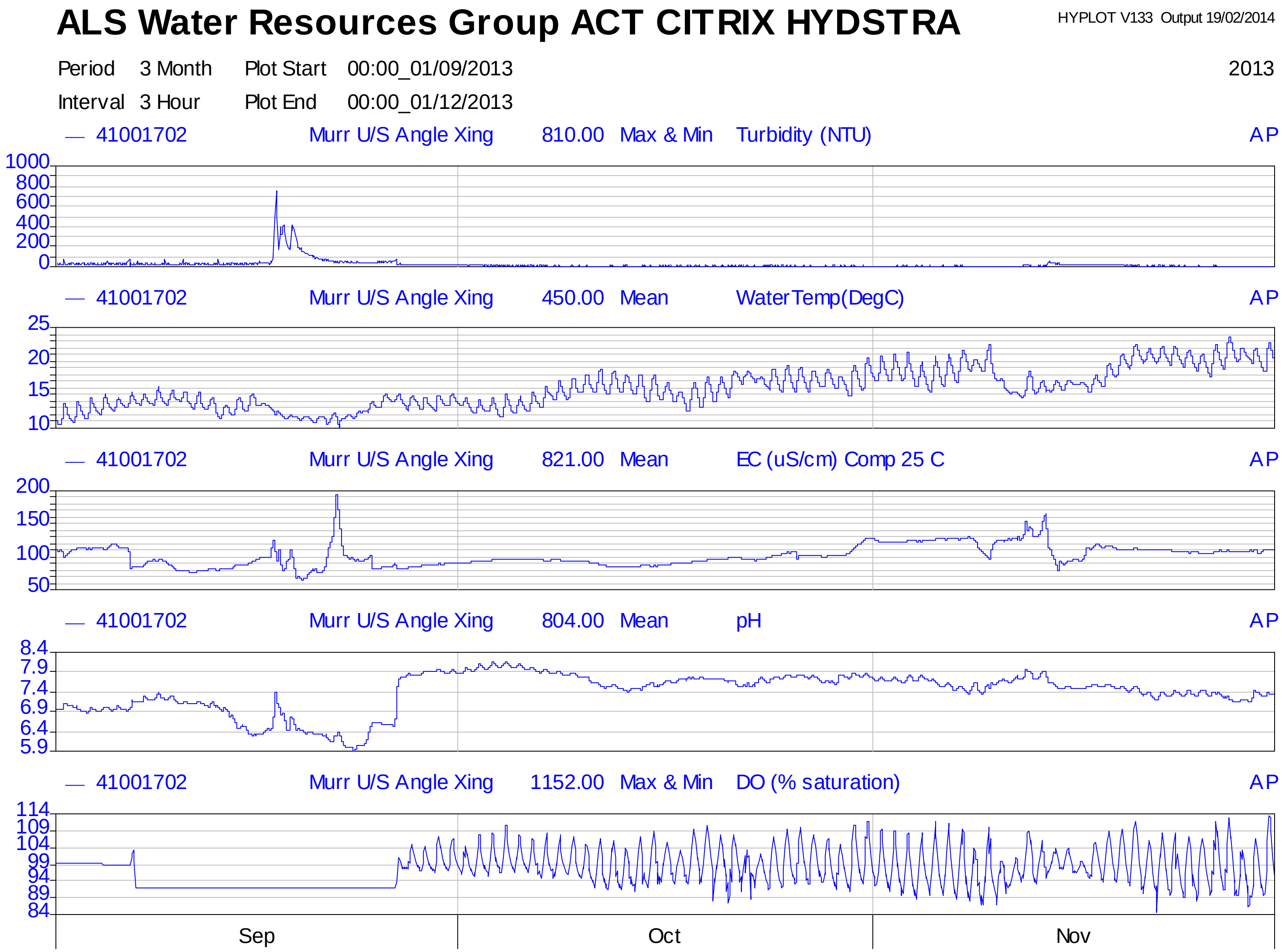

Figure 4-5. Continuous water quality records from upstream Angle Crossing (41001702) for spring 2013

Table 4-3. Compliance (%) to ANZECC & ARMCANZ (2000) guideline values from the continuous gauging stations upstream (41001702) and downstream (410761) of Angle Crossing

Analyte	Electrical Conductivity (µS/cm) (30-350)		pH (6.5-8)		Turbidity (NTU) (2-25)		Dissolved Oxygen (% Saturation) (90-110)	
Location	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**
September	100	100	73	100	43	97	100	100
October	100	100	87	100	100	100	100	100
November	100	100	100	93	97	80	100	100
Spring (including September)	**100**	**100**	**87**	**98**	**80**	**92**	**100**	**100**
Spring (excluding September)	**100**	**-**	**94**	**-**	**99**	**-**	**100**	**-**

Note: Compliance values are expressed as the percentage of days throughout the spring period (based on daily means) that values met the guidelines.

Table 4-4. Monthly water quality statistics from upstream (41001702) and downstream (410761) of Angle Crossing

Analyte	Temperature (°C)		Electrical Conductivity (µS/cm) (30-350)		pH (6.5-8)		Turbidity (NTU) (2-25)		Dissolved Oxygen (% Saturation) (90-110)	
Location	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**
September	13.13	13.03	93.6	84.29	6.92	7.53	51.58	24.73	91.7 – 101.0	90.9 - 94.6
October	15.74	15.96	95.83	91.70	7.76	7.63	6.58	6.65	96.6 – 102.6	90.9 – 95.4
November	18.74	18.87	115.51	115.00	7.51	7.86	8.74	8.73	95.0 – 101.1	90.8 – 95.1
Spring (including September)	**15.9**	**16.0**	**101.6**	**97.0**	**7.4**	**7.7**	**22.3**	**13.4**	**91.7 - 102.6**	**90.8-95.4**
Spring (excluding September)	**17.24**	**-**	**105.7**	**-**	**7.6**	**-**	**7.66**	**-**	**95.0 – 102.6**	**-**

Note: All values means, except dissolved oxygen (% saturation) which is expressed as mean monthly minimums and maximums. Maximum values for turbidity are the maximum daily mean value- in parentheses. ANZECC & ARMCANZ (2000) guidelines are inside red parentheses.

4.4 Periphyton

Periphyton analysis indicates no link in the spatial patterns exhibited in the chlorophyll *a* or AFDM data to the Murrumbidgee to Googong project.

Periphyton biomass, assessed as chlorophyll- a was similar throughout all sites (Figure 4-6) with the highest values occurring at MUR 23 and MUR 28 and the lowest occurring at the upstream site MUR 16. Mean chlorophyll-a ranged from 7229 (MUR 16) to 18905 µg/m^2 (MUR 23). By location, the upstream sites had lower values (mean = 12107 ± 3453 µg/m^2) compared to downstream (mean = 16500 ± 4624 µg/m^2); however this difference was not statistically significant ($F_{1,4}$ = 1.13; *P*=0.35; Table 4-5). The majority of the model variation occurred at the site level, which accounted for 82.5% while sites within location accounted for the remaining 18%.

Mean ash free dry mass (AFDM) ranged from 1987 at MUR 19 to 5299 mg/m^2 at MUR 15 (Figure 4-7). The highest values occurred upstream of Angle Crossing at MUR 15 and MUR 16 (Figure 4-7) and were on average higher at the upstream sites (mean = 4121 ± 1462 mg/m^2) compared to downstream sites (mean = 3385 ± 910 mg/m^2) but there was no significant location effect for AFDM ($F_{1,4}$ = 0.69; *P*=0.69; Table 4-5). Model variance was explained mostly by site to site variation (83%), while site variation with location accounted for 16% and a nominal 1% was accounted to the location effect. This is believed to be an artefact of the two outliers at MUR 15 and MUR 16 (Figure 4-7).

Table 4-5. Nested analysis of variance results for chlorophyll-a and AFDM concentrations Angle Crossing

Response	Source	DF	F	P-value
Chlorophyll-*a*	Location	1	1.13	0.35
	Site [Location]	4	2.18	0.10
	Total	35		
AFDM	Location	1	0.19	0.69
	Site [Location]	4	2.40	0.07
	Total	35		

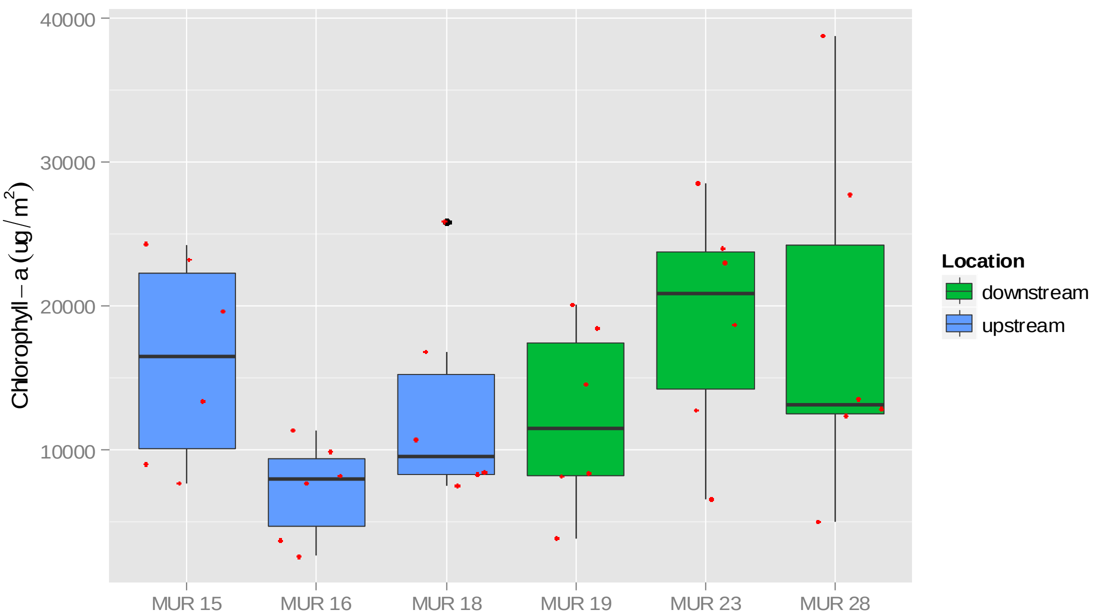

Figure 4-6. Chlorophyll-a concentrations at Angle Crossing sites

Note: Red points represent the raw values for each site.

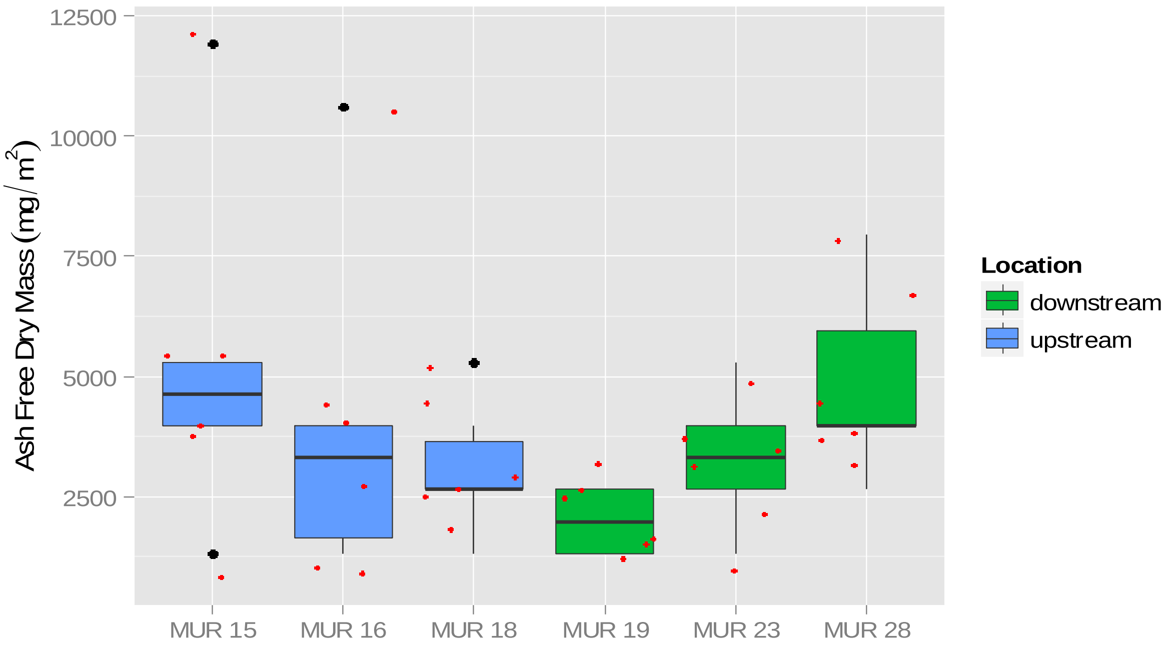

Figure 4-7. Ash free dry mass at Angle Crossing sites

Note: Red points represent the raw values for each site.

4.5 Macroinvertebrates

4.5.1 Community assemblages

Riffle habitat

The ANOSIM results indicate that the macroinvertebrate community assemblages did not differ significantly between location (R=0.11; *P*=0.39). The low global R value indicates very little separation between upstream and downstream sites, which can be seen in Figure 4-8. The group patterns in the ordination plot show 50% similarity amongst all sites, while at the 65% similarity level, the sites form three groups; the largest of which, contains both upstream and downstream sites, while the two smaller clusters are formed by MUR 28 and MUR 15.

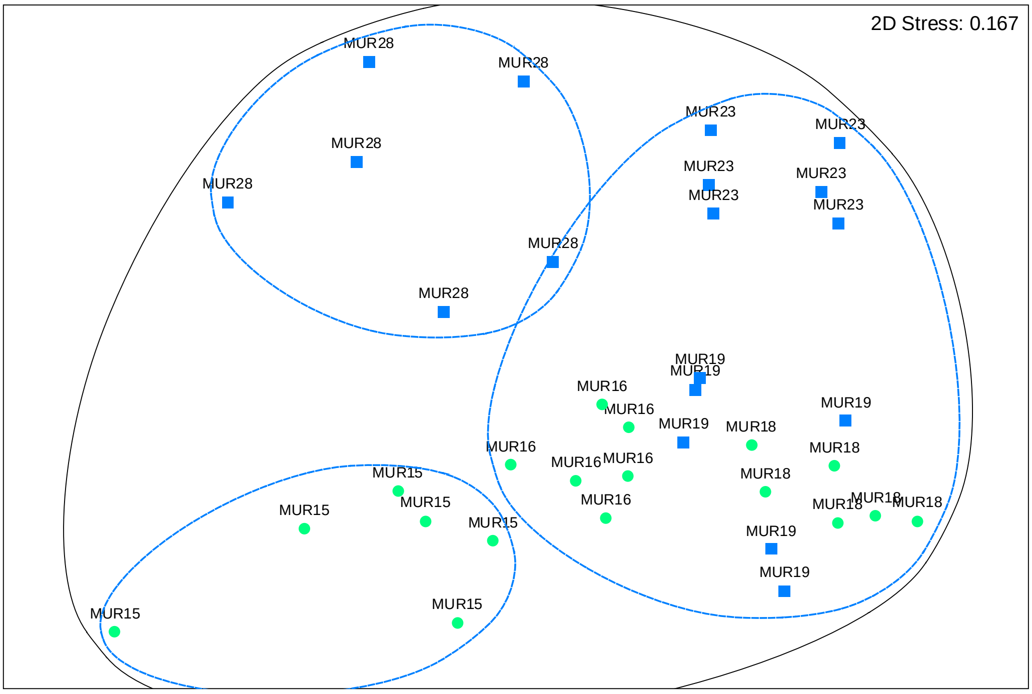

Figure 4-8 Non metric multidimensional scaling of macroinvertebrate (genus level) data collected from the riffle habitat

The blue ellipses represent 65% similarity and the black ellipse indicates 50% similarity groups. Green circles are upstream sites and blue squares are downstream sites.

All sites were dominated by high abundances of moderately tolerant dipteran taxa including: Simuliidae (SIGNAL =5) and Orthocladiinae (SIGNAL-2 = 4). Other dominant groups in the riffle communities included the mayfly families: Baetidae (SIGNAL-2 = 5) and Leptophlebiidae (SIGNAL-2 = 8) and the caddisfly family – Hydropsychidae (SIGNAL-2 = 6).

Taxonomic richness at the family level tended to be higher downstream of Angle Crossing (range: 18-23) compared to upstream (range: 15-21) (Figure 4-9). MUR 23 continues to contain the richest riffle habitat macroinvertebrate assemblage (23 families: 30 genera) while MUR 18 had the lowest number of families (15) and MUR 15 had the lowest number of genera. Compared to the spring 2012 sampling run, there were declines in the number of families at MUR 15 and MUR 18 and declines in the number genera at all of the upstream sites (MUR 15,16 and 18) and at MUR 28. EPT richness was relatively consistent among sampling sites (Figure 4-12) ranging from 6 families at MUR 18 to 10 families at MUR 23 and between 10 and 13 genera. The changes in the EPT richness show that since spring 2012 there were declines in the number of families at all sites except MUR 23 (a gain of 1 family) and MUR 28 (no change) (

Figure 4-11). EPT at the genus level (EPTg) was reduced compared to spring 2012, with reductions ranging from 1 taxon (at MUR 15 and MUR 18) to 5 taxa at MUR 16 and MUR 28.

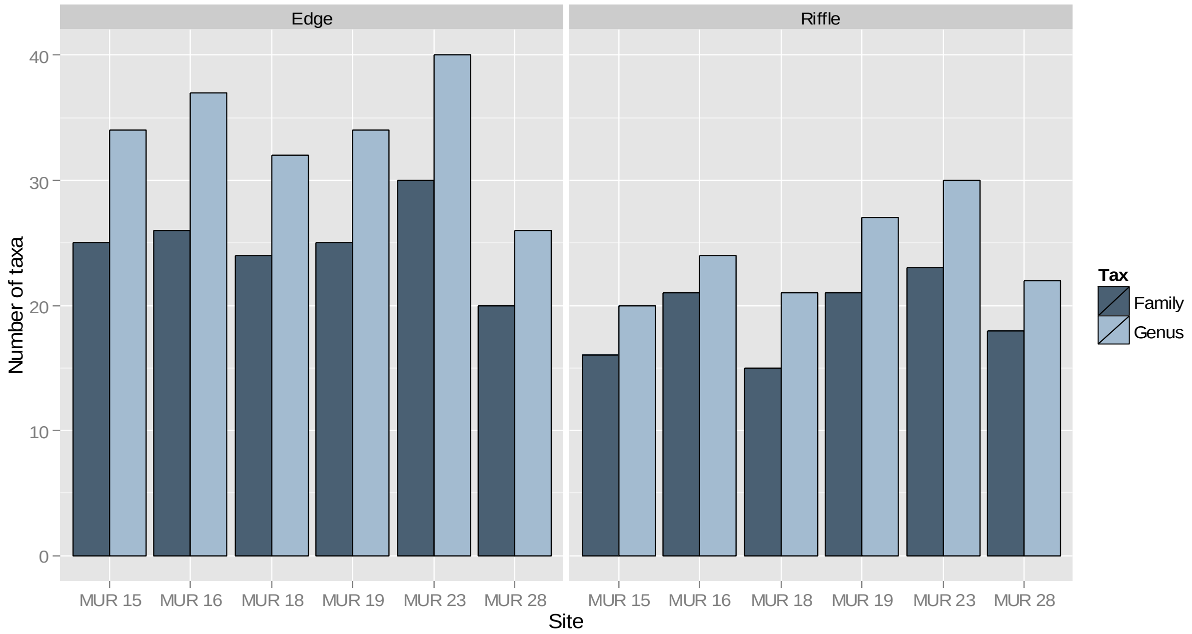

Figure 4-9. Total number of taxa at genus and family level from riffle and edge habitats

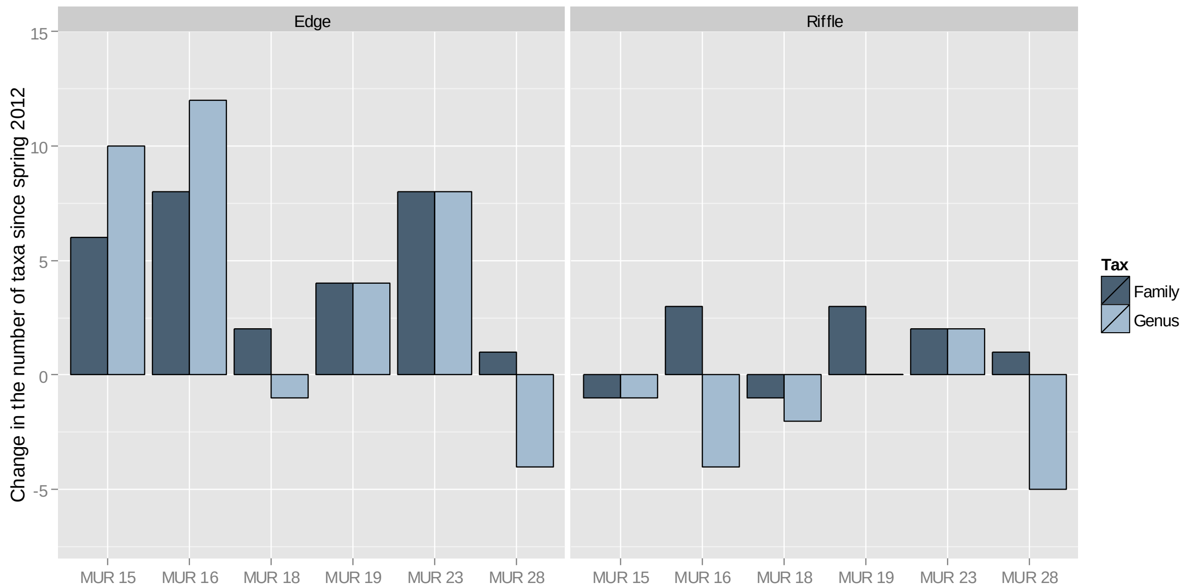

Figure 4-10 Change in the total number of taxa since spring 2012

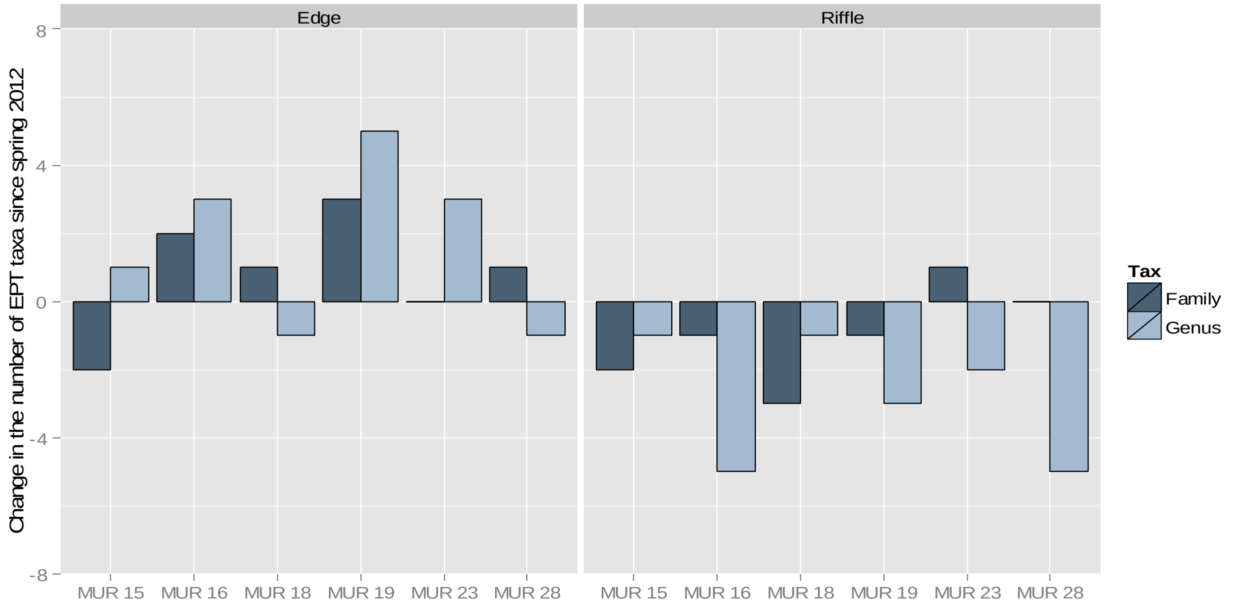

Figure 4-11. Change in the number of EPT taxa since spring 2012

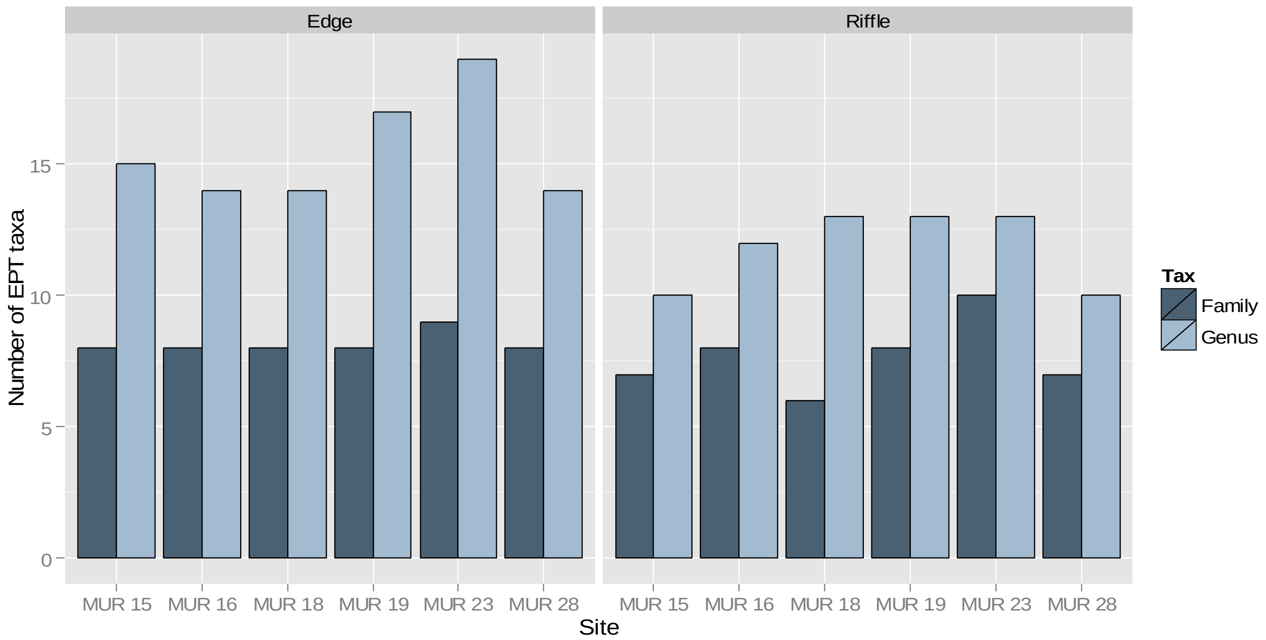

Figure 4-12. Total number of EPT taxa at genus and family level from riffle and edge habitats

Edge habitat

ANOSIM results for the edge samples show no significant location effect (Global-R = 0.26; *P*=0.19). Despite this non-significant result, the slightly higher Global-R value and the final output from the ordination analysis does suggest a certain degree of separation between upstream and downstream sites (Figure 4-13). The large within site variance at MUR 28 and the overlap of that site with MUR 18 is the likely reason that the R-value is lower than the majority of the data would suggest.

Macroinvertebrates characteristic of the edge habitat included: Corixidae (SIGNAL-2 = 2); Orthocladiinae (SIGNAL-2 = 4); Chironominae (SIGNAL-2 = 3) and Caenidae (SIGNAL-2 = 4). These taxa were ubiquitous amongst sampling locations and were present in high relative abundances.

The most diverse site was MUR 23, which had 40 genera, in 30 families, while at the least diverse site, MUR 28, there were 26 genera, in 20 families. There was very little EPT family diversity amongst sampling sites (Figure 4-12), with the same eight families being collected at five of the six sampling sites; nine families were collected at MUR 23 (Calamoceratidae (SIGNAL-2 = 7) was the additional family collected at that site). The number of genera in the EPT group ranged from 14 at MUR 16 and MUR 18 to 19 at MUR 23.

Increases in taxa richness at the family level were found at all sites and ranged from 1 at MUR 28, to 8 at MUR 16 and MUR 23. Declines in the number genera were found at MUR 18 (1) and MUR 28 (4). However, substantial increases were seen at MUR 15 (10) and MUR 16 (12) (Figure 4-10). Changes in the EPT richness since spring 2012 show no consistent pattern amongst sites although generally, there were increases in the edge habitat and losses in the riffle habitat at all sites (Figure 4-11).

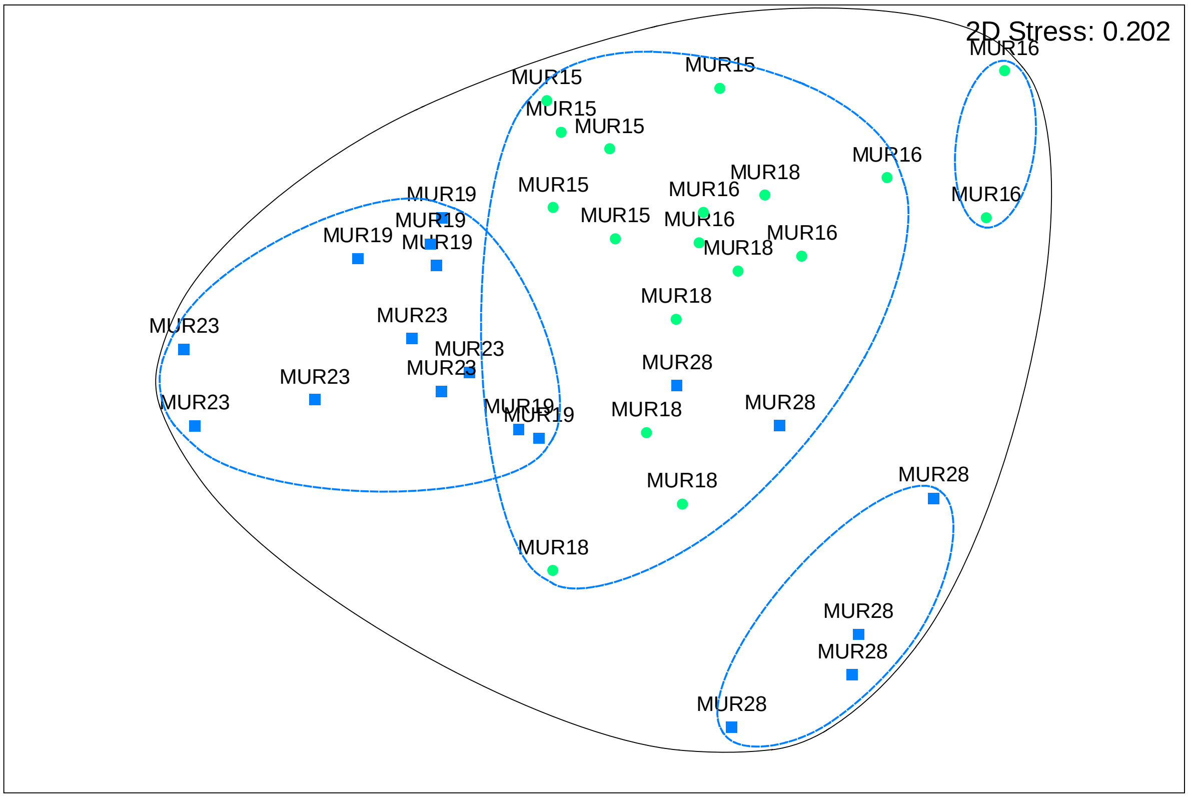

Figure 4-13. Non metric multidimensional scaling of macroinvertebrate (genus level) data collected from the edge habitat

The blue ellipses represent 65% similarity and the black ellipse indicates 50% similarity groups. Green circles are upstream sites and blue squares are downstream sites.

4.5.2 AUSRIVAS

Riffle

Overall habitat assessments for the riffle showed that four of the sites were assessed as Band B (MUR 16, 18, 19 & 28), MUR 23 was assessed as Band A; while MUR 15 and MUR 28 were given no reliable assessment (NRA) on the basis that there was more than a band-width difference between the highest and lowest score amongst the sub samples in the riffle and edge habitats respectively (i.e. BAND A-C) (Table 4-8).

Although these results were retained in the final analysis and presented in Table 4-8, it should be noted that we recommend that replicate 2 from MUR 15 (Table 4-8) be removed because it appears to be erroneous and it is probably not representative of the site overall. Of the suite of taxa predicted to occur at that site, 11 were absent from MUR 15 (replicate 2) (Appendix E). Many taxa, including: Oligiochaeta (SIGNAL-2=2), Chironominae (SIGNAL-2=3), Leptophlebiidae (SIGNAL-2=8), Caenidae (SIGNAL-2=4) and Hydropsychidae (SIGNAL-2=6) were otherwise present in reasonably high numbers in all of the other replicates. These taxa also had high probabilities of occurrence (0.65-1.00) suggesting that for a given sample, there is a reasonably high probability that they would be collected (as they were in the remaining samples). It is also noteworthy that this sample appears as an outlier in the NMDS plot (Figure 4-8) in the far left corner.

The BAND C result at MUR 28 is less distinctive than for MUR 15. Only one family (Leptophlebiidae) separated this particular sample from returning a BAND B assessment. And as with MUR 15, this particular taxon was found in all of the other samples at this site, suggesting that this could have been due to sub-sampling error or just due to chance. Whatever the reason, the main point is that in this assessment, Leptophlebiidae was represented within this habitat (MUR 28) and should be assessed accordingly (i.e. assigned a BAND B). As we believe there is neither ecological explanation for the absence of these taxa nor any reason to penalise the overall assessment because of chance misrepresentation by only two sub samples, given that the macroinvertebrate families in question occurred within all of the other samples, we again suggest that this replicate be removed from the AUSRIVAS assessment and the edge habitat at MUR 28 be assigned a BAND B (and hence the same for the overall site assessment).

The mean O/E 50 scores for the riffle habitat were found to be slightly higher at the downstream sites (0.88) when compared to the upstream sites (0.82). While comparatively in the edge habitat, mean OE/50 scores were slightly higher at upstream sites (1.02) compared to downstream sites (0.96). The ANOVA did not show a statistical difference for either the riffle habitat ($F_{1,4} = 0.31$; $P = 0.61$; Table 4-6; Figure 4-14) based on location, or the edge habitat ($F_{1,4} = 0.36$ $P = 0.58$; Table 4-7; Figure 4-14).

The mean SIGNAL-2 score was higher for the downstream sites (5.18), compared to the upstream sites (5.03) in the riffle habitat. While in the edge habitat mean SIGNAL-2 score was higher for the upstream sites (4.30) compared to the downstream sites (4.24). Similarly, the mean SIGNAL-2 scores were also not found to be significantly different for either the riffle habitat ($F_{1,4} = 0.38$; $P = 0.47$; Table 4-6; Figure 4-14) or the edge habitat ($F_{1,4} = 0.07$; $P = 0.80$; Table 4-6; Figure 4-14) based on location.

Edge

There were few missing taxa from the edge habitat for spring 2013, with the only taxa consistently missing from sites being Ceratopogonidae, which has a relatively tolerant SIGNAL-2 score of 4 (Appendix E). Comparatively, there were a total of 16 families missing from the edge model throughout the riffle habitat, with 5 families consistently absent across all sites. These taxa were Elmidae (SIGNAL-2 = 7), Psephenidae (SIGNAL-2 = 6), Hydrobiosidae (SIGNAL-2 = 8), Glossosomatidae (SIGNAL-2 = 9) and Conoesucidae (SIGNAL-2 = 7), which all have relatively sensitive SIGNAL-2 scores. The mutual absence of these taxa from all sites suggest a broader study area impact or poor reference site data, rather than impacts associated with water abstraction at Angle Crossing.

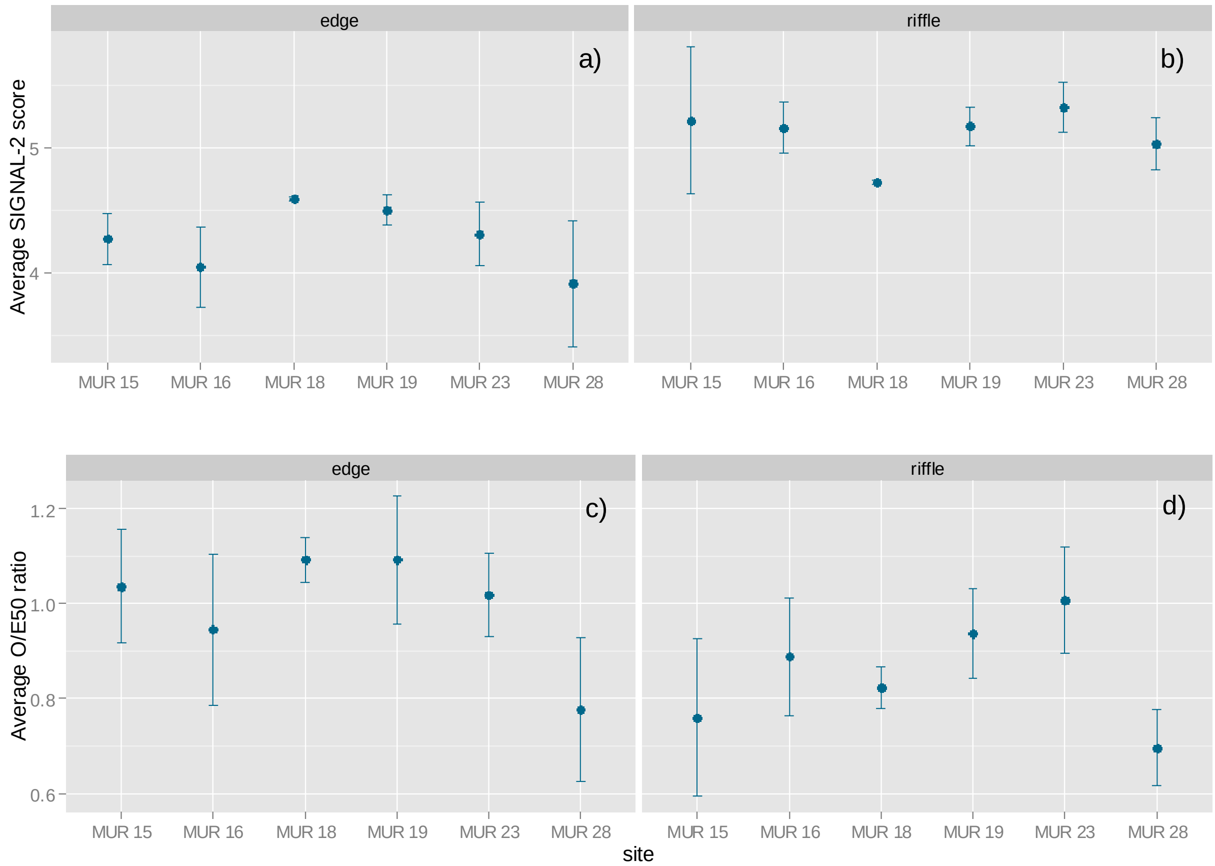

Figure 4-14. Means plots of SIGNAL-2 scores and O/E 50 ratios for edge and riffle habitats

Note: Error bars are 95% confidence intervals.

Table 4-6. Nested analysis of variance results for the O/E 50 ratios and SIGNAL-2 scores from the riffle habitat

Response	Source	DF	F	P-value
O/E 50	Location	1	0.31	0.61
	Site [Location]	4	8.35	<0.001
	Total	35		
SIGNAL-2	Location	1	3.83	0.47
	Site [Location]	4	0.64	0.01
	Total	35		

Table 4-7. Nested analysis of variance results for the O/E 50 ratios and SIGNAL-2 scores from the edge habitat

Response	Source	DF	F	P-value
O/E 50	Location	1	0.36	0.58
	Site [Location]	4	7.17	<0.001
	Total	35		
SIGNAL-2	Location	1	0.07	0.80
	Site [Location]	4	6.82	<0.001
	Total	35		

Table 4-8. AUSRIVAS and SIGNAL-2 scores for spring 2013

Site	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS band		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
MUR 15	1	4.91	4.22	0.88	1.00	A	A	**NRA**	**A**	**NRA**
MUR 15	2	6.33	4.00	0.48	0.89	C	A			
MUR 15	3	4.78	4.55	0.72	1.22	B	X			
MUR 15	4	5.11	4.44	0.72	1.00	B	A			
MUR 15	5	5.09	4.20	0.88	1.11	A	A			
MUR 15	6	5.09	4.22	0.88	1.00	A	A			
MUR 16	1	5.09	4.20	0.85	1.11	B	A	**B**	**B**	**B**
MUR 16	2	5.25	4.33	0.93	1.00	A	A			
MUR 16	3	5.50	3.86	1.08	0.78	A	B			
MUR 16	4	5.10	4.40	0.77	1.11	B	A			
MUR 16	5	5.10	3.86	0.77	0.78	B	B			
MUR 16	6	4.92	3.63	0.93	0.89	A	A			
MUR 18	1	4.73	4.56	0.85	1.00	B	A	**B**	**A**	**B**
MUR 18	2	4.70	4.60	0.77	1.11	B	A			
MUR 18	3	4.70	4.60	0.77	1.11	B	A			
MUR 18	4	4.73	4.60	0.85	1.11	B	A			
MUR 18	5	4.73	4.60	0.85	1.11	B	A			
MUR 18	6	4.73	4.60	0.85	1.11	B	A			
MUR 19	1	5.18	4.38	0.85	0.89	B	A	**B**	**A**	**B**
MUR 19	2	5.25	4.33	0.92	1.00	A	A			
MUR 19	3	5.00	4.60	0.85	1.11	B	A			
MUR 19	4	5.36	4.60	1.08	1.11	A	A			
MUR 19	5	5.00	4.55	0.92	1.22	A	X			
MUR 19	6	5.23	4.55	1.00	1.22	A	X			
MUR 23	1	5.15	4.00	1.02	0.89	A	A	**A**	**A**	**A**
MUR 23	2	5.31	4.22	1.02	1.00	A	A			
MUR 23	3	5.60	4.22	1.18	1.00	X	A			
MUR 23	4	5.09	4.60	0.86	1.11	A	A			
MUR 23	5	5.33	4.60	0.94	1.11	A	A			
MUR 23	6	5.46	4.22	1.02	1.00	A	A			
MUR 28	1	5.10	4.38	0.75	0.89	B	A	**B**	**NRA**	**NRA**
MUR 28	2	5.00	4.14	0.67	0.78	B	B			
MUR 28	3	4.89	4.00	0.67	0.89	B	A			
MUR 28	4	5.22	4.13	0.67	0.89	B	A			
MUR 28	5	5.25	3.83	0.60	0.66	B	B			
MUR 28	6	4.73	3.00	0.82	0.55	B	C			

= Anomalous result. The results presented here are the raw data; however for the reasons discussed in section 4.5.2, we suggest removing the highlighted cells and giving the riffle at MUR 15 a BAND B assessment and thus the overall site assessment will also be BAND B. Similarly, at MUR 16 remove the C BAND for the edge and give the final habitat scare a BAND B and the overall site assessment BAND B.

4.6 Discussion

4.6.1 Water quality

The water quality results presented in this report are consistent with the spring 2012 data, except for some improvements in the dissolved oxygen concentrations in this sampling run (Table 4-2). Both sampling periods had high levels of compliance with the ANZECC and ARMCANZ water quality guidelines (Table 4-3), with the exception of total nitrogen and total phosphorus. Both of these parameters regularly occur above the upper limits of the guidelines and should be considered to be within the background concentrations for these sites in the upper Murrumbidgee River. For example the range of values for TN in spring 2013 was 0.36 – 0.41 mg/L which is within the 50th and 70th percentile range of spring samples since the inception of the MEMP (GHD, 2014). Similarly, the TP results for this sampling round ranged from 0.028 – 0.04 mg/L which fall into the 30th and 60th percentile range respectively. Furthermore, there was no evidence to suggest that these exceedances values were related to M2G because there were equally high values recorded upstream and downstream of Angle Crossing and this consistent with all of the results collected to date, including periods during construction.

The continuous data also showed no evidence of a location related impact. Both gauging stations displayed what are considered to be normal responses to high flow events (Figure 4-4 and 4-5). There was some fouling and potential damage sustained at the upstream Angle Crossing gauging station, which occurred following a high flow event earlier in the year; and because of access difficulties to the gauging site, these data remained un-archived up until the time of writing this report. For this reason, the compliance values are presented with and without the September data (Table 4-3; Table 4-4) for the upstream site.

4.6.2 Periphyton

Periphyton biomass estimated by AFDM and chlorophyll *a* was not statistically different upstream of Angle Crossing compared to the downstream section. Both parameters exhibited differences in mean concentrations between locations, but due to the high variance surrounding the estimates, the differences were not statistically different. The majority of the variance explained by the ANOVA model was found between sites (AFDM = 83% and chlorophyll *a* = 82%) irrespective of location, indicating site-specific influences (for example, nutrient delivery, light regime and geomorphology) as the main drivers of these patterns as opposed to factors related to M2G.

The overall patterns in the data and the interpretation of the statistical analysis are similar with previous sampling runs. However compared to spring 2012, ash free dry mass showed a 20% decline upstream of Angle Crossing and approximately a 40% reduction downstream; while chlorophyll *a* showed an approximately 20% reduction at both locations.

These differences in mean biomass estimates are attributable to the differences in flow magnitude and timing between the two sampling occasions. Prior to sampling in spring 2012, the high flow event that disrupted sampling was less than 50% of the magnitude of the event preceding the 2013 sampling event (1760 ML/d and 3560 ML/d) and occurred within a week of sampling; whereas the event preceding the spring 2013 sampling run was larger in volume, but occurred approximately two weeks prior to sampling.

4.6.3 AUSRIVAS and macroinvertebrate community assemblages

The event preceding the spring 2013 sampling run reached an instantaneous maximum peak flow of 3,695 ML/d at the Lobbs Hole gauging station. This event represented a 1:1 year ARI flow event (Log Pearson Annual series), which is relatively small for the Murrumbidgee River in recent years (GHD, 2014). However in mid-September, a 1:2 year event went through the catchment, which peaked at 20,100 ML/d.

Since there were no M2G maintenance runs during the spring 2013 period, it appears that based on the characteristics of the faunal assemblages amongst sampling sites, that the main influence on the results was the previously mentioned high flow events. The size of the event in September is likely to have lowered the diversity and abundance of macroinvertebrates in both habitats, but because of the time between that event and the sampling run, there should have been high rates of recovery in diversity and abundances (Niemi *et. al*., 1990). However, it is impossible to determine the extent of the impact of the larger event because of the occurrence of the second event prior to sampling, which may have had an effect on recovery rates by again reducing diversity and abundances. The timing of these events may explain the lower number of overall taxa richness and EPT richness in the riffle habitat (Figure 4-10; Figure 4-11) in this sampling run compared to 2012, because while the timing was similar between this and the previous sampling run, the magnitude of peak flows, was much lower in 2012.

The ordination analysis of the macroinvertebrate assemblages (Figure 4-8; Figure 4-13) shows that all sites are approximately 50% similar for both habitats; but at the 65% similarity level, subgroups appear in the dataset. The larger of these sub groups contain sites from both upstream and downstream locations, and this is the reason for the non-significant ANOSIM results. All of the riffle sites were dominated by high abundances of Chironomidae, Simuliidae, several mayfly genera and Oligochaetes. The high amount of variation seen within sampling sites largely comes from patchy distributions and differences in the abundances of caddisfly genera (Appendix F).

The community assemblages in the edge habitat were also dominated by three or four highly abundant taxa, including: Corixidae, Simuliidae, Chironomidae and Caenidae, but there was also more variability between and within sites, which probably reflects the greater habitat diversity seen at the sites sampled in spring 2013. The macroinvertebrate communities seen in this sampling run are typical of faunas soon after floods. For example, Chironomids, Simuliids and certain Ephemeroptera (mayflies) have certain life history characteristics that facilitate rapid re-colonisation rates (Death, 2008).

For both habitats, the similar macroinvertebrate assemblages amongst sites is consistent with the idea that locations within rivers prone to flooding or recovering from floods can have remarkably similar faunas, which are usually dominated by the aforementioned suite of taxa as seen in this sampling run. Patchiness at various scales can occur after high flow events, resulting in areas of high or low diversity and / or abundances of various taxa, which is consistent with the results of this study.

There were only minor differences in the AUSRIVAS results between the spring 2012 and spring 2013 sampling occasions, which is probably also reflective of the similarities in the timing of high flow events and sampling periods between both sampling runs.

Individual habitat assessments showed that aside from MUR 15, all the assessments were the same as those obtained in spring 2012 and of the edge assessments, only MUR 16 showed a definitive change (from BAND A to BAND B) since spring 2012. The change from BAND A to BAND B at this site was due to Baetidae (SIGNAL-2 = 5) and Ceratopogonidae (SIGNAL-2 = 4) being missing from the spring 2013 results in replicate 1, indicating that the decline in AUSRIVAS should not necessarily be interpreted as a decline in health *per se*, but could be due to increased patchiness (suggested earlier as a potential response to the most recent high flow event), or to chance absences by these otherwise common macroinvertebrate families (Barmuta *et al*., 2003).

Statistical testing of the O/E 50 and SIGNAL-2 scores indicated that there were no significant differences between locations for either the riffle or edge habitats (Table 4-6 and Table 4-7), which is consistent with previous results (GHD, 2012). Taxa missing from the riffle habitats included a range of sensitive and tolerant taxa (Appendix E) and included Oligiochaeta[2] (SIGNAL-2=2), Hydrobiosidae (SIGNAL-2=8) and Glossosomatidae (SIGNAL-2=9). Many of the missing taxa did not exhibited spatial patterns, suggesting that their absence was due to broader catchment factors rather than specifically related to M2G operations at Angle Crossing.

It is also worth noting that the sensitive mayfly family: Coloburiscidae (SIGNAL-2 = 8) was observed at all sampling sites during our stream side live scans, but were not found in the sub-sampling process. This would not have impacted the final AUSRIVAS results, because at all sites, this family had a low probability of occurrence (≤ 50%). However, the absence of this family may have slightly underestimated the final SIGNAL-2 scores, which again would have had a negligible impact on the final assessment given that they were found at all sampling sites and in relatively low numbers.

4.7 Conclusions and recommendations

In the absence of M2G maintenance runs during the spring period, the results presented in this report are entirely reflective of the natural flow regime. The results presented here for water quality, periphyton and benthic macroinvertebrates are indicative of the majority of previous sampling occasions, which in essence highlights the stability of the upper Murrumbidgee Catchment over prolonged periods; and despite being subject to several large high flow events (post 2010), the ability to recover from these short term disturbances is apparent.

While high flow events have dominated recent sampling periods, there was a period in 2009, towards the end of the “millennium” drought that to some extent exposed the vulnerability of the Murrumbidgee River. During this period, there was evidence of changing water quality parameters, which is consistent with the findings of Rolls *et al.*, (2012); and a loss of several sensitive macroinvertebrate taxa. In the same review Rolls *et al.*, (2012) suggested that poor water quality due to reduced flow conditions was a key driver of ecological responses. Long term analysis (GHD, 2014) has identified this period as distinctly different in terms of macroinvertebrate communities from all other sampling years. Currently, base flows in the Murrumbidgee River are showing a downward trend on the back of a particularly dry year (BOM, 2013). If this trajectory continues, the results from subsequent sampling runs should provide some insight to potential chemical and biological tipping points in relation to low flow hydrology and any potential risks (Lake, 2011) associated with future water abstractions from Angle Crossing.

Autumn sampling should be undertaken to best examine these responses by either targeting the next round of APPLE maintenance runs for M2G should they proceed, or undertaking sampling while base flows remain low.

[2] Only missing from two samples. These two samples were the two which were assessed as BAND C and included several other taxa that were otherwise ubiquitous in the samples.

5. Burra Creek

5.1 Summary of sampling and river condition

Sampling was conducted on the 15th & 16th of October 2013 at the Burra Creek and Queanbeyan River sites. This was to coincide with a scheduled APPLE run as part of the M2G infrastructure maintenance program; however that was postponed until soon after the sampling had been completed.

Weather conditions during the two days of sampling were fine with light winds and maximum air temperatures in Canberra reaching 19.4°C and 23.3°C respectively (BOM, 2013). River levels were receding during this time following a high flow event that occurred in mid-September. A single riffle sample at BUR 1a was the only sample which was missed in spring 2013 sampling round due to the limited availability of this habitat because of the prevailing low flows.

Several of the sampling sites showed evidence of disturbance as a result of the mid-September high flow event, with some small areas of new erosion apparent along the banks, while a section of cobbled riffle had been washed downstream at site BUR 1a. The Queanbeyan River was also impacted with a cobble island in the south-eastern braid being washed out at QBYN revealing a bedrock step (Erksine, 2005) (Plate 5-1). The sampled riffle habitat was located downstream of the step, because the usual riffle habitat sampled, located in the north-western anabranch, was dry at the time of sampling. A full range of Burra Creek site photographs for the spring 2013 sampling round can be found in Plate 5-2.

Plate 5-1. Newly exposed bedrock cascade at QBYN 1

BUR1a – Looking upstream from the riffle habitat (2.8 ML/d)

BUR 1c – Looking upstream (2.8 ML/d)

BUR 2a – Looking downstream from the riffle habitat (2.8 ML/d)

BUR 2b – Looking downstream (2.7 ML/d)

BUR 2c – Looking downstream over the riffle habitat (2.7 ML/d)

QBYN 1 – Looking downstream at the riffle habitat (90 ML/d)

Plate 5-2. Photographs of the Burra Creek and Queanbeyan River sites during spring 2013 sampling

Note: Flow values from the relevant gauging sites (410774 (Burra Creek) and 410781 (Queanbeyan River))).

5.2 Hydrology and rainfall

During spring 2013, three notable high flow events occurred in the Burra Creek catchment (Figure 5-1; Figure 5-3). The first occurred on the 17th of September and peaked at 3,000 ML/d in Burra Creek (> 11,000 ML/d in the Queanbeyan River) and two smaller events occurred in mid- November within four days of one another. These smaller events peaked at just over 50 and 70 ML/d on the 12th & 16th of November respectively in Burra Creek. Similar patterns were seen in the Queanbeyan River, although there was a third hydrograph peak there, which did not register in Burra Creek.

Rainfall during spring at the Burra Creek rainfall gauge was highly variable as shown in Figure 5-2. September rainfall was the highest since the inception of the MEMP program with 132.4 mm, while October rainfall was the lowest total for the last five years with 24 mm (Table 5-1). Rainfall during November was the third highest over the previous five years with 79.6 mm (Table 5-1).

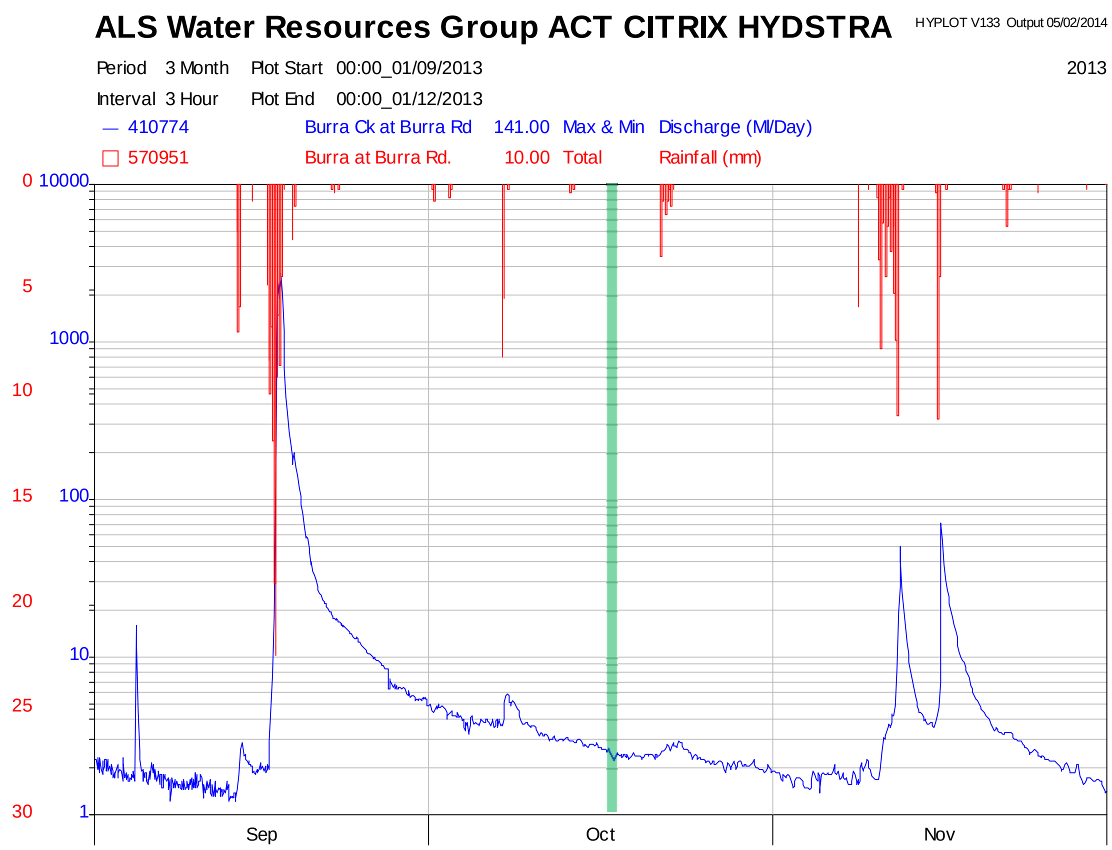

Figure 5-1. Hydrograph and rainfall from Burra Creek (410774) during spring 2013

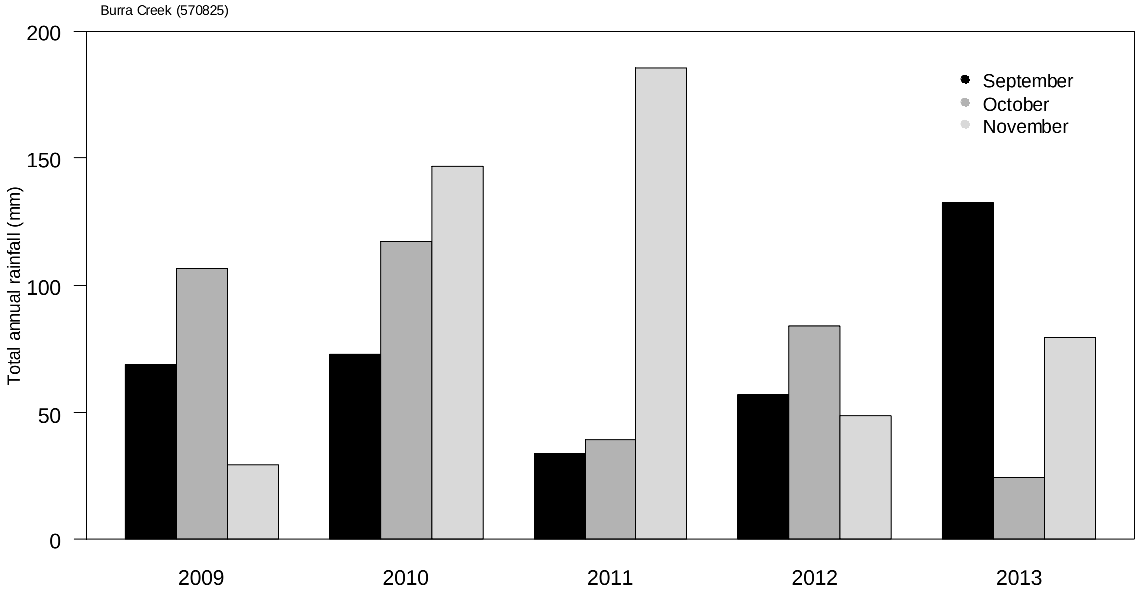

Figure 5-2. Annual comparisons of spring rainfall (mm) recorded at Burra Creek (570951)

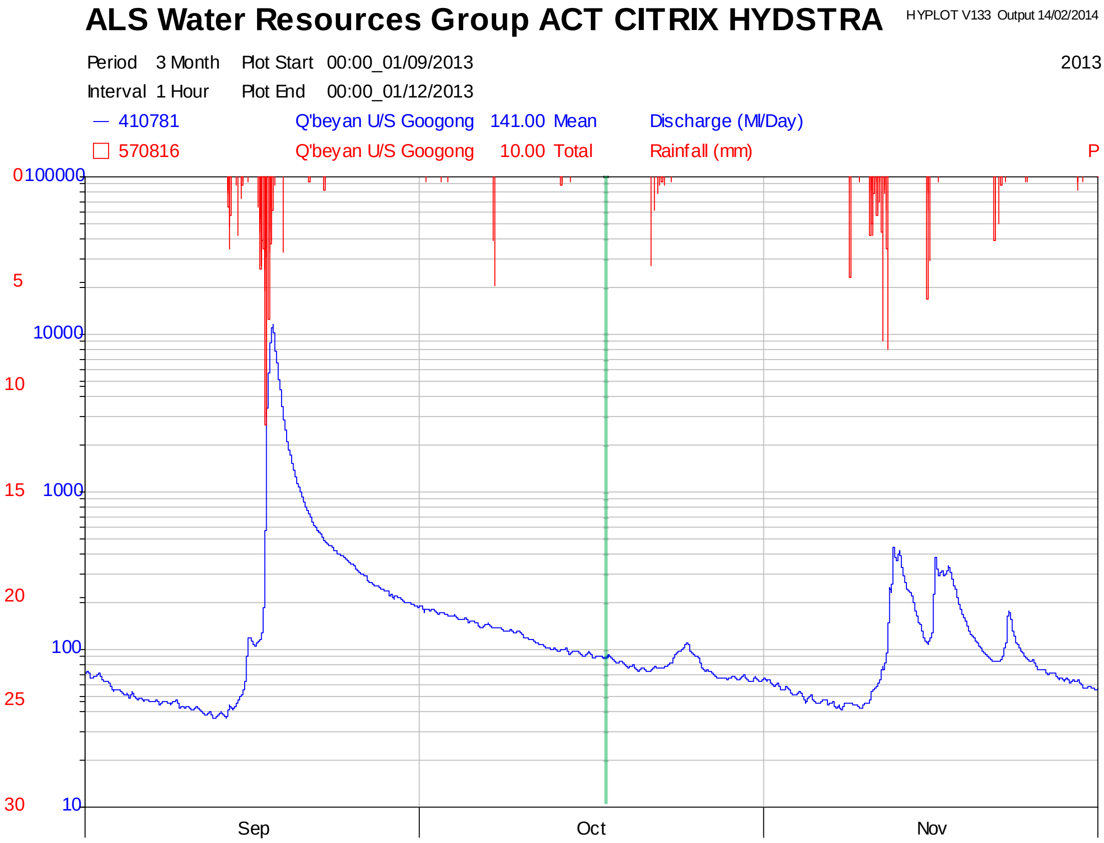

Figure 5-3. Hydrograph and rainfall from the Queanbeyan River (410781) during spring 2013

Note: the green vertical bar represents the sampling period

Table 5-1. Spring rainfall and flow summaries for Burra Creek and the Queanbeyan River for spring 2013

	Burra Creek (410774)		Queanbeyan River (410781)	
	Total Rainfall (mm)	Mean Flow (ML/d)	Total Rainfall (mm)	Mean Flow (ML/d)
September	132.4	73	138.8	590
October	24.0	3.0	17.3	110
November	79.6	4.9	86.6	110
Spring (mean)	236 (78.7)	27	242.7 (80.9)	270

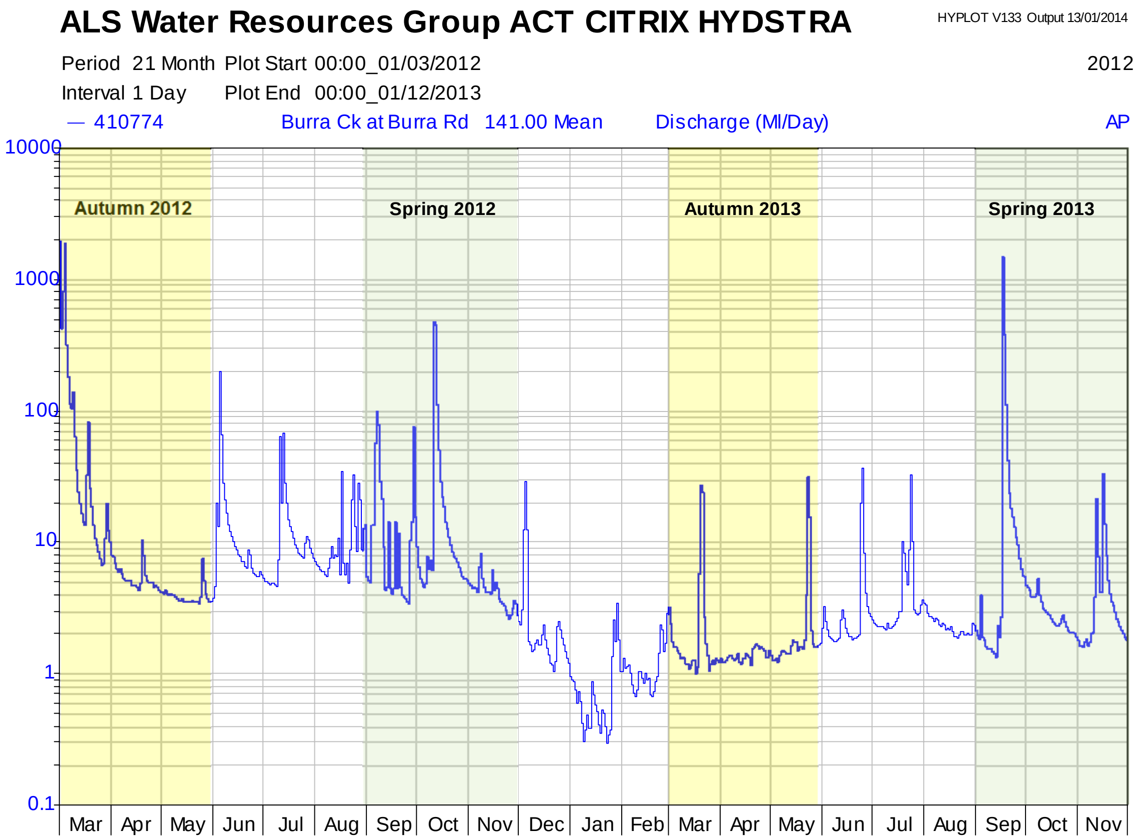

Figure 5-4. Burra Creek hydrograph highlighting the past four sampling periods between March 2012 and November 2013

5.3 Water quality

5.3.1 Grab samples and *in-situ* parameters

Grab sample and *in-situ* parameter results are shown in Table 5-2. The number of ANZECC & ARMCANZ (2000) guideline exceedances in spring 2013 was similar to spring 2012. Water temperatures ranged from a low of 8.1°C at BUR 2c to 16.7°C at QBYN 1. The electrical conductivity (EC) guideline was exceeded at all Burra Creek sites, downstream of BUR 1a. The pH readings at all Burra Creek sites have reduced from spring 2012, however only BUR 2a had fallen sufficiently to be within the recommended range The pH reading at BUR 1c was on the cusp of being within the guideline range, while BUR 2b & BUR 2c remain outside the recommended range. All of the turbidity readings were within the ANZECC & ARMCANZ (2000) recommended range.

As was recorded during spring 2012, dissolved oxygen (DO) was below the recommended range at BUR 1a. BUR 2c exceeded the recommended range for DO in spring 2013, and had increased by 15% increase compared to spring 2012 levels.

Nitrogen levels have reduced since spring 2012, particularly with respect to total nitrogen (TN). In spring 2013, only BUR 1a and BUR 2a exceeded the recommended trigger levels for TN, compared to all sites during spring 2012. In the same period, total phosphorus (TP) levels increased, with BUR 1a exceeding the recommended trigger level in spring 2012. By comparison, there were two sites on the cusp of the trigger level (BUR 1a & QBYN 1) in spring 2012, but no exceedances for TP. All parameters on the Queanbeyan River were within the ANZECC & ARMCANZ (2000) guidelines during spring 2013, compared to spring 2012 when TN was exceeding the trigger level and TP was on the cusp.

5.3.2 Continuous water quality monitoring

The continuous water quality monitoring station at the Burra Creek Weir (410774) showed all monitored parameters responded to the high flow event that occurred in September. There was a clear spike in the turbidity readings at the time of the event, with drops in both EC and pH, while the normal diurnal trend of temperature and DO were interrupted (Figure 5-5). This was repeated to a lesser extent during the two smaller flow events in November. A small spike in turbidity during early October corresponded with a very minimal increase in flow during a rainfall event. The small scale of this event, even in the case of Burra Creek, is likely to be the reason that this event did not impact any other parameters (Figure 5-5).

During spring 2013, both EC and pH were in excess of the ANZECC & ARMCANZ (2000) recommended ranges for a majority of the period, and were reduced to within the recommended ranges during the high flow events. Turbidity guideline exceedances were only present during the periods of higher flow. The diurnal trend in the DO showed a wide range through the period with daily variability between approximately 70% and 110% saturation, with daily means consistently around 90% saturation.

As was the case with the Burra Creek continuous water quality monitoring data, the Queanbeyan River station also recorded changes in the water quality parameters coinciding with the high flow events during mid-September and mid-November (Figure 5-6). ANZECC & ARMCANZ (2000) guidelines exceedances were mostly limited to periods of high flow, particularly for turbidity. pH values increased towards the end of spring, with six of the daily means exceeding the upper limit of the ANZECC & ARMCANZ (2000) recommended range during November. The natural diurnal trend of dissolved oxygen was found to be outside the recommended range for short periods of time, however all daily means were within the recommended range. EC values were within the guideline range for the entire spring period.

Table 5-2. *In-situ* water quality results from Burra Creek and Queanbeyan River during spring 2013

ANZECC and ARMCANZ (2000) guidelines are in red bold parentheses, yellow cells indicate values outside of the guidelines, orange cells indicate value is on the cusp of the guideline

	Site	Date	Time	Temp. (°C)	EC (µs/cm) (30-350)	Turbidity (NTU) (2-25)	SS mg/L	pH (6.5-8)	D.O.(% Sat.) (90-110)	D.O. (mg/L)	Alkalinity (mg/L)	NOx (mg/L) (0.015)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L) (0.02)	TN (mg/L) (0.25)
Upstream	BUR 1a	15/10/2013	9:45	10.1	97.1	22.7	14	6.9	77.8	7.95	20	0.007	0.005	0.002	0.002	0.032	0.41
	BUR 1c	15/10/2013	12:30	14.9	383	4.15	3	8.0	103	9.46	145	0.007	0.007	< 0.002	< 0.002	0.010	0.23
Downstream	BUR 2a	15/10/2013	14:20	15.1	488	4.82	6	8.1	106.5	9.70	189	0.17	0.17	< 0.002	< 0.002	0.012	0.37
	BUR 2b	16/10/2013	9:30	13	498	7.93	4	8.2	92.8	8.89	193	0.014	0.014	< 0.002	< 0.002	0.012	0.24
	BUR 2c	16/10/2013	14:45	8.1	490	2.77	4	8.4	117.2	10.10	198	0.028	0.028	< 0.002	0.003	0.009	0.18
Control	QBYN 1	16/10/2013	12:10	16.7	82.3	3.63	5	7.9	106.4	9.42	34	< 0.002	< 0.002	< 0.002	< 0.002	0.016	0.23

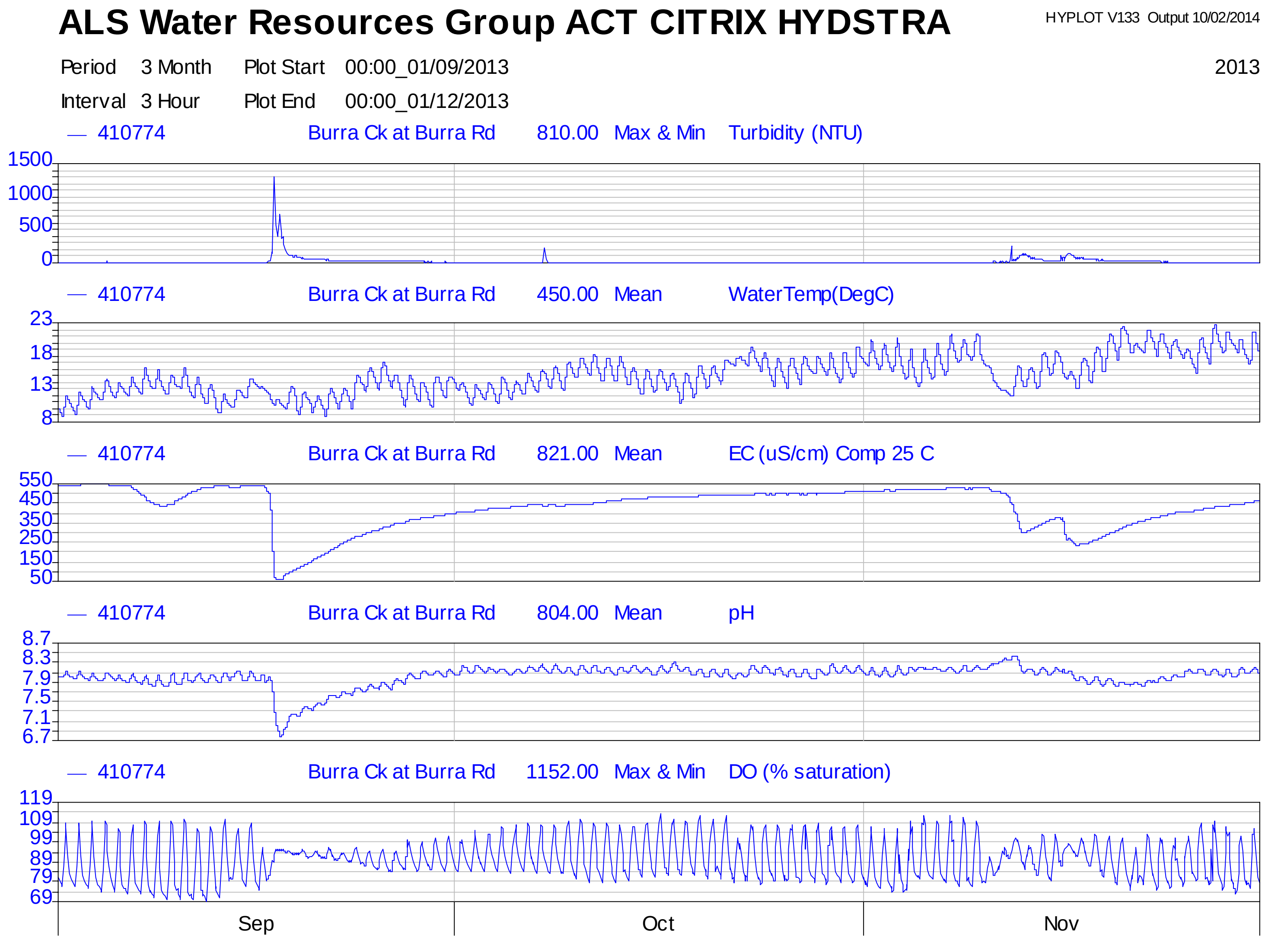

Figure 5-5. Continuous water quality records from Burra Creek (410774) for spring 2013

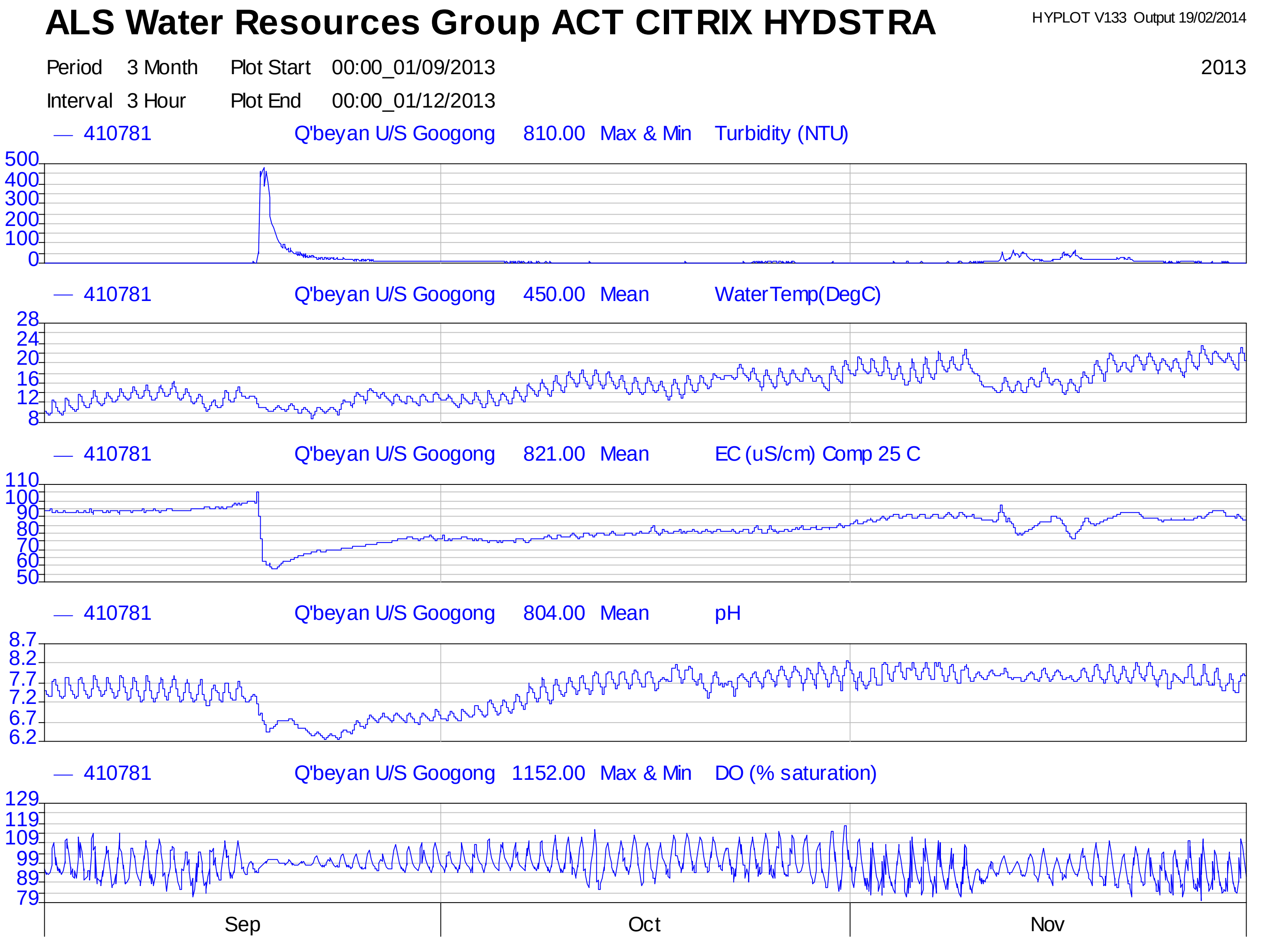

Figure 5-6. Continuous water quality records from the Queanbeyan River (410781) for spring 2013

5.4 Periphyton

On a site-by-site basis, average chlorophyll *a* concentrations ranged from 4,598 ug/m^2 (± 7,919 95% CI) at the Queanbeyan River control site and 30,252 (± 7,366 95% CI) at BUR 2a (Figure 5-7). Grouped by location, downstream sites had higher chlorophyll *a* concentrations (24,878 ± 4,631 95% CI) compared to the upstream sites in Burra Creek (10,566 ± 5,688 95% CI). All these results are suggestive of an association of location with chlorophyll *a* concentrations. These differences were found not to be statistically significant at the α=0.05 level ($F_{2,35}$ = 2.59; *P*=0.09: Table 5-3). Over half of the model variance (56%) was due to the location effect while the remaining was attributed to within site variation (28%) and among site variation nested in location (16%).

Average ash free dry mass displayed similar spatial patterns as the chlorophyll *a* at the upstream sites and the Queanbeyan Control site (Figure 5-8). However, downstream of the discharge point the mean values varied considerably less compared to the chlorophyll *a* results. Although, the maximum values at these sites were considerably higher than the upstream sites. AFDM was statistically different between locations ($F_{2,35}$ = 12.08; *P*=0.03: Table 5-3). Post-hoc analysis showed this difference was between the downstream (9,936 ± 2,440 mg/m^2 CI 95%) and control locations (1,899 ± 656 mg/m^2 CI 95%) (*P*=0.012; Table 5-4). However, there was no evidence of a location difference within Burra Creek (*P*=0.811; Table 5-4).

Table 5-3. Nested analysis of variance results for chlorophyll-a and AFDM concentrations for Burra Creek

Response	Source	DF	F	P-value
Chlorophyll-*a*	Location	2	2.59	0.09
	Site [Location]	3	4.42	0.01
	Total	35		
AFDM	Location	2	12.08	0.03
	Site [Location]	3	2.28	0.10
	Residual	35		

Table 5-4. Post hoc comparisons of AFDM between each sampling location

	Control	Upstream	Downstream
Control			
Upstream	0.065*		
Downstream	0.012*	0.811*	

**P*-values estimated from the Markov Chain Monte Carlo (MCMC) procedure with 9999 restarts

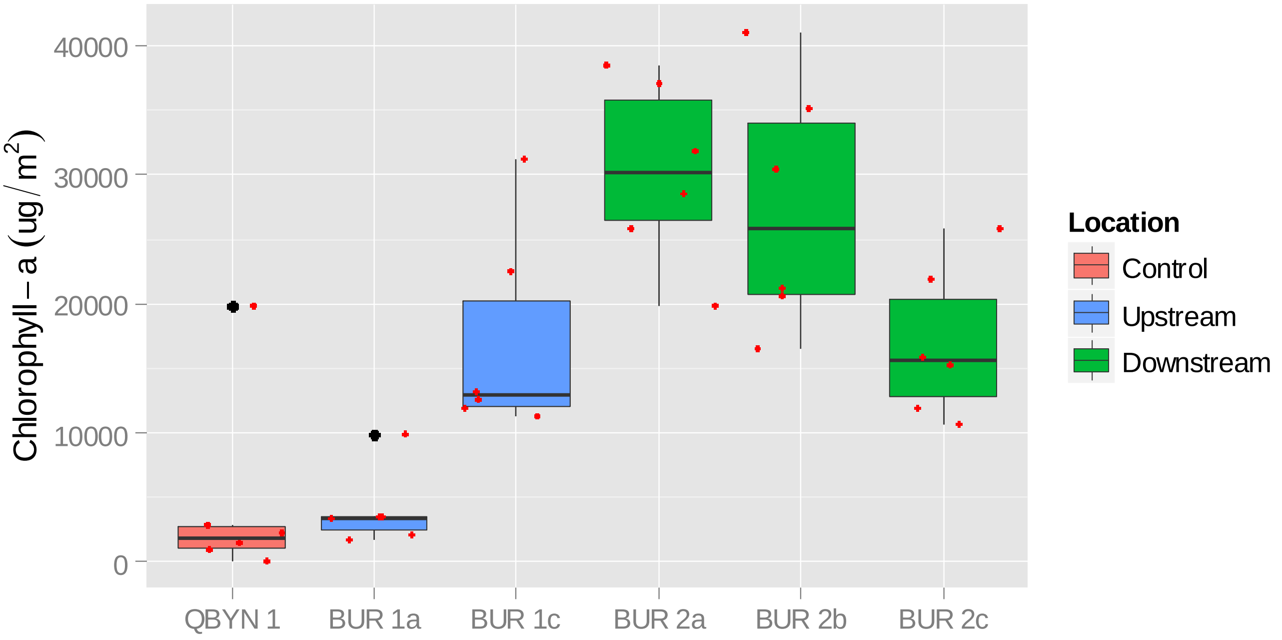

Figure 5-7. Chlorophyll-a concentrations in Burra Creek and the Queanbeyan River

Note: Red points represent the raw values for each site.

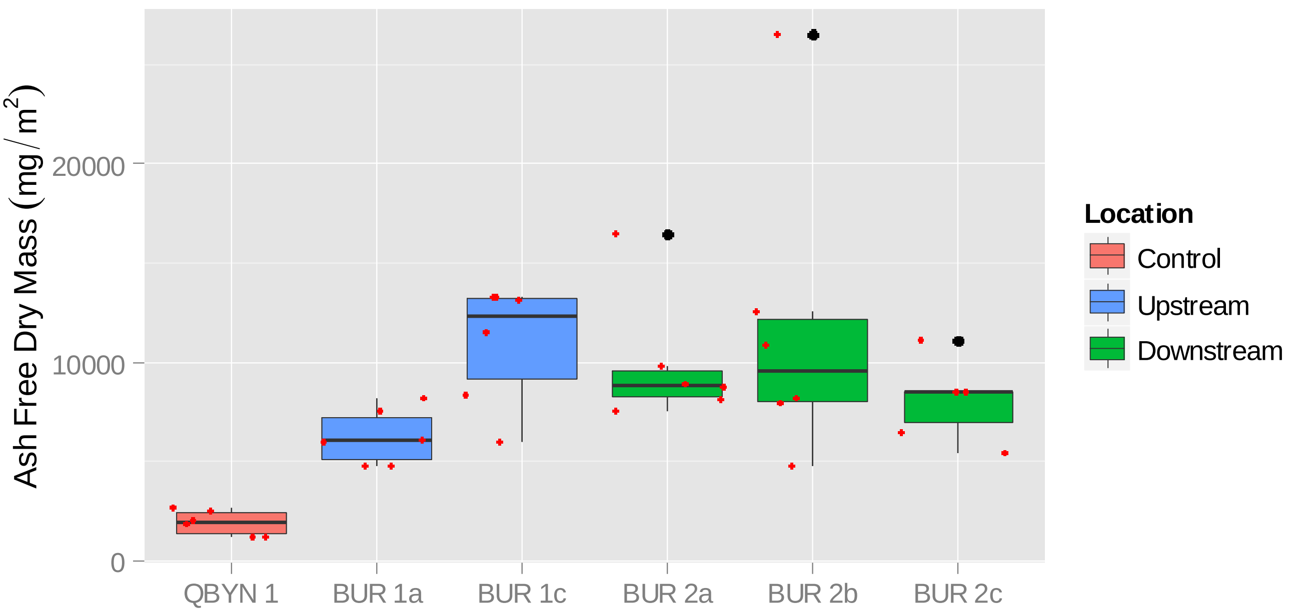

Figure 5-8. Ash free dry mass in Burra Creek and the Queanbeyan River

Note: Red points represent the raw values for each site.

5.5 Macroinvertebrates

5.5.1 Community Assemblages

Riffle Habitat

The ANOSIM test indicates riffle communities showed significant group separation between sampling locations (Global-R = 0.55: P=0.02). Pairwise tests indicate that macroinvertebrate community composition was significantly different downstream of the discharge point in Burra Creek compared to upstream sites (R=0.44; P=0.012) and also different between the downstream sites and the perennial control site (R=0.087; P=0.036). Upstream and downstream locations did not differ significantly (R=0.25; P=0.30) despite the apparent separation of sites within those locations in the ordination plot (Figure 5-9). The reason for this is the low number of replicates within those locations, which, because of the way the ANOSIM permutation procedure works, limits the lower boundaries of possible permutations. In this case the 0.1 is the lowest possible p-value under the current test with only ten possible permutations (Clarke and Warwick, 2001).

SIMPER analysis was carried out on the raw data following the significant Global ANOSIM test and the results are summarised in

Table 5-5. These results show which taxa best distinguished the differences between locations. Taxa characterising the upstream sites were mainly Dipterans, including: Ceratopogonidae (biting midges); Simuliidae (black flies) and Chironomidae (non-biting midges). Downstream of the discharge point, the riffle communities were also dominated by the above mentioned Dipteran taxa, but the community there also included Leptophlebiidae and Caenidae and the riffle beetle, Elmidae. At the perennial control site, the main riffle taxa included a similar set of those described above; however Gripopterygidae and Elmidae were collected in higher numbers than the Burra Creek sites.

The sites with the highest diversity of macroinvertebrates were BUR 2a and BUR 2c, with 32 genera from 24 different families at BUR 2a and 25 different families at BUR 2c (Figure 5-10). At the other end of the scale, only 22 genera were collected at BUR 1a from 21 different families, while BUR 1c was represented by 25 genera from only 20 families.

In regards to the diversity of EPT taxa collected, BUR 2a, again, had the highest number of genera, equalling QBYN 1 with 15, but only 8 families were collected at BUR 2a compared to 11 at QBYN 1 (Figure 5-11). The site with the least diversity of EPT taxa was BUR 1a where 7 genera were collected from 6 different families.

There was a decline in the number of EPT genera collected, compared to the previous spring season at four of the sites with BUR 1a, BUR 1c, BUR 2a and BUR 2c reducing by 3, 1, 4 & 2 taxa respectively, while genera diversity increased at BUR 2b and QBYN 1 by 1 & 3 taxa respectively (Figure 5-12). There were no corresponding reductions in family diversity between spring 2012 and spring 2013 for BUR 1a and BUR 2a.. All other Burra Creek sites showed an increase of a single family compared to spring 2012, while QBYN 1 results showed 3 additional families were collected in spring 2013 compared to spring 2012.

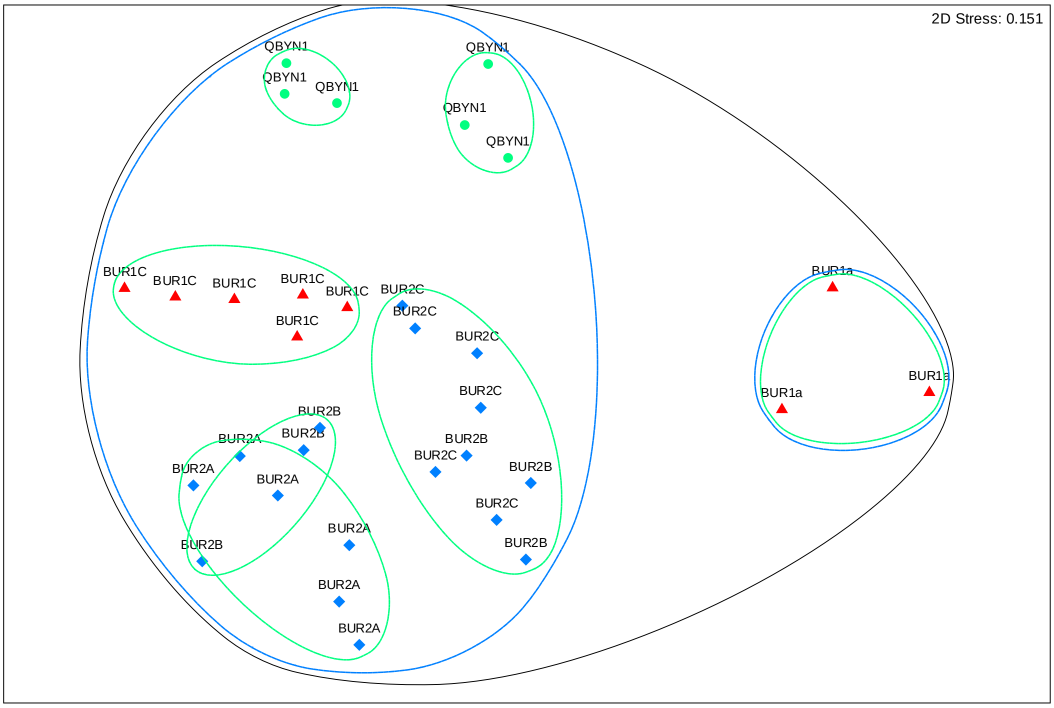

Figure 5-9. Non-metric multidimensional scaling ordination plot of genus level macroinvertebrate data from the spring riffle samples

Note: Ellipses represent 60% (black), 70% (blue) and 80% (green) similarity groupings derived from cluster analysis. Red triangles represent sites upstream of the discharge point, blue diamonds are sites downstream of the discharge point and green circles represent the control site.

Table 5-5. Discriminating taxa between sampling locations from the riffle habitat

Family	Genus	Average abundance	Average abundance	% contribution	Family SIGNAL-2 score
upstream versus downstream		upstream	downstream		
Simuliidae	*Austrosimulium*	7	5.1	13.8	5
Ceratopogonidae		4.1	1.6	8.65	4
Caenidae	*Tasmanocoenis*	2	3.5	4.65	4
Leptophlebiidae	*Atalophlebia*	1.1	2.3	3.46	8
Gripopterygidae	*Dinotoperla*	2	1	2.86	8
upstream versus control		upstream	control		
Orthocladiinae		7.3	4.5	7.66	4
Simuliidae	*Austrosimulium*	7	9.7	11.33	5
Gripopterygidae	*Illiesoperla*	1.1	4	6.89	8
Elmidae	*Stetholus*	0	2.2	3.91	7
Leptophlebiidae	*Atalophlebia*	1.1	2.6	3.71	8
downstream versus control		downstream	control		
Simuliidae	*Austrosimulium*	5.1	8.7	10.51	5
Orthocladiinae		8.3	4.5	10.10	4
Gripopterygidae	*Illiesoperla*	1.1	4	6.76	8
Baetidae		2	0	4.72	5
Elmidae	*Stetholus*	0	2.2	3.88	7
Chironominae		0.3	1.7	3.93	3
Leptophlebiidae	*Atalophlebia*	1.2	2.6	2.86	8

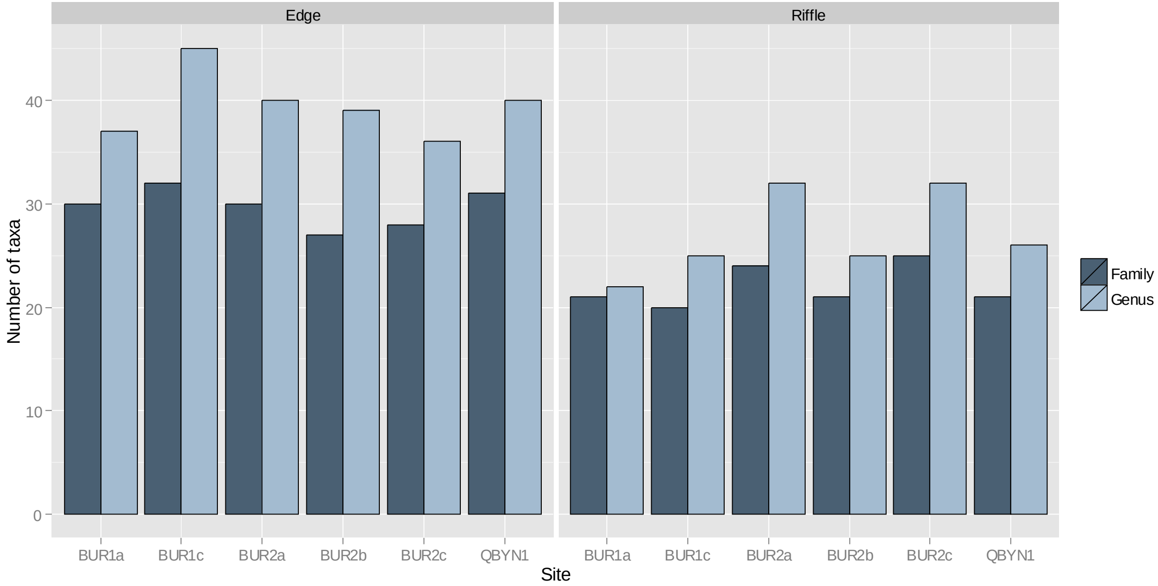

Figure 5-10. Number of taxa collected from the riffle and edge habitats

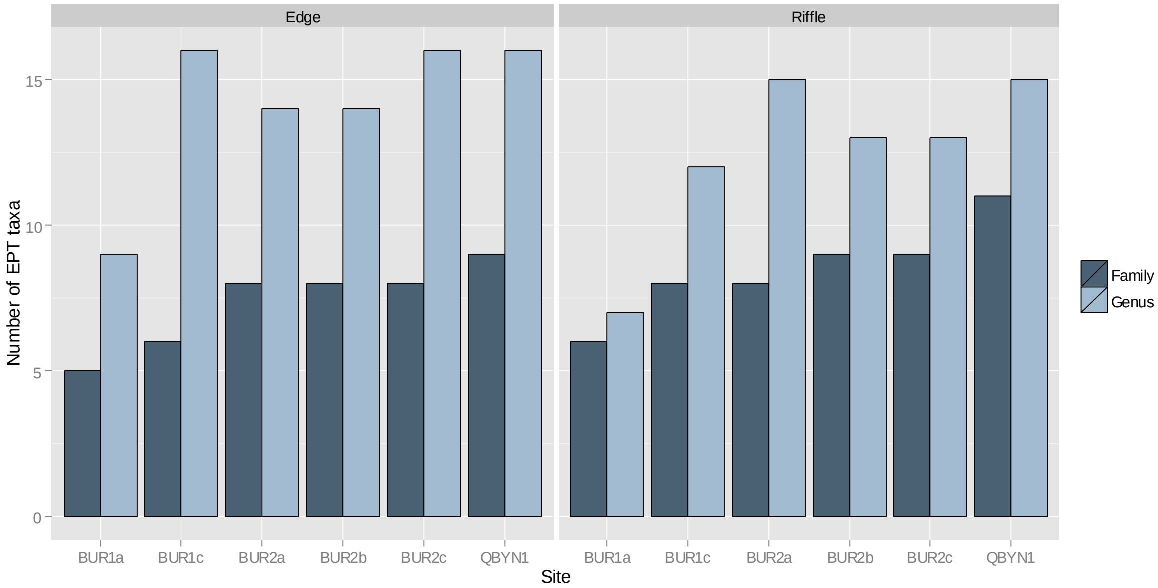

Figure 5-11. Number of EPT taxa collected from the riffle and edge habitats

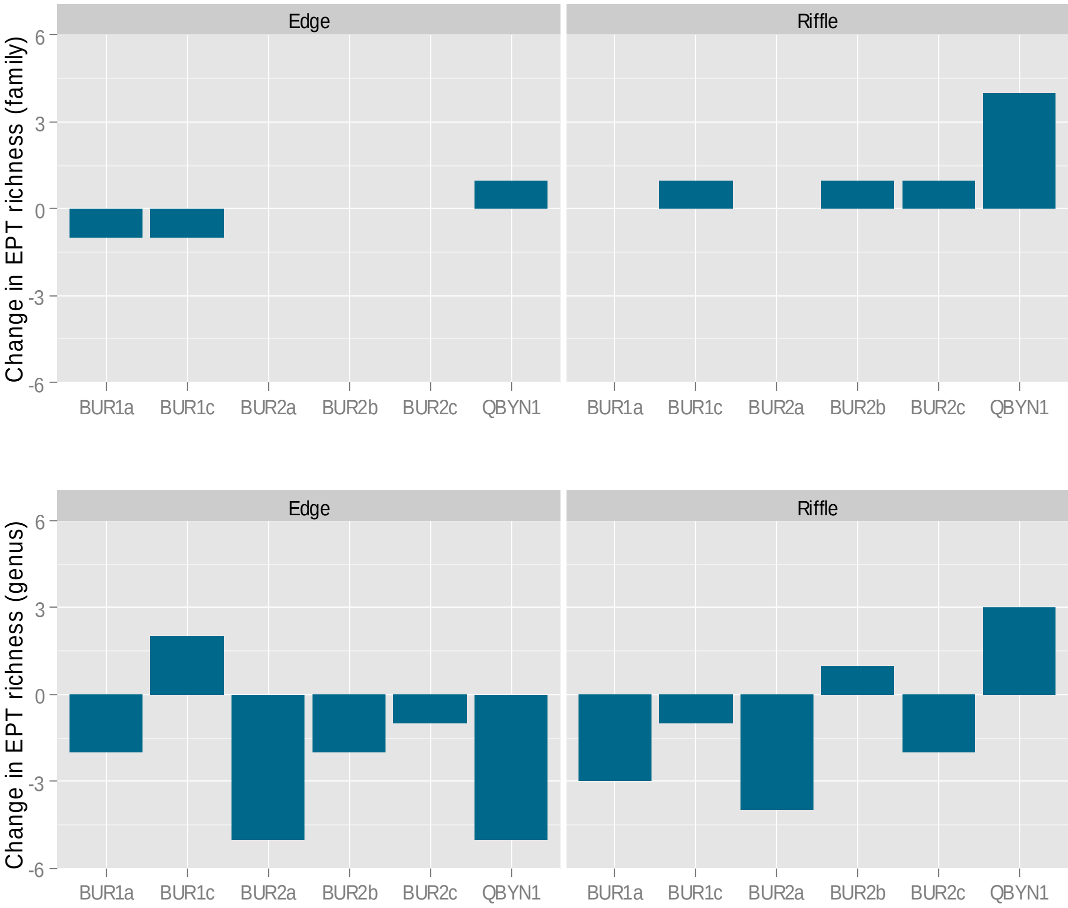

Figure 5-12. Change in the number of EPT taxa at the family level (top) and genus level (bottom) compared to spring 2012

Edge Habitat

As was the case for the riffle macroinvertebrate community, the ANOSIM results indicated significant group differences in macroinvertebrate community structure between locations (Global-R = 0.53; *P* =0.02), which is also evident from visual analysis of the ordination plots (Figure 5-13). Pairwise tests showed that this was due to differences in macroinvertebrate community composition between the downstream sites and the control sites (R = 1; *P* =0.03). Comparisons between macroinvertebrate communities in upstream and downstream locations were not significantly different (R = 0.23; *P* =0.12), nor were those for the upstream sites and the control sites (R = 0.57; *P* =0.13) despite a moderately strong separation of groups implied by the R-value. The reason for this was, as explained for the riffle sample analysis, that the low number of replicates within those locations limits the lower boundaries of possible permutations. In these situations, interpretation should be based on assessments of the R value (which is not affected by small sample sizes) and biological features amongst sites rather than relying solely on the p-values (Clarke and Warwick, 2001).

SIMPER analysis was carried out on the edge data following the significant ANOSIM results and the most discriminating taxa (between locations) are presented in Table 5-6. Generally, the taxa that discriminated the control site with sites within Burra Creek were higher abundances of sensitive taxa such as Gripopterygidae and Oniscigastridae. Atyidae was in very low numbers at the upstream sites which is consistent with the shallow pools and overall poor habitat quality at the sites.

In the case of the edge habitat samples, taxa richness was found to be slightly lower at the upstream sites (BUR 1a & 1c) during spring 2012 compared to downstream and Queanbeyan River sites. In spring 2013, however, taxa richness was similar across all sites, with BUR 1c showing the highest richness values with 45 genera belonging to 32 different families (Figure 5-10). The lowest family richness value was from BUR 2b (27), while the lowest genus richness was recorded at BUR 2c (36). EPT richness was lowest at the most upstream site (BUR 1a) where 9 genera belonging to 5 different families were collected. In comparison to this, 9 families were collected at QBYN 1. QBYN 1 also shared the highest genus diversity (16) with sites BUR 1c and 2c.

The number of families collected remained the same compared to spring 2012 at all downstream Burra Creek sites. The number of families collected reduced by 1 at both upstream sites. In comparison to this, the number of families collected at the Queanbeyan River control site increased by 1. The only site that showed an increase in the number of genera since the previous spring sampling run was BUR 1c, with additional 2 genera recorded at this site in spring 2013. Diversity reduced at all other sites, ranging from a loss of 1 genus at BUR 2c to a loss of 5 genera at both BUR 2a and the Queanbeyan River control site.

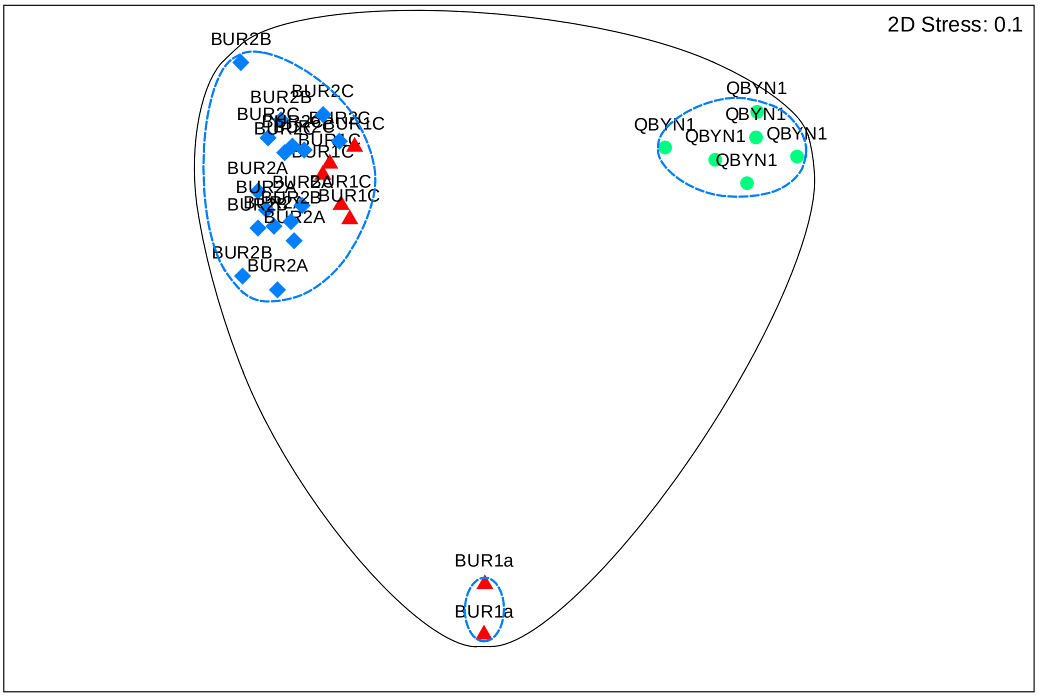

Figure 5-13. Non-metric multidimensional scaling ordination plot of genus level macroinvertebrate data from the spring edge samples

Note: Ellipses represent 40% (black) and 60% (blue) similarity groupings derived from cluster analysis. Red triangles represent sites upstream of the discharge point, blue diamonds are sites downstream of the discharge point and green circles represent the control site.

Table 5-6. Discriminating taxa between sampling locations from the edge habitat

Family	Genus	Average abundance	Average abundance	% contribution	Family SIGNAL-2 score
downstream versus control		downstream	control		
Tanypodinae		4.9	3.9	3.9	4
Gripopterygidae	*Dinotoperla*	0.2	5.3	8.5	8
	Leptoperla	2	0	2.5	8
Orthocladiinae		8.6	3.9	3.6	4
Caenidae	*Tasmanocoenis*	3.7	8.2	7.6	4
	Irapacaenis	0	1.8	2.9	4
Leptoceridae	*Notalina*	0	3.8	5.5	6
Oniscigastridae	*Tasmanophlebia*	0	1.5	1.8	8
upstream versus control		upstream	control		
Caenidae	*Tasmanocoenis*	2.7	8.2	3.6	4
Gripopterygidae	*Dinotoperla*	0.4	5.3	5.2	8
	Leptoperla	2.2	0	2.4	8
Leptoceridae	*Notalina*	0.9	3.8	4.8	6
Atyidae	*Paratya*	0.3	2.1	1.9	3
Gomphidae	*Austrogomphus*	0	1.4	1.8	5

5.5.2 AUSRIVAS

The average O/E 50 scores for the riffle habitat were found to be the highest at the control site (1.05), compared to the downstream sites (1.02) and the upstream sites (0.95). However, there was no significant difference detected between locations ($F_{2,3}$=0.77; *P*=0.54; Table 5-7). The average SIGNAL-2 scores for the riffle habitat followed the same pattern with the highest score from the control site (5.04), followed by the downstream sites (4.88) and then the upstream sites (4.81), and again we found these means not significantly different amongst locations ($F_{2,3}$=0.55; *P*=0.63; Table 5-7). Most of the model variation occurred amongst sites within a given location (53.4%) (Figure 5-14).

The average O/E 50 score derived from the edge samples at the upstream sites (1.15) was higher than the downstream sites (1.09) and the perennial control site (1.04). Location defences accounted for 16.5 of the model variance, however, the mean scores were not statistically different ($F_{2,3}$=0.55; P=0.21; Table 5-8). Average SIGNAL-2 scores for the edge habitat were the highest at the control site (4.86) followed by the upstream sites (4.83) and the downstream sites showing the lowest score

(4.65). As with the riffle, there were no statistical differences found between locations for the SIGNAL-2 scores from the edge habitat.

The indications of river health, based on the AUSRIVAS assessments, show that over the previous three years that the conditions within Burra Creek have been improving (Table 5-9). The Queanbeyan River (QBYN 1) control site, in comparison to this, has consistently been assessed as Band B for autumn and Band A for spring.

The individual habitat assessments in Table 5-10 show that both riffle and edge habitats for all sites, with the exception of BUR 1c, have been assessed as Band A or “similar to reference” in spring 2013. In the riffle habitat 85% of replicates were assessed as Band A, with only 6% and 9% being assessed as Band B (“significantly impaired”) and Band X (”more diverse than reference conditions”) respectively. The edge habitat showed 43% of replicates to be assessed as Band A and 57% as Band X, with a mixture of these bands present at each site. Two of the six replicates from the riffle habitat at BUR 1c were assessed as Band B, with the remaining assessed as Band A, and in accordance with the AUSRIVAS methods was given the overall habitat assessment of Band B (Coysh, 2000). These two Band B replicates were only found to be missing a single taxa compared to the other replicates which were assessed as Band A, that being Leptophlebiidae (SIGNAL-2 = 8) (Appendix E). All replicates in the BUR 1c edge habitat on the other hand were assessed as Band X “*more diverse than expected*.” The habitat assessments of Band B and Band X resulted in an overall site assessment of Band B. This is in accordance with standard AUSRIVAS practice with the explanation from Coysh et al. (2000), but belies the fact that, in real terms, diversity was at least as good if not better than that expected under reference conditions.

Missing taxa from the riffle samples ranged from 2 to 5 (Appendix E), with BUR 2b, missing the most taxa. Missing taxa included Acarina (SIGNAL-2 = 6), Hydropsychidae (SIGNAL-2 = 6) and Elmidae (SIGNAL-2 = 7). While the missing taxa from the edge habitat ranged from 0 to 3 (Appendix E), with BUR 2c missing the most taxa. Missing taxa from edge habitat included Baetidae (SIGNAL-2 = 5) and Leptoceridae (SIGNAL-2 = 6).

Table 5-7. Nested analysis of variance results for O/E 50 and SIGNAL-2 scores for Burra Creek from the riffle habitat

Response	Source	DF	F	P-value
O/E 50	Location	2	0.77	0.54
	Site [Location]	3	5.67	<0.001
	Total	32		
SIGNAL-2	Location	2	0.55	0.63
	Site [Location]	3	10.34	<0.001
	Residual	32		

Table 5-8. Nested analysis of variance results for O/E 50 and SIGNAL-2 scores for Burra Creek from the edge habitat

Response	Source	DF	F	P-value
O/E 50	Location	2	2.69	0.21
	Site [Location]	3	1.05	0.39
	Total	29		
SIGNAL-2	Location	2	0.77	0.54
	Site [Location]	3	13.88	<0.001
	Residual	29		

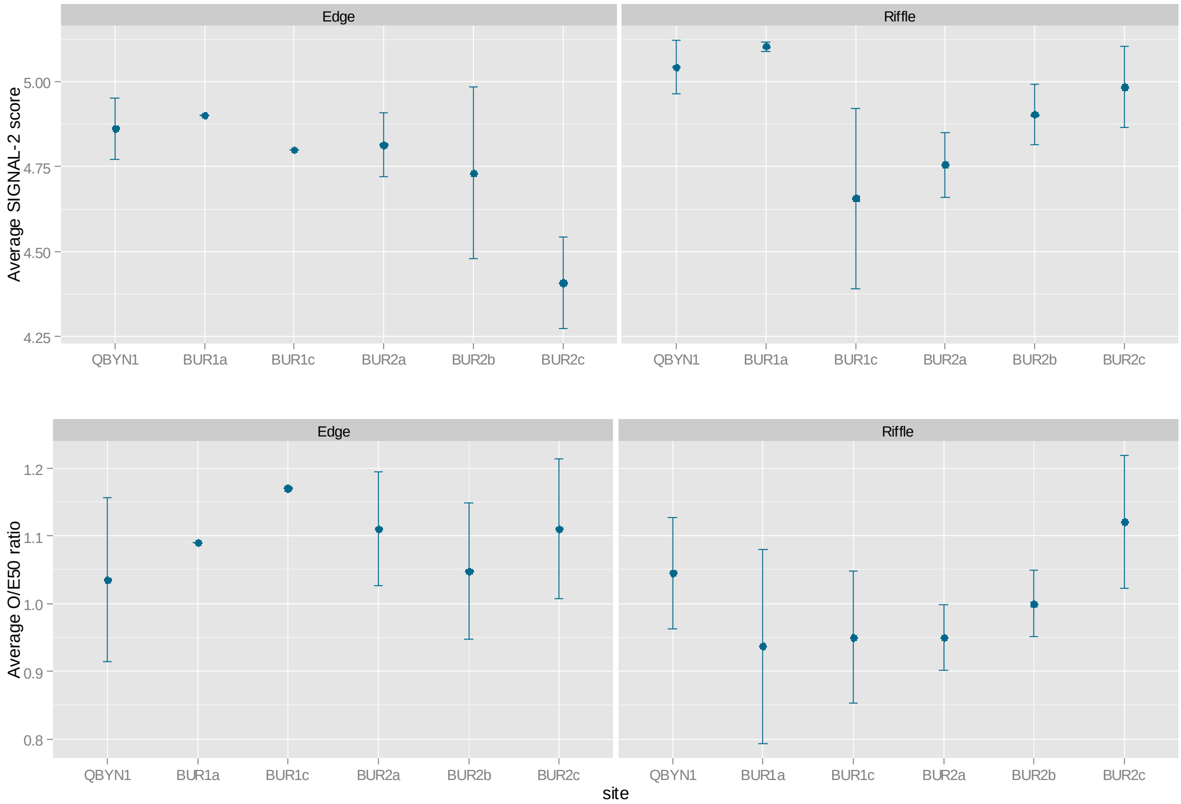

Figure 5-14 Means plots of SIGNAL-2 scores and O/E 50 ratios for edge and riffle habitats

Note: Error bars are 95% confidence intervals.

Table 5-9. Overall site assessments from Burra Creek for autumn and spring since 2011

	Autumn 2011	Spring 2011	Autumn 2012	Spring 2012	Autumn 2013	Spring 2013	Change since previous spring sampling run
QBYN 1	B	A	B	A	B	A	-
BUR 1a	B	B	B	B	NS	A	↑
BUR 1c	NS	NRA	B	B	B	B	-
BUR 2a	NRA	NRA	B	A	B	A	↑
BUR 2b	B	B	B	B	B	A	↑
BUR 2c	B	B	B	A	A	A	-

Notes: NRA= no reliable assessment; NS = no sample

Table 5-10. AUSRIVAS and SIGNAL-2 scores for spring 2013 Note: NS = no sample

Site	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS band		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
QBYN 1	1	5.00	5.00	1.01	0.98	A	A	A	A	A
QBYN 1	2	5.00	4.88	1.11	0.87	A	A			
QBYN 1	3	5.08	4.78	1.11	0.98	A	A			
QBYN 1	4	5.18	4.80	1.01	1.09	A	A			
QBYN 1	5	5.00	4.80	1.11	1.09	A	A			
QBYN 1	6	5.00	4.91	0.92	1.20	A	X			
BUR 1a	1	5.11	4.90	0.87	1.09	A	A	A	A	A
BUR 1a	2	5.10	NS	0.97	NS	A	NS			
BUR 1a	3	5.10	NS	0.97	NS	A	NS			
BUR 1a	4	NS	4.90	NS	1.09	NS	X			
BUR 1c	1	4.82	4.80	1.01	1.17	A	X	B	X	B
BUR 1c	2	4.33	4.80	0.83	1.17	B	X			
BUR 1c	3	4.82	NS	1.01	NS	A	NS			
BUR 1c	4	4.82	4.80	1.01	1.17	A	X			
BUR 1c	5	4.82	4.80	1.01	1.17	A	X			
BUR 1c	6	4.33	4.80	0.83	1.17	B	X			
BUR 2a	1	4.70	4.91	0.92	1.20	A	X	A	A	A
BUR 2a	2	4.70	4.67	0.92	0.99	A	A			
BUR 2a	3	4.70	4.91	0.92	1.20	A	X			
BUR 2a	4	4.91	4.80	1.01	1.09	A	A			
BUR 2a	5	4.82	4.80	1.01	1.09	A	A			
BUR 2a	6	4.70	4.80	0.92	1.09	A	A			
BUR 2b	1	4.90	4.67	0.97	1.05	A	A	A	A	A
BUR 2b	2	5.00	4.75	0.97	0.93	A	A			
BUR 2b	3	4.80	NS	0.97	NS	A	NS			
BUR 2b	4	5.00	4.80	1.06	1.16	A	X			
BUR 2b	5	4.90	4.44	0.97	1.05	A	A			
BUR 2b	6	4.82	5.00	1.06	1.05	A	A			
BUR 2c	1	4.92	4.40	1.10	1.11	A	A	A	A	A
BUR 2c	2	4.82	4.40	1.01	1.11	A	A			
BUR 2c	3	4.92	4.33	1.20	1.00	X	A			
BUR 2c	4	5.08	4.55	1.20	1.22	X	X			
BUR 2c	5	5.08	4.22	1.20	1.00	X	A			
BUR 2c	6	5.09	4.55	1.01	1.22	A	X			

5.6 Discussion

5.6.1 Water quality

Water quality exhibited seasonal variability consistent with previous spring sampling runs. Total nitrogen values were generally lower or equivalent to the values recorded in spring 2012. The highest reading came from BUR 1a (0.41 mg/L), which, although this exceeds the water quality guidelines of ANZECC and ARMCANZ (2000), is not unusually high compared to the historical data set for this site (GHD, 2014). All other water quality parameters closely resembled those recorded in spring 2012, when base flows were approximately 1.5 ML/d higher than the spring 2013 run (Figure 5-4).

Continuous water quality records were also highly comparable to those recorded in spring 2012. Normal responses to rainfall and high flow events were recorded for the entire spring period, with the most obvious pulse response occurring in mid-September to the 3,000 ML/d event. Temperature expectedly showed a monotonic trend over the three month period and other parameters displayed diurnal changes that are expected in a normal system in the absence of exogenous factors. These trends were mirrored at the Queanbeyan Control (Figure 5-6).

5.6.2 Periphyton

Despite the differences in chlorophyll *a* concentrations between spring 2012 and spring 2013, the spatial patterns remain largely the same, with the lowest biomass seen at the QBYN 1 and BUR 1a increasing to BUR 2b and then declining at BUR 2c (Figure 5-7). Chlorophyll *a* concentrations did not differ statistically among sampling locations (Table 5-3), however the total variance in chlorophyll *a* concentration explained by the location component was 56% (i.e. the differences between the downstream sites and the control and upstream Burra Creek sites). The non-significant result is explained by the high values at BUR 1c and the potential outlier (retained in the model) at QBYN 1.

The contrast between the three-fold increases in the mean biomass at BUR 1c compared to BUR 1a is likely due to more consistent surface flow at that site. Surface flows, albeit with low velocities and shallow water depths resulted in notable macrophyte inundation, higher surface temperatures and high light penetration at BUR 1c compared to other sites. In contrast, BUR 1a dries more regularly than the other sites in the Burra Creek sampling programme, so cycling between periods of growth and desiccation occur more often in the upper reaches. The low periphyton biomass (Figure 5-7 and Figure 5-8) seen at BUR 1a probably is a result of very low surface flows following a particularly wet September and the driest October since the beginning of the MEMP (Figure 5-2), which (Biggs and Close, 1989; Biggs *et al*., 1998) may place restrictions on nutrient uptake by standing stocks.

While sites downstream of the discharge structure at Williamsdale Road Bridge have similar channel unit features, the nutrient inputs from Holder Creek are likely to have some influence on these the periphyton communities in this reach. The increased chlorophyll *a* concentrations downstream of the discharge point (Figure 5-7) are correlated with slightly reduced nutrient concentrations. This suggests possible nutrient uptake by existing standing crops of periphytic algae downstream of the discharge point as a maintenance process for regulating nutrient levels in the water column.

5.6.3 AUSRIVAS and macroinvertebrate assemblages

On average, flows in Burra Creek during spring 2013 were higher than the same period in 2012. While both sampling periods experienced high flow events, it was the timing and magnitude of these events that distinguished each of the two sampling periods from one another. It has been well documented that these factors, as well as historical flows, (e.g. Boulton and Lake, 1992; Bond and Cottingham, 2008; Finn *et al*., 2009) can have important consequences for macroinvertebrate community structure (e.g. Kennen *et al*., 2010; Poff and Zimmerman, 2010)

For example, in this sampling run, the larger of the two events occurred in September (~3,000 ML/d) with an annual recurrence interval (ARI) of 2.5 years, whereas the event recorded in spring 2012 was less than a 1:1 yr ARI and occurred in October, approximately one week prior to sampling. There was approximately three weeks between the spring 2013 high flow event and macroinvertebrate sampling, allowing more time for recovery from this event.

The magnitude of the event in September is likely to have contributed to the improved AUSRIVAS scores BUR 1a, BUR 2a and BUR 2b since spring 2012, due to the removal of silt from riffle bed habitat. Silt can impact macroinvertebrate communities by smothering important habitat, and interstitial spaces on the creek bed thereby reducing primary production and preventing colonisation by taxa that require clean substrates for survival (Hynes, 1970; Minshall, 1984; Extence *et al*., 2011). These three sites all changed from BAND B in spring 2012 to BAND A in spring 2013 (Table 5-9). There was no change at QBYN 1, BUR 1c, or BUR 2c for the same period, which remained ranked Band A, Band B and Band A, respectively. However, the edge habitat samples from BUR 1c was more diverse than expected under reference conditions, indicating that, in real terms, diversity had increased since spring 2012 at this site.

Comparisons of missing taxa between the two sampling runs show that the improvements at the previously mentioned sites are largely due to four taxa: Caenidae, Baetidae and Gripopterygidae being collected at these sites in spring 2013, but were missing in spring 2012. These taxa, with the possible exception of Caenidae (Gooderham and Tsyrlin, 2005), prefer clean substrates and tend to prefer cooler, fast flowing water (Gooderham and Tsyrlin, 2005; Elliot, 2008), suggesting that the higher base flows experienced as a result of higher rainfall in the current sampling period is also a likely factor contributing to the improvements in AUSRIVAS bands.

Missing macroinvertebrate families from the AUSRIVAS predictions include Elmidae and Hydropsychidae, which prefer faster flowing water (Elliot, 2008). BUR 1c is prone to sedimentation due to long periods of low base flows in between rainfall events, so it is unlikely that given these environmental constraints, that these taxa will regularly occur at that site. BUR 1a is usually characterised by taxa with preferences for lower velocities and taxa that are more tolerant to other stressors such as changes in water quality (e.g. higher water temperatures and low dissolved oxygen).

The composition of the whole macroinvertebrate communities, based on the ANOSIM results and the ordination analysis shows strong separation of sites in both habitats, which is not surprising given the very different geological and hydrological features between the three location categories. Macroinvertebrates characterising the upstream sites were generally tolerant true fly families including Orthocladiinae, Simuliidae and Chironomids, with several highly sensitive taxa collected farther upstream at BUR 1a. The distinction between the two locations in Burra Creek is somewhat distorted by the degree of difference between BUR 1a, and BUR 1c, which is also most as extreme as the differences between BUR 1c and the Queanbeyan River control site (Figure 5-9; Figure 5-13). Statistically, combining these sites with the factor location improves the power of the ANOSIM procedure to detect true differences should they exist.

There were no obvious spatial patterns in the overall taxonomic richness values either at the genus or family levels (Figure 5-10). However, there was a weak longitudinal increase in the number of EPT genera in both habitats (Figure 5-11) which is potentially related to increasing water volume with distance downstream. Increasing numbers of EPT taxa corresponded to increasing SIGNAL -2 scores in the riffle habitat, suggesting the additional taxa had moderate to high sensitivity scores, which would make sense if the high flow event in September scoured out some of the fine sediment at these sites, thereby facilitating colonisation of taxa that prefer clean substrates.

The edge data shows almost the opposite pattern; where the tendency of increasing genera seemed to correlate with lower SIGNAL-2 scores. The explanation for this pattern is unclear, but could be partly due to the relatively high numbers of the genus *Tasmanocoenis sp.* (Caenidae) in downstream site samples, which has one of the lowest SIGNAL-2 scores among the EPT suite of taxa (SIGNAL-2

=4). Overall, the results from the macroinvertebrate community data show, as they did in spring 2012, improvements in AUSRIVAS assessments. This was likely attributed to a high flow event in September, which removed silt from riffle bed habitat and maintained flow for the period leading up to sampling.

5.7 Conclusion and recommendations

Macroinvertebrate assemblages in Burra Creek appear to respond quickly to natural increases in surface flow from runoff events; and there was some evidence of improvements (albeit small) that were recognised by the brief period of previous M2G maintenance and trial releases into Burra Creek in spring 2012. Once M2G is fully operational, the releases from the Murrumbidgee River are likely to improve the overall health of Burra Creek inferred from AUSRIVAS and habitat assessments.

Changes in surface water quality are also likely to occur with increasing Murrumbidgee River water, and this was one of the key threatening processes identified during the EIS phase of the project. At this stage of the project, the risks associated with surface water quality (medium and long term) are uncertain given the limited number of M2G runs that have occurred in the past 18 months. Based on the data to date, and the patterns of "recovery" following natural high flow events, long term changes in surface water characteristics appear to be unlikely from short term events, though the impact from long duration M2G discharge has not yet been able to be assessed..

Long term analysis is currently underway as part of the MEMP. This follows the recommendations in the autumn 2013 sampling round report and focuses on water quality trends and long term patterns in the macroinvertebrate communities. The Burra Creek program could be improved by reviewing the water quality guideline values that have been mentioned in previous reports and assessing environmental thresholds associated with important macroinvertebrate taxa – this would improve our understanding of likely responses to increasing frequency and volumes of water once M2G is used on a regular basis. It is therefore recommended that autumn sampling should occur as soon as possible following any scheduled releases. Ideally this would occur two to three weeks after the next full ramp up/ramp down schedule and would ideally avoid natural high flow events, so that potential benefits from these releases can be identified without being confounded by natural events.

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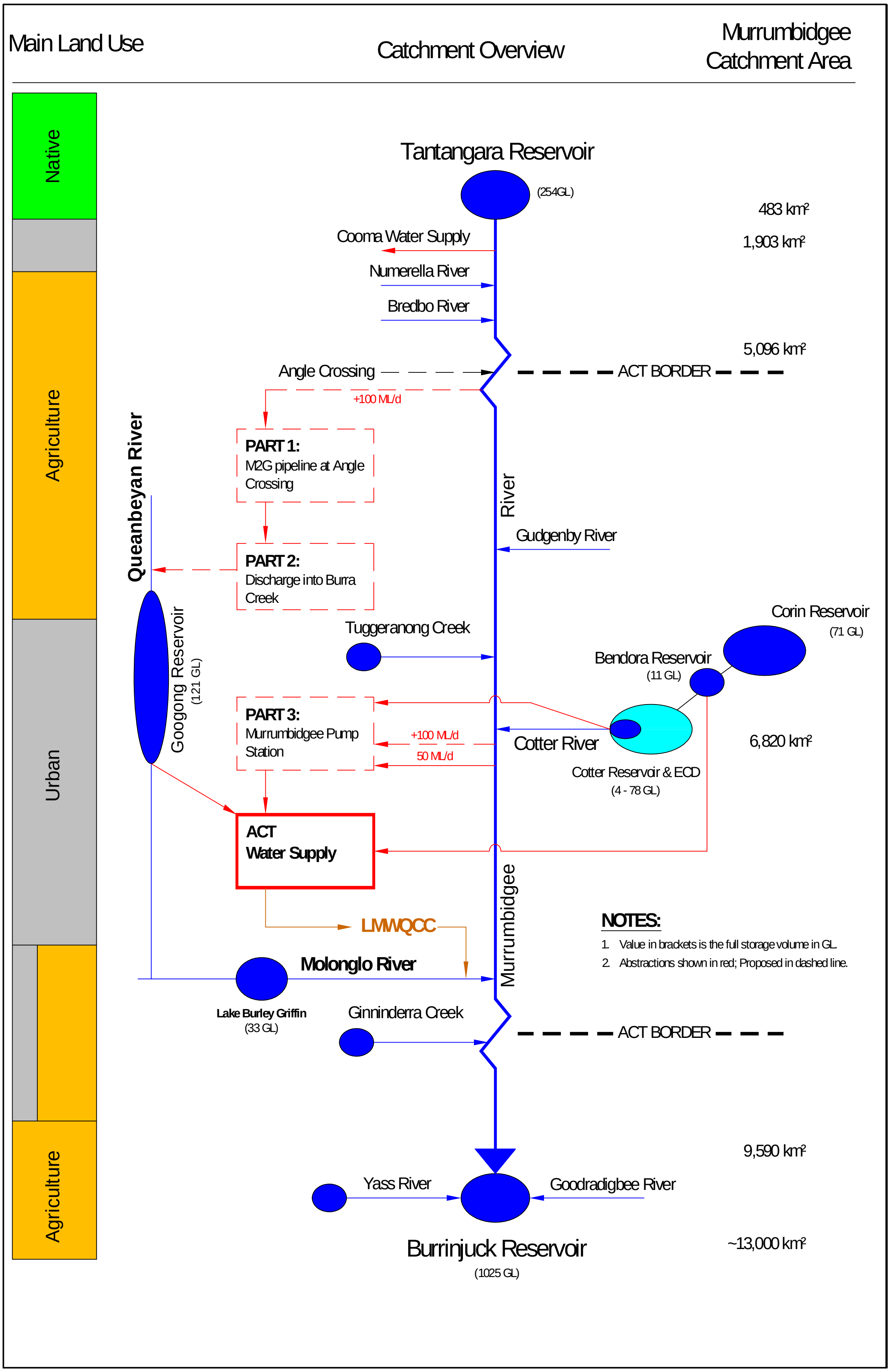
Appendices

Appendix A – Schematic representation of the Murrumbidgee Catchment and ACTEW Waters' major projects

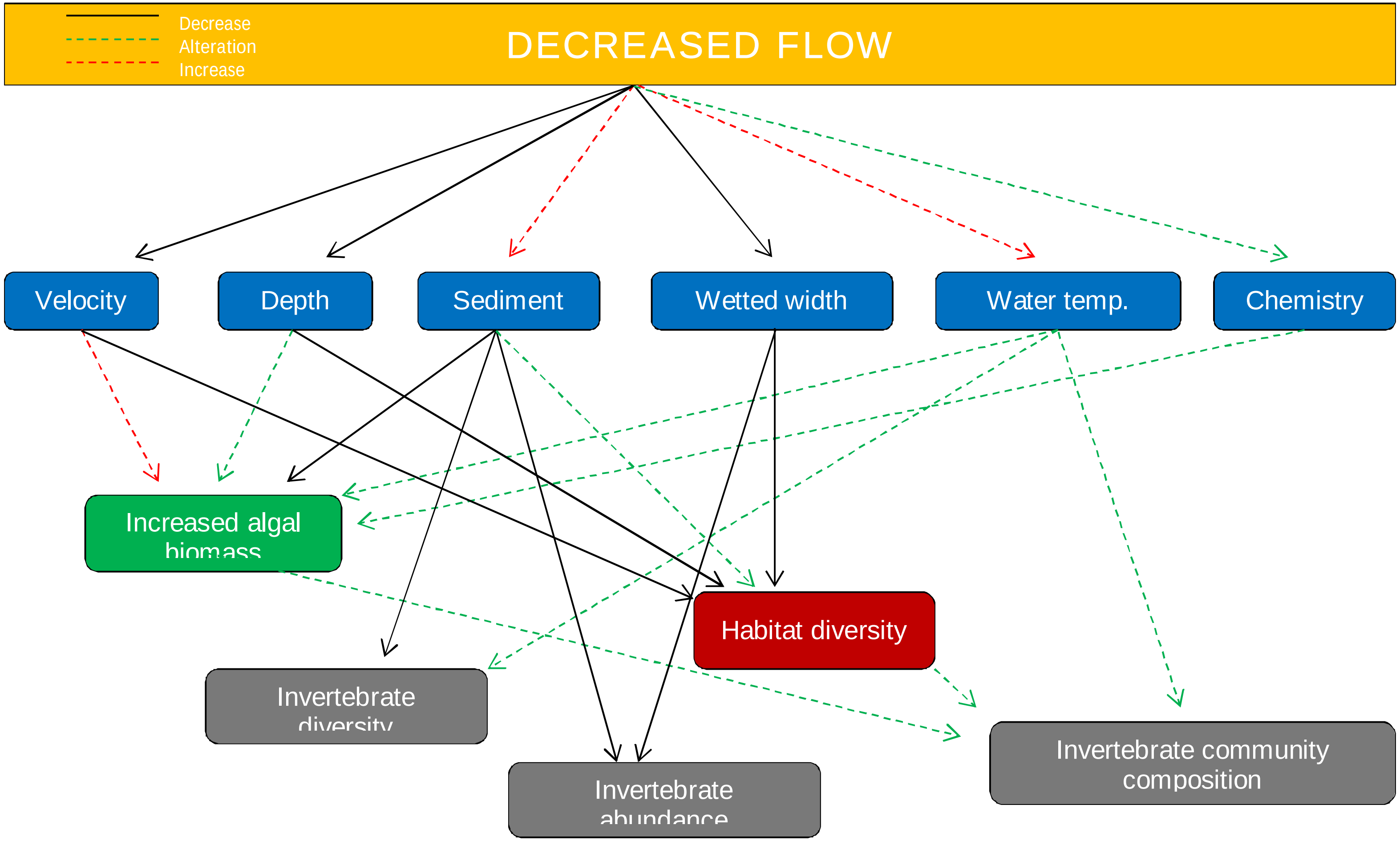
Appendix A1 – Overview of ACTEW Waters' major projects



Appendix B - Conceptual framework of the effects of reduced flow

Appendix B1 – Summary of the effects of reduced flows on various habitat conditions and macroinvertebrate communities (Dewson, 2007)*

Note: Reproduced with permission from the authors.



Appendix C - QA/QC Result

Appendix C1 – QA/QC results from the spring 2013 Angle Crossing and Burra Creek samples

		Site Code	**BUR1C**		**BUR2B**		**QBYN1**		**MUR16**		**MUR19**		**MUR28**	
		Habitat	**RIFFLE**		**EDGE**		**EDGE**		**Riffle**		**RIFFLE**		**Riffle**	
		Sample	**1**		**2**		**2**		**2**				**2**	
		QSN	**MEMP13/04**		**MEMP13/15**		**MEMP13/23**		**MEMP13/29**		**MEMP13/37**		**MEMP13/45**	
		Date Collected	**15/10/2013**		**16/10/2013**		**16/10/2013**		**29/11/2013**		**28/11/2013**		**28/11/2013**	
		Replicate	**1**	**QA**	**1**	**QA**	**3**	**QA**	**1**	**QA**	**3**	**QA**	**2**	**QA**
Order	**Family**	**Genus**												
Acarina	sp.		4	4			2	2	5	5	26	26	3	3
Bivalvia	Sphaeriidae	Musculium (Sphaerium)					4	4						
Coleoptera	Dytiscidae	Antiporus			2	1								
Coleoptera	Dytiscidae	Necterosoma			6	7								
Coleoptera	Dytiscidae	Platynectes	1	1										
Coleoptera	Dytiscidae	sp.					1	1						
Coleoptera	Elmidae	Austrolimnius					2	2						
Coleoptera	Scirtidae	sp.			3	3								
Decapoda	Atyidae	Paratya			1	1								
Decapoda	Parastacidae	Cherax	1	1										
Diptera	Ceratopogonidae	Ceratopoginae	4	4	9	10	5	5						
Diptera	Chironominae	sp.	4	4	1	1	5	5	4	4	8	7	1	1
Diptera	Empididae	sp.									4	4		
Diptera	Dixidae	Dixa			2	2								
Diptera	Orthocladiinae	sp.	61	60	69	67	7	7	21	21	62	63	34	34
Diptera	Simuliidae	Austrosimulium	45	45			2	2	242	239	63	62	82	80
Diptera	Simuliidae	sp.	25	25			5	5	19	21	16	16	58	57
Diptera	Stratiomyidae	Odontomyia			1	1								
Diptera	Tanypodinae	sp.	7	7	16	16	20	21	4	4	7	7		
Diptera	Tipulidae	sp.	1	1							4	4	3	3
Ephemeroptera	Baetidae	Baetidae Genus 2									4	4	2	2
Ephemeroptera	Baetidae	Centroptilum sp			4	4								
Ephemeroptera	Baetidae	Cloeon			2	2								
Ephemeroptera	Baetidae	sp.	1	1	1	1	5	5	2	2	2	2	3	3
Ephemeroptera	Caenidae	Irapacaenis					2	2						

		Site Code	BUR1C		BUR2B		QBYN1		MUR16		MUR19		MUR28	
		Habitat	RIFFLE		EDGE		EDGE		Riffle		RIFFLE		Riffle	
		Sample	1		2		2		2				2	
		QSN	MEMP13/04		MEMP13/15		MEMP13/23		MEMP13/29		MEMP13/37		MEMP13/45	
		Date Collected	15/10/2013		16/10/2013		16/10/2013		29/11/2013		28/11/2013		28/11/2013	
		Replicate	1	QA	1	QA	3	QA	1	QA	3	QA	2	QA
Order	**Family**	**Genus**												
Ephemeroptera	Caenidae	Tasmanocoenis	13	13			52	51			9	9		
Ephemeroptera	Caenidae	sp.	1	1	14	14	9	9			2	2		
Ephemeroptera	Leptophlebiidae	Atalophlebia			3	3	1	1						
Ephemeroptera	Leptophlebiidae	Jappa							3	3	1	1		
Ephemeroptera	Leptophlebiidae	sp.	2	2	5	5			4	4	2	2	2	2
Gastropoda	Lymnaeidae	sp.					1	1						
Gastropoda	Physidae	Physa			1	1								
Hemiptera	Corixidae	Micronecta			4	4								
Hemiptera	Notonectidae	Enithares			1	1								
Hemiptera	Notonectidae	sp.			1	1								
Hemiptera	Veliidae	Microvelia			1	1								
Lepidoptera	Crambidae	sp.							1	1				
Odonata	Gomphidae	Austrogomphus					5	5						
Odonata	Zygoptera	sp.			1	1								
Oligochaeta	sp.		31	31	46	46	20	19	3	3	54	53		
Ostracoda	sp.													
Plecoptera	Gripopterygidae	Dinotoperla	7	7			23	23						
Plecoptera	Gripopterygidae	Illiesoperla	2	2					4	4	4	4		
Plecoptera	sp.		1	1										
Trichoptera	Ecnomidae	Ecnomus			2	2					1	1	3	3
Trichoptera	Ecnomidae	sp.							2	2				
Trichoptera	Hydrobiosidae	Taschorema	2	2										
Trichoptera	Hydrobiosidae	Ulmerochorema									1	1		
Trichoptera	Hydropsychidae	Asmicridea							3	3	3	3		
Trichoptera	Hydropsychidae	Cheumatopsyche							11	11	15	15	16	16
Trichoptera	Hydropsychidae	sp.							4	4	1	1	6	6

		Site Code	**BUR1C**		**BUR2B**		**QBYN1**		**MUR16**		**MUR19**		**MUR28**	
		Habitat	**RIFFLE**		**EDGE**		**EDGE**		**Riffle**		**RIFFLE**		**Riffle**	
		Sample	**1**		**2**		**2**		**2**				**2**	
		QSN	**MEMP13/04**		**MEMP13/15**		**MEMP13/23**		**MEMP13/29**		**MEMP13/37**		**MEMP13/45**	
		Date Collected	**15/10/2013**		**16/10/2013**		**16/10/2013**		**29/11/2013**		**28/11/2013**		**28/11/2013**	
		Replicate	**1**	**QA**	**1**	**QA**	**3**	**QA**	**1**	**QA**	**3**	**QA**	**2**	**QA**
Order	**Family**	**Genus**												
Trichoptera	Hydroptilidae	Hydroptila									1	1		
Trichoptera	Hydroptilidae	Oxyethira					22	22	1	1	1	1		
Trichoptera	Hydroptilidae	sp.							1	1				
Trichoptera	Leptoceridae	Notalina			1	1	9	9						
Trichoptera	Leptoceridae	Triplectides					1	1						
Trichoptera	sp.		1	1										
Turbellaria	Dugesiidae	Dugesia					1	1						
Ephemeroptera	Leptophlebiidae	Nousia	1	1										
Plecoptera	Gripopterygidae	Leptoperla			3	2								
Ephemeroptera	Leptophlebiidae	Koorinonga			1	1								
Ephemeroptera	Oniscigastridae	Tasmanophlebia					4	4						
		Percent Taxa Count	**99.53%**		**97.01%**		**98.56%**		**98.50%**		**98.63%**		**98.59%**	
		Pass/Fail	**Pass**		**Pass**		**Pass**		**Pass**		**Pass**		**Pass**	

Appendix D - Site summary sheets

Part 1: Angle Crossing

MUR15

Bumbalong Road
29/11/2013 10:00 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
19.6	96.5	10.4	9	7.89	100.4	8.42

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
19	0.005	0.003	< 0.002	0.008	0.038	0.38

Daily Flow: 330 ML/day

Recorded at the closest station (410050) - located on the Murrumbidgee River at Billilingra. (Source: www.water.nsw.gov.au)

Compared to current flow:

Spring 2012: 

Autumn 2013: 

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	A	B	NRA
Edge Habitat	A	B	A
Overall Site Assessment	A	B	NRA

Riffle Habitat

- Dominant substrate was cobble

Dominant Taxa

- Simuliidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Coloburiscidae
- Gripopterygidae
- Leptophlebiidae
- Hydrobiosidae

Edge Habitat

- Dominant trailing bank vegetation was from overhanging shrubs and trees

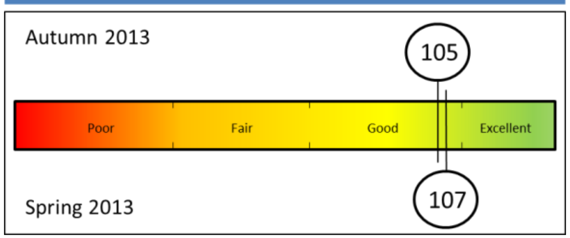
Dominant Taxa

- Corixidae
- Amphipoda

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae

Site Quality Assessment



Additional Comments

- Turtle observed at the site
- *Myriophyllum sp.* growth extensive throughout the site

MUR16

The Willows – Near Michelago
29/11/2013 12:15 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
20.3	105.6	9.49	19	7.93	103.5	8.54

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
41	0.004	0.003	< 0.002	0.007	0.040	0.40

Daily Flow: 330 ML/day

Recorded at the closest station (410050), located on the Murrumbidgee River at Billilingra. (Source: www.water.nsw.gov.au)

Compared to current flow:

Spring 2012:  Autumn 2013: 

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	B	B	B
Edge Habitat	A	B	B
Overall Site Assessment	B	B	B

Riffle Habitat

- Some small patches of *Myriophyllum sp.* throughout the habitat
- Dominant substrate was sand

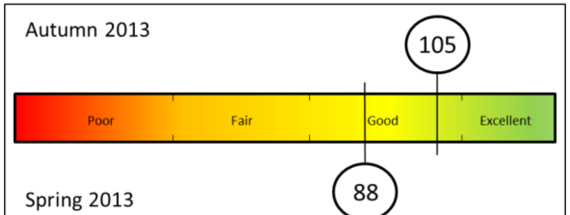
Dominant Taxa

- Simuliidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Hydrobiosidae
- Coloburiscidae
- Leptophlebiidae

Site Quality Assessment



Edge Habitat

- Edge habitat collected along opposite bank (photo above) and second sample collected further upstream than previous due to current flow level
- Dominant trailing bank vegetation was overhanging native shrubs

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

Additional Comments

- None

MUR18

Upstream Angle Crossing
29/11/2013 2:45 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
21.1	109.1	7.65	8	8.21	104.4	8.49

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
42	0.002	< 0.002	< 0.002	0.007	0.028	0.36

Daily Flow: 350 ML/day

Recorded at the closest station (41001702), located on the Murrumbidgee River at upstream Angle Crossing.

Compared to current flow:

Spring 2012: 

Autumn 2013: 

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	B	B	B
Edge Habitat	A	B	A
Overall Site Assessment	B	B	B

Riffle Habitat

- Reduced velocity through the riffle zone
- Dominant substrate was cobble

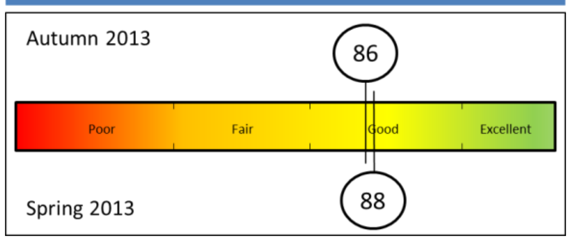
Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae
- Hydrobiosidae

Site Quality Assessment



Edge Habitat

- Dominant trailing bank vegetation was wood debris and overhanging native shrubs

Dominant Taxa

- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae

Additional Comments

- None

MUR19

Downstream Angle Crossing
28/11/2013 2:00 pm

Temp. (°C)	EC (μs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
21.9	108.3	6.52	10	8.06	103.4	8.25

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
42	< 0.002	< 0.002	< 0.002	0.004	0.030	0.37

Daily Flow: 440 ML/day

Recorded at the closest station (410761), located on the Murrumbidgee River at Lobb's Hole.

Compared to current flow:

Spring 2012: ↑ Autumn 2013: ↓

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	B	B	B
Edge Habitat	A	B	A
Overall Site Assessment	B	B	B

Riffle Habitat

- Abundance of *Myriophyllum sp.* throughout the habitat
- Dominant substrate was cobble and sand

Dominant Taxa

- Chironomidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Hydrobiosidae
- Coloburiscidae
- Leptophlebiidae

Additional Comments

- None

Edge Habitat

- Dominant trailing bank vegetation was overhanging willow

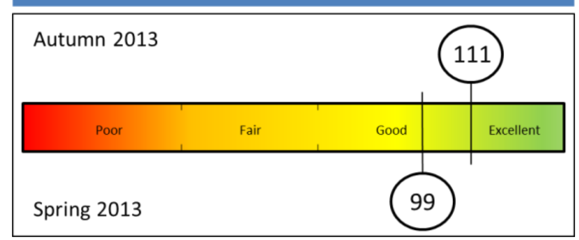
Dominant Taxa

- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae

Site Quality Assessment



MUR23

Point Hut Crossing
28/11/2013 11:40 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
23.4	112.5	9.71	11	7.94	101.5	7.88

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
44	< 0.002	< 0.002	< 0.002	0.005	0.032	0.38

Daily Flow: 440 ML/day

Recorded at the closest station (410761), located on the Murrumbidgee River at Lobb's Hole.

Compared to current flow:

Spring 2012: 

Autumn 2013: 

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	A	B	A
Edge Habitat	A	B	A
Overall Site Assessment	A	B	A

Riffle Habitat

- Some small patches of *Myriophyllum sp.* and filamentous green algae throughout the habitat
- Dominant substrate was bedrock

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Coloburiscidae
- Gripopterygidae
- Leptophlebiidae
- Hydrobiosidae

Additional Comments

- None

Edge Habitat

- Good habitat depth
- Dominant trailing bank vegetation was macrophytes (*Phragmites australis*)

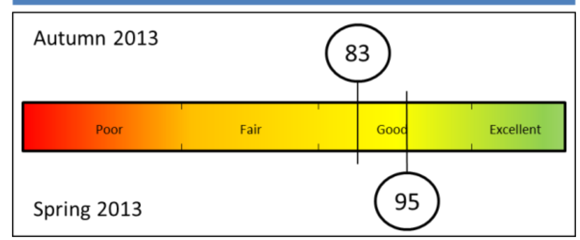
Dominant Taxa

- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae

Site Quality Assessment

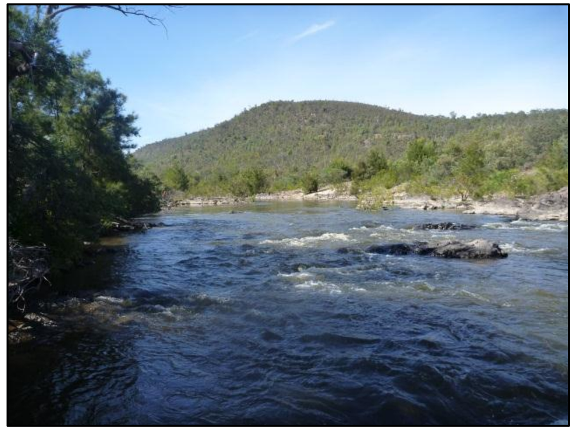


MUR28

Upstream Cotter River Confluence
28/11/2013 9:30 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
21.0	116.8	7.3	12	8.04	102.5	8.42

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
45	< 0.002	< 0.002	< 0.002	0.007	0.030	0.41



Daily Flow:

440 ML/day
Recorded at station 410761, located on the Murrumbidgee River at Lobb's Hole.

510 ML/day
Recorded at station 410738, located on the Murrumbidgee River at Mt. MacDonald.

25 ML/day
Recorded at station 410700, located on the Cotter River at Cotter Kiosk (below the Enlarged Cotter Dam).

The variation in flows down the Cotter River limit the comparability of this site's flow between seasons, which is further complicated by the operation of the Bendora Scour Valve.

Riffle Habitat

- Little organic matter in the samples, likely due to higher velocities at this site
- Dominant substrate was gravel

Dominant Taxa

- Simuliidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Hydrobiosidae

Edge Habitat

- Dominant trailing bank vegetation was overhanging wattle and wood debris

Dominant Taxa

- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae

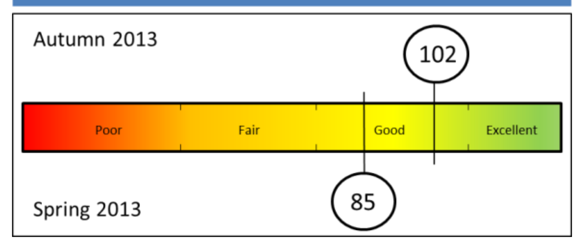
AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	B	B	B
Edge Habitat	B	B	NRA
Overall Site Assessment	B	B	NRA

Additional Comments

- None

Site Quality Assessment



Part 2: Burra Creek

BUR1a

Burra Native
15/10/2013 9:45 am

Temp. (°C)	EC (µs/cm)	Turb. (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
10.1	97.1	22.7	14	6.9	77.8	7.95

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
20	0.007	0.005	0.002	0.002	0.032	0.41

Daily Flow: 3.7 ML/day

Recorded at the closest station (410774), located on Burra Creek at Burra Road.

Compared to current flow:

Spring 2012: ↑ Autumn 2013: ↓

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	B	NS	A
Edge Habitat	A	NS	A
Overall Site Assessment	B	NS	A

Riffle Habitat

- Only a single sample was collected due to limited habitat availability
- Dominant substrate was pebble

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Dixidae

Edge Habitat

- Dominant trailing bank vegetation was overhanging *Juncus sp.*, *Kunzea sp.* and wood debris

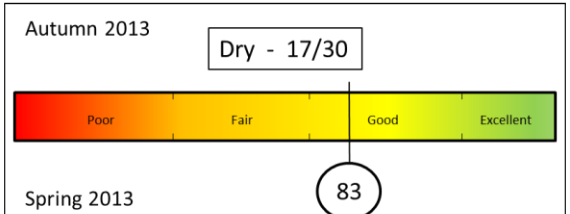
Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Conoesucidae
- Gripopterygidae
- Leptophlebiidae

Site Quality Assessment



Additional Comments

- Flows are very low
- Some new erosion observed
- Some cobbled areas have been moved downstream, with some other changes present within the substrate, likely from the recent event

BUR1c

Upstream Williamsdale Road
15/10/2013 12:30 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
14.9	383	4.15	3	8.0	103.0	9.46

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
145	0.007	0.007	< 0.002	< 0.002	0.010	0.23

Daily Flow: 3.7 ML/day

Recorded at the closest station (410774), located on Burra Creek at Burra Road.

Compared to current flow:

Spring 2012: ↑ Autumn 2013: ↓

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	B	B	B
Edge Habitat	A	B	X
Overall Site Assessment	B	B	NRA

Riffle Habitat

- Poor quality riffle with little flow and shallow in parts
- Less diverse than edge sample but highly abundant
- Dominant substrate was cobble and pebble

Dominant Taxa

- Simuliidae
- Gripopterygidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae
- Hydrobiosidae

Edge Habitat

- Sample was diverse
- Dominant trailing bank vegetation was *Eleocharis sp.*

Dominant Taxa

- None

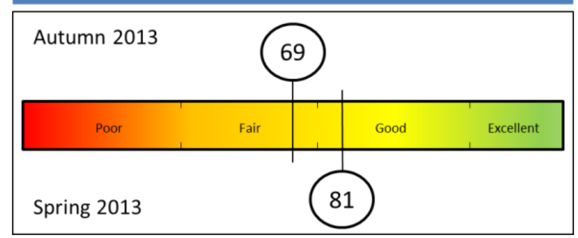
Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae

Additional Comments

- New macrophyte growth (*Eleocharis sp.*) crowding the main channel, with previous die off still present
- High periphyton coverage
- Water mark from the previous high flow observed

Site Quality Assessment



BUR2a

Downstream Williamsdale Road

15/10/2013 2:20 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
15.1	488	4.82	6	8.1	106.5	9.7

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
189	0.17	0.17	< 0.002	< 0.002	0.012	0.37

Daily Flow: 3.7 ML/day

Recorded at the closest station (410774), located on Burra Creek at Burra Road.

Compared to current flow:

Spring 2012: ↑

Autumn 2013: ↓

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	A	B	A
Edge Habitat	A	B	A
Overall Site Assessment	A	B	A

Riffle Habitat

- Dominant substrate is pebble

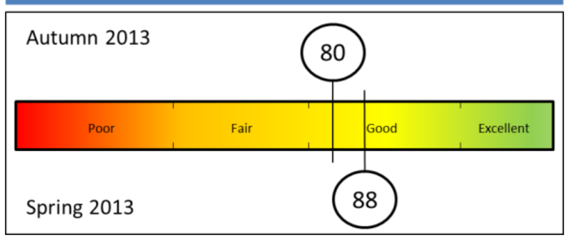
Dominant Taxa

- Leptophlebiidae
- Dytiscidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Hydrobiosidae
- Gripopterygidae

Site Quality Assessment



Edge Habitat

- *Gambusia holbrooki* observed within the habitat
- Dominant trailing bank vegetation was macrophytes (mainly *Phragmites australis* and *Eleocharis sp.*)

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae
- Oniscigastridae?

Additional Comments

- Noticeable increase in the wetted width at the site
- Site habitat is similar to that of previous seasons

BUR2b

Downstream Burra Road
16/10/2013 9:30 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
13.0	498	3.7	4	8.2	92.8	8.89

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
193	0.014	0.014	< 0.002	< 0.002	0.012	0.24

Daily Flow: 3.6 ML/day

Recorded at the closest station (410774), located on Burra Creek at Burra Road.

Compared to current flow:

Spring 2012: ↑ Autumn 2013: ↓

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	B	B	A
Edge Habitat	B	B	A
Overall Site Assessment	B	B	A

Riffle Habitat

- Habitat was highly silted
- Dominant substrate is boulder

Dominant Taxa

- Gripopterygidae
- Hydropsychidae
- Ceratopogonidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Hydrobiosidae
- Gripopterygidae
- Leptophlebiidae
- Telephlebiidae?

Additional Comments

- Reduced macrophyte growth compared to previous spring seasons

Edge Habitat

- Dominant trailing bank vegetation is macrophytes (mainly *Phragmites australis*)

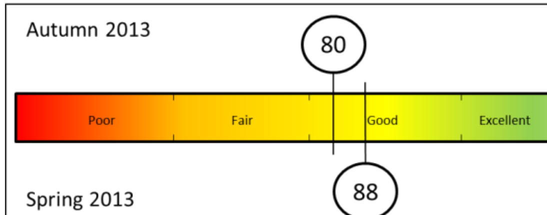
Dominant Taxa

- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae
- Hydrobiosidae

Site Quality Assessment



BUR2c

Upstream London Bridge
16/10/2013 2:45 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
8.1	490	2.77	4	8.35	117.2	10.1

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
198	0.028	0.028	< 0.002	0.003	0.009	0.18

Daily Flow: 3.6 ML/day

Recorded at the closest station (410774), located on Burra Creek at Burra Road.

Compared to current flow:

Spring 2012: 

Autumn 2013: 

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	A	A	A
Edge Habitat	A	A	A
Overall Site Assessment	A	A	A

Riffle Habitat

- Very good quality habitat
- Some deterioration of banks along riffle
- Dominant substrate was cobble

Dominant Taxa

- Leptophlebiidae
- Gripopterygidae
- Chironomidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae
- Hydrobiosidae

Edge Habitat

- Quality habitat with good depth
- Dominant trailing bank vegetation was macrophytes (mainly *Phragmites australis* and *Eleocharis sp.*)

Dominant Taxa

- Corixidae

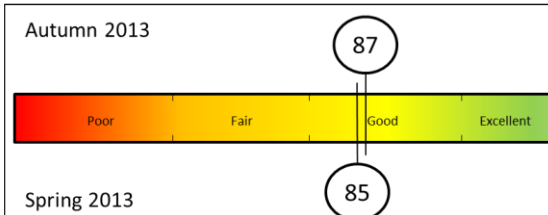
Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae
- Telephlebiidae

Additional Comments

- Both habitats contain a high organic load
- Some new undercuts and erosion along the left bank upstream of the site
- Reduced macrophyte growth compared to previous spring periods

Site Quality Assessment



QBYN1

Flynn's Crossing
16/10/2013 12:10 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
16.7	82.3	3.63	5	7.9	106.4	9.42

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
34	< 0.002	< 0.002	< 0.002	< 0.002	0.016	0.23

Daily Flow: 92 ML/day

Recorded at the closest station (410781), located on the Queanbeyan River, upstream of Googong Dam.

Compared to current flow:

Spring 2012:

Autumn 2013:

AUSRIVAS Results

	Spring 2012	Autumn 2013	Spring 2013
Riffle Habitat	A	B	A
Edge Habitat	X	B	A
Overall Site Assessment	A	B	A

Riffle Habitat

- Normal riffle almost dry (see above right), sampled the southern braid
- Clean substrate with limited periphyton
- Dominant substrate was cobble

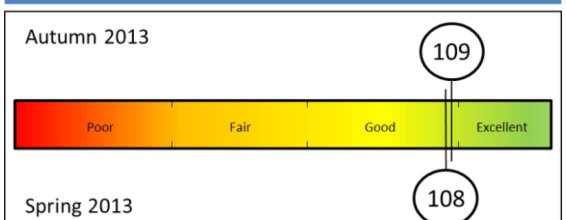
Dominant Taxa

- Gripopterygidae
- Simuliidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Coloburiscidae
- Gripopterygidae
- Hydrobiosidae
- Leptophlebiidae

Site Quality Assessment



Edge Habitat

- Limited submerged structure within the habitat
- Dominant trailing bank vegetation was wood debris and overhanging *Kunzea sp.*

Dominant Taxa

- Atyidae
- Leptoceridae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae

Additional Comments

- Morphology has changed during the previous event with a small cobble island removed from the channel with the dominant feature now a bedrock drop across the width of the channel
- Larger riffle now present
- Periphyton patches along the edges of the channel

Appendix E - Taxa predicted to occur with >50% probability, but were not collected

Appendix E1 – Taxa predicted to occur with >50% probability but not collected in the riffle habitat from Angle Crossing sites

Site	Taxa	Oligochaeta	Elmidae	Psephenidae	Tipulidae	Ceratopogonidae	Simuliidae	Tanypodinae	Chironominae	Baetidae	Leptophlebiidae	Caenidae	Gripopterygidae	Hydrobiosidae	Glossosomatidae	Hydropsychidae	Conoesucidae	Total number of missing taxa
	SIGNAL -2	2	7	6	5	4	5	4		5	8	4	8	8	9	6	7	
MUR15	Riffle		0.93	0.51										0.50	0.56	0.54	0.51	6
MUR15		1.00		0.51	0.52			0.69	0.93	0.65	0.85	0.88			0.56	0.54	0.51	11
MUR15			0.93	0.51				0.69		0.65			0.88	0.50	0.56		0.51	8
MUR15			0.93	0.51	0.52			0.69		0.65				0.50	0.56		0.51	8
MUR15			0.93	0.51				0.69						0.50	0.56		0.51	6
MUR15			0.93	0.51				0.69						0.50	0.56		0.51	6
MUR16	Riffle		0.93	0.50		0.50						0.88		0.50	0.55		0.50	7
MUR16				0.50		0.50						0.88		0.50	0.55		0.50	6
MUR16			0.93	0.50		0.50											0.50	4
MUR16			0.93	0.50	0.51	0.50						0.88		0.50	0.55		0.50	8
MUR16			0.93	0.50	0.51	0.50						0.88		0.50	0.55		0.50	8
MUR16			0.93	0.50	0.51									0.50	0.55		0.50	6
MUR18	Riffle		0.95	0.60									0.93	0.56	0.68		0.64	6
MUR18			0.95	0.60			0.68						0.93	0.56	0.68		0.64	7
MUR18			0.95	0.60			0.68						0.93	0.56	0.68		0.64	7
MUR18			0.95	0.60									0.93	0.56	0.68		0.64	6
MUR18			0.95	0.60									0.93	0.56	0.68		0.64	6
MUR18			0.95	0.60									0.93	0.56	0.68		0.64	6
MUR19	Riffle		0.95	0.60					0.91					0.56	0.68		0.64	6
MUR19			0.95	0.60	0.62										0.68		0.64	5
MUR19			0.95	0.60	0.62									0.56	0.68		0.64	6
MUR19				0.60											0.68		0.64	3
MUR19			0.95	0.60										0.56	0.68		0.64	5
MUR19			0.95	0.60											0.68		0.64	4
MUR23	Riffle			0.55										0.53	0.62		0.58	4
MUR23			0.94	0.55										0.53			0.58	4
MUR23				0.55													0.58	2
MUR23			0.94	0.55				0.66					0.90		0.62		0.58	6
MUR23			0.94	0.55				0.66							0.62		0.58	5
MUR23				0.55				0.66							0.62		0.58	4
MUR28	Riffle			0.65				0.59				0.89	0.95	0.60	0.76		0.73	7
MUR28		1.00		0.65				0.59			0.94		0.95	0.60	0.76		0.73	8
MUR28			0.96	0.65				0.59			0.94	0.89	0.95		0.76		0.73	8
MUR28		1.00	0.96	0.65					0.89				0.95	0.60	0.76		0.73	8

Site	Taxa	Oligochaeta	Elmidae	Psephenidae	Tipulidae	Ceratopogonidae	Simuliidae	Tanypodinae	Chironominae	Baetidae	Leptophlebiidae	Caenidae	Gripopterygidae	Hydrobiosidae	Glossosomatidae	Hydropsychidae	Conoesucidae	Total number of missing taxa
	SIGNAL -2	2	7	6	5	4	5	4		5	8	4	8	8	9	6	7	
MUR28		*1.00*	*0.96*	*0.65*				*0.59*				*0.89*	*0.95*	*0.60*	*0.76*		*0.73*	9
MUR28			*0.96*	*0.65*									*0.95*	*0.60*	*0.76*		*0.73*	6

Appendix E2 – Taxa predicted to occur with >50% probability but not collected in the edge habitat from Angle Crossing sites

Site	Taxa	Ceratopogonidae	Tanypodinae	Baetidae	Leptophlebiidae	Gripopterygidae	Leptoceridae	Total number of missing taxa
	SIGNAL-2	4	4	5	8	8	6	
MUR15	Edge	*0.65*			*0.82*			2
MUR15		*0.65*			*0.82*		*0.88*	3
MUR15								0
MUR15		*0.65*					*0.88*	2
MUR15					*0.82*			1
MUR15		*0.65*			*0.82*			2
MUR16	Edge					*0.62*		1
MUR16				*0.62*			*0.88*	2
MUR16		*0.65*		*0.62*		*0.62*	*0.88*	4
MUR16							*0.88*	1
MUR16		*0.65*		*0.62*		*0.62*	*0.88*	4
MUR16				*0.62*	*0.82*	*0.62*		3
MUR18	Edge	*0.65*		*0.62*				2
MUR18		*0.65*						1
MUR18		*0.65*						1
MUR18		*0.65*						1
MUR18		*0.65*						1
MUR18		*0.65*						1
MUR19	Edge	*0.65*		*0.62*			*0.88*	3
MUR19				*0.62*			*0.88*	2
MUR19		*0.65*						1
MUR19		*0.65*						1
MUR19								0
MUR19								0
MUR23	Edge	*0.65*			*0.82*		*0.88*	3
MUR23		*0.65*			*0.82*			2
MUR23		*0.65*			*0.82*			2
MUR23		*0.65*						1
MUR23		*0.65*						1
MUR23		*0.65*			*0.82*			2
MUR28	Edge	*0.65*		*0.62*			*0.88*	3
MUR28		*0.65*	*0.97*	*0.62*		*0.62*		4
MUR28		*0.65*				*0.62*	*0.88*	3
MUR28			*0.97*	*0.62*		*0.62*		3
MUR28		*0.65*	*0.97*	*0.62*		*0.62*	*0.88*	5
MUR28		*0.65*	*0.97*	*0.62*	*0.82*	*0.62*	*0.88*	6

Appendix E3 – Taxa predicted to occur with >50% probability but not collected in the riffle habitat from the Burra Creek sites

Site	Taxa	Sphaeriidae	Acarina	Elmidae	Ceratopogonidae	Simuliidae	Tanypodinae	Baetidae	Leptophlebiidae	Caenidae	Gripopterygidae	Hydropsychidae	Total number of missing taxa
	SIGNAL-2	5	6	7	4	5	4	5	8	4	8	6	
QBYN1	Riffle	*0.52*						*0.67*				*0.52*	3
QBYN1		*0.52*										*0.52*	2
QBYN1		*0.52*						*0.67*					2
QBYN1		*0.52*			*0.51*			*0.67*					3
QBYN1		*0.52*										*0.52*	2
QBYN1		*0.52*		*0.91*	*0.51*			*0.67*					4
BUR1a	Riffle					*0.77*		*0.67*		*0.87*		*0.52*	4
BUR1a								*0.67*		*0.87*		*0.52*	3
BUR1a								*0.67*		*0.87*		*0.52*	3
BUR1C	Riffle	*0.53*		*0.91*								*0.51*	3
BUR1C		*0.53*	*0.72*	*0.91*					*0.78*			*0.51*	5
BUR1C		*0.53*		*0.91*								*0.51*	3
BUR1C		*0.53*	*0.72*	*0.91*									3
BUR1C		*0.53*		*0.91*								*0.51*	3
BUR1C		*0.53*	*0.72*	*0.91*					*0.78*			*0.51*	5
BUR2A	Riffle	*0.51*	*0.73*	*0.92*								*0.52*	4
BUR2A		*0.51*	*0.73*	*0.92*								*0.52*	4
BUR2A		*0.51*	*0.73*	*0.92*								*0.52*	4
BUR2A		*0.51*	*0.73*									*0.52*	3
BUR2A		*0.51*		*0.92*								*0.52*	3
BUR2A		*0.51*	*0.73*	*0.92*								*0.52*	4
BUR2B	Riffle			*0.92*			*0.74*					*0.53*	3
BUR2B			*0.74*		*0.50*							*0.53*	3
BUR2B					*0.50*						*0.85*	*0.53*	3
BUR2B				*0.92*			*0.74*						2
BUR2B				*0.92*						*0.87*		*0.53*	3
BUR2B				*0.92*								*0.53*	2
BUR2C	Riffle	*0.54*		*0.91*									2
BUR2C		*0.54*		*0.91*								*0.51*	3
BUR2C				*0.91*									1
BUR2C		*0.54*											1
BUR2C		*0.54*											1
BUR2C		*0.54*			*0.51*							*0.51*	3

Appendix E4 – Taxa predicted to occur with >50% probability but not collected in the Edge habitat from the Burra Creek sites

Site	Taxa	Acarina	Ceratopogonidae	Chironomidae	Baetidae	Leptophlebidae	Gripopterygidae	Leptoceridae	Total number of missing taxa
	SIGNAL-2	6	4		5	8	8	6	
QBYN1	Edge		0.61		0.63				2
QBYN1		0.54	0.61		0.63				3
QBYN1		0.54			0.63				2
QBYN1		0.54							1
QBYN1		0.54							1
QBYN1									0
BUR1A	Edge				0.65				1
BUR1A					0.65				1
BUR1C	Edge								0
BUR1C									0
BUR1C									0
BUR1C									0
BUR1C									0
BUR2A	Edge								0
BUR2A		0.52						0.89	2
BUR2A									0
BUR2A		0.52							1
BUR2A		0.52					0.70		2
BUR2A		0.52							1
BUR2B	Edge							0.89	1
BUR2B			0.63					0.89	2
BUR2B									0
BUR2B									0
BUR2B				1.00					1
BUR2C	Edge							0.88	1
BUR2C								0.88	1
BUR2C					0.62			0.88	2
BUR2C									0
BUR2C			0.65			0.82			2
BUR2C									0

Appendix F - Taxonomic inventory

Appendix F1 – Taxonomic inventory of macroinvertebrates collected from the riffle habitat for the Angle Crossing component of the MEMP

CLASS / Order	Family / Sub-Family	Genus	MUR15	MUR16	MUR18	MUR19	MUR23	MUR28
ACARINA			■	■	■	■	■	■
BIVALVIA	Corbiculidae	*Corbicula*					■	
Coleoptera	Elmidae	*Austrolimnius*					■	■
		Stetholus				■	■	
		sp.	■	■			■	■
Decapoda	Palaemonidae	*Macrobrachium*			■			
	Parastacidae	*Cherax*				■		
Diptera	Ceratopogonidae	*Ceratopoginae*	■	■			■	
	Chironomidae		■			■		
	Chironominae		■	■	■	■	■	■
	Empididae		■	■	■	■	■	■
	Orthocladiinae		■	■	■	■	■	■
	Simuliidae	*Austrosimulium*	■	■	■	■	■	■
		Simulium					■	
		sp.	■	■	■	■	■	■
	Tanypodinae		■	■	■	■	■	■
	Tipulidae		■	■	■	■	■	■
Ephemeroptera	Baetidae	*Baetidae Genus 2*	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
	Caenidae	*Irapacaenis*	■		■		■	
		Tasmanocoenis	■		■	■	■	■
		sp.	■	■	■	■	■	■
	Coloburiscidae	*Coloburiscoides*					■	
	Leptophlebidae	*Austrophlebioides*			■	■		
		Atalophlebia			■		■	■
		Jappa	■	■	■	■	■	■
		Nousia			■		■	
		sp.	■	■	■	■	■	■
GASTROPODA	Ancylidae	*Ferrissia*					■	
		sp.					■	
Hemiptera	Corixidae	*Micronecta*				■		■
Lepidoptera	Crambidae			■			■	■
Nemertea						■		
OLIGOCHAETA			■	■	■	■	■	■
Plecoptera	Gripopterygidae	*Dinotoperla*				■		
		Illiesoperla	■	■		■	■	
		sp.	■			■	■	
Trichoptera	Ecnomidae	*Ecnomus*		■	■	■	■	■
		sp.		■	■	■	■	
	Glossosomatidae	*Agapetus*		■			■	
	Hydrobiosidae	*Ulmerochorema*				■	■	■
		sp.	■	■		■	■	
	Hydropsychidae	*Asmicridea*		■	■	■	■	■
		Cheumatopsyche		■	■	■	■	■
		Diplectrona						■
		sp.	■	■	■	■	■	■
	Hydroptilidae	*Hellyethira*			■		■	
		Hydroptila	■	■	■	■	■	■
		Oxyethira	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
Turbellaria	Dugesiidae	*Dugesia*		■				

Appendix F2 – Taxonomic inventory of macroinvertebrates collected from the edge habitat for the Angle Crossing component of the MEMP

CLASS / Order	Family / Sub-Family	Genus	MUR15	MUR16	MUR18	MUR19	MUR23	MUR28
ACARINA			■	■	■	■	■	■
BIVALVIA	Corbiculidae	Corbicula		■				
	Sphaeriidae	Musculium (Sphaerium)	■					
Coleoptera	Dytiscidae	Necterosoma		■				
		Platynectes		■				
		sp.			■			
	Elmidae	Austrolimnius				■	■	
		sp.			■	■		
	Gyrinidae	Macrogyrus					■	
	Hydraenidae	Hydraena					■	
	Hydrochidae	Hydrochus			■			
	Hydrophilidae	Berosus	■					
		sp.		■	■		■	
	Sperchidae						■	
Decapoda	Atyidae	Paratya			■	■		■
	Palaemonidae	Macrobrachium			■	■	■	
Diptera	Ceratopogonidae	Ceratopoginae	■	■		■		
		Forcipomyiinae		■				
		sp.						■
	Chironominae		■	■	■	■	■	■
	Empididae		■	■	■	■	■	■
	Orthocladiinae		■	■	■	■	■	■
	Psychodidae		■			■	■	
	Simuliidae	Austrosimulium	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
	Tanypodinae		■	■	■	■	■	■
	Tipulidae		■	■	■	■	■	■
Ephemeroptera	Baetidae	Baetidae Genus 1		■	■	■	■	
		Baetidae Genus 2	■					
		Baetis	■					
		Centroptilum sp			■			
		sp.	■	■	■	■	■	■
	Caenidae	Irapacaenis	■	■		■	■	■
		Tasmanocoenis	■	■	■	■	■	■
		sp.	■		■	■	■	■
	Leptophlebiidae	Atalophlebia		■	■	■		■
		Jappa		■	■			
		sp.	■	■	■	■	■	■
GASTROPODA	Ancylidae	Ferrissia					■	
Gastropoda	Lymnaeidae	Pseudosuccinea					■	
	Physidae	Physa				■	■	
Hemiptera	Corixidae	Micronecta	■	■	■	■	■	■
		sp.						■
	Gerridae	Rheumatometra		■				
		sp.		■				■
	Hydrometridae	Hydrometra		■				
	Notonectidae	Anisops		■				
		Enithares	■	■				
		Notonecta		■	■			
		Paranisops	■					
		sp.		■	■	■		
	Veliidae	Microvelia		■				
Lepidoptera	Crambidae	sp.	■		■		■	
Nematoda						■		
Odonata	Gomphidae	Austrogomphus	■					
OLIGOCHAETA			■	■	■	■	■	■
Plecoptera	Gripopterygidae	Dinotoperla	■		■	■	■	■
		Illiesoperla			■		■	
		sp.	■	■	■	■	■	■
Temnocephalida	Temnocephalidae	Temnocephala			■		■	
Trichoptera	Calamatoceridae	Anisocentropus					■	
	Ecnomidae	Ecnomus		■	■	■	■	■
		sp.	■	■	■	■	■	■
	Hydropsychidae	Asmicridea					■	
		Cheumatopsyche		■		■	■	■
		sp.	■	■	■	■	■	■
	Hydroptilidae	Hellyethira	■	■	■	■	■	■
		Hydroptila	■	■		■	■	■
		Orthotrichia				■	■	
		Oxyethira	■		■	■	■	■

CLASS / Order	Family / Sub-Family	Genus	MUR15	MUR16	MUR18	MUR19	MUR23	MUR28
		sp.						
	Leptoceridae	Notalina						
		Oecetis						
		Triaenodes						
		Triplectides						
		sp.						
Turbellaria	Dugesiidae	Dugesia						

Appendix F3 – Taxonomic inventory of macroinvertebrates collected from the riffle habitat for the Burra Creek component of the MEMP

CLASS / Order	**Family / Sub-Family**	**Genus**	BUR1A	BUR1C	BUR2A	BUR2B	BUR2C	QBYN1
ACARINA								
BIVALVIA	Sphaeriidae							
Coleoptera	Dytiscidae	*Necterosoma*						
		Platynectes						
		sp.						
	Elmidae	*Austrolimnius*						
		Coxelmis						
		Stetholus						
		sp.						
	Gyrinidae							
	Scirtidae							
Decapoda	Palaemonidae	*Macrobrachium*						
	Parastacidae	*Cherax*						
Diptera	Ceratopogonidae	*Ceratopoginae*						
	Chironominae							
	Dixidae	*Dixa*						
	Dolichopodidae							
	Empididae							
	Orthocladiinae							
	Psychodidae							
	Simuliidae	*Austrosimulium*						
		Simulium						
		sp.						
	Stratiomyidae	*Odontomyia*						
	Tanypodinae							
	Tipulidae							
Ephemeroptera	Baetidae	*Baetidae Genus 1*						
		Baetidae Genus 2						
		sp.						
	Caenidae	*Irapacaenis*						
		Tasmanocoenis						
		sp.						
	Coloburiscidae	*Coloburiscoides*						
	Leptophlebiidae	*Atalophlebia*						
		Jappa						
		Nousia						
		sp.						
GASTROPODA	Lymnaeidae	*Pseudosuccinea*						
	Physidae	*Physa*						
Hemiptera	Corixidae	*Micronecta*						
		sp.						
Nematoda								
Odonata	Epiproctophora							
	Gomphidae	*Austrogomphus*						
		sp.						
	Telephlebiidae	*Telephlebia*						
OLIGOCHAETA								
Plecoptera	Gripopterygidae	*Dinotoperla*						
		Illiesoperla						
		Leptoperla						
		sp.						
Temnocephalida	Temnocephalidae	*Temnocephala*						
Trichoptera	Conoesucidae	*Coenoria*						
	Ecnomidae	*Ecnomus*						
		sp.						
	Glossosomatidae	*Agapetus*						
	Hydrobiosidae	*Apsilochorema*						
		Taschorema						
		Ulmerochorema						
		sp.						
	Hydropsychidae	*Asmicridea*						
		Cheumatopsyche						
	Hydroptilidae	*Hellyethira*						
		Hydroptila						
		Oxyethira						
		sp.						
	Leptoceridae	*Notalina*						
		sp.						
	Philopotamidae	*Chimarra*						
Turbellaria	Dugesiidae	*Dugesia*						

Appendix F4 – Taxonomic inventory of macroinvertebrates collected in the edge habitat for the Burra Creek component of the MEMP

CLASS / Order	**Family / Sub-Family**	**Genus**	BUR1A	BUR1C	BUR2A	BUR2B	BUR2C	QBYN1
ACARINA	sp.		■	■	■		■	■
Amphipoda	Talitridae			■				
BIVALVIA	Corbiculidae	*Corbicula*		■	■			■
	Sphaeriidae	*Musculium*						■
		sp.					■	■
Coleoptera	Dytiscidae	*Antiporus*		■		■	■	
		Necterosoma	■	■	■	■	■	■
		Rhantus	■	■		■	■	
		Sternopriscus	■	■		■		
		sp.	■		■	■	■	■
	Elmidae	*Austrolimnius*	■					■
		Coxelmis					■	
	Hydraenidae	*Hydraena*	■					
	Hydrochidae	*Hydrochus*	■	■	■			
	Hydrophilidae	*Berosus*				■		
		sp.	■			■	■	■
	Scirtidae		■	■	■	■		
Decapoda	Atyidae	*Paratya*	■	■	■	■		■
	Parastacidae	*Cherax*		■	■			
Diptera	Ceratopogonidae	*Ceratopoginae*	■	■	■	■	■	■
	Chironominae		■	■	■	■	■	■
	Culicidae	*Aedes*	■	■				
		sp.	■			■		
	Dixidae	*Dixa*			■	■		
	Empididae		■				■	
	Orthocladiinae		■	■	■	■	■	■
	Psychodidae		■		■		■	
	Simuliidae	*Austrosimulium*	■	■	■	■	■	■
		sp.		■	■	■	■	■
	Stratiomyidae	*Odontomyia*		■	■	■		
	Tabanidae					■		
	Tanypodinae		■	■	■	■	■	■
	Tipulidae		■					
Ephemeroptera	Baetidae	*Baetidae Genus 1*		■	■	■		
		Baetidae Genus 2			■			
		Centroptilum		■	■	■	■	■
		Cloeon		■	■	■	■	
		sp.		■	■	■	■	■
	Caenidae	*Irapacaenis*		■				■
		Tasmanocoenis	■	■	■	■	■	■
		sp.		■	■	■	■	■
	Leptophlebiidae	*Atalophlebia*		■	■	■		■
		Jappa		■		■		■
		Koorinonga		■	■	■	■	■
		Nousia		■	■	■		■
		sp.	■	■	■	■	■	■
	Oniscigastridae	*Tasmanophlebia*						■
GASTROPODA	Ancylidae	*Ferrissia*		■	■			■
	Lymnaeidae	*Pseudosuccinea*	■		■		■	
		sp.						■
	Physidae	*Physa*		■	■	■	■	■
Hemiptera	Corixidae	*Micronecta*		■	■	■	■	■
		sp.			■	■		
	Gerridae							■
	Notonectidae	*Enithares*	■	■		■	■	
		Paranisops			■			■
		sp.		■	■	■		
	Veliidae	*Microvelia*	■			■		
Lepidoptera	Crambidae				■			
Nematoda				■		■		
Odonata	Aeshnidae	*Brevyistyla*		■				
	Coenagrionidae	*Ischnura*		■	■		■	
	Epiproctophora		■					
	Gomphidae	*Austrogomphus*			■		■	■
		sp.	■					■
	Libellulidae		■					
	Synlestidae	*Synlestes*						■
	Zygoptera		■	■	■	■		■
OLIGOCHAETA			■	■	■	■	■	■
Plecoptera	Gripopterygidae	*Dinotoperla*	■					■

CLASS / Order	Family / Sub-Family	Genus	BUR1A	BUR1C	BUR2A	BUR2B	BUR2C	QBYN1
		Illiesoperla						
		Leptoperla						
		sp.						
Trichoptera	Ecnomidae	*Ecnomus*						
	Hydrobiosidae							
	Hydroptilidae	*Hellyethira*						
		Hydroptila						
		Oxyethira						
		sp.						
	Leptoceridae	*Notalina*						
		Oecetis						
		Triaenodes						
		Triplectides						
		sp.						
Turbellaria	Dugesiidae	*Dugesia*						

GHD

16 Marcus Clarke St Canberra ACT 2601
PO Box 1877 Canberra ACT 2601 Australia
T: +61 2 6113 3200 F: +61 2 6113 3299 E: cbrmail@ghd.com.au

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Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
1	Phil Taylor Josh Cox	Jamie Corfield		Norm Mueller		28/03/2014
2	Phil Taylor			Norm Mueller		30/04/2014

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