Icon Water

Murrumbidgee Ecological Monitoring Program

Spring 2014

April 2015

Executive summary

The Murrumbidgee Ecological Monitoring Program commenced in 2008. The project is being undertaken by the GHD Water Sciences Group for Icon 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, Icon 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 Overview

ACTEW Water constructed an intake structure and pipeline to abstract water from the Murrumbidgee River at 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. There are operating rules in place that limit when and how much water can be extracted to ensure that environmental harm is minimised. The Angle Crossing component of the MEMP has focused on the assessment of potential impacts associated with flow reductions in the Murrumbidgee River downstream of Angle Crossing as a result of water abstraction. However, during the current reporting period the only pumping which was undertaken by Icon Water was that of maintenance flows. These flows only have a minimal impact upon flow in the Murrumbidgee River.

Part 1 – Angle Crossing Spring 2014

In spring 2014, the magnitude of the high flow events in the Murrumbidgee River was considerably lower than the previous spring sampling period. There were two events of note, one peaking at just over 3,000 ML/d and a second at just over 5,000 ML/d. There were no events recorded in November and, in fact, flows showed a consistent downward trend following the larger of the two high flow events in mid-October, resulting in base flows of approximately 100 ML/d in the latter part of November.

Total Phosphorus and Total Nitrogen levels exceeded the guideline range at each site, which is consistent with the previous spring, except that concentrations were slightly lower in this study. The pH guideline range was exceeded at two sites: one upstream and one downstream of Angle Crossing and all of the dissolved oxygen (% saturation readings) were below the recommended lower limit of 90%. However, these readings were within the natural range of variation seen at the monitored sites and may have been a response to the increasing surface water temperatures with the accompanying low flows.

Periphyton production (biofilm growth on submerged rocks) can be a useful indicator of flow alteration. In this study, periphyton biomass was estimated from chlorophyll-a concentrations and ash free dry mass (AFDM). The results show that compared to spring 2013, chlorophyll-a and AFDM concentrations were spatially similar. Most of the variation in the periphyton data is attributed to site to site differences such as flow, land use, water quality and biological processes rather than specific changes in the downstream reaches due to M2G.

As with previous sampling events, the water-bug communities found in the riffle and pool/edge habitats were comprised mainly of families that can survive in environments with poorer water quality and some sediment deposition and are less dependent on flowing conditions. This pattern was seen at all monitoring sites, indicating that this was a broad scale response to the low flow conditions at the time of sampling and was unlikely to have any connection with the M2G project.

The river health assessments (based on AUSRIVAS) show that the edge/pool habitat was generally in better condition than the riffle habitats because the number of missing water bugs expected to occur in the edge habitat was low compared to the number of missing water bugs expected to occur in the riffle habitats. This is presumably a result of the low flows encountered over the spring 2014 period because riffle habitats are usually the first to show stress responses to low flow conditions. Even though there were a number of Band A assessments in the edge habitat, the overall site assessments were generally given Band B assessments (‘significantly impaired”), which is consistent not only with the spring 2013 results, but also over the course of the MEMP.

Part 1 – Angle Crossing Recommendations

Over the course of the Murrumbidgee Ecological Monitoring Program, a number of recommendations have been brought forward to Icon Water. Many of these were in line with the adaptive management framework of the MEMP to adjust some of the sampling methods, frequency and scope to accommodate the changes needs of the program and different needs of ICON Water. Most of these recommendations have been compiled into a recommendations summary report (ALS, 2012) and in the last report (GHD, 2014b) five recommendations were added, which included a review of current monitoring methods and a statistical evaluation of two of the key monitoring stations on the Murrumbidgee River, namely Lobb’s Hole and the station located upstream of Angle Crossing. Outside of these items, there are no further recommendations for the Angle Crossing component of this study.

Part 2 –Burra Creek Overview

The operational phase of the M2G will involve the transfer of water from Angle Crossing to Burra Creek, where it will be released as a run of river flow into Googong reservoir for storage. Up to 100 ML/d will be pumped to Burra Creek, with the natural flow regime characterised by low base flows and peak flow events that only exceed 100 ML/d for short periods of time. Consequently, this could potentially result in changes to the hydrological regime of this system and subsequent changes to its ecology (both detrimental and beneficial). The Burra Creek component of the MEMP has focused on assessing the potential impacts of changes in hydrology on aquatic biota.

Monitoring for the Angle Crossing and Burra Creek components of the MEMP has been carried out in autumn and spring for five years. This includes a baseline monitoring phase between 2009 and 2012 and, nominally, an operation phase from August 2012 to present. However, since the completion of the M2G in August 2012, the system has only been operating in standby mode. Only limited trial and maintenance abstractions and releases have occurred. Hence the monitoring to date, including the last two years, largely represents an extended baseline survey. However, it has encompassed a range of natural flow conditions and, consequently, has been useful in terms of collecting data that allows a better understanding of the relationships between biota and flow with better predictive capacity in respect to the likely nature of changes that will occur once the M2G goes into full operation.

Monitoring to date has covered ACT AUSRIVAS macroinvertebrate sampling, periphyton sampling, water quality monitoring (via in situ testing, laboratory analysis and continuous data loggers) and an assessment of hydrology at locations upstream and downstream of Angle Crossing and the nominated release point in Burra Creek.

Part 2 –Burra Creek Spring 2014

Rainfall in spring 2014 was the lowest recorded in the Burra Creek catchment since the inception of the MEMP. As a result, the mean flow in Burra Creek was approximately four times lower compared to 2013. There were fewer high flow events in 2014 and those that did occur were of a much lower magnitude than peak flow events of previous years.

Electrical conductivity predictably exceeded guideline values at all sites downstream of Cassidy’s Creek, while pH was higher than the recommended upper limit of 8.0 at all of the sites downstream of Williamsdale Bridge and at the Queanbeyan control site. Total Nitrogen values exceeded the guideline values at all sites, including the Queanbeyan Control sites, which may be a result of concentration effects from low flows. Dissolved oxygen was also outside of the guideline values and this may also be due to low flows and elevated surface water temperatures prevailing in 2014.

In this study, there were no location differences in periphyton biomass; however at the site immediately downstream of the discharge point, there was a spike in chlorophyll-a concentrations, which is in agreement with our field observations that there were several large patches of filamentous algal growth at this site. It is unclear why this site saw such a significant spike in chlorophyll-a, although one potential explanation is that there is a greater groundwater contribution to surface flows at this site. Holden's Creek has previously been suggested to contribute to higher nutrient inputs at this site, but during spring 2014 base flows were negligible, so this source of nutrients has been largely ruled out.

Water-bug communities showed a moderate amount of similarity between sampling locations for both the riffle and the pool/edge samples. The water bugs from the riffle samples were dominated by numbers of moderately pollution-tolerant families that feed preferentially on algae which was commonly observed in this habitat. There was an increase in the number of flow-sensitive water-bugs with distance downstream of the discharge point on Burra Creek, which we suggest is in response to the natural increase in flow volume with distance downstream. This also correlates strongly with increasing SIGNAL scores with distance downstream.

One reason for this variability is that in response to low flow stress, aquatic ecosystems can show greater patchiness in water-bug distributions because low flows impact on water quality and result in aquatic habitat contraction. Nonetheless, this variation was seen at all sampling sites, which indicates that the overriding impact on the system during spring was a prolonged period of low flows across the broader study area.

Overall, the AUSRIVAS results show no change in condition at the Queanbeyan control site or at the site immediately downstream of the discharge point in Burra Creek since 2013, but do show a decline in condition at the upstream site and at the Burra Creek sites downstream of Burra Road. The assessment at upstream site on Burra Creek in spring 2014 is the first "close to reference" assessment for that site and is somewhat at odds with the general condition of this site, given the heavy inundation by macrophytes, low flows and heavily silted riffle habitat. It is unclear why there health improved at this site, but there were increases in taxa richness at four of the five sites sampled, which may suggest that more favourable conditions existed over a broader scale at the time of sampling, including this site.

In the edge habitat, however, there was a significant decrease in water-bug diversity compared to last year. The loss of taxa occurred from six higher taxonomic groups, most of which were not used in the AUSRIVAS model. This explains why, despite the reduction of taxa richness by approximately 50% compared to spring 2013, there were no obvious impacts on the AUSRIVAS river health assessment results for edge habitat. Factors such as declines in the water level and large patches of algal growth on the substrate and the surface may have contributed to the reduced number of water-bug diversity in edge habitat.

Part 2– Burra Creek Recommendations

In the last monitoring report (autumn 2014), five additional recommendations were made to those previously brought forward. These included a revision of the periphyton monitoring methods and, in fact, a revision of all sampling methods in recognition of the potentially long term "maintenance" mode of operation for M2G. It was also recommended that two additional water quality monitoring locations be included into the program to capture event based water quality information in accordance with the M2G operational plan (specifically looking at TN and TP) and also to include a sample collection point at the discharge point to help better understand that dilution process.

In terms of the revised MEMP, after reading the Jacobs review of the MEMP (Jacobs, 2014) and taking into consideration the different modes of operation that have been proposed to guide future monitoring of Burra Creek, it is recommended that the inclusion of BUR 2c be reconsidered for the impact monitoring component of the project for the following reasons:

1. The riffle habitat is immediately downstream of an erosion hotspot. Therefore linkages between significant erosion, should it occur during operation, and potential impacts to riffle quality and river health will be relatively straight forward;

2. This is a key site given that it is close to Googong reservoir so understanding whether any potential impacts from M2G extend this far downstream is considered to be an important part of the monitoring program;

3. The baseline data recorded for this site is of a very high standard, which will make impact assessments very informative in terms of comparisons to the historical records.

Table of contents

Table index

Figure index

Plate index

Appendices

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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 (Icon Water 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 Program

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 Program (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 Icon 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, Icon 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;
- changes to channel morphology;
- changes to velocity; and
- changes to water 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 forms 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 nominal 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). 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.	Davies *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 comprised of 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 to 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; including fish species (GHD, 2015). This is potentially due to the use of fish egg filters which were installed during the construction phase of M2G.
	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, 2013).

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.

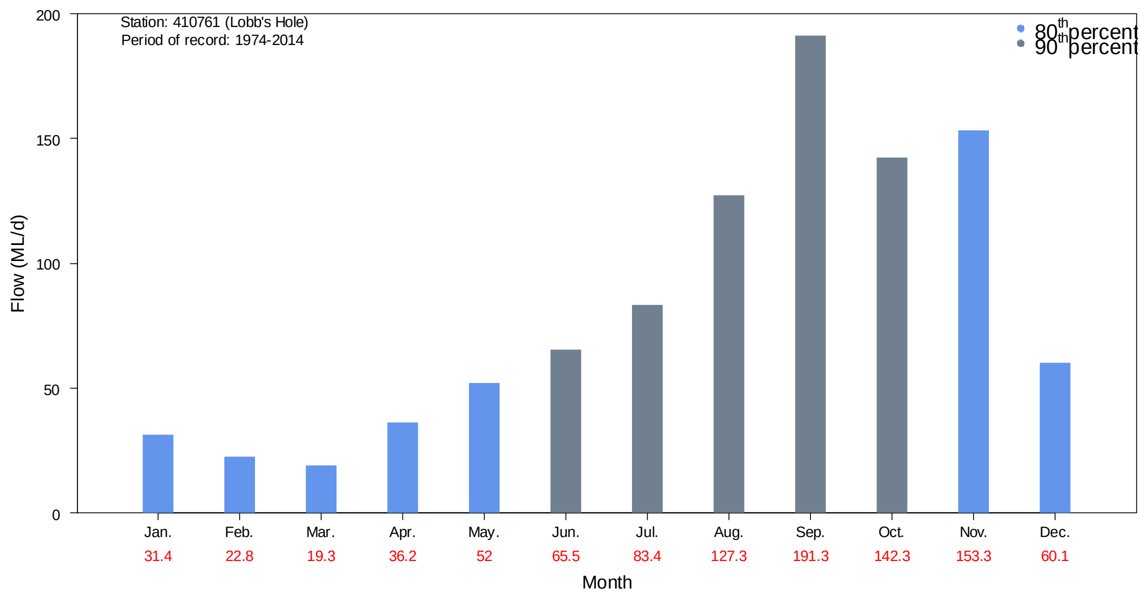

Figure 1-1. Environmental flow values for the operation of the M2G pipeline

Note: Flow data values for data to 30/11/2014. 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 are 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, 2014).

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. In the spring of 2010, the drought broke in the ACT and surrounding NSW regions and frequent high flow events occurred throughout that year, resulting in an upward trend in the monthly average base flows (Figure 1-2). More recently, during the period between November 2012 and May 2013, there was a decline in base flows in the Murrumbidgee River following a particularly dry summer and autumn. As of 30th November 2014 base flows in the Murrumbidgee River are currently trending upwards after a particularly dry summer (Figure 1-2).

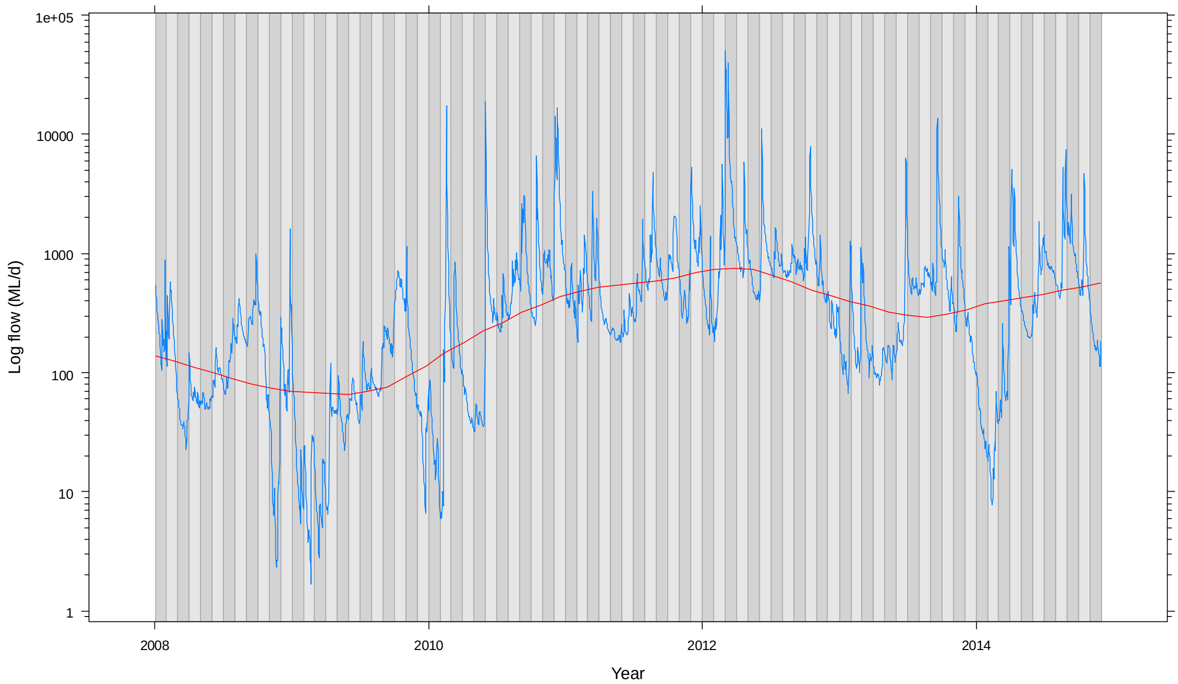

Figure 1-2. Hydrograph of the Murrumbidgee River at Lobb's Hole (410761) from 2008 to November 2014

Note: The red line is a locally weighted smoother (LOESS) trend line with a smoothing coefficient of 0.3.

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). Burra 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 at >80% capacity, the lower sections of Burra Creek become inundated by the reservoir.

The mean daily flow in Burra Creek (from January 1st 2008 to the 30th November 2014) was 11.2 ML/d.

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 % (1.3%) 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). Summer in 2014 was the driest since 2010, however autumn rainfall balanced out the smoothing curve resulting in positive trend since September 2013.

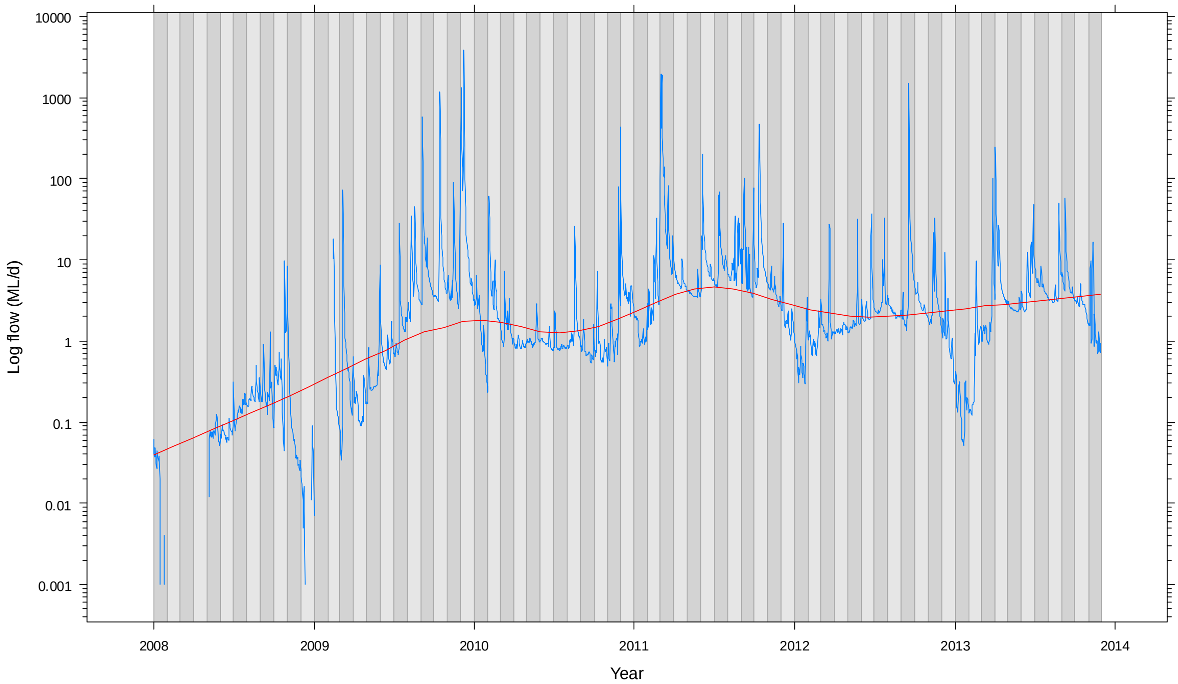

Figure 1-3. Hydrograph of Burra Creek at the Burra Road weir (410774) from 2008 to November 2014

Note: The red line is locally weighted smoother (LOESS) trend line with a smoothing function coefficient of 0.3.

1.5 Project objectives

The Murrumbidgee Ecological Monitoring Program (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, notwithstanding potential increase in EC associated with the transferred water.

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 Corporation, 2010) of the OEMP (ACTEW Corporation, 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 Icon 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 Icon 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 Icon 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 2014 sampling. Specifically, as outlined in the MEMP proposal to ACTEW Water (GHD, 2014) this work includes:

- Sampling conducted in spring 2014;
- 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 (as measured by Ash Free Dry Mass) 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, 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 number and location of sites to be included in this study were then reviewed by an independent biometrician (Robinson, 2009), which resulted in the final site selection. Robinson (2009) also provided recommendations towards the number replicates and sub-samples that should be included in this program. 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 locations and details

Component of the MEMP		Site Code	Location	Alt. (m)	Landuse	Latitude	Longitude
PART 1	**Angle Crossing**	MUR 15	Near Colinton - Bumbalong Road	658	Grazing / Recreation	**-35.866300**	**149.135017**
		MUR 16	The Willows - Near Michelago	646	Grazing / Recreation	**-35.688033**	**149.136867**
		MUR 18	U/S Angle Crossing	608	Grazing	**-35.587542**	**149.109902**
		MUR 19	D/S Angle Crossing	608	Grazing / Recreation	**-35.583027**	**149.109486**
		MUR 23	Point Hut Crossing	561	Recreation / Residential	**-35.451317**	**149.074400**
		MUR 28	U/S Cotter River confluence	468	Grazing	**-35.324382**	**148.950381**
PART 2	**Burra Creek**	BUR 1a	Upper Burra Creek	815	Native	**-35.598461**	**149.228868**
		BUR 1c	Upstream Williamsdale Road	762	Grazing / residential	**-35.556511**	**149.221238**
		BUR 2a	Downstream Williamsdale Road	760	Grazing	**-35.554345**	**149.224477**
		BUR 2b	Downstream Burra Road Bridge	751	Woodland / Grazing	**-35.541985**	**149.230407**
		BUR 2c	Approximately 1 km u/s London Bridge	730	Recreational / Grazing	**-35.517894**	**149.261452**
		QBYN 1	Flynn's Crossing	685	Recreational / Native	**-35.524317**	**149.303300**

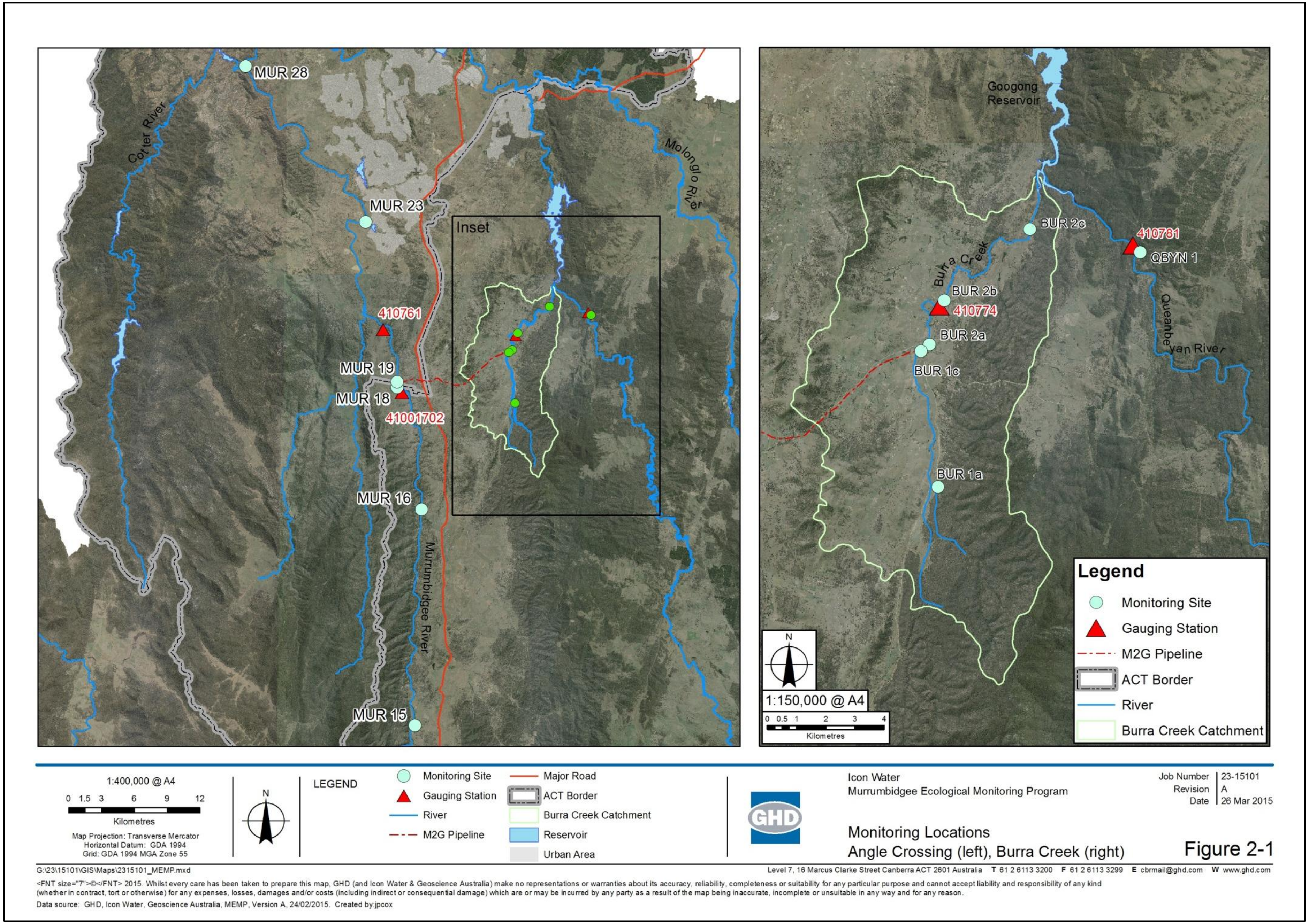

Figure 2-1. Map of site locations on the Murrumbidgee River, Burra Creek and the Queanbeyan River for the MEMP

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.*

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 (Nichols *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 (Nichols *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 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 Nichols *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 net *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. Genus identification was recommended by Chessman (2008) from his review of the MEMP project design. 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 were 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 3.1.2 (R Development Core Team, 2014). Descriptive statistics performed on rainfall, hydrology and continuous water quality parameters were organised in the time series data management software - HYDSTRA©. 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 “LMERConvenienceFucntions” (Tremblay and Ransijn, 2013).

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 2014 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.

Where appropriate, post-hoc tests were carried out using the p-values function available in the R package “LMERConvenienceFucntions” (Trembley and Ransijn, 2013).

Taxa Richness

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 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.

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.

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	EDGE	Explanation
	O/E Band width	O/E Band width	
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.

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 produced using lme4 (Bates *et al*., 2013) a statistical package applied in the R environment (R Development Core Team, 2014). 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.

4. Angle Crossing

4.1 Summary of sampling and river conditions

Spring sampling was originally scheduled to occur in the week of the 20th of October, however a high flow event on the 16th and 17th meant a delay of three weeks to the 11th and 12th of November.

Conditions over the two day period were fine, with maximum air temperatures recorded as 26.9 °C and 27.2 °C on the 11th and 12th of November respectively (BOM, 2014). River flow at Lobb's Hole was continuing to fall following the high flow events (~5,000 ML/d) in mid-October, which disrupted the original dates for the sampling run. All sampling sites appeared to have benefitted from the two events during this spring as indicated by noticeably less sand and silt in the riffle habitat. The exception was at MUR 18, where it looked like there were fresh sand deposits through the main riffle habitat and along the river margins.

Two samples from both the edge and riffle habitats were collected at all Angle Crossing sites with the exception of MUR 28, where there was insufficient edge habitat for a second sample (Table 4-1). Site photographs are shown in Plate 4-1, while full site summaries can be found in Appendix D.

Table 4-1. Samples collected during spring 2014 at Angle Crossing

Site	Riffle	Edge	Comment
MUR 15	2	2	All samples collected
MUR 16	2	2	All samples collected
MUR 18	2	2	All samples collected
MUR 19	2	2	All samples collected
MUR 23	2	2	All samples collected
MUR 28	2	1	Insufficient edge habitat for a second sample

MUR 15 – 190 ML/d

MUR 16 – 190 ML/d

MUR 18 – 220 ML/d

MUR 19 – 220 ML/d

MUR 23 – 170 ML/d

MUR 28 – 170 ML/d

Plate 4-1. Photographs of the Angle Crossing sites during spring 2014 sampling

Note: Flow values from the relevant gauging sites (410050: MUR 15 & 16; 41001702: MUR 18 & 19; 410761: MUR 23 & 28)

4.2 Hydrology and rainfall

Rainfall during spring 2014 is the lowest recorded since prior to 2009 (Figure 4-1) with a total of 92.4 mm at the Lobb's Hole rainfall gauge (Table 4-2). The highest rainfall occurred during October at both rainfall stations (Lobb's Hole: 410761; upstream Angle Crossing: 41001702), with 53.8 mm at Lobb's Hole, compared to the lowest rainfall during September with 9.0 mm at Lobb's Hole. Total rainfall for the period was 107.0 mm at the upstream Angle Crossing rainfall gauge (Table 4-2). Rainfall and flow summaries for the season are presented in Table 4-2.

The hydrograph at the beginning of spring was receding from 2,000 ML/d following a large high flow event which peaked on the 27th of August (Figure 4-3). Although very little rainfall was recorded during September, the first high flow event of the season occurred, with flows increasing from already elevated levels peaking at almost 3,500 ML/d at Lobb's Hole (Figure 4-2). This high flow event was the result of rainfall farther upstream in the catchment. The largest high flow event of the season occurred in October and peaked at over 5,000 ML/d at Lobb's Hole, which postponed sampling until mid-November, at which time, flows had reduced to near base flow levels.

During spring 2014 sampling, flow was more than 100 ML/d lower at the upstream sites and more than 200 ML/d lower at the downstream sites when compared to spring 2013 sampling. Overall flow during spring 2014 was lower compared to spring 2013 with the 95th percentile for 2014 over 2,200 ML/d compared to the 95th percentile from spring 2013 of over 4,900 ML/d. This difference is largely due to the large event during September 2013, which reached almost 20,000 ML/d, which was the largest event in the Murrumbidgee River in the last two years (Figure 4-3).

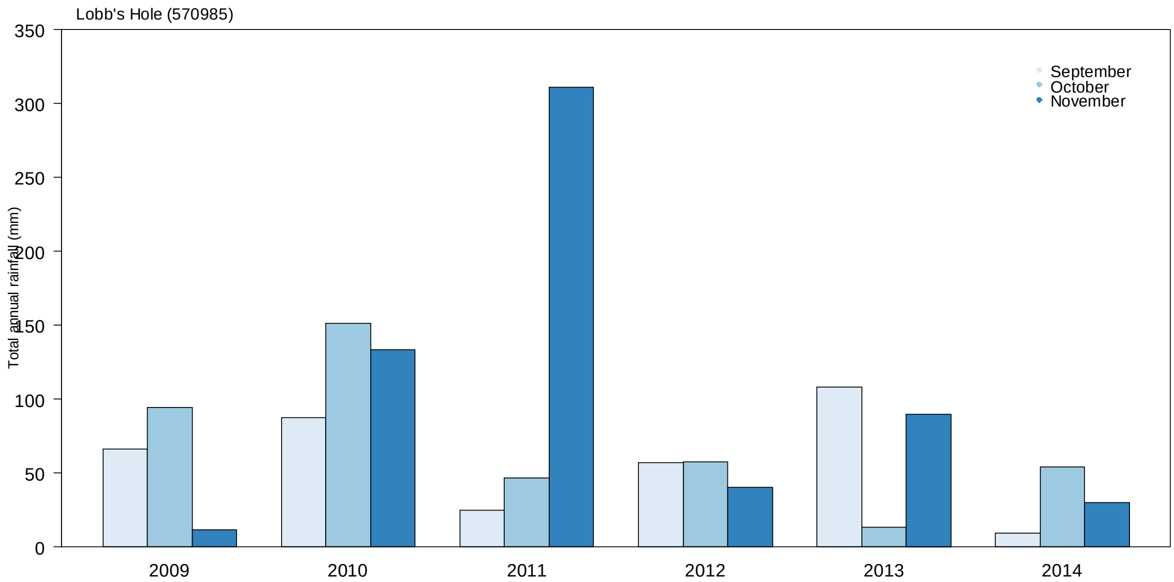

Figure 4-1. Annual comparison of spring rainfall (mm) recorded at Lobb's Hole (570985)

Table 4-2. 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	34.8	1,200	9.0	1,300
October	47.0	870	53.8	890
November	25.2	230	29.6	190
Spring (mean)	107.0 (35.7)	770	92.4 (30.8)	800

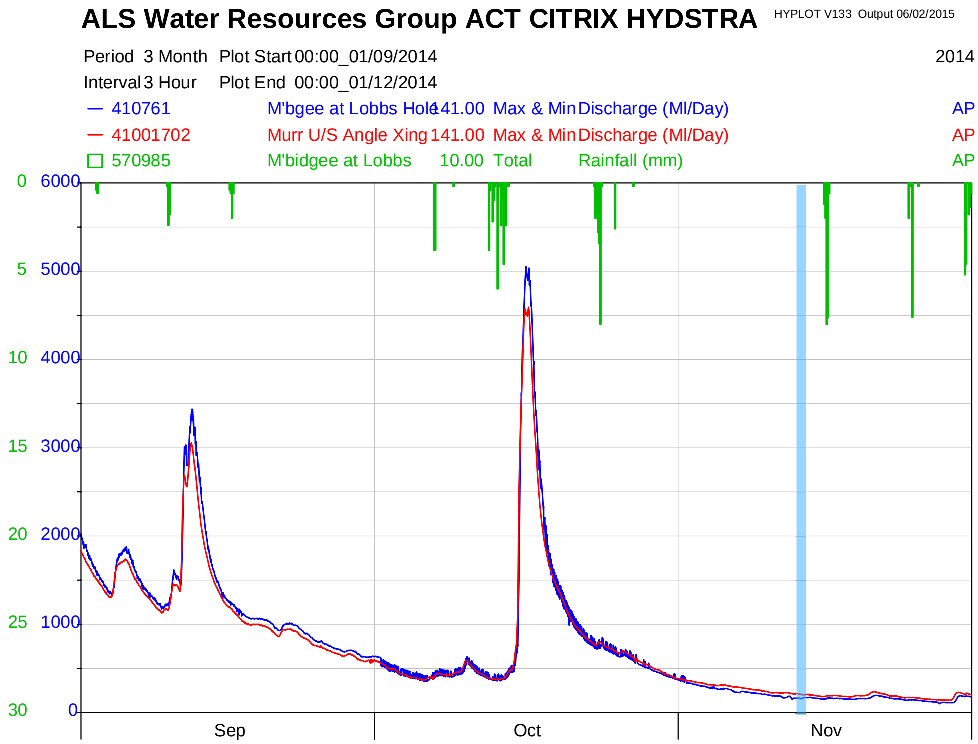

Figure 4-2. Spring hydrograph of the Murrumbidgee River upstream (41001702) and downstream (410761) of Angle Crossing

Note: Sampling time highlighted by blue shading.

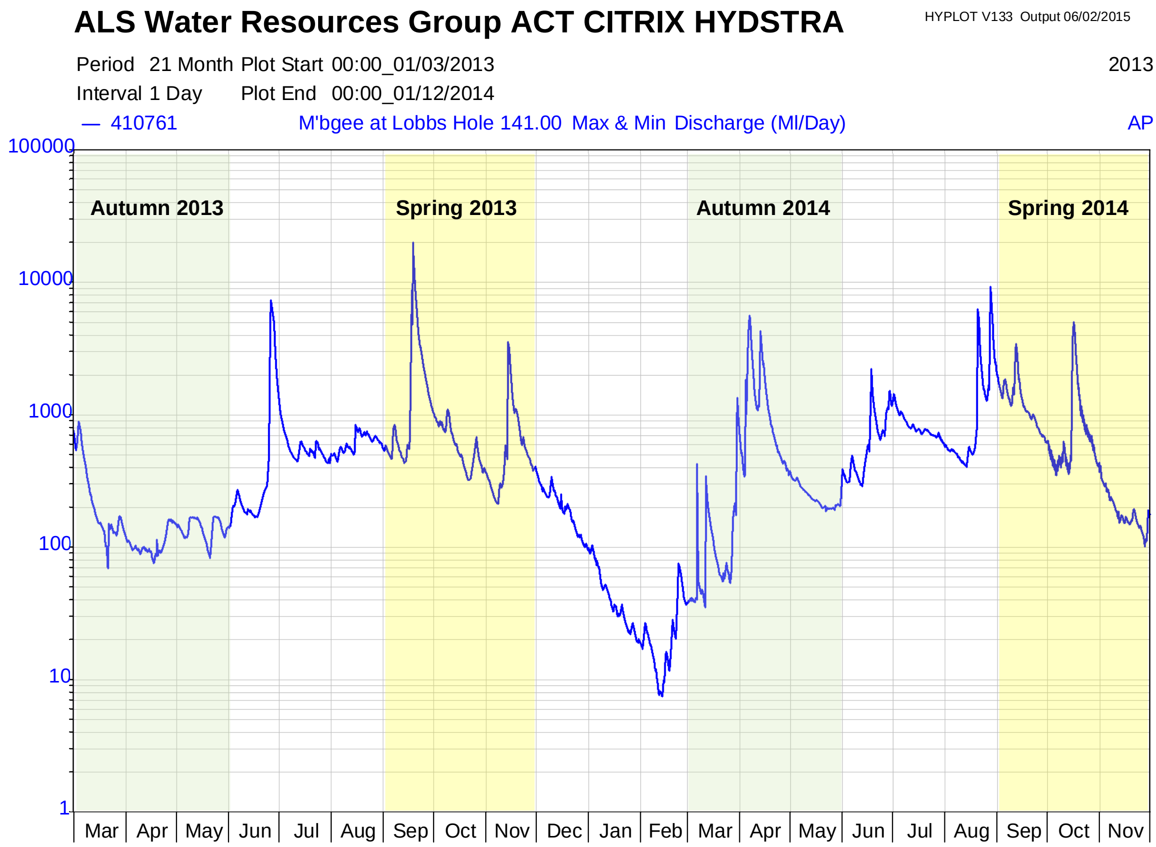

Figure 4-3. Hydrograph from Lobb's Hole highlighting the past four sampling periods between March 2013 and November 2014

4.3 Water quality

4.3.1 Grab samples and *in-situ* parameters

Results from the *in-situ* recorded parameters and grab samples are presented in Table 4-3, highlighting the exceedances, which were recorded against the ANZECC & ARMCANZ (2000) guidelines. There was no evidence of any differences between upstream and downstream reaches in the grab sample and *in-situ* recorded parameters. Exceedances for the season were found for four parameters, with electrical conductivity (EC), turbidity, and NO_X all recorded within the recommended ranges at all sites.

Values for pH were outside the recommended range at two sites (MUR 16 and MUR 19)in spring 2014, which was slightly less than in spring 2013 (3 sites). The two sites which exceeded the guidelines for pH during spring 2014, MUR 16 & 19, have only increased marginally in value by 0.11 and 0.01 pH units respectively. The pH readings at all of the other sites decreased compared to values recorded in spring 2013. Dissolved oxygen (DO) readings were all below the lower recommended range during spring 2014 with values ranging from 80.6 – 89.7% saturation (Table 4-3). All of the Angle Crossing sites were recorded at greater than 100% saturation and within the recommended range (90-110% saturation) during spring 2013, meaning that there has been a reduction in DO across all sites of greater than 10% since that time, most likely due to the reduced flow conditions.

Nutrient levels were elevated above the ANZECC & ARMCANZ (2000) guidelines at all sites for total nitrogen (TN) and total phosphorus (TP), while NO_X values were not only all below the guideline range, they were below the detectable limit (0.002 mg/L), with the exception of MUR 28 which recorded 0.003 mg/L (Table 4-3). These results are consistent with those recorded during spring 2013 when all sites also exceeded the ANZECC & ARMCANZ (2000) upper limits for TN & TP. All sites recorded lower values for TN & TP in spring 2014 when compared to spring 2013, with the exception of TP at MUR 18, which was recorded at 0.028 mg/L during both spring sampling rounds.

4.3.2 Continuous water quality monitoring

The continuous water quality data collected from Lobb's Hole (410761) and upstream Angle Crossing (41001702) are presented in Figure 4-4 and Figure 4-5 respectively. Summary statistics presented in Table 4-4 show that ANZECC & ARMCANZ (2000) guideline exceedances were minimal during spring 2014, with most exceedances related to increased turbidity from the high flow events during September and October. There were also some DO readings at the upstream Angle Crossing site during both October and November that were outside the guideline range. Monthly and seasonal values are shown in Table 4-5.

The water quality parameters at the two stations responded as expected during the high flow events of the season including a decrease in EC, an increase in turbidity and reduced variability in the DO diurnal trend. Outside of the high flow events parameters were consistent with diurnal trends present in the temperature, pH and EC data, with temperatures steadily increasing towards the beginning of summer. Turbidity readings at Lobb's Hole (Figure 4-4) showed high variability during October and November; however recorded values were still predominantly within the ANZECC & ARMCANZ (2000) recommended range. This data has not been verified and archived at the time of writing and this high variability is likely to be removed once this process has been completed.

Table 4-3. *In-situ* water quality results from Angle Crossing during spring 2014

ANZECC and ARMCANZ (2000) guidelines are in yellow parentheses, yellow cells indicate values outside of the guidelines.

	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)	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	11/11/2014	9:30	21.6	96.3	10.10	10	7.78	84.3	7.43	43	< 0.002	< 0.002	< 0.002	< 0.002	0.032	0.30
	MUR 16	11/11/2014	12:20	22.5	96.9	12.5	12	8.04	86.1	7.44	45	< 0.002	< 0.002	< 0.002	< 0.002	0.035	0.34
	MUR 18	12/11/2014	13:15	22.8	98.2	8.48	11	7.99	88.6	8.16	58	< 0.002	< 0.002	< 0.002	< 0.002	0.028	0.33
Downstream	MUR 19	11/11/2014	14:50	22.9	101.2	9.13	9	8.07	86.5	7.37	46	< 0.002	< 0.002	< 0.002	< 0.002	0.026	0.32
	MUR 23	12/11/2014	11:00	22.9	110.9	9.11	10	7.79	89.7	7.96	48	< 0.002	< 0.002	< 0.002	< 0.002	0.030	0.34
	MUR 28	12/11/2014	9:15	22.1	107.0	8.62	10	7.84	80.6	7.03	50	0.003	0.003	< 0.002	< 0.002	0.025	0.36

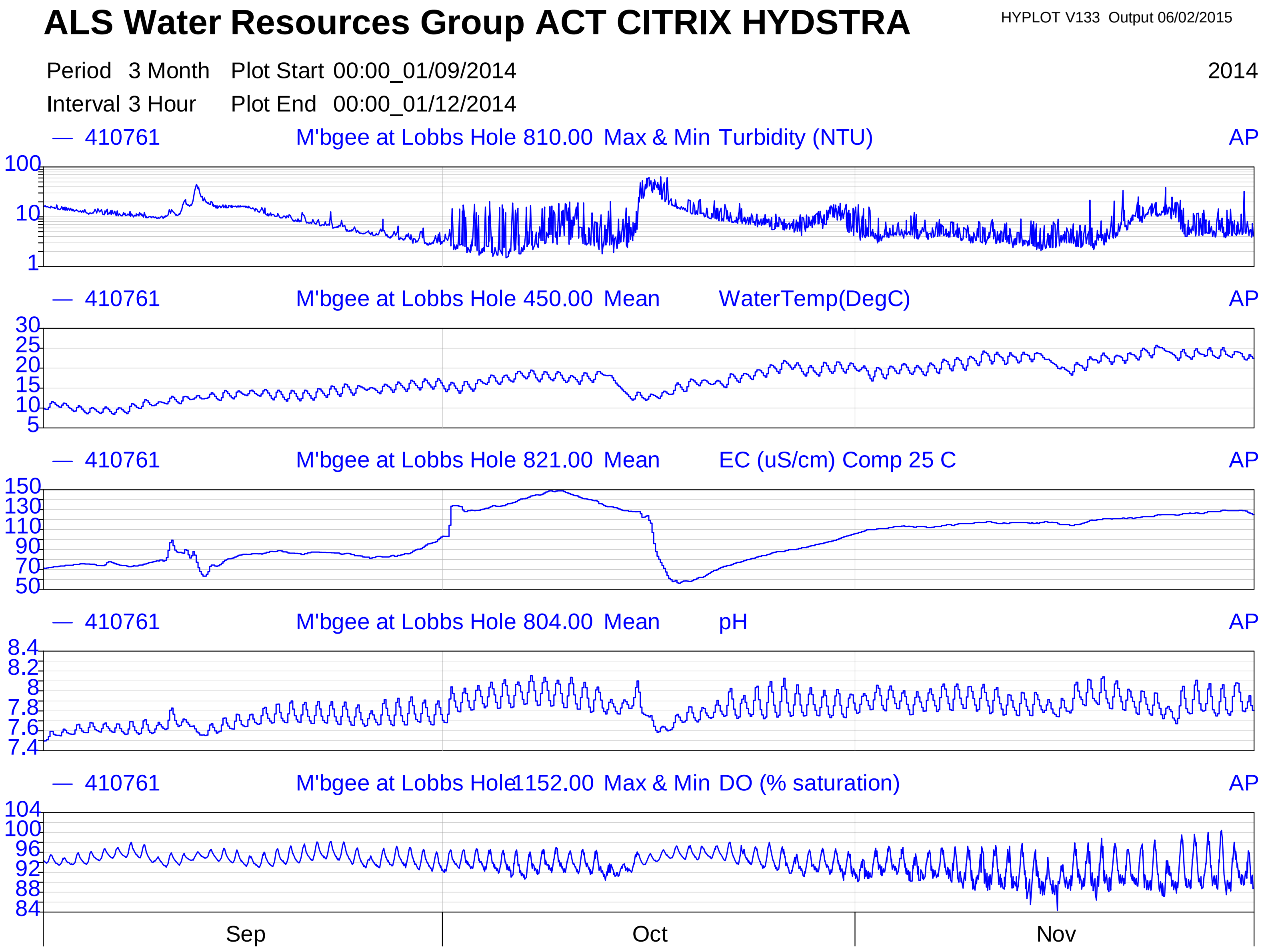

Figure 4-4. Continuous water quality records from Lobb's Hole (410761) for spring 2014

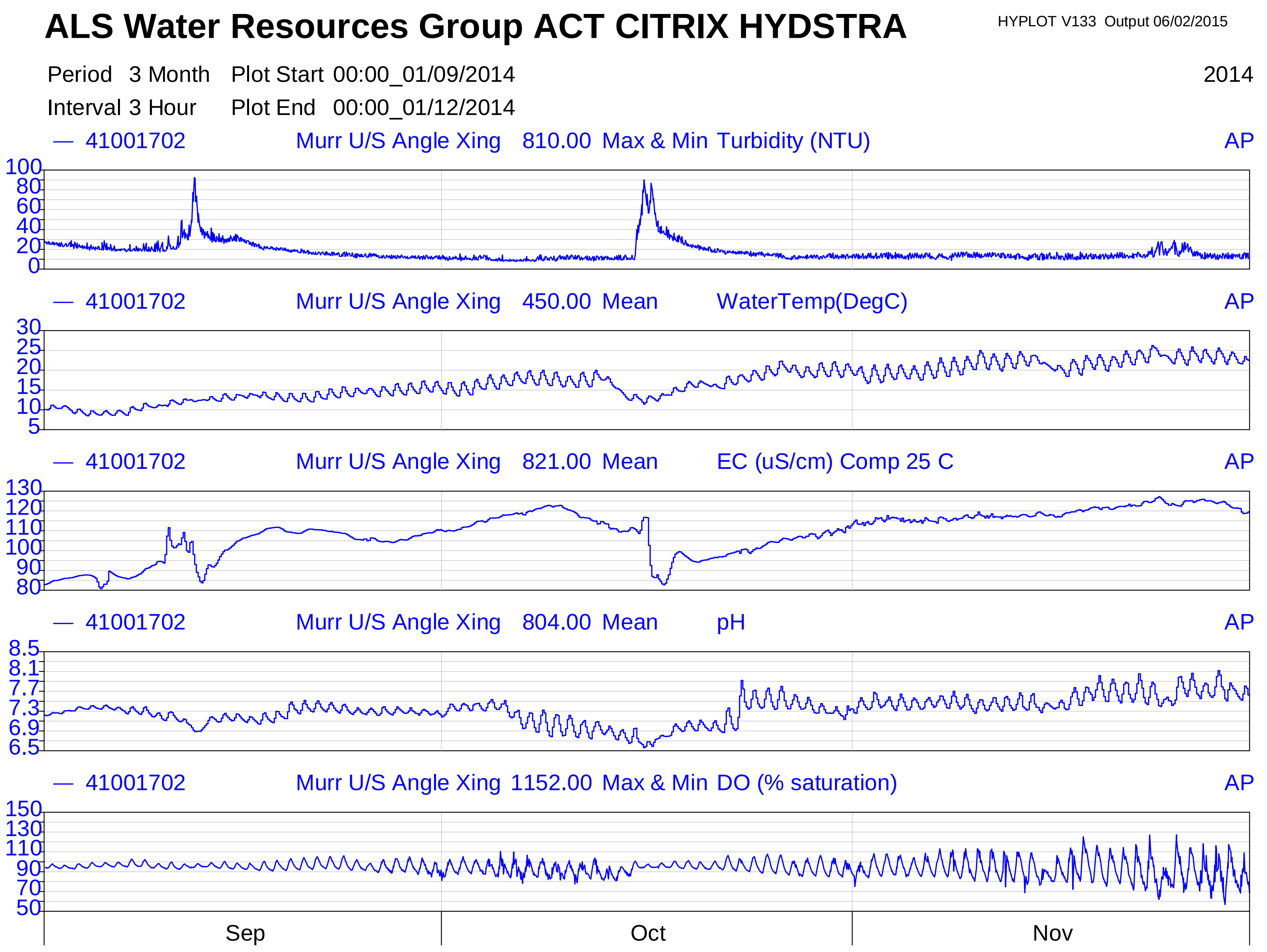

Figure 4-5. Continuous water quality records from upstream Angle Crossing (41001702) for spring 2014

Table 4-4. 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	100	100	76.7	96.7	100	100
October	100	100	100	100	87.1	93.5	93.5	100
November	100	100	100	100	100	100	80.0	100
Spring	**100**	**100**	**100**	**100**	**87.9**	**96.7**	**91.2**	**100**

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

Table 4-5. 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	12.57	12.78	99.91	81.88	7.25	7.69	21.18 (92.30)	10.75 (44.52)	91.58-98.03	93.77-96.17
October	17.08	17.21	108.29	108.54	7.15	7.87	16.55 (90.10)	9.43 (63.60)	86.54-97.69	92.01-95.91
November	21.68	21.90	119.33	118.67	7.55	7.89	13.48 (28.90)	5.64 (38.50)	80.90-99.33	90.04-94.08
Spring	**17.11**	**17.30**	**109.18**	**103.03**	**7.32**	**7.82**	**17.07 (92.30)**	**8.61 (63.60)**	**80.90-99.33**	**90.04-96.17**

Note: All values are means, except dissolved oxygen (% saturation) which is expressed as daily mean minimums and maximums for the month. ANZECC & ARMCANZ (2000) guidelines are inside yellow parentheses. Turbidity readings are monthly means with monthly instantaneous maximums in parentheses.

4.4 Periphyton

The range of values from spring 2014 were comparable to those for spring 2013 (GHD, 2014a) although there were some differences in the spatial patterns between sampling events. For example, in this study there was a decrease in median values of chlorophyll at MUR 18 and MUR 19 even though the maximums were approximately the same (~20,000 µg/m^2) at MUR 19 for both sampling periods. There was a three-fold increase in the maximum value at MUR 16 and concentrations declined significantly at MUR 15 compared to spring 2013.

Upstream of Angle Crossing the estimates of chlorophyll a ranged from 1,729 µg/m^2 at MUR 15 to 31,069 µg/m^2 at MUR 16 with an average of 12,697 µg/m^2 (± 5,609 µg/m^2 CI) (Figure 4-6). Downstream of Angle Crossing the range was between 3,186 µg/m^2 and 45,444 µg/m^2 at MUR 19 and MUR 28 respectively with an average of 18,489 µg/m^2 (± 5,507 µg/m^2 CI), although these differences in means were not statistically significant ($F_{1,4}$ = 0.96; *P*=0.37: Table 4-6). This reflects the high degree of variability between sampling sites irrespective of location.

Site to site variation was visually less pronounced in the AFDM results (Figure 4-7) compared to the chlorophyll a samples and this is further indicated by the lower amount of variance explained by site effects (3.83%; Table 4-6**).** The highest amount of organic matter was found at MUR 18 (19,873 µg/m^2) and MUR 19 (21,198 µg/m^2) while median values were highest at MUR 18 and MUR 28. AFDM was slightly higher at upstream sites (5,514 µg/m^2 ± 2,250 µg/m^2 CI) compared to downstream sites (4,306 µg/m^2 ± 2,687 µg/m^2 CI), but there was no evidence that this difference was statistically significant ($F_{1,4}$ = 0.96; *P*=0.37: Table 4-6).

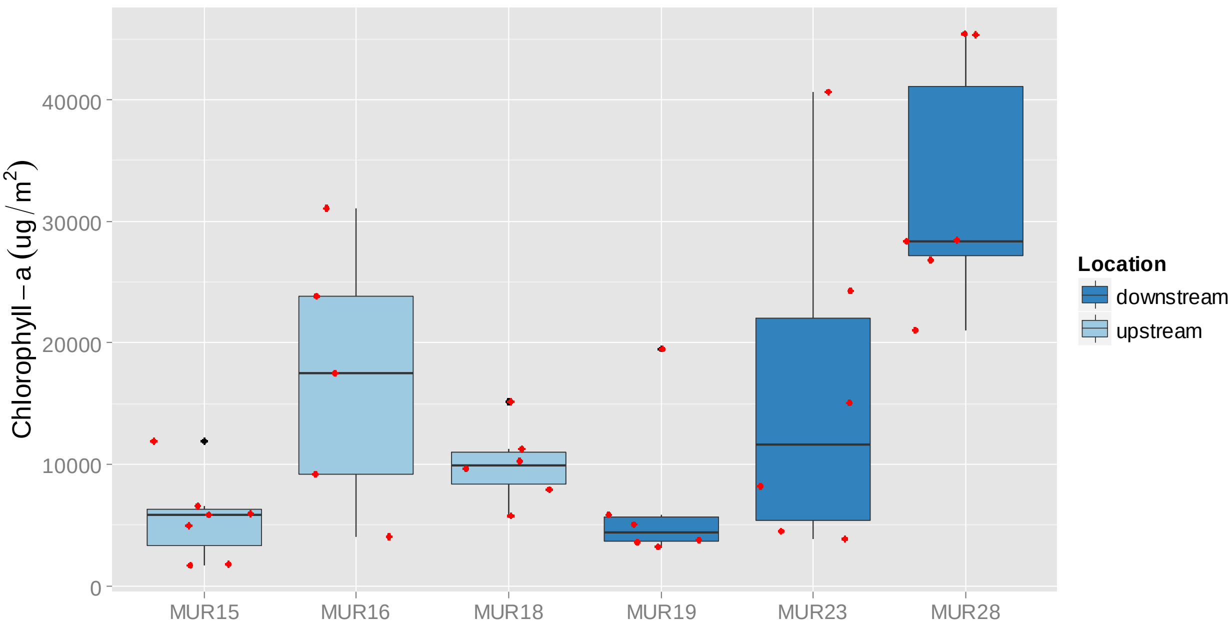

Figure 4-6. Chlorophyll-a concentrations at Angle Crossing sites

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

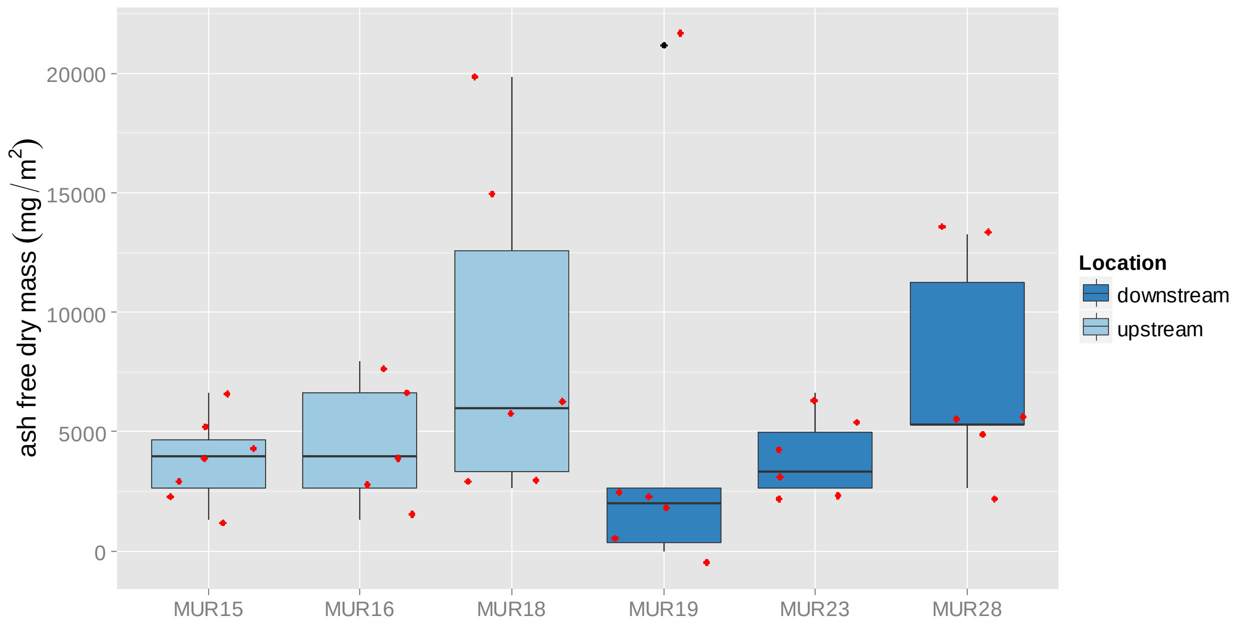

Figure 4-7. Ash free dry mass at Angle Crossing sites

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

Table 4-6. Nested analysis of variance results for chlorophyll-a and AFDM concentrations

Response	Source	DF	F	P-value	Variance component (%)
Chlorophyll-*a*	Location	1	0.96	0.37	0.00
	Site [Location]	4	7.95	0.00	53.70
	Total	35			
AFDM	Location	1	0.00	0.91	0.00
	Site [Location]	4	1.24	0.32	3.83
	Total	35			

4.5 Macroinvertebrates

4.5.1 Community assemblages

Riffle Habitat

Results from the ordination analysis indicate that there is little to distinguish the macroinvertebrate faunas between the upstream and downstream locations (R=0.18; *P*=0.20). All of the sampling sites form a single group with 55% similarity and at 60% similarity only MUR 15 branches to form its own cluster (Figure 4-8). High abundances of Dipterans (Simuliidae; Orthocladinae and Chironomidae) tended to characterise all of the monitoring sites, as well as moderately tolerant mayflies such as Caenidae (SIGNAL 2 = 4), Baetidae (SIGNAL=5) and Hydroptilidae (SIGNAL=4). The pattern in the NMDS ordination plot is suggestive of a longitudinal gradient from MUR 15 (farthest upstream site) to MUR 23 and MUR 28.

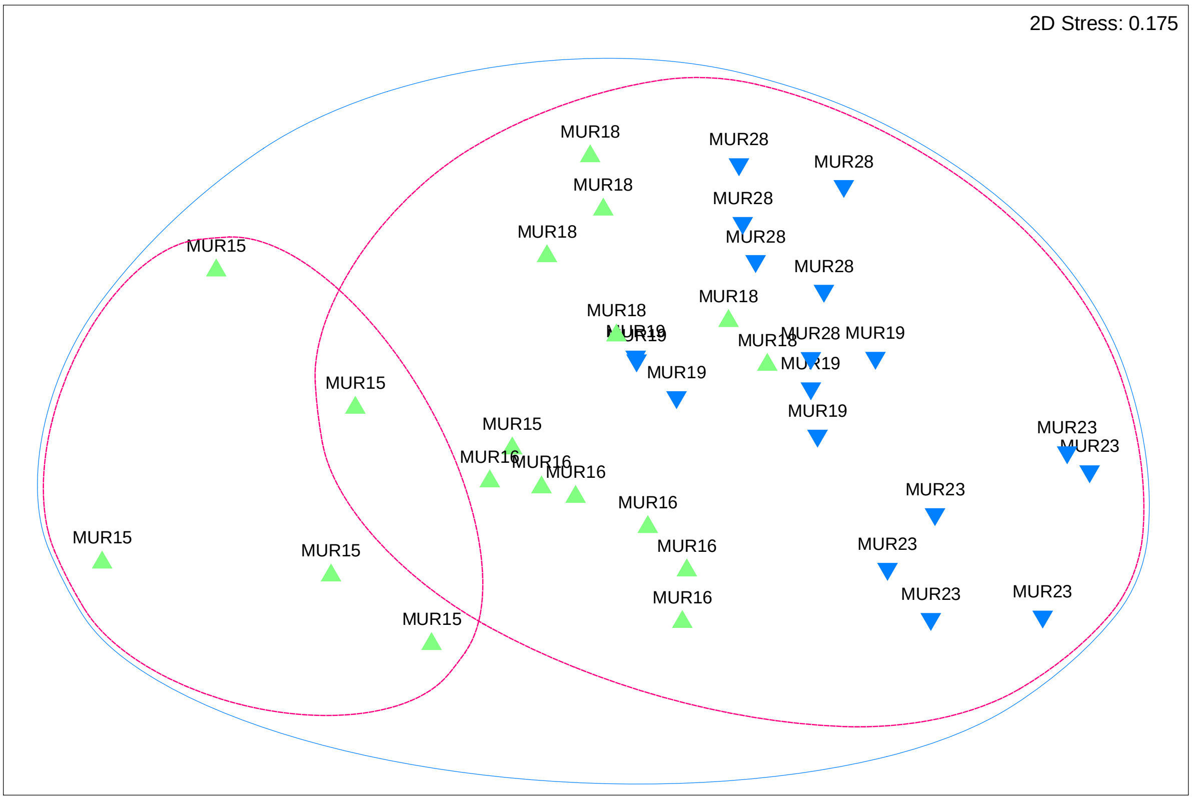

Figure 4-8. Non-metric multidimensional scaling of macroinvertebrate data (genus level) collected from the riffle habitat

Note: Blue ellipses represent 55% similarity and the red ellipses indicate 60% similarity groups. Green triangles are upstream sites and blue triangles are downstream sites.

The number of macroinvertebrate families fell within a relatively small range in spring 2014 (18-22). The highest richness value was found at MUR 18, while the lowest (18) were recorded at all of the downstream sites. Genus richness showed a higher degree of variation and ranged from 22 at MUR 23 to 31 at MUR 18 (Figure 4-9). There was no change in the number of families in the Ephemeroptera, Plecoptera and Trichoptera (EPT) index of sensitive taxa at MUR 16 or MUR 19. However, there were gains in taxa at MUR 15 and MUR 18 and losses at MUR 19 and MUR 23 compared to spring 2013. At the genus level, however, there were up to ten additional taxa compared to spring 2013. Increased genus richness was found at all of the upstream sites and MUR 28. The largest increase was at MUR 18 (10 genera) and MUR 15 (seven genera). Compared to spring 2013, EPT richness ranged from six families at MUR 23 to nine families at MUR 18. At the genus level, EPT ranged from 12 at MUR 23 to 17 at MUR 18.

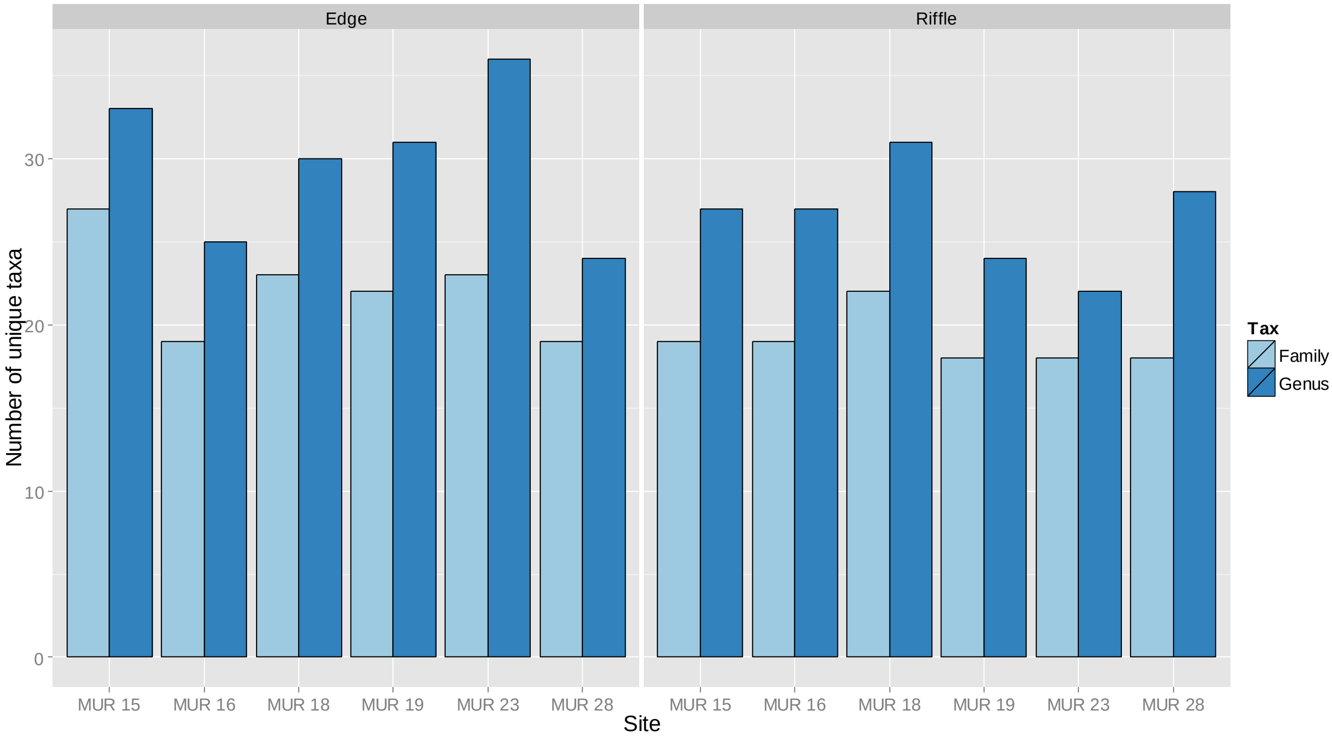

Figure 4-9. Total number of taxa at genus and family level from riffle and edge habitats

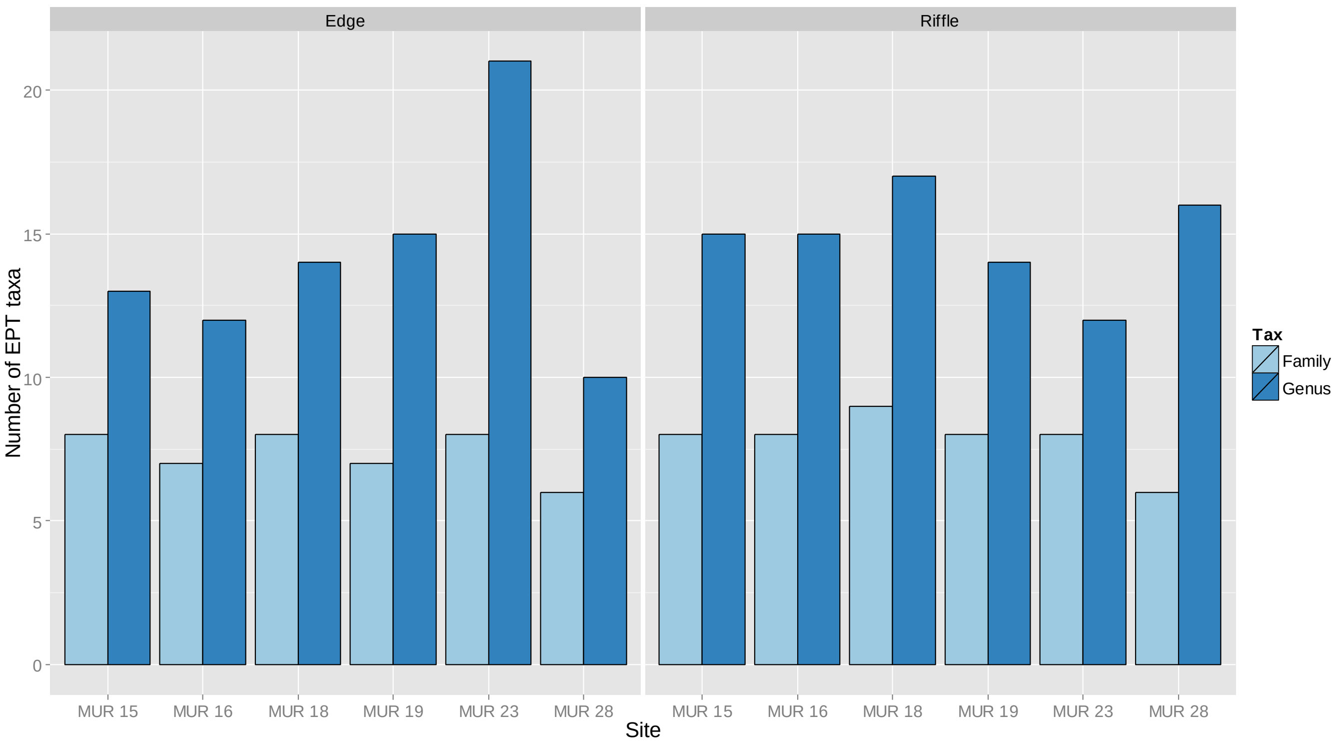

Figure 4-10. Total number of EPT taxa at genus and family level from riffle and edge habitats

Edge Habitat

Edge samples showed a high degree of similarity amongst sites (R=0.15; *P*=0.40; Figure 4-11). All sites were approximately 50% similar; as indicated by the ellipse from the cluster analysis. This pattern is identical to the results from spring 2013; where all of the sites formed a single group at 50% similarity (GHD, 2014a). However, with the exception of some of the outlier samples from MUR 19 and MUR 28, there is some indication from the NMDS plot that the upstream and downstream communities are separated. The high stress in the 2-d plot may be distorting the ordination solution, but looking at these data in 3 dimensions is not much clearer, although the stress (0.14) is lower.

Edge samples were characterised by high numbers of Chironominae (SIGNAL=3), Orthocladinae (SIGNAL = 4) and the moderately tolerant Hydroptilidae (SIGNAL=4); together contributing to approximately 40% of the similarity of macroinvertebrate communities amongst sites. Typical edge – fauna such has *Micronecta* spp. (SIGNAL =2) and Notonectidae (SIGNAL = 1) also characterised the sites sampled in this study.

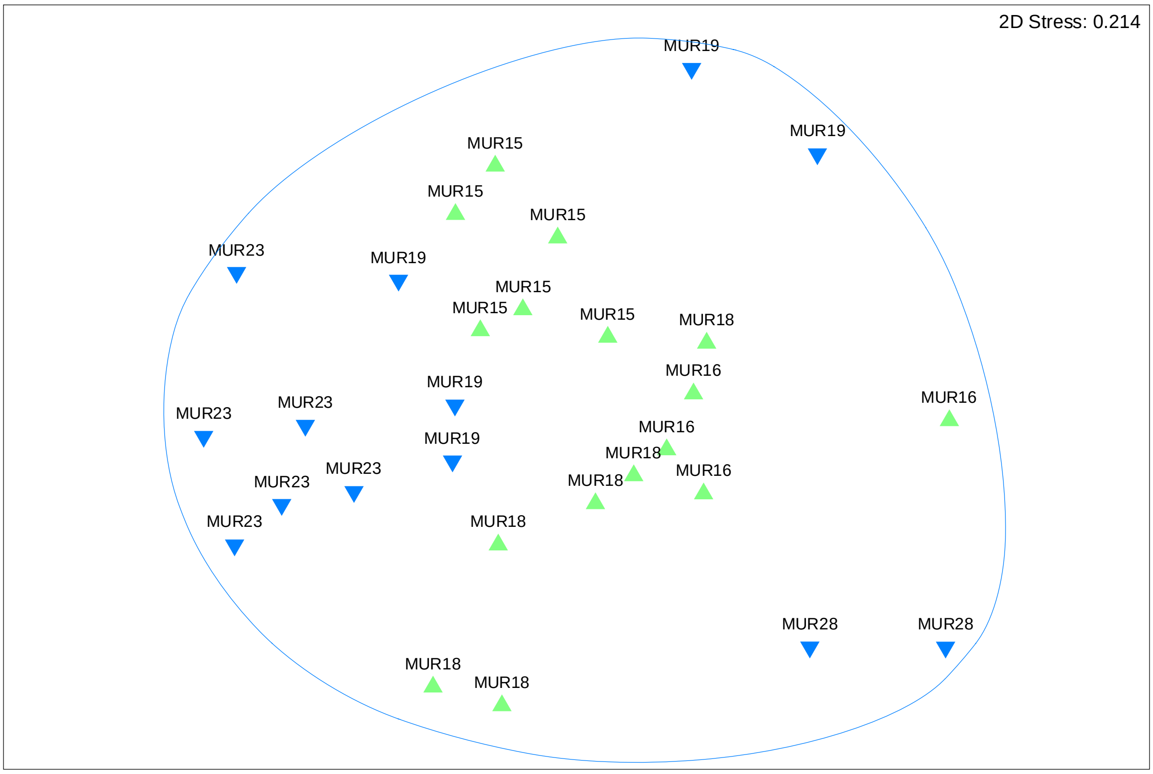

Figure 4-11. Non-metric multidimensional scaling of macroinvertebrate data (genus level) collected from the edge habitat

Note: Blue ellipses represent 50% similarity. Green triangles are upstream sites and blue triangles are downstream sites.

Family richness ranged from 19-27 at MUR 28 and MUR 15 respectively (Figure 4-9). MUR 15 was the only site where edge habitat family richness had increased since spring 2013. All of the other sites were less diverse than they were in spring 2013; particularly MUR 16 and MUR 23, which both had seven fewer families, and site MUR 16 where there were also 12 fewer genera than there were in the spring 2013 sampling period. EPT richness was consistent amongst sites at the family level (range: 8-9); however there was a tendency for the number of genera to increase from MUR 15 to MUR 23, followed by a significant decline in EPT genera at MUR 28 (Figure 4-10).

4.5.2 AUSRIVAS and SIGNAL 2

Half of the sites sampled in this study had changes to their overall AUSRIVAS Bands since spring 2013 (Table 4-9). MUR 15 changed from Band B to Band A; MUR 19 moved to a Band A from its previous (spring 2013) assessment of Band B and MUR 23 went from Band A in spring 2013 to Band B in this study.

However, it should be noted that because of the variation amongst replicates at MUR 15 and MUR 19 resulting "no reliable assessment" being given to both sites for the riffle habitat assessments. The riffle sample results from these sites ranged from Band A to Band C. The procedure for when this happens involves a number of quality control steps (which were carried out); and if these steps (summarised in Barmuta *et al.*, 2003) do not remedy the issue, then the advice, (when there is more than one Band width difference amongst replicates) is to assign that site or habitat as "no reliable assessment".

The discrepancy in the A and C Band widths at MUR 15 only occurred in one replicate due to the absence of Acarina (SIGNAL 2 = 6); despite this taxa being present in all of the other replicates (APPENDIX E). The number of missing taxa ranged from 6 – 10 (APPENDIX E), which further highlights how it only takes one unusually sparse sample to produce very different assessments. At MUR 19 there was a similar situation where the absence of one family resulted in a Band C assessment.

Average O/E50 scores from the riffle samples (Figure 4-12) were higher upstream of Angle Crossing (averaged over all sites) (mean = 0.87) compared to the downstream sites (mean=0.80); however given the degree of between and within site variation at all sampling sites, these means were not statistically different ($F_{1,4}$=0.75; *P*=0.43; Table 4-7). Mean SIGNAL 2 scores from the riffle samples were highest at MUR 18 (5.44) and MUR 19 (5.43) and the two lowest scores were recorded from sites MUR 16 (4.98) and MUR 28 (4.87)(Figure 4-12). As these maximums and minimums were not confined to a particular location, the location effect on the mean SIGNAL 2 scores was not statistically significant ($F_{1,4}$=0.30; *P*=0.62; Table 4-7).

The edge was largely regarded as "close to reference" (Band A) except for MUR 16 which was assessed as "significantly impaired" by the AUSRIVAS model (Table 4-10). However, as previously discussed, when interpreting these results, it should also be recognised that three of the replicates at MUR 16 contained several Band A subsamples. Further, in each case, the difference between Band A and Band B in these samples was based on the absence of only one family, which was present in the other samples from that site (APPENDIX E2). Nevertheless, the statistical interpretation of the AUSRIVAS Band results remains the same regardless; and this result shows that there was no difference in the AUSRIVAS scores between the upstream and downstream sites ($F_{1,4}$=0.15; *P*=0.72; Table 4-8). There was also no evidence of a location effect for the SIGNAL 2 scores ($F_{1,4}$=0.16; *P*=0.62; Table 4-8).

Missing taxa from the edge habitat, which were expected to occur according to the AUSRIVAS modelling included sensitive taxa such as: Leptophlebiidae (SIGNAL =8) and Gripopterygidae (SIGNAL = 8) and moderately sensitive taxa such as Baetidae (SIGNAL=5) and Leptoceridae (SIGNAL =6). There was no apparent pattern to the presence or absence of any of these taxa which may link their absence to M2G. Gripopterygidae were not found at all at site MUR 28, but these sensitive stoneflies are often missing or in very low numbers at this site; which we attribute to poor habitat quality.

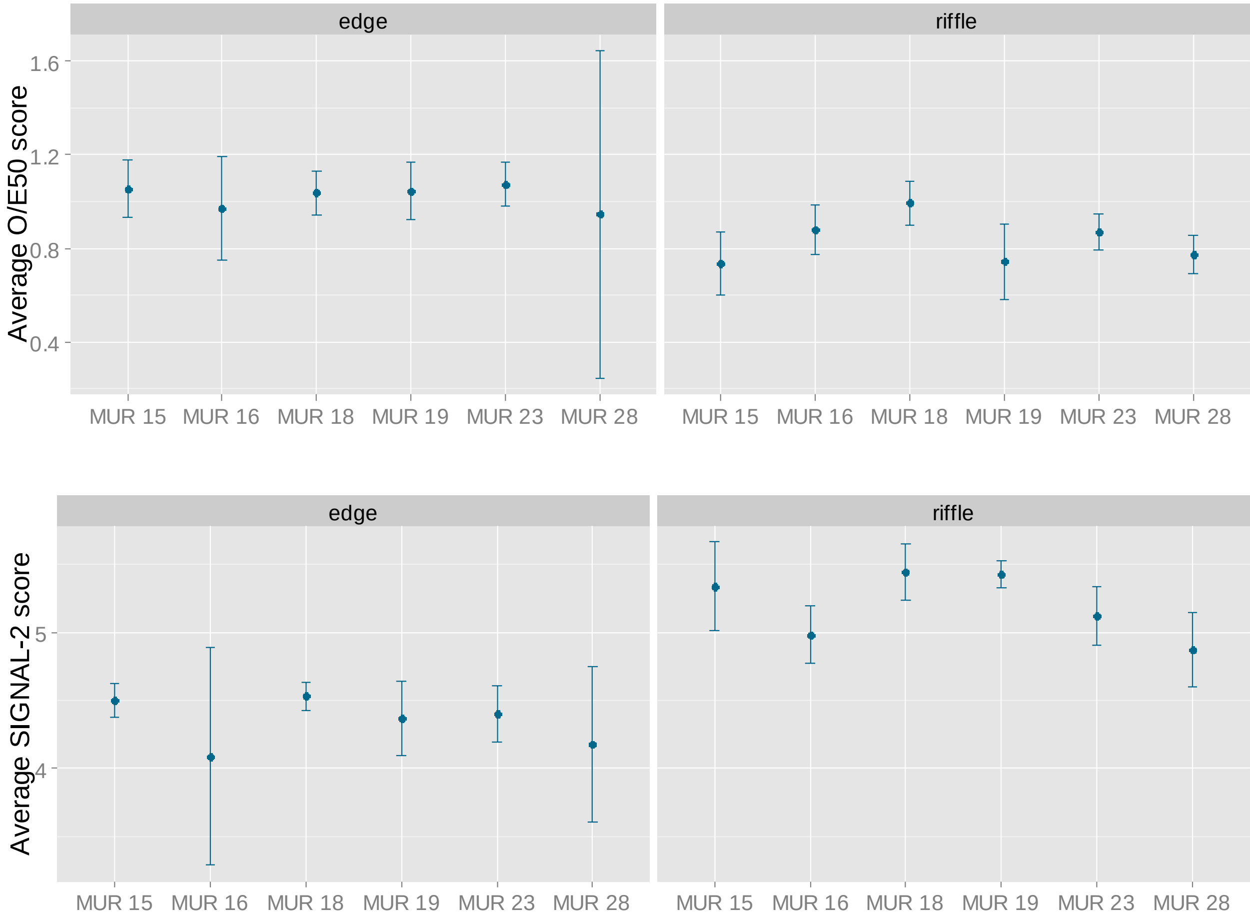

Figure 4-12. Means plot of SIGNAL-2 scores and O/E 50 ratios for the edge and riffle habitats

Note: Error bars are 95% confidence intervals.

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

Response	Source	DF	F	P-value
O/E 50	Location	1	0.75	0.43
	Site [Location]	4	5.57	0.00
	Total	35		
SIGNAL-2	Location	1	0.30	0.62
	Site [Location]	4	8.29	0.00
	Total	35		

Table 4-8. 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	0.05	0.84
	Site [Location]	4	1.04	0.41
	Total	28		
SIGNAL-2	Location	1	0.16	0.70
	Site [Location]	4	3.48	0.02
	Total	28		

Table 4-9. Overall site assessments for autumn and spring since 2011

	Autumn 2011	Spring 2011	Autumn 2012	Spring 2012	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014	Change since previous sampling run
MUR 15	B	A	B	A	B	B	B	A	↑
MUR 16	B	A	B	B	B	B	B	B	↔
MUR 18	B	B	B	B	B	B	B	B	↔
MUR 19	A	A	B	B	B	B	B	A	↑
MUR 23	B	A	B	B	B	A	B	B	↓
MUR 28	B	B	B	B	B	B	C	B	↔

Table 4-10. AUSRIVAS and SIGNAL-2 scores for spring 2014

Note: NS = No Sample; Edge samples from MUR 16, 18, 23 & 28 are ***"nearly outside the experience of the model."***

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**	5.00	4.60	0.72	1.11	B	A	**NRA**	**A**	**A**
	2	5.71	4.38	0.56	0.89	C	A			
	3	5.00	4.33	0.88	1.00	A	A			
	4	5.45	4.56	0.88	1.00	A	A			
	5	5.44	4.60	0.72	1.11	B	A			
	6	5.38	4.55	0.64	1.22	B	X			
MUR 16	**1**	5.00	3.43	0.96	0.78	A	B	**B**	**B**	**B**
	2	5.00	4.33	0.96	1.00	A	A			
	3	5.00	4.60	0.96	1.11	A	A			
	4	5.27	4.00	0.88	1.00	A	A			
	5	5.10	NS	0.80	NS	B	NS			
	6	5.67	NS	0.72	NS	B	NS			
MUR 18	**1**	5.64	4.60	0.85	1.11	B	A	**B**	**A**	**B**
	2	5.36	4.44	1.08	1.00	A	A			
	3	5.54	4.60	1.01	1.11	A	A			
	4	5.36	4.60	1.08	1.11	A	A			
	5	5.25	4.56	0.93	1.00	A	A			
	6	5.46	4.38	1.01	0.89	A	A			
MUR 19	**1**	5.09	4.44	0.85	1.00	B	A	**NRA**	**A**	**A**
	2	5.00	4.60	0.92	1.11	A	A			
	3	5.09	4.40	0.85	1.11	B	A			
	4	5.00	4.40	0.54	1.11	C	A			
	5	5.22	4.00	0.69	0.89	B	A			
	6	5.50	NS	0.61	NS	B	NS			
MUR 23	**1**	5.00	4.22	0.95	1.00	A	A	**B**	**A**	**B**
	2	4.80	4.60	0.79	1.11	B	A			
	3	5.33	4.22	0.95	1.00	A	A			
	4	5.09	4.55	0.87	1.22	A	X			
	5	5.27	4.60	0.87	1.11	A	A			
	6	5.00	4.22	0.79	1.00	B	A			
MUR 28	**1**	4.80	4.13	0.75	0.89	B	A	**B**	**A**	**B**
	2	5.09	4.22	0.82	1.00	B	A			
	3	5.25	NS	0.90	NS	A	NS			
	4	4.44	NS	0.67	NS	B	NS			
	5	4.80	NS	0.75	NS	B	NS			
	6	4.80	NS	0.75	NS	B	NS			

4.6 Discussion

4.6.1 Water quality

The water quality grab samples and *in-situ* parameters recorded during spring 2014 were consistent with previous spring results recorded through the duration of the MEMP. Although two sites exceeded the ANZECC & ARMCANZ (2000) recommended upper range for pH, this is not unusual for this reach of the Murrumbidgee River. Dissolved oxygen (DO) levels were below the recommended range at all sites, with some exceedances also recorded for this parameter in the continuous monitoring data also. While this is likely to be linked with the low flows and increasing temperatures in the river, it is also important to acknowledge that although these readings are outside the guideline range, they are also within the natural range of the diurnal trend recorded at the continuous monitoring stations. Importantly though, these values are not low enough to start impacting upon the aquatic life within the reach, particularly the threatened fish species which are highly sensitive to low levels of dissolved oxygen.

The high levels of total phosphorus (TP) and total nitrogen (TN) recorded at all sites, exceed the ANZECC & ARMCANZ (2000) guidelines. This is not uncommon at these sites and they have been recorded in exceedance of the guidelines previously, most recently in spring 2013 (GHD, 2014a). It is evident from these results that the initial nutrient enrichment occurs upstream of the current study area, however there are also multiple increases in the TP and TN across the sites suggesting further inputs. These are likely to be from agricultural sources and also urban inflows for sites MUR 23 & 28. However, there is no evidence of increased nutrients from M2G with nutrient levels immediately downstream (MUR 19) of the intake structure reducing from those immediately upstream (MUR 18), indicating some natural biological uptake of the available nutrients, which is expected because M2G did not operate during this reporting period.

The grab sample and *in-situ* parameters recorded showed no evidence of a location impact at Angle Crossing, while the continuous data also showed no evidence of a location impact with most guidelines exceedances the result of the high flow events during September and October.

4.6.2 Periphyton

Results from the periphyton analysis show that the location accounted for negligible amount (<1%) of the total variation in the data and that most of that variation was explained by site to site (random) variation by the mixed effects model. A common pattern in the periphyton analysis is to see an increase in chlorophyll a and AFDM at MUR 23 and MUR 28 (the results in this study are no exception). This has been largely attributed to increasing nutrient concentrations (particularly TP) with changes in catchment land use.

One of the most notable changes in the periphyton data was the almost three-fold increase in the maximum chlorophyll-a concentrations and a two-fold increase in the median value recorded at MUR 16 since spring 2013. However, it should be noted that there were increases seen at most of the monitoring sites (MUR 19 was the exception) during this season compared to spring 2013. The most likely explanation for this is the change in the spring hydrographs between 2013 and 2014. As flow is considered to be a proximate variable affecting the rates of accrual and loss (Biggs, 1996), it would be fair to say that in the absence of other obvious differences in nutrients, water temperature or other controlling factors between the upstream and downstream sites, that the differences between the two hydrographs in terms of flow magnitude and timing is likely to have been the most likely reason for the observable difference in periphyton. Longer periods between events and lower magnitude of high flow events in spring 2014 would have resulted in longer accrual periods with fewer, or smaller scouring or bed disturbances during this process.

4.6.3 AUSRIVAS and macroinvertebrate community assemblages

Multivariate analysis of the macroinvertebrate community data between upstream and downstream reaches shows no evidence of an ecological impact due to the Murrumbidgee to Googong project, which is to be expected due to the pipeline not being used for operational purposes during this reporting period. It is suggested that because of the low spring rainfall and low base flows in the upper Murrumbidgee River Catchment, during spring and the similar climatic and hydrological conditions seen across all sampling sites has resulted in high similarity measures in both habitats (Figure 4-8 and Figure 4-11). Much of the variation seen in the samples occurred because of an accumulation of small differences in the number of genera within certain family groups such as the Baetidae and Hydroptilidae.

Analyses of the AUSRIVAS ratios and SIGNAL 2 scores also showed no statistical difference between locations. Average O/E50 ratios upstream of Angle Crossing were 0.87 compared to the downstream average of 0.80. Although these averages fall into two different AUSRIVAS Band boundaries (Band A and Band B respectively) there was considerable within and between site variation, which inflated the confidence intervals around the means and lowered the power to detect a difference.

The highest SIGNAL 2 scores occurred at MUR 18 and MUR 19 which are the two most proximate sites to Angle Crossing and had the highest velocity readings of any of the sampling sites which resulted in these sites have more rheophilic taxa with high SIGNAL-2 scores relative to the other sites.

Ecological health assessments were unchanged compared to the previous spring at MUR 16, MUR 18 and MUR 28. In the case of MUR 18 it should be noted that five of the six sub samples were Band A and only one was Band B, resulting in the overall assessment of Band B. In the case of MUR 16 and MUR 28, 50% and 83% of samples were Band B. At MUR 15 and MUR 19, although the overall assessments resulted in a Band A for both sites, it should be noted that this assessment is based only on the edge habitat result because the riffle habitat resulted in “no reliable assessment” owing to the inconsistent and wide spread of results (i.e. AUSRIVAS Bands ranged from Band C to Band A) from the sub samples.

Point Hut crossing (MUR 23) declined in condition since spring 2013 due to a Band B assessment in the riffle habitat. Taxa missing from the riffle habitat at that site included three sensitive taxa: Hydrobiosidae (SIGNAL =8); Leptophlebiidae (SIGNAL =8) and Elmidae (SIGNAL=7), which may indicate a response to the dry spring and warming surface water temperatures or other changes to the water quality at that site. However, the water quality parameters recorded in spring 2014 were very similar to those recorded in 2013, which makes the direct linkage to water quality difficult.

A more general comment on the missing taxa from riffle samples, however, is that at all sites, Hydrobiosidae were missing from the majority of samples, as was Elmidae (except at MUR 18 presumably because of the higher velocity at that site). Leptophlebiidae, although not absent entirely, was missing more frequently at all of the downstream sites (Appendix A1). Therefore, the more broad scale indication is that due to the less frequent and lower magnitude high flow events during spring 2014; there was a build-up of silt and algae resulting in subtle changes in water chemistry. These factors may have acted as environmental filters (Chessman and Royal, 2004) by progressively removing the more sensitive taxa, which resulted in macroinvertebrate communities dominated by high numbers of Simuliidae, chironomids (including Orthocladinae which preferentially feed on algae) and low to moderately tolerant mayfly taxa.

Results from the edge samples were similar to the riffle samples in that there were high similarities in the assemblages based on ordination analysis and in that there was no location effects found for any of the univariate indices used in this study. This is not surprising given that there were no maintenance runs prior to the spring sampling run and the high level of consistency of shared taxa amongst monitoring sites. Overall, however, edge samples had higher O/E50 scores than the riffle habitat, indicating by the high frequency of Band A assessments, that most of the taxa predicted to be present were collected, resulting in near reference condition assessments at all but one of the monitoring sites.

The only site which resulted in a Band B assessment for the edge habitat was MUR 16, which was unsurprising because at the time of sampling, the field team commented on the poor condition of the edge habitat in terms of it being very shallow, having poor substrate diversity and having little in the way of vegetative cover.

4.7 Conclusions and recommendations

Results presented in this report represent responses of water quality parameters; periphyton and macroinvertebrates to natural variation given that there have been no maintenance runs during the spring period. These results are what would be expected following a relatively dry and hydrologically stable spring period in that the water quality parameters were comparable to previous seasons with similar flow conditions. Periphyton biomass estimates were elevated compared to last spring, where flow magnitudes were several times higher and the period of time between sampling and the last high flow event was longer. In terms of the macroinvertebrate communities there was some evidence to indicate that taxa with a preference for cooler, fast flowing water were declining in presence and abundance.

The consistency that we have encountered in this study, and in fact for the duration of the MEMP, is embedded in two fundamental concepts of stream ecology, and these are resistance and resilience, which have been discussed frequently in previous reports. Historically, the Murrumbidgee River has been subjected to periods of zero flow, when the river is reduced to pools during periods of drought (Kendall, 1981), but even after such severe disturbances, and to a lesser extent the period in early 2009 when we found evidence for the early onset of water quality changes and macroinvertebrate community changes in relation to the extremely low base flows, it appears that given time, communities in the Murrumbidgee River will recover. However, it has been suggested that this ability to recover, or to resist change will decrease as the frequency of disturbance increases, suggesting cumulative impacts over time (Finn et al., 2009; Marsh et al., 2012).

The implications to the future management of M2G is that antecedent flow conditions must be factored into future pumping rules concerning, volume, frequency and timing as these factors may play a larger role in the ability of communities to recover from, or resist change than previously expected.

Over the course of the Murrumbidgee Ecological Monitoring Program, a number of recommendations have been brought forward to Icon Water. Many of these were in line with the adaptive management framework of the MEMP to adjust some of the sampling methods, frequency and scope to accommodate the changes needs of the program and different needs of Icon Water. Most of these recommendations have been complied into a recommendations summary report (ALS, 2012) and in the last report (GHD, 2014b) five recommendations were added, which included a review of current monitoring methods and a statistical evaluation of two of the key monitoring stations on the Murrumbidgee River, namely Lobb’s Hole and the station located upstream of Angle Crossing. Outside of these items, there are no further recommendations.

5. Burra Creek

5.1 Summary of sampling and river conditions

Sampling of Burra Creek was conducted on the 4th and 5th of November just prior to the scheduled M2G APPLE[2] run. Conditions over the two day period were fine, with maximum air temperatures recorded as 25.2 °C and 27.2 °C on the 4th and 5th respectively (BOM, 2014). There was not much evidence of the high flow event (e.g. scouring) which occurred in September, likely due to the relatively low magnitude of the event and the time since it occurred.

As was the case in spring 2013, low flow conditions in Burra Creek was the key feature during this sampling run. The low flow conditions resulted in the cessation of surface flow (but only recently) at BUR 1a, meaning that only edge samples were collected at that site. At BUR 1c only one riffle and one edge sample was collected due lack of habitat owing to the flow conditions and heavy inundation by *Schoenoplectus sp.* (Plate 5-1). A single riffle sample was also collected at BUR 2a due to limited habitat during sampling (Table 5-1).

Table 5-1. Samples collected during autumn 2014 at Burra Creek sites

Site	Riffle	Edge	Comments
BUR 1a	0	2	No riffle habitat available for sampling
BUR 1c	1	1	Riffle & edge habitat largely covered by macrophytes limiting the habitat available appropriate for sampling
BUR 2a	1	2	Insufficient riffle habitat for a second sample
BUR 2b	2	2	All samples collected
BUR 2c	2	2	All samples collected
QBYN 1	2	2	All samples collected

[2] Angle Crossing Planned Pumping Lubrication Exercise

BUR 1a – Almost completely dry

BUR 1c – 1.5 ML/d

BUR 2a – 1.6 ML/d

BUR 2b – 1.6 ML/d

BUR 2c – 1.5 ML/d

QBYN 1 – 39 ML/d

Plate 5-1. Photographs of the Burra Creek and Queanbeyan River sites during spring 2014 sampling

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

5.2 Hydrology and rainfall

Rainfall at the Burra Creek rainfall station (570951) was 118.8 mm during the spring 2014 period (Table 5-2). This total is the lowest rainfall recorded during spring since prior to the commencement of the MEMP (Figure 5-2). The largest rainfall event that occurred during spring 2014 occurred in September and featured 28 mm of rainfall within a 24 hour period. This resulted in the only high flow event in Burra Creek for the spring 2014 period peaking at just under 150 ML/d, while flows in the Queanbeyan River peaked at over 800 ML/d (Figure 5-1; Figure 5-3).

During sampling, flows were stable at less than 2 ML/d for the two days with flows preceding sampling consistently less than 5 ML/d following the recession from the September high flow event (Figure 5-1). Flows in the Queanbeyan River during sampling were just under 40 ML/d with flow receding to base flow levels following a small event during mid-October that was isolated to the Queanbeyan River and reached approximately 350 ML/d.

Table 5-2. Rainfall and flow summaries for Burra Creek and the Queanbeyan River for spring 2014

	Burra Creek (410774)		Queanbeyan River (410781)	
	Total Rainfall (mm)	Mean Flow (ML/d)	Total Rainfall (mm)	Mean Flow (ML/d)
September	45.6	7.8	32.72	240
October	41.8	3.0	38.4	99
November	31.4	3.1	32.6	32
Spring (mean)	118.8 (36.0)	14	103.72 (34.57)	130

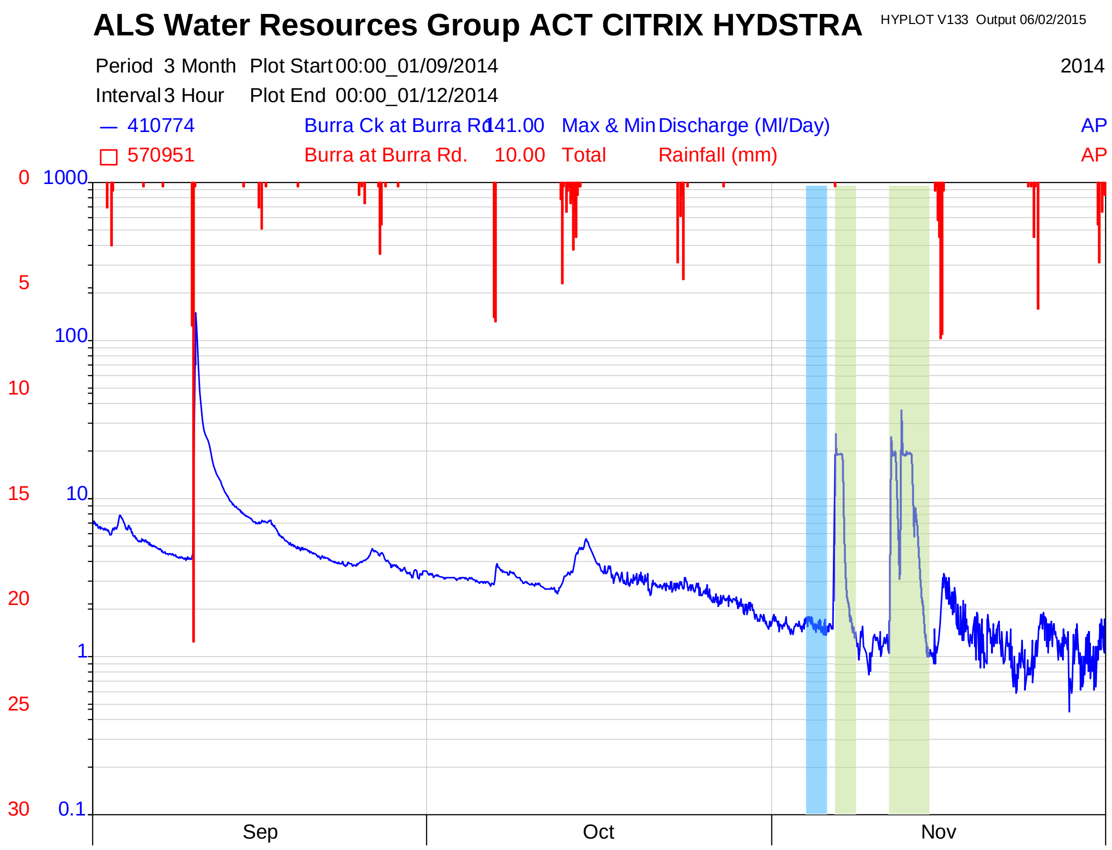

Figure 5-1. Hydrograph and rainfall from Burra Creek (410774) during spring 2014

Note: Sampling time highlighted by blue shading; M2G APPLE flows highlighted by green shading.

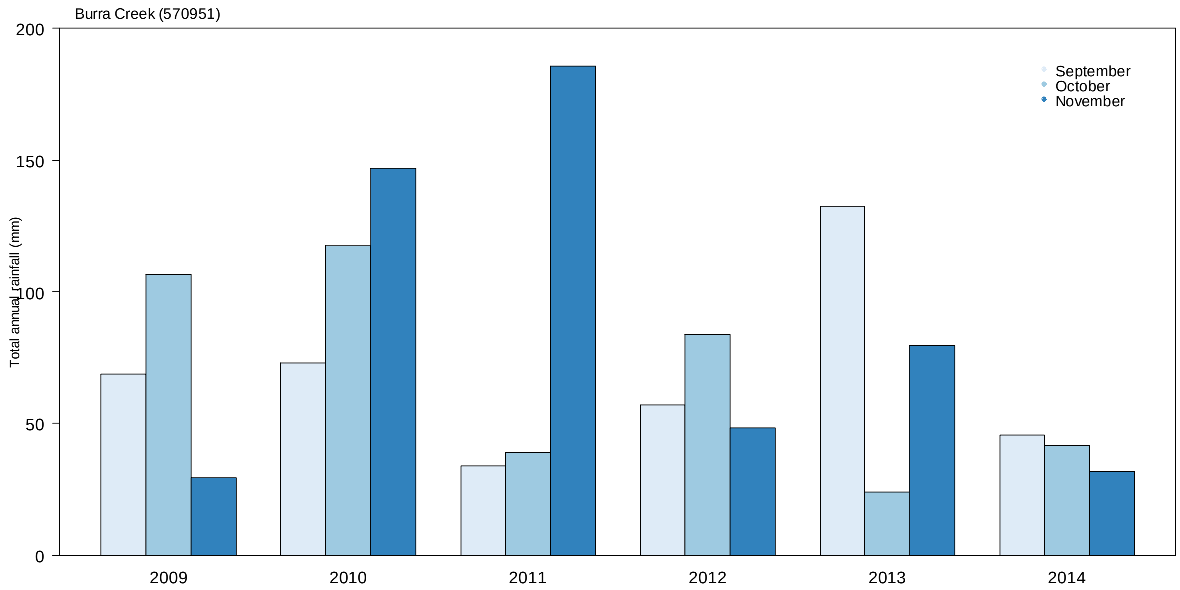

Figure 5-2. Annual comparisons of spring rainfall (mm) recorded at Burra Creek (570951)

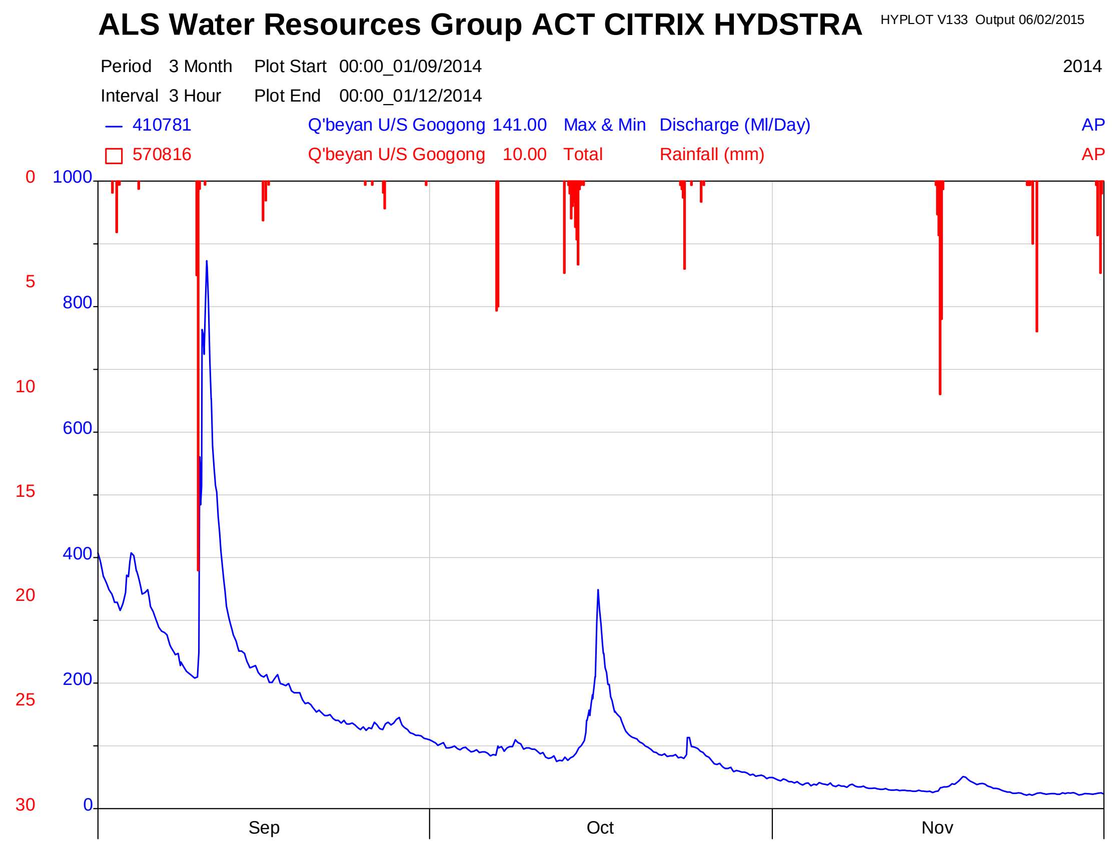

Figure 5-3. Hydrograph and rainfall from the Queanbeyan River (410781) during spring 2014

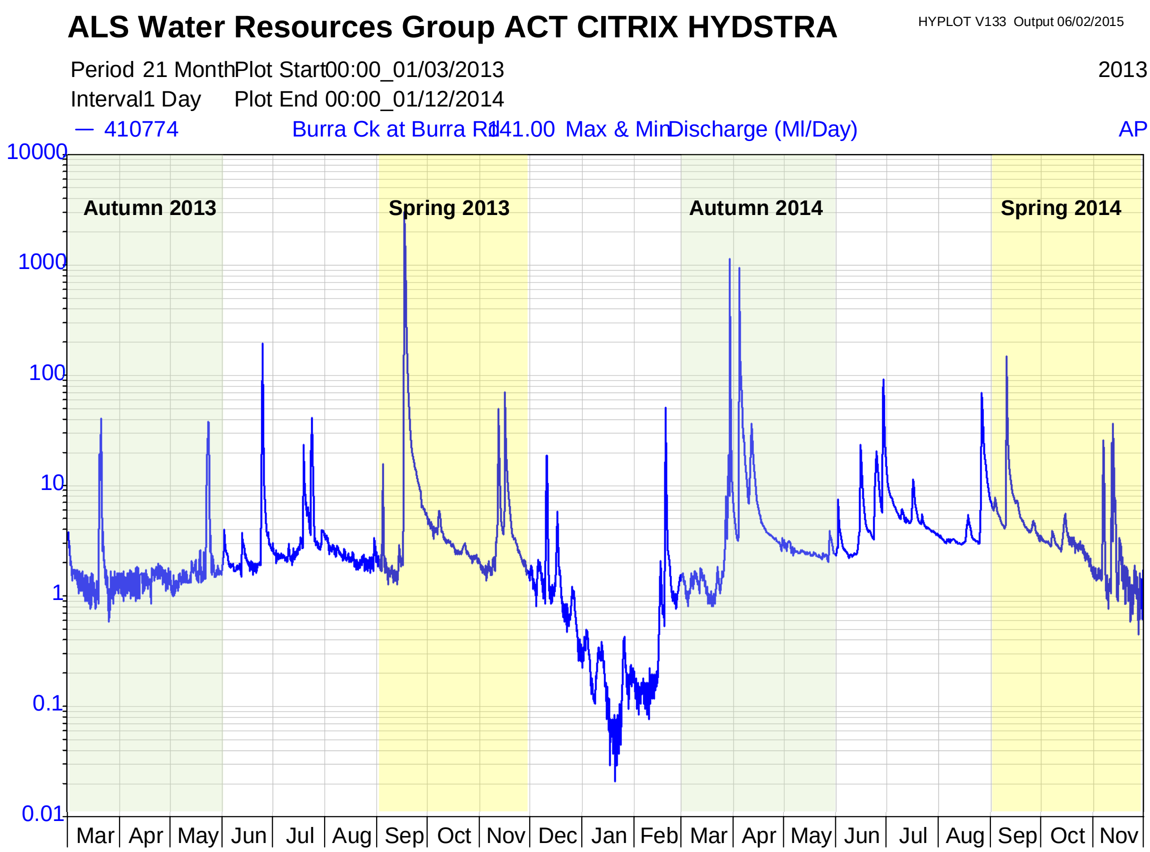

Figure 5-4. Burra Creek hydrograph highlighting the past four sampling periods between March 2013 and November 2014

5.3 Water quality

5.3.1 Grab samples and *in-situ* parameters

Water quality results from the grab samples and *in-situ* parameters for Burra Creek and Queanbeyan River are presented in Table 5-3. The results show exceedances of the ANZECC & ARMCANZ (2000) guidelines for all parameters with the exception of turbidity, which was within the recommended range at all sites.

Guideline exceedances for electrical conductivity (EC) at all Burra Creek sites downstream of BUR 1a is normal for Burra Creek and is attributed to high groundwater contributions and the local geology.Results in spring 2014 are consistent with the spring 2013 results. Similarly, pH exceedances at all downstream Burra Creek sites are considered within normal range for Burra Creek when considering previous spring sampling runs (GHD, 2013a; GHD, 2014a). However, pH at QBYN 1 was also outside the recommended range during spring 2014. This is the first time since the inception of the MEMP program that this site has exceeded the ANZECC & ARMCANZ (2000) pH upper limit (QBYN 1 was recorded on the cusp of the limit in spring 2011). Dissolved oxygen (DO) was also recorded below the recommended lower limit for % saturation at all Burra Creek sites.

Nutrient levels in Burra Creek were variable, with isolated exceedances of the ANZECC & ARMCANZ (2000) guidelines for NOX and TP, but widespread exceedances for TN. Increased levels of NOX were detected at BUR 2a, which exceeded the guideline, while slightly increased levels of ammonia were also recorded at this site compared to the upstream sites. Levels of total phosphorus were also recorded above guideline levels at BUR 2b. The major guidelines exceedances were for TN, with all sites exceeding the guideline, except for BUR 2c which was on the cusp. This is consistent with results from spring 2012, however different to spring 2013. This is likely due to the large magnitude flow during September 2013 flushing the majority of nutrients from the Burra Creek system, while a flow of this magnitude was absent during spring 2012 and 2014.

5.3.2 Continuous water quality monitoring

Continuous water quality data recorded from the two continuous monitoring stations is shown in Figure 5-5 and Figure 5-6. Water quality results behaved as expected in response to the high flow event during September, however, the response was slightly different to the flow during October. Although there was only a small increase in flow in Burra Creek as a result of some rainfall, there was no increase in turbidity levels. There was a drop in temperature and also the diurnal trend for both pH and DO were slightly disrupted. There was a similar response in the Queanbeyan River; however, there was a larger increase in flow in the Queanbeyan River, again with no increase in turbidity, but a drop in temperature and EC reacted with a slight fall and then a subsequent increase in response to the event.

This also occurred in the Queanbeyan River during November, after sampling had taken place, where the rainfall event that occurred had little impact on the flow, but the water temperature dropped slightly and the pH was reduced for a couple of days as a result of the lower pH rain water.

The reaction of the water quality to the introduction of the Murrumbidgee River water into Burra Creek during the M2G APPLE run was as expected, with the lower conductivity of the Murrumbidgee water considerably reducing EC, similar to what would be expected from a high flow event. The natural diurnal trend of the pH data remained, however, the range was reduced with the influence of the lower pH Murrumbidgee River water. The DO trend was disrupted during pumping, but was not reduced to levels outside of the normal range recorded during the spring 2014 assessment period.

Table 5-3. *In-situ* water quality results from Burra Creek and Queanbeyan River during spring 2014

Note: ANZECC and ARMCANZ (2000) guidelines are in yellow 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	4/11/2014	9:30	16.4	112.9	14	2	6.91	76.4	7.26	30	< 0.002	< 0.002	< 0.002	< 0.002	0.016	0.36
	BUR 1c	5/11/2014	9:00	16.5	433.0	5.2	15	7.92	85.3	8.29	171	< 0.002	< 0.002	< 0.002	< 0.002	0.015	0.31
Downstream	BUR 2a	4/11/2014	11:45	17.2	512.0	7.2	4	8.11	74.8	7.22	219	0.049	0.049	< 0.002	0.007	0.015	0.29
	BUR 2b	4/11/2014	13:45	21.1	529.0	9.01	16	8.13	89.6	8.04	227	< 0.002	< 0.002	< 0.002	< 0.002	0.028	0.34
	BUR 2c	5/11/2014	11:16	18.2	498.0	2.82	6	8.23	86.8	8.93	218	0.010	0.010	< 0.002	< 0.002	0.007	0.25
Control	QBYN 1	5/11/2014	13:30	20.9	94.3	3.6	3	8.30	97.2	8.77	43	< 0.002	< 0.002	< 0.002	< 0.002	0.015	0.30

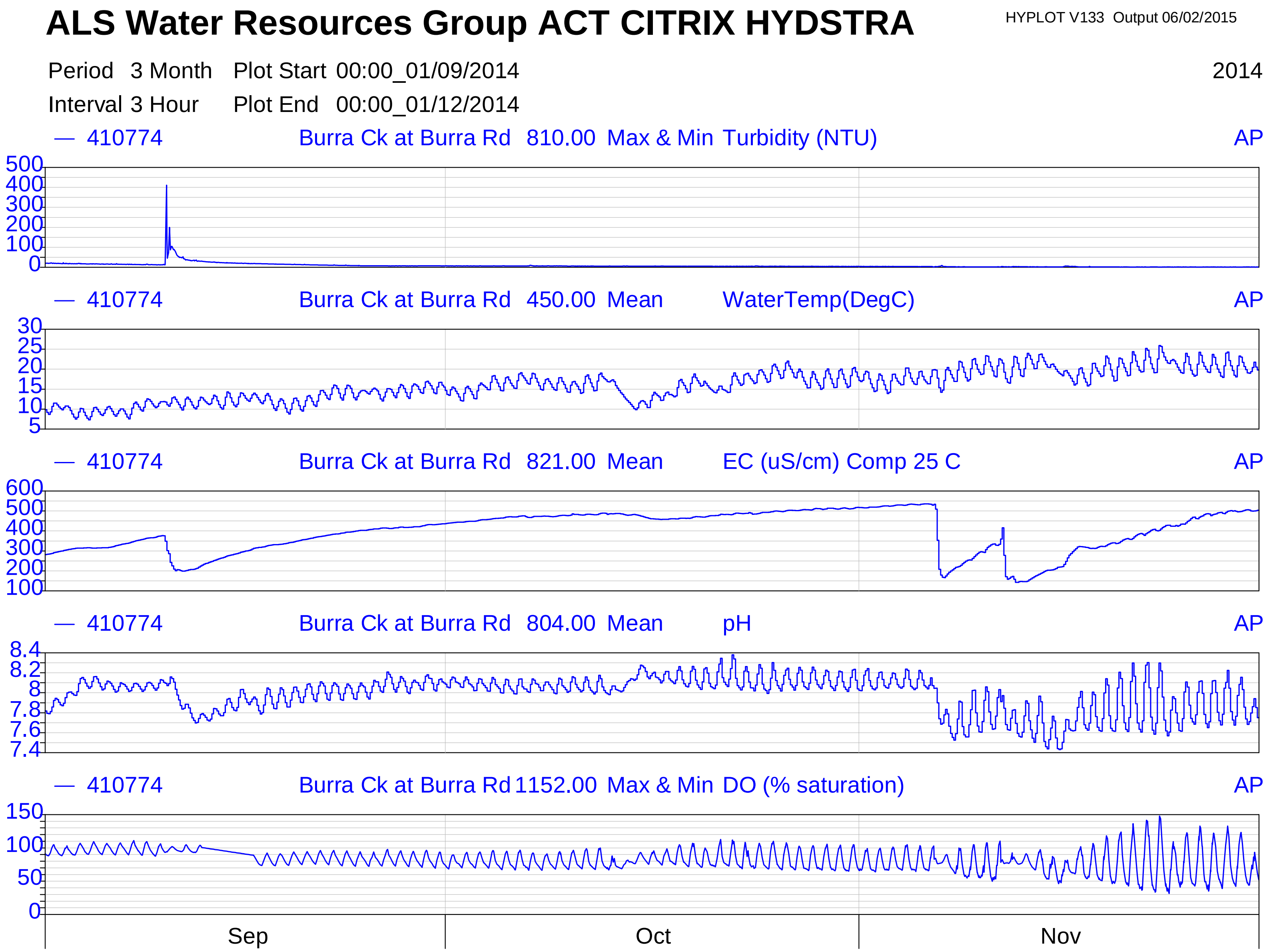

Figure 5-5. Continuous water quality records from Burra Creek (410774) for spring 2014

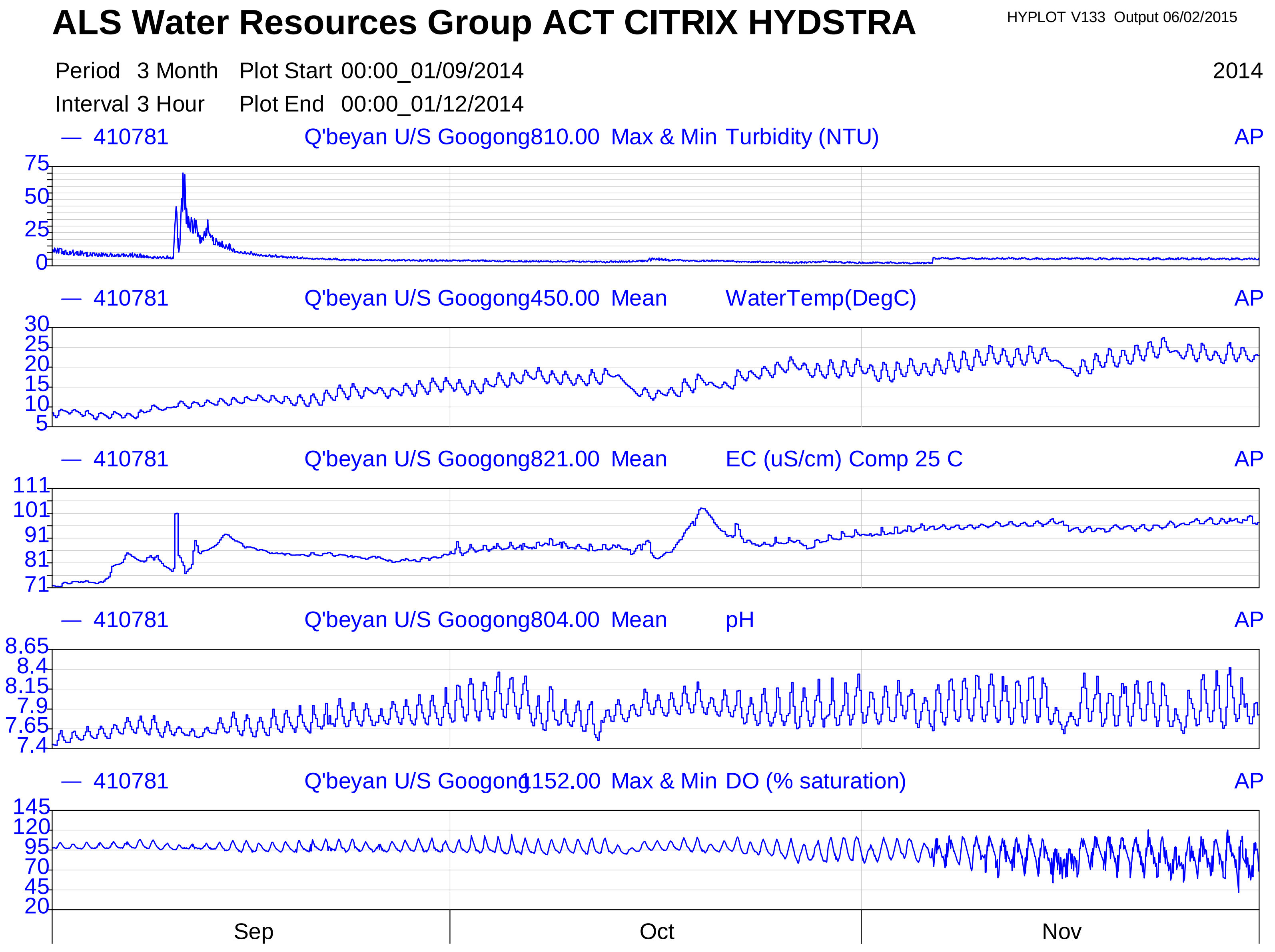

Figure 5-6. Continuous water quality records from the Queanbeyan River (410781) for spring 2014

5.4 Periphyton

There were significant increases in chlorophyll a concentrations at all sampling locations compared to spring 2013. For example, there was a 2.2 fold increase in chlorophyll a concentrations at the site upstream of the Burra Creek discharge point in spring 2014 (24,072 µg/m^2) compared to spring 2013 (~10,566 µg/m^2); while there was a similar 1.5 fold increase seen at the downstream sites in spring 2014 (37,394 µg/m^2) compared to spring 2013 (24,878 µg/m^2). The highest values were seen at BUR 2a and then there was almost a 50% decrease in the median concentrations moving downstream. Despite the obvious spike at BUR 2a, there were no significant effect in terms of the sampling location ($F_{2,3}$=0.45; *P*=0.67: Table 5-4) and this is supported by the zero variance component in the ANOVA model (Table 5-4).

There were very high concentrations of AFDM recorded at BUR 1a and BUR 1c and, including BUR 2a, these sites all had the highest median concentrations of organic material. Compared to spring 2013, these values showed similar increases to those described for the chlorophyll a samples above. For example, upstream sites (33,564 µg/m^2) showed a 2.2 fold increase compared to spring 2013 (15,000 µg/m^2) and a 1.8 fold increase was observed at the downstream sites (18,475 µg/m^2)) compared to spring 2013 (9,936 µg/m^2)). These increases were seen at all sampling locations and resulted in no statistical differences attributable to location being found for the current sampling period ($F_{2,3}$=1.82; *P*=0.30; Table 5-4).

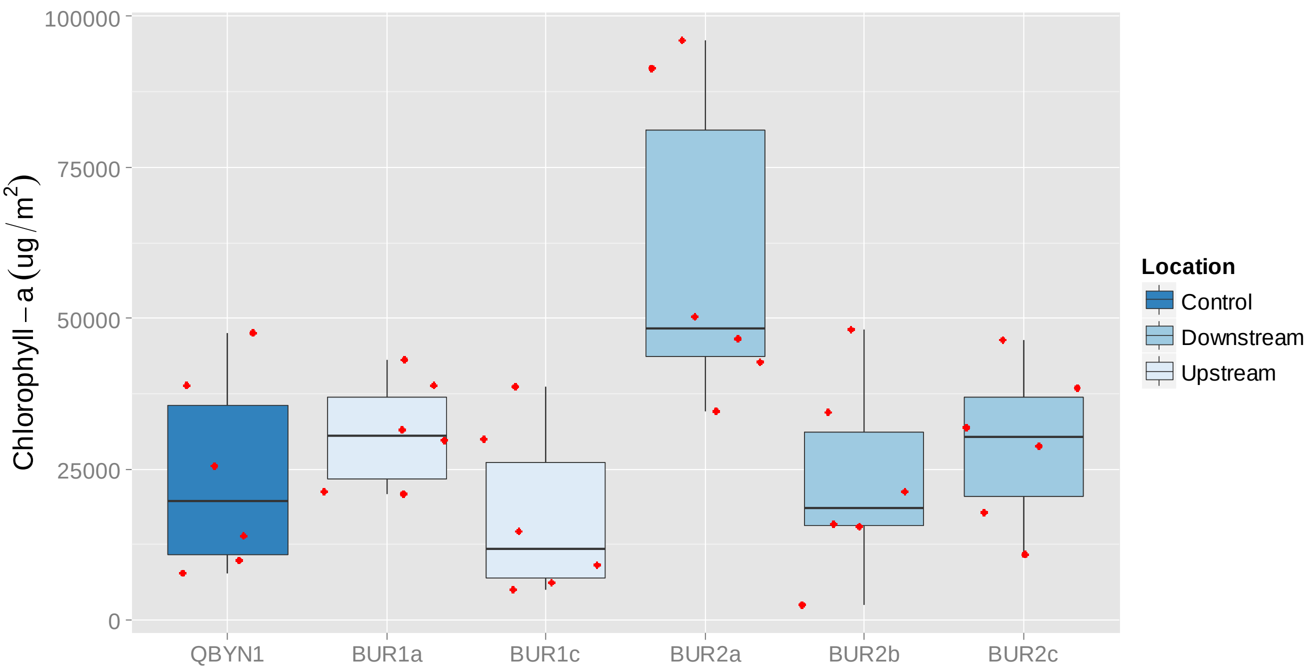

Figure 5-7. Chlorophyll-a concentrations in Burra Creek and the Queanbeyan River

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

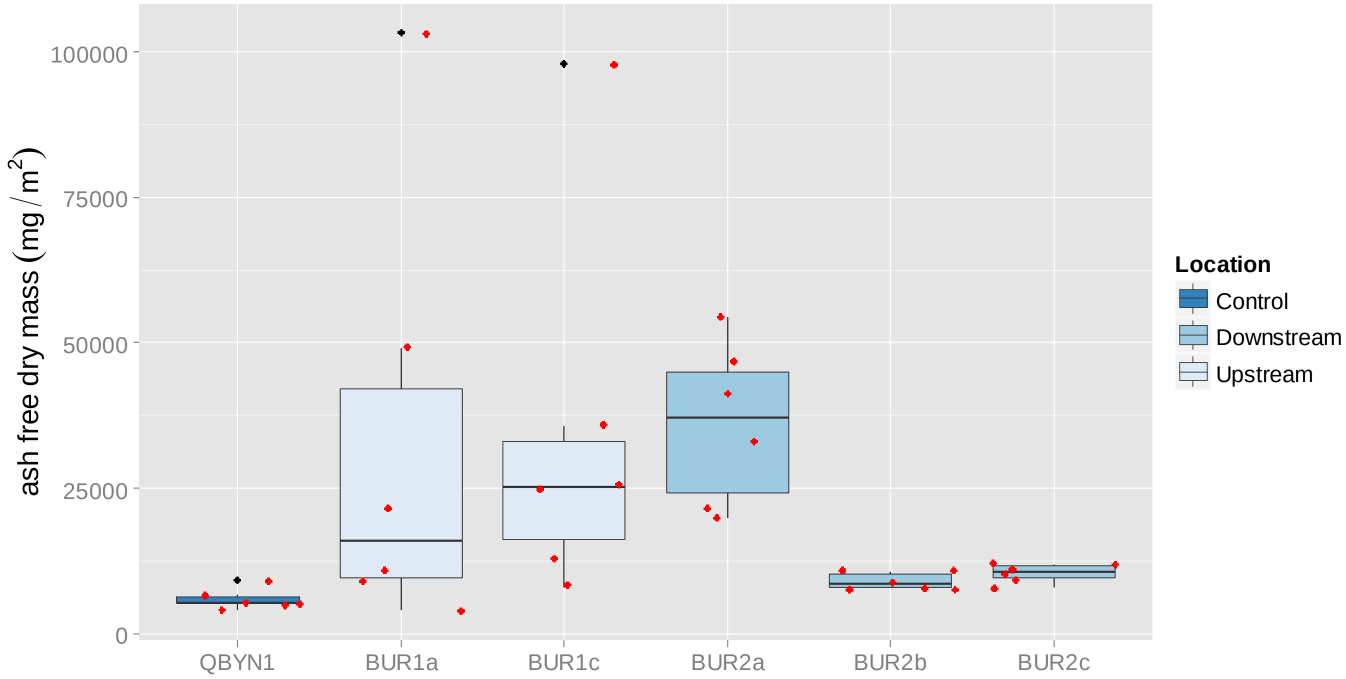

Figure 5-8. Ash free dry mass in Burra Creek and the Queanbeyan River

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

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

Response	Source	DF	F	P-value	Variance component (%)
Chlorophyll-a	Location	2	0.45	0.67	0.00
	Site [Location]	3	6.41	<0.001	47.40
	Total	35			
AFDM	Location	2	1.82	0.30	2.60
	Site [Location]	3	1.09	0.35	0.51
	Total	35			

5.5 Macroinvertebrates

5.5.1 Community assemblages

Riffle Habitat

Cluster analysis revealed four groups amongst the Burra Creek riffle samples (Figure 5-9), with 60% similarity. All except one of those groups contains only samples from the same site suggesting distinct separation in the macroinvertebrate communities between sites at the 60% similarity level. BUR 1c and BUR 2a formed their own cluster group and, because these sites are classified as upstream and downstream treatments respectively, the similarity between these sites resulted in no evidence of separation amongst locations (R=0.04; *P*=0.40). Despite the ANOSIM results, there are clear differences between the Queanbeyan control site and the Burra Creek sites and between BUR 2b and BUR 2c and the group containing BUR 1c and BUR 2a. BUR 1c and BUR 2a were characterised by high numbers of Chironomids and moderately tolerant mayflies, including the families: Baetidae (SIGNAL=5) and Caenidae (SIGNAL=4). BUR 2b was similar in that Chironomids dominated the samples. The key difference at this site was an increase in the number of Simuliidae (SIGNAL=5), Leptophlebiidae (SIGNAL=8) and Gripopterygidae (SIGNAL=8); while the key difference at BUR 2c was an increase of Trichoptera diversity.

The Queanbeyan River control site was the most diverse in this study with 30 families and 38 genera. In Burra Creek, the highest diversity occurred at BUR 2c (28 families and 34 genera), whereas the lowest diversity occurred at BUR 2a (20 families and 22 genera) (Figure 5-10). EPT richness ranged from 8 families, recorded at BUR 1c and BUR2a to 10 families at BUR 2c and QBYN 1. The number of EPT genera ranged from 10 at BUR 2a to 16 at BUR 2c and QBYN 1.

Compared to spring 2013, these results show an overall increase in the diversity of taxa, not only in Burra Creek, but also the Queanbeyan River. An increase of up to nine families (Queanbeyan River) was seen in this study. The largest increase in Burra Creek was five more macroinvertebrate families at BUR 2b. Even though there was an increase in the overall diversity at most of the sampling sites, most of the taxa were not in the EPT suite of taxa, because increases in this metric only occurred at BUR 2c and QBYN 1.

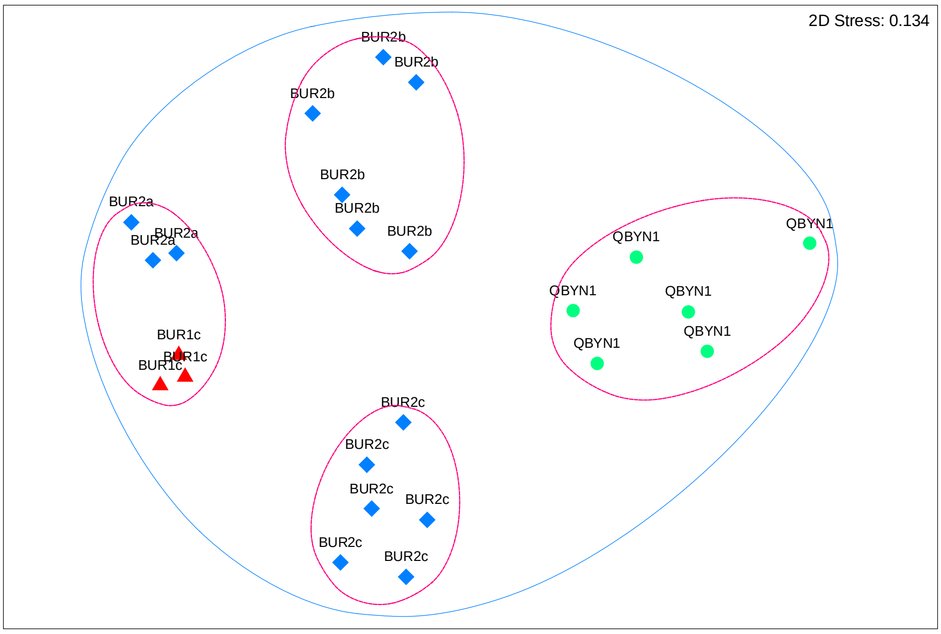

Figure 5-9. Non-metric multidimensional scaling of macroinvertebrate data (genus level) from the spring riffle samples

Note: Ellipses represent 40% (blue) and 60% (red) 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.

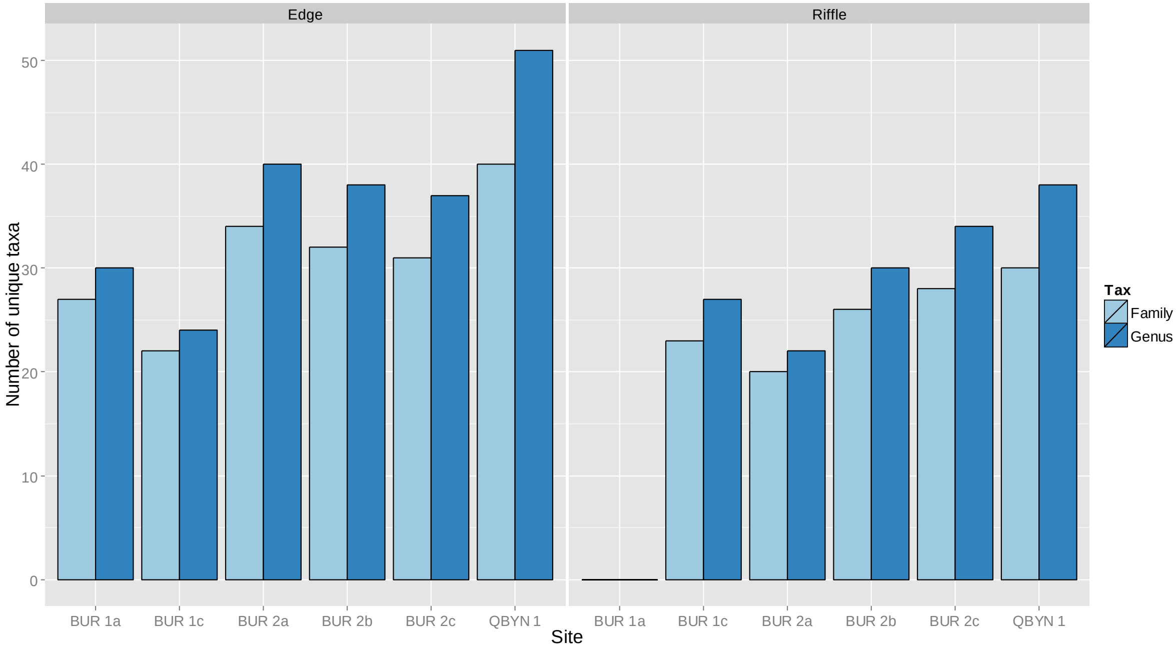

Figure 5-10. Number of taxa collected from the riffle and edge habitats

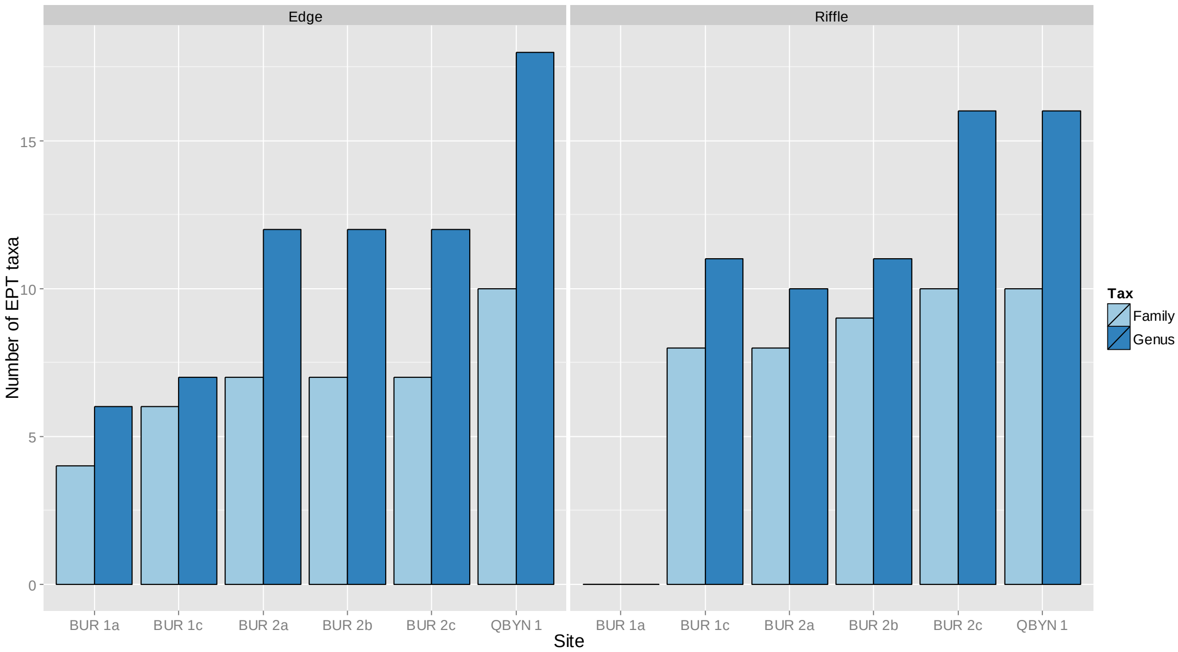

Figure 5-11. Number of EPT taxa collected from the riffle and edge habitats

Edge Habitat

Edge samples at BUR 1a (native site) appeared to be dissimilar to all of the other monitoring sites (Figure 5-12). There was no difference, statistically, between locations (R=0.41; *P*=0.16) which is a direct result of the differences between BUR 1a and BUR 1c. BUR 1c is more similar to the downstream sites than it is to BUR 1a and this is lowering the rank similarities between sites resulting in a relatively low R-value and non-significant *P*-value.

There are a few key differences between BUR 1a and BUR 1c (relevant because both sites are "upstream" sites in the current study design) that are worth mentioning. Diversity at BUR 1a was high compared to BUR 1c (Figure 5-10) but low compared to all of the Burra Creek sites and the Queanbeyan River site. However, in terms of EPT richness, BUR 1a had the lowest diversity off all sites in this study (Figure 5-11) which reflects the poor habitat at that site (i.e. a lot of silt on the bed, low dissolved oxygen, and low water level).

There was a decline in taxa richness at both of the upstream sites compared to spring 2013. At BUR 1a there were three fewer families and seven fewer genera; and at BUR 1c there were 10 fewer families and 21 fewer genera. All of the remaining sites had increases in the number of taxa; which ranged from three families at BUR 2c to 9 families at QBYN 1.

Most of the taxa that accounted for the unusually large decrease in genus and family richness at BUR 1c came from the following (higher taxonomic groups):

- **Diptera** - True flies;
- **Decapoda** - (Order of crustaceans which includes: shrimp, prawns, crabs and crayfish);
- **Coleoptera** (several genera of Dysticidae);
- **Gastropods** (snails);
- **Bivalves** (mussels and clams);
- **Odonata** (dragonflies and damselflies);

many of which are not used in the AUSRIVAS model for these sites.

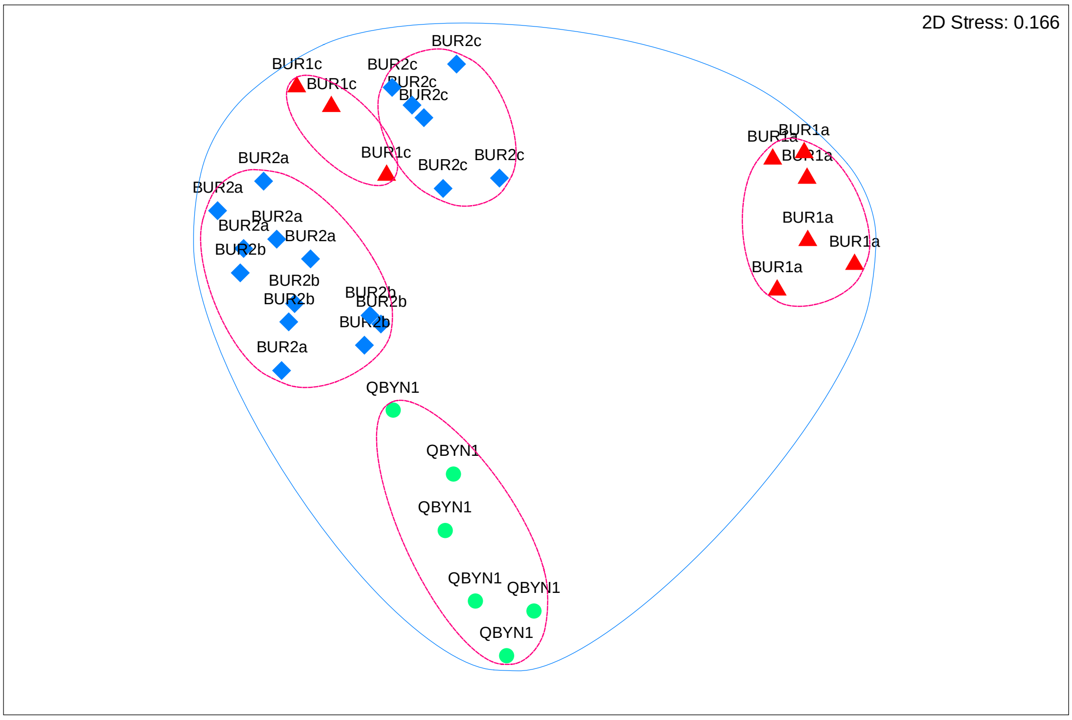

Figure 5-12. Non-metric multidimensional scaling of macroinvertebrate data (genus level) from the spring 2014 edge samples

Note: Ellipses represent 40% (blue) and 60% (red) 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.

5.5.2 AUSRIVAS

The average O/E50 scores for the riffle habitat ranged from 1.03 for BUR 2b, 1.05 at the Queanbeyan control site and 1.18 at BUR 2c. Owing to the low number of samples at some of these sites, namely BUR 1c (n=3) and BUR 2a (n=3) the confidence intervals around the means are quite large and this has resulted in non-significant differences between locations ($F_{2,23}$ = 0.14; P=0.88; Table 5-7). The average SIGNAL 2 scores ranged from 4.36 at BUR 1c to 5.21 at QBYN 1 and 4.79 at the sites downstream of the discharge point (Figure 5-13) and the results from the mixed effects model found these differences to be statistically difference ($F_{2,23}$ = 46.8; P=0.02; Table 5-7). Post-hoc comparisons found that all pairwise combinations were also statistically different (P<0.001; Table 5-8). Results from the edge habitat were similar to the riffle in that there was no statistical difference in the O/E50 scores between locations ($F_{2,32}$=3.00; P=0.18; Table 5-9); but there was a evidence of a difference in the SIGNAL 2 scores between sampling locations ($F_{2,32}$=19.23; P=0.02; Table 5-9). Post-hoc comparisons of each group were also highly significant between each sampling location (Table 5-10).

Overall sites assessments for spring 2014 resulted in three Band A assessments (“close to reference”) and three Band B assessments (“significantly impaired”) (Table 5-6). The three Band A assessments were attributed to QBYN 1, BUR 1c and BUR 2c; while the three Band B’s were attributed to BUR 1a, BUR 2b and BUR 2c. Compared to spring 2013, these results show no change at QBYN 1 or BUR 2a; whereas there were improved condition assessments at BUR 1c and a decline in condition at BUR 1a, BUR 2b and BUR 2c. Missing taxa from the AUSRIVAS riffle model ranged from 0 at BUR 2b and BUR 2c to 5 at BUR 2b, resulting in no reliable assessment at that site because the range of AUSRIVAS Bands (X – B) was greater than one Bandwidth. Most commonly, Elmidae (SIGNAL = 7) and Sphaeriidae (SIGNAL = 5) were missing – Elmidae from sites BUR 1c, BUR 2a and BUR 2c and Spaeriidae from QBYN 1 and BUR 2c (Appendix E3). Taxa missing from BUR 1a included three mayfly families including: Caenidae (SIGNAL =4); Baetidae (SIGNAL=5) and Leptophlebiidae (SIGNAL=8). The sensitive stonefly, Gripopterygidae (SIGNAL=8) was also missing from that site, BUR 2b and BUR 2c (Appendix E4).

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

	Autumn 2011	Spring 2011	Autumn 2012	Spring 2012	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014	Change since previous Spring sampling run
QBYN 1	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	↔
BUR 1a	**B**	**B**	**B**	**B**	**NS**	**A**	**C**	**B**	↓
BUR 1c	**NS**	**NRA**	**B**	**B**	**B**	**B**	**B**	**A**	↑
BUR 2a	**NRA**	**NRA**	**B**	**A**	**B**	**A**	**B**	**A**	↔
BUR 2b	**B**	**B**	**B**	**B**	**B**	**A**	**B**	**B**	↓
BUR 2c	**B**	**B**	**B**	**A**	**A**	**A**	**B**	**B**	↓

Note: NRA= no reliable assessment; NS = no sample.

Table 5-6. AUSRIVAS and SIGNAL-2 scores for spring 2014

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	5.18	4.80	1.01	1.17	A	X	**A**	**A**	**A**
QBYN 1	2	5.20	4.78	0.92	1.05	A	A			
QBYN 1	3	5.36	4.80	1.01	1.17	A	X			
QBYN 1	4	5.17	4.80	1.11	1.17	A	X			
QBYN 1	5	5.17	4.44	1.11	1.05	A	A			
QBYN 1	6	5.17	4.80	1.11	1.17	A	X			
BUR 1a	1	NS	3.83	NS	0.65	NS	B	**NS**	**B**	**B**
BUR 1a	2	NS	4.43	NS	0.76	NS	B			
BUR 1a	3	NS	4.43	NS	0.76	NS	B			
BUR 1a	4	NS	4.67	NS	0.98	NS	A			
BUR 1a	5	NS	4.25	NS	0.87	NS	A			
BUR 1a	6	NS	3.83	NS	0.65	NS	B			
BUR 1c	1	4.64	4.80	1.06	1.08	A	A	**A**	**A**	**A**
BUR 1c	2	4.92	4.89	1.16	0.97	X	A			
BUR 1c	3	4.92	4.44	1.16	0.97	X	A			
BUR 2a	1	4.82	4.44	1.06	0.99	A	A	**A**	**A**	**A**
BUR 2a	2	4.92	4.89	1.16	0.99	X	A			
BUR 2a	3	4.90	4.80	0.97	1.10	A	A			
BUR 2a	4	NS	4.67	NS	0.99	NS	A			
BUR 2a	5	NS	4.89	NS	0.99	NS	A			
BUR 2a	6	NS	4.67	NS	0.99	NS	A			
BUR 2b	1	5.18	4.44	1.06	0.97	A	A	**B**	**B**	**B**
BUR 2b	2	5.50	4.44	0.77	0.97	B	A			
BUR 2b	3	5.13	4.44	0.77	0.97	B	A			
BUR 2b	4	4.92	4.50	1.16	0.86	X	B			
BUR 2b	5	5.08	4.60	1.26	1.08	X	A			
BUR 2b	6	4.83	4.29	1.16	0.75	X	B			
BUR 2c	1	4.83	5.00	1.11	1.08	A	A	**A**	**B**	**B**
BUR 2c	2	5.08	4.60	1.20	1.08	X	A			
BUR 2c	3	4.82	4.91	1.01	1.19	A	X			
BUR 2c	4	5.07	4.67	1.29	0.97	X	A			
BUR 2c	5	5.08	4.67	1.20	0.97	X	A			
BUR 2c	6	5.07	4.50	1.29	0.86	X	B			

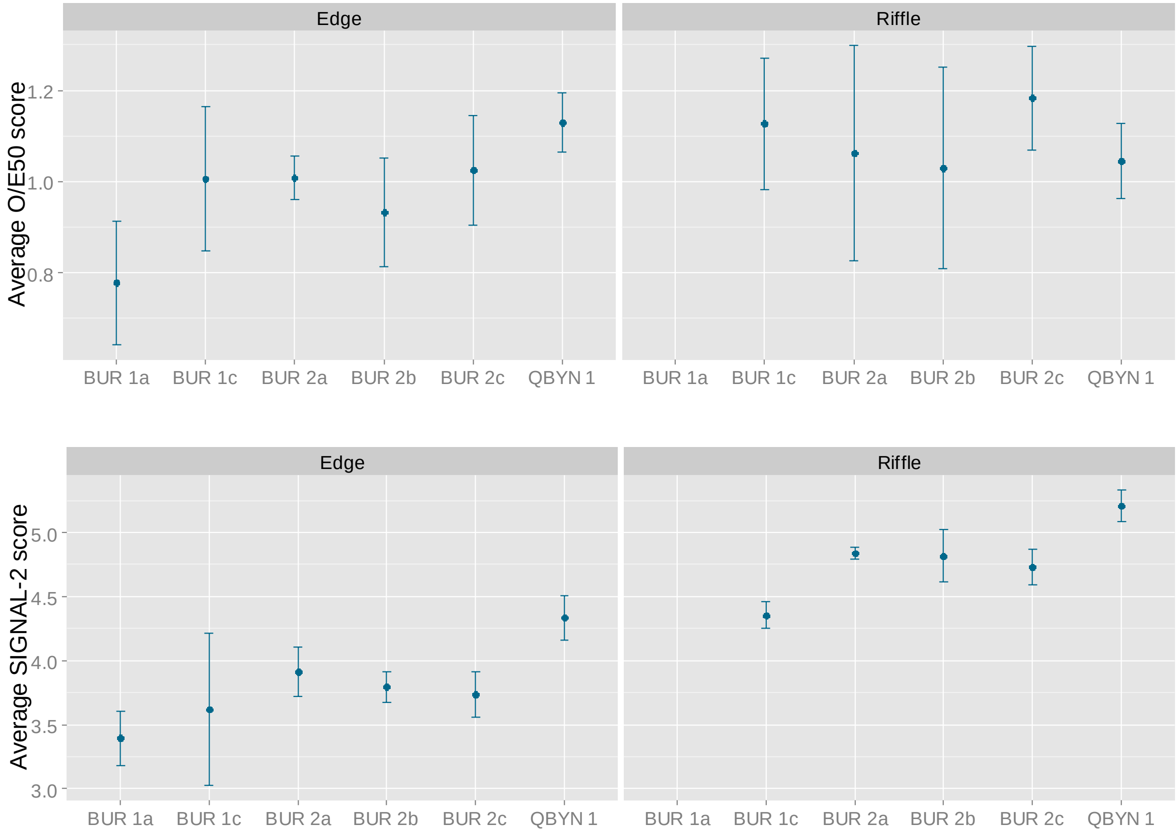

Figure 5-13. Means plot of SIGNAL-2 and O/E 50 scores for edge and riffle habitats

Note: Error bars are 95% confidence intervals.

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	0.14	0.88
	Site [Location]	2	15.33	0.00
	Total	23		
SIGNAL-2	Location	2	46.87	0.02
	Site [Location]	2	0.89	0.43
	Residual	23		

Table 5-8. Post-hoc comparisons of SIGNAL-2 scores from riffle habitat between sampling locations

	Control	Upstream	Downstream
Control			
Upstream	<0.001		
Downstream	<0.001	<0.001	

Note: P-values are estimates from the Markov Chain Monte Carlo (MCMC) re-sampling procedure with 9,999 restarts.

Table 5-9. 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	3.00	0.18
	Site [Location]	2	4.76	0.01
	Total	23		
SIGNAL-2	Location	2	19.23	0.02
	Site [Location]	2	2.20	0.11
	Residual	23		

Table 5-10. Post-hoc comparisons of SIGNAL-2 scores from edge habitat between sampling locations

	Control	Upstream	Downstream
Control			
Upstream	<0.001		
Downstream	<0.001	0.005	

Note: P-values are estimates from the Markov Chain Monte Carlo (MCMC) re-sampling procedure with 9,999 restarts.

5.6 Discussion

5.6.1 Water quality

The water quality results were within the same range of values as those that were recorded during spring 2013; and as expected there were elevated electrical conductivity (EC) and pH readings in Burra Creek. These are characteristic of this creek during periods of low flow. The elevation in pH was also recorded at QBYN 1, where it exceeded the ANZECC & ARMCANZ (2000) guideline for the first time since the inception of the MEMP. Dissolved oxygen (DO) levels were below the recommended range at all Burra Creek sites. Similar to Angle Crossing this is likely to be linked with the low flows and increasing temperatures in the creek. However, taxa present within the creek are likely to be adapted to periods of low DO as, during warmer months combined with low flow, reduced DO is likely to be common within Burra Creek.

Total nitrogen (TN) was elevated above the guideline at all sites (BUR 2c on the cusp), while BUR 2b also exceeded the total phosphorus (TP) guideline. Similar levels of nutrient enrichment have been recorded in Burra Creek during previous spring sampling runs (GHD, 2013a), but were not present during spring 2013 (GHD, 2014a). This may be linked to the size of the event during September 2013 which may have had a flushing effect on the creek clearing out large amounts of accumulated nutrients, while the smaller event during September 2014 did not have the same impact.

Increased levels of NO_x and ammonia at BUR 2a were recorded prior to the M2G APPLE run during November and are attributable to inflow from Holden's Creek. Holden's Creek flows into Burra Creek immediately upstream of the M2G discharge (and downstream of BUR 1c) structure and has previously been tested as a source of increased levels of NO_x (GHD, 2012). However, there was no increase in either TN or TP levels downstream of the Holden's Creek inflow as NO_x and ammonia levels reduced to below detectable limits at the next site downstream (BUR 2b).

There was no evidence of a negative impact on the continuous water quality data during the period of the M2G APPLE run, with the pumping mostly impacting the EC and pH at the continuous monitoring station. The APPLE water actually increased compliance with the ANZECC & ARMCANZ (2000) guidelines for these two parameters reducing both to below the respective upper limits of the recommended range.

5.6.2 Periphyton

There were significant increases in chlorophyll a and AFDM compared to spring 2013, which is most likely explained by the absence of scouring disturbances and longer residence times of nutrients as a function of the preceding low base-flow conditions during the spring period. This scenario was brought on by the lowest spring rainfall since the implementation of the MEMP in 2008.

The spatial patterns of the chlorophyll-a data show a spike at BUR 2a, which corresponded to the field observations noting larger patches of filamentous algae compared to other sites. At BUR 1a, BUR 1c and BUR 2a there were observable differences in the amount of detrital matter, which is indicated by the higher AFDM estimates at these sites (Figure 5-8).

In previous reports, we have noted that nutrient inputs from Holden's Creek may influence the accrual rates of the biofilms downstream of Williamsdale Road. However an important point to make is that, this only applies to wet periods when there is sufficient runoff to generate surface flow in Holden's Creek as most the time, Holden's Creek is more intermittent than Burra Creek. Furthermore, data from this sampling run indicates that there are high concentrations occurring in the upper reaches of Burra Creek (Table 5-3) which may equally influence periphyton accrual and filamentous algae growth. The high concentrations of phosphorus at BUR 1a might be due to differences in the geology of this reach of Burra Creek, while the elevated total nitrogen levels may be due to grazing stock with access to the creek.

5.6.3 AUSRIVAS and macroinvertebrate assemblages

In spring 2014 there were no riffle samples collected at BUR 1a as the site was almost completely dry (Plate 5-1). Surface water was reduced to isolated pools (Plate 5-1), but there were small areas of flowing water under the surface cobbles and pebbles.

Ordination analysis of the macroinvertebrate assemblages show that all of the riffle samples are approximately 40% similar; but at 60% similarity, four groups emerge. These essentially contain samples from each sampling site. However, BUR 1c and BUR 2a form their own group, which is an indication of their geographic relatedness and other similarities between the sites. Due to the closeness of these two sites and because they are classified as upstream and downstream sites respectively, there was no statistically difference found between sampling locations. The multivariate analysis of the edge samples produced a similar result, showing that some sites were more similar to sites in other locations (e.g. BUR 2b and QBYN 1 and BUR 1c and BUR 2c) than they were to sites within the same location.

Riffle samples in Burra Creek were dominated by high numbers of Orthocladinae (SIGNAL =4), Chironominae (SIGNAL =3) and Caenidae (SIGNAL =4). These characterising taxa are similar to those described in spring 2013 except that Simuliidae were less abundant and less common in the current study, presumably because of the longer period of low flows leading up to the sampling run. Downstream of the discharge point there was an increase in the number of mayflies in the family: Leptophlebiidae (SIGNAL = 8), an increase in the number of riffle beetles (Elmidae: SIGNAL =7) and a general increase in overall diversity and EPT diversity (Figure 5-10 and Figure 5-11) which might be an indication of the increasing discharge with distance downstream (Gordon *et al.,* 2004). This can be seen in Figure 5-13 which shows an increase in SIGNAL 2 scores with distance downstream and then again in the perennial Queanbeyan River.

Although a similar pattern of increasing O/E50 scores with distance downstream was seen in spring 2013, the same pattern was not seen in this study, which may have been due to the high amount of variation in O/E50 scores within sampling sites. Low flow disturbances can result in a reduction of wetted width, available habitat and changes to surface water chemistry through dilution and / or through increasing groundwater contributions. This can lead to increasing “patchiness” in the distribution of macroinvertebrate taxa in response to stress triggers (Stanley *et al.*, 1997). Young *et al.* (2011), found that after seeing an increase in the variability of macroinvertebrate communities within and between sites; this variability decreased soon after the resumption of surface flows, which they suggested was due to homogenisation of environmental and hydrological filters across a range of habitats.

The AUSRIVAS results showed no change in condition at QBYN 1 or BUR 2a compared to 2013, declines in condition at BUR 1a and BUR 2b and improved health assessments at BUR 1c. The assessment at BUR 1c is the first “close to reference” assessment for that site and is somewhat at odds with the general condition of this site, given the heavy inundation by macrophytes, low flows and heavily silted riffle habitat. In the present study, only Elmidae were missing from the AUSRIVAS model compared to last year when there were up to eight families missing. It is unclear why there were improved health assessments given to the BUR 1c, but there were increases in taxa richness at four of the five sites sampled, which may suggest that more favourable conditions existed over a broader scale at the time of sampling.

In the edge habitat, however, there was a significant decrease in taxa richness at BUR 1c compared to spring 2013. The loss of taxa occurred from six higher taxonomic groups (see section 5.5.1), most of which are not used in the AUSRIVAS model. This explains why, despite the reduction of taxa richness by approximately 50% compared to spring 2013 (GHD, 2014a), there were no obvious impacts upon the AUSRIVAS river health assessment results. A reduction in taxa richness was also found at BUR 1a and BUR 1c from the edge habitat and in both cases, the water level in the edge habitat was noted to have dropped since previous sampling runs. There was also considerable algal growth on the substrate and the surface and, at BUR 1c, there was heavy encroachment from instream macrophytes. All of these factors may have contributed to the reduced number of taxa as low taxa richness in intermittent streams is often attributed to the more extreme conditions, including variable and often reduced aquatic habitat due to drying in these environments (Boulton and Suter, 1986).

Sheldon (2005) produced a conceptual model of intermittent streams where it was suggested that given some indicator of river health, there will be a gradual decline in that condition indicator with time since the last flood (or high flow event) through natural variation. While this may also provide some explanation for certain aspects of the results presented (loss of diversity and increase in periphyton biomass) here it does suggest that the use of AUSRIVAS in an intermittent stream environment may not be the best indicator given that the results at certain sites (primarily BUR 1c), seems anomalous given the very low surface flows and problems associated with low flows, such as: sedimentation and increased algal mats. This was also raised by Chessman *et al.* (2010), where they added that the problem with the model in intermittent streams is that they may not be comparing these sites to the most appropriate reference sites and the existing models may not take the intermittent nature of the streams into account.

5.7 Conclusions and recommendations

In spring 2014 there were obvious signs of a prolonged period of low flows and gradual drying of the system. These signs included increased inundation of macrophytes into the stream channel (which was particularly notable at BUR 1c and BUR 2b) and a stratified pattern of dried algae at ever decreasing layers along the banks of the channel as the water level continued to drop. Results presented here do not fully reflect these observations, given that there were improvements in AUSRIVAS Bands and there were no obvious changes in water quality (except maybe the lower dissolved oxygen recorded at all monitoring sites). However, the significant increase in periphyton biomass estimates and the loss of a number of taxa at BUR 1a and BUR 1c, which were the most, obviously affected sites do provide evidence of an initial change.

In section 4.7 there is a reference to a summary document which lists the majority of the recommendations made by GHD to Icon Water over the course of the MEMP. In addition to this, an operational monitoring plan was also written in 2011 (ALS, 2011), which took into account the different monitoring requirements that the MEMP may have to adopt during the operational phase of the MEMP. In the last monitoring report (GHD, 2014b), five additional recommendations were made, which included a revision of the periphyton monitoring methods and, in fact, a revision of all sampling methods in recognition of the potentially long term “maintenance” mode of operation for M2G. It was also recommended that two additional water quality monitoring locations be included into the program to capture event based water quality information in accordance with the M2G operational plan (specifically looking at TN and TP) and also to include a sample collection point at the discharge point to help better understand that dilution process.

In terms of the revised MEMP, after reading the Jacobs review of the MEMP (Jacobs, 2014) and taking into consideration the different modes of operation that have been proposed to guide future monitoring of Burra Creek, it is recommended that the inclusion of BUR 2c be reconsidered for the impact monitoring component of the project for the following reasons:

4. The riffle habitat is immediately downstream of an erosion hotspot. Therefore linkages between significant erosion, should it occur during operation, and potential impacts to riffle quality and river health will be relatively straight forward;

5. This is a key site given that it is close to Googong reservoir so understanding whether any potential impacts from M2G extend this far downstream is considered to be an important part of the monitoring program;

6. The baseline data recorded for this site is of a very high standard, which will make impact assessments very informative in terms of comparisons to the historical records.

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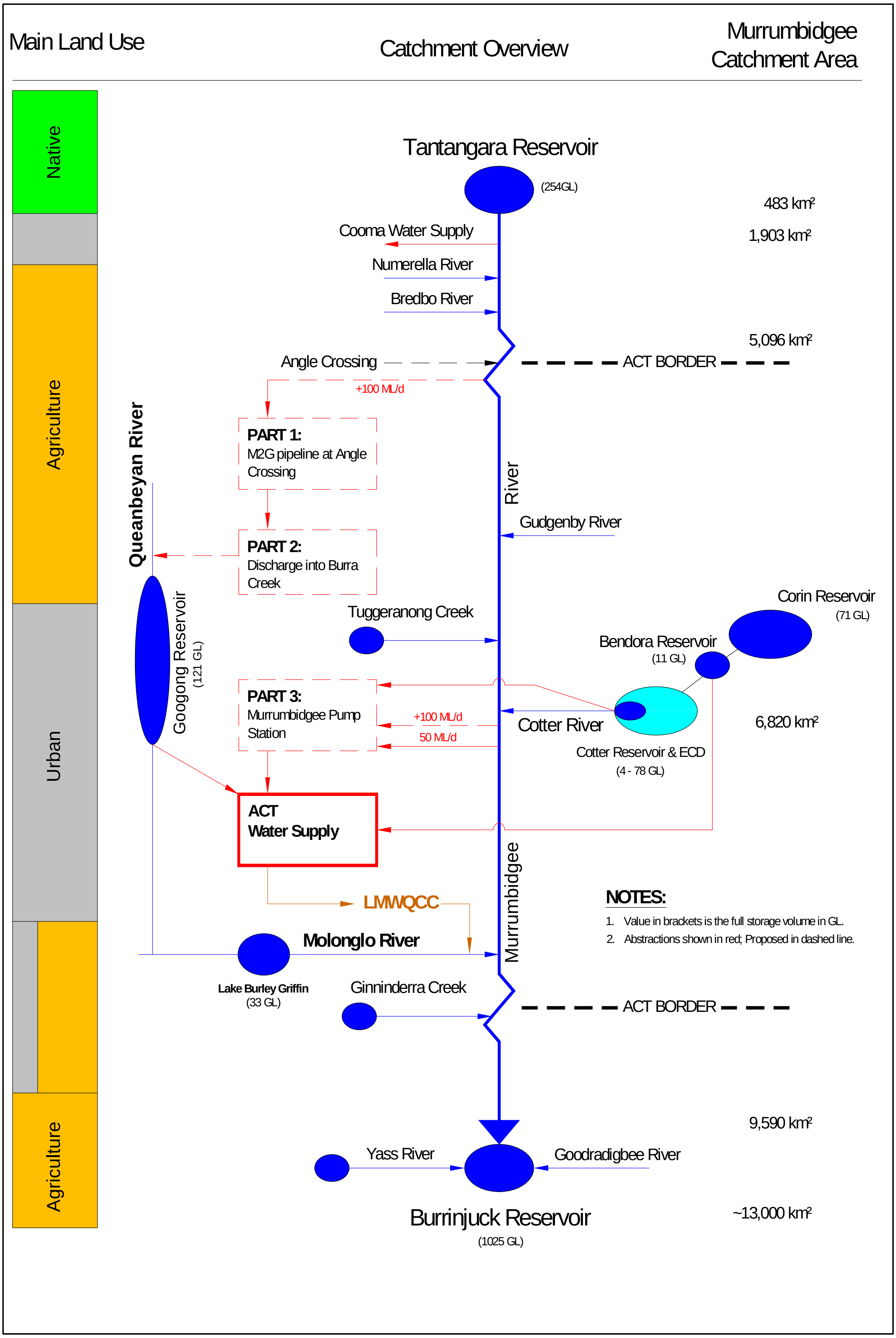
Appendices

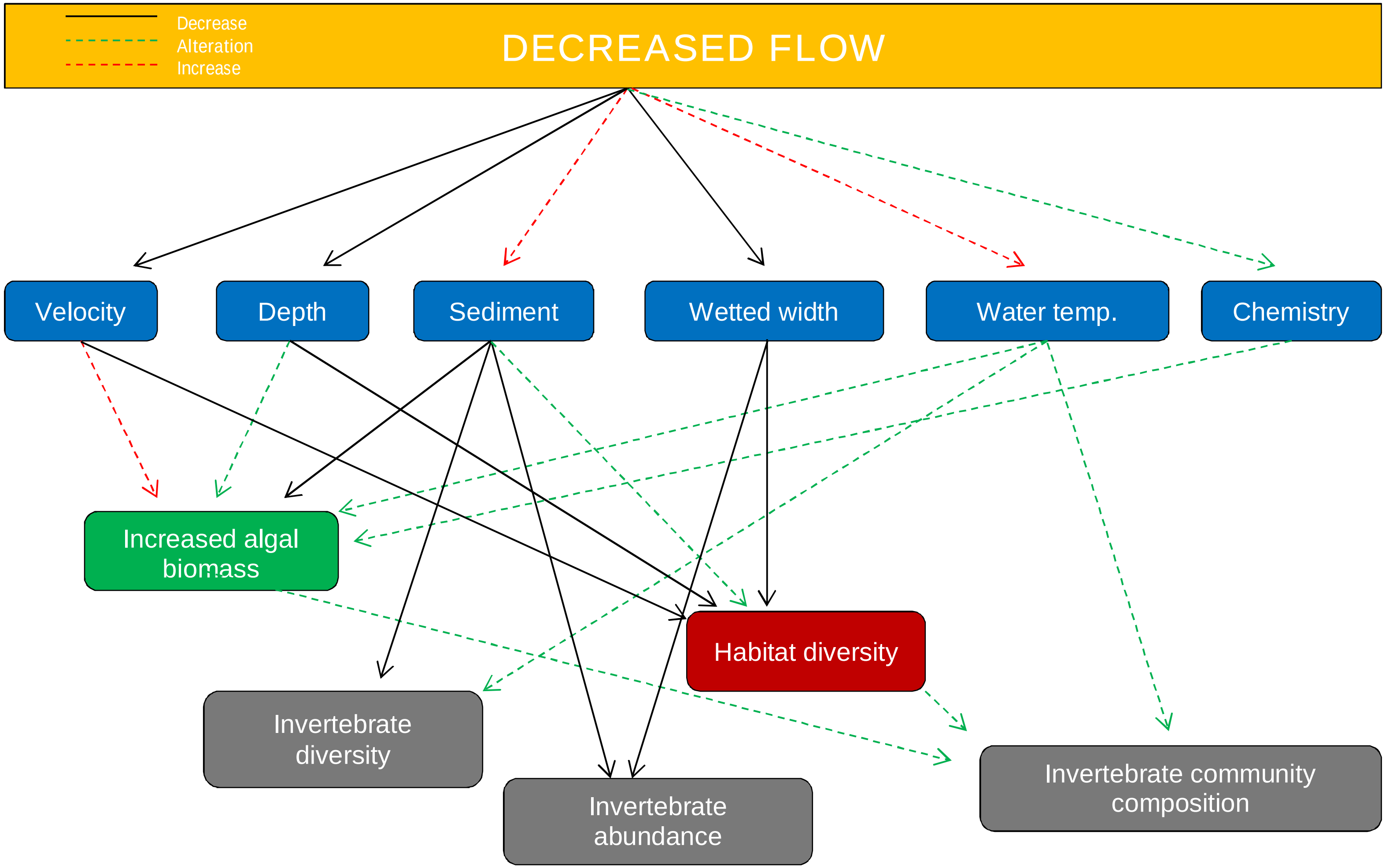
Appendix A - Schematic representation of the Murrumbidgee Catchment and Icon Water's major projects


Main Land Use
Catchment Overview
Murrumbidgee Catchment Area
Native
Agriculture
Urban
Agriculture
Tantangara Reservoir
(254GL)
483 km²
Cooma Water Supply
1,903 km²
Numerella River
Bredbo River
5,096 km²
Angle Crossing
ACT BORDER
+100 ML/d
PART 1:
M2G pipeline at Angle Crossing
PART 2:
Discharge into Burra Creek
Queanbeyan River
Googong Reservoir
(121 GL)
Murrumbidgee River
Gudgenby River
Tuggeranong Creek
Corin Reservoir
(71 GL)
Bendora Reservoir
(11 GL)
PART 3:
Murrumbidgee Pump Station
+100 ML/d
50 ML/d
Cotter River
Cotter Reservoir & ECD
(4 - 78 GL)
6,820 km²
ACT
Water Supply
LMWQCC
Molonglo River
Lake Burley Griffin
(33 GL)
Ginninderra Creek
ACT BORDER
NOTES:
1. Value in brackets is the full storage volume in GL.
2. Abstractions shown in red; Proposed in dashed line.
9,590 km²
Yass River
Goodradigbee River
Burrinjuck Reservoir
(1025 GL)
~13,000 km²

Appendix B – Conceptual framework of the effects of reduced flow

Appendix B. 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 Results

Appendix C1. QA/QC results for Angle Crossing and Burra Creek for spring 2014 (discrepancies highlighted in yellow)

		Site Code	BUR 2A		BUR 2B		QBYN 1		MUR 16		MUR 19		MUR 18	
		Habitat	RIFFLE		RIFFLE		EDGE		RIFFLE		EDGE		RIFFLE	
		Sample	1		2		1		1		1		1	
		Replicate	2	QA	3	QA	2	QA	1	QA	2	QA	3	QA
CLASS / Order	Family / Sub-Family	Genus												
ACARINA			1	1	18	19	2	2	6	6			13	13
BIVALVIA	Sphaeriidae	*Pisidium*					2	2						
		sp.			9	9								
Coleoptera	Dytiscidae	*Necterosoma*					1	1						
	Elmidae	*Austrolimnius*			1	1								
		sp.			2	2	1	1					1	1
	Gyrinidae	*Macrogyrus*									1	1		
	Hydrophilidae	*Sternolophus*					1	1						
	Scirtidae		1	1	4	4								
Decapoda	Atyidae	*Paratya*					5	5			1	1		
Diptera	Ceratopogonidae	*Ceratopoginae*	3	3	5	5	5	5					1	1
		Forcipomyiinae			1	1								
	Chironominae		93	91	16	16	15	16	2	2	20	20	2	2
	Culicidae	*Aedes*					17	16						
	Dixidae						9	9						
	Empididae		1	1	2	2								
	Orthocladiinae		28	28	35	34	23	23	11	11	24	24	27	27
	Simuliidae	*Austrosimulium*	1	1					87	86	5	5	143	139
		Simulium			1	1			1	1			4	4
		sp.			5	5			8	8	8	8	14	14
	Stratiomyidae	*Odontomyia*	1	1										
	Tanypodinae		6	6	1	1	11	12	3	3	9	9		
	Tipulidae								2	2			2	2
Ephemeroptera	Baetidae	*Baetidae Genus 1*	2	2	2	2					2	2		
		Baetidae Genus 2							1	1			1	1
		sp.	21	22	26	25			3	3	2	2	1	1
	Caenidae	*Irapacaenis*					4	4			1	1		
		Tasmanocoenis	5	5			22	22	4	4	30	31		
		sp.			3	3	19	19	18	18	4	4	3	3

		Site Code	BUR 2A		BUR 2B		QBYN 1		MUR 16		MUR 19		MUR 18	
		Habitat	RIFFLE		RIFFLE		EDGE		RIFFLE		EDGE		RIFFLE	
		Sample	1		2		1		1		1		1	
		Replicate	2	QA	3	QA	2	QA	1	QA	2	QA	3	QA
CLASS / Order	**Family / Sub-Family**	**Genus**												
	Coloburiscidae	*Coloburiscoides*							1	1				
	Leptophlebiidae	*Atalophlebia*									1	1		
		Jappa	9	9					7	7				
		Koornonga					1	1						
		sp.	16	16	4	4	4	4	11	11			3	3
GASTROPODA	Physidae	*Physa*					5	5						
Gastropoda	Planorbidae (Ancylidae)	*Ferrissia*			3	3								
	Gerridae						1	1						
	Micronectidae	*micronecta*	1	1							10	10		
	Notonectidae	*Paranisops*					2	2						
		sp.									4	4		
	Veliidae	*Microvelia*					1	1						
Hirudinea	Erpobdellidae						1	1						
Odonata	Aeshnidae	*Adversaeschna*					2	2						
	Cordulephyidae	*Cordulephya*					1	1						
	Epiprocta						1	1						
	Gomphidae	*Austrogomphus*					1	1						
		sp.					1	1						
OLIGOCHAETA			18	18	9	9	9	9	23	24	34	32	2	2
Plecoptera													1	1
	Gripopterygidae	*Dinotoperla*	2	2			5	5			4	4	3	3
		Illiesoperla	2	2					3	3				
		sp.							2	2	9	9		
Trichoptera							1	1						
	Calamatoceridae	*Anisocentropus*					1	1						
	Ecnomidae	*Ecnomus*	3	3										
	Glossosomatidae	*Agapetus*											1	1
	Hydrobiosidae				1	1								
	Hydropsychidae	*Cheumatopsyche*	1	1					3	3			1	1
		sp.	5	5	7	7	2	2	21	21			7	7
	Hydroptilidae	*Hellyethira*	1	1	3	3	8	8			19	19		

		Site Code	BUR 2A		BUR 2B		QBYN 1		MUR 16		MUR 19		MUR 18	
		Habitat	RIFFLE		RIFFLE		EDGE		RIFFLE		EDGE		RIFFLE	
		Sample	1		2		1		1		1		1	
		Replicate	2	QA	3	QA	2	QA	1	QA	2	QA	3	QA
CLASS / Order	**Family / Sub-Family**	**Genus**												
		Hydroptila							2	2	1	1	3	3
		Oxyethira	1	1	13	13	4	4	2	2	4	4	3	3
		sp.			2	2			5	5				
	Leptoceridae	*Notalina*					6	6						
		Oecetis					36	36						
		Triplectides					4	4			1	1		
		sp.					8	8						
Turbellaria	Dugesiidae	*Dugesia*			1	1	1	1					1	1
		Error	1.36%		1.73%		1.23%		0.88%		1.55%		1.72%	
		Pass Rate	< 5%		< 5%		< 5%		< 5%		< 5%		< 5%	
		Pass / Fail	**Pass**		**Pass**		**Pass**		**Pass**		**Pass**		**Pass**	

Appendix D - Site Summaries

Part 1: Angle Crossing

MUR15

Bumbalong Road
11/11/2014 9:30 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
21.6	96.3	10.1	10	7.78	84.3	7.43

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
43	< 0.002	< 0.002	< 0.002	< 0.002	0.032	0.30

Daily Flow: 190 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 2013: ↑ Autumn 2014: ↑

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	NRA	B	NRA
Edge Habitat	A	B	A
Overall Site Assessment	NRA	B	A

Riffle Habitat

- Silt and sand flushed out from most recent event
- Good habitat availablilty
- Dominant substrate was cobble

Dominant Taxa

- Simuliidae
- Leptophlebiidae
- Gripopterygidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Coloburiscidae
- Hydrobiosidae
- Gripopterygidae
- Leptophlebiidae

Additional Comments

- Some large patches of *Myriophyllum sp.*

Edge Habitat

- Dominant trailing bank vegetation was from overhanging shrubs and trees (willow)

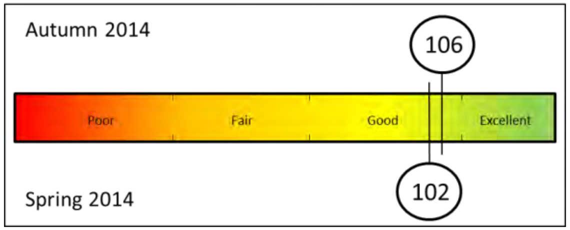
Dominant Taxa

- Gripopterygidae
- Corixidae
- Acarina
- Dysticidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae

Site Quality Assessment



MUR16

The Willows – Near Michelago
11/11/2014 12:20 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
22.5	96.9	12.5	12	7.32	86.1	7.44

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	< 0.002	0.035	0.34

Daily Flow: 190 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 2013: ↑ Autumn 2014: ↑

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	B	B	B
Edge Habitat	B	B	B
Overall Site Assessment	B	B	B

Riffle Habitat

- Silt and sand has been flushed from the riffle by recent high flow events
- Dominant substrate was cobble

Dominant Taxa

- Simuliidae
- Baetidae
- Gripopterygidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae
- Coloburiscidae
- Hydrobiosidae

Edge Habitat

- Dominant trailing bank vegetation was overhanging native shrubs

Dominant Taxa

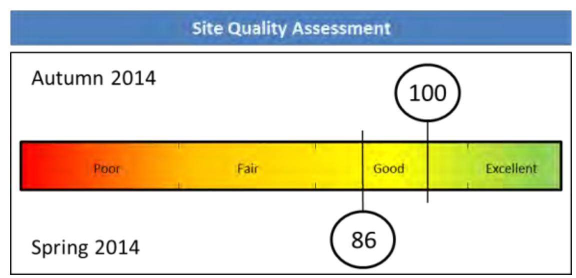
- Corixidae
- Notonectidae
- Chironomidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- None

Additional Comments

- Very few macrophytes observed at the site



MUR18

Upstream Angle Crossing
12/11/2014 1:15 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
22.8	98.2	8.48	11	7.31	88.6	8.16

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
58	< 0.002	< 0.002	< 0.002	< 0.002	0.028	0.33

Daily Flow: 220 ML/day

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

Compared to current flow:

Spring 2013: ↑ Autumn 2014: ↑

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	B	B	B
Edge Habitat	A	B	A
Overall Site Assessment	B	B	B

Riffle Habitat

- Samples collected in habitat ~100m upstream of normal riffle habitat where no habitat was present
- Dominant substrate was cobble

Dominant Taxa

- Gripopterygidae
- Baetidae
- Hydropsychidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Coloburiscidae
- Leptophlebiidae

Additional Comments

- None

Edge Habitat

- Edge samples collected in habitat ~100m upstream of normal edge, due to better quality habitat
- Dominant trailing bank vegetation was overhanging willows

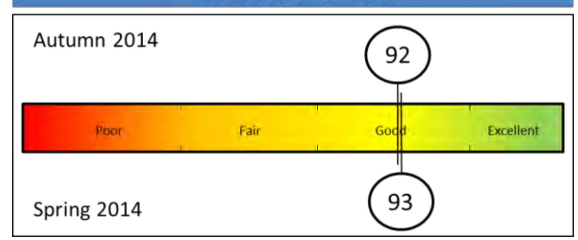
Dominant Taxa

- Notonectidae
- Atyidae
- Gripopterygidae
- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae

Site Quality Assessment



MUR19

Downstream Angle Crossing
11/11/2014 2:30 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
22.9	101.2	9.13	9	7.45	86.5	7.37

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
46	< 0.002	< 0.002	< 0.002	< 0.002	0.026	0.32

Daily Flow: 180 ML/day

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

Compared to current flow:

Spring 2013: ↑ Autumn 2014: ↑

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	B	B	NRA
Edge Habitat	A	B	A
Overall Site Assessment	B	B	A

Riffle Habitat

- Dominant substrate was sand and cobble

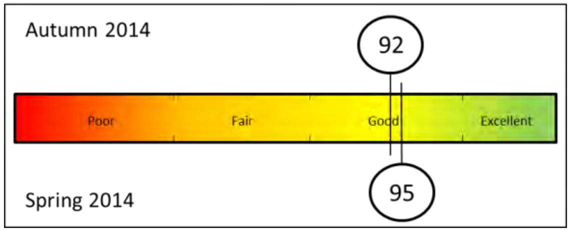
Dominant Taxa

- Hydropsychidae
- Gripopterygidae
- Baetidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae

Site Quality Assessment



Edge Habitat

- Dominant trailing bank vegetation was overhanging willows

Dominant Taxa

- Gyrinidae
- Corixidae
- Notonectidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae

Additional Comments

- Submerged macrophytes uncommon, when compered to previous seasons

MUR23

Point Hut Crossing
12/11/2014 11:00 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
22.9	110.9	9.11	10	7.79	89.7	7.96

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
48	< 0.002	< 0.002	< 0.002	< 0.002	0.030	0.34

Daily Flow: 170 ML/day

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

Compared to current flow:

Spring 2013: ↑ Autumn 2014: ↑

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	A	B	B
Edge Habitat	A	B	A
Overall Site Assessment	A	B	B

Riffle Habitat

- Dominant substrate was sand

Dominant Taxa

- Gripopterygidae
- Leptophlebiidae
- Chironomidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Coloburiscidae
- Leptophlebiidae

Edge Habitat

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

Dominant Taxa

- Corixidae
- Dysticidae
- Notonectidae
- Leptoceridae

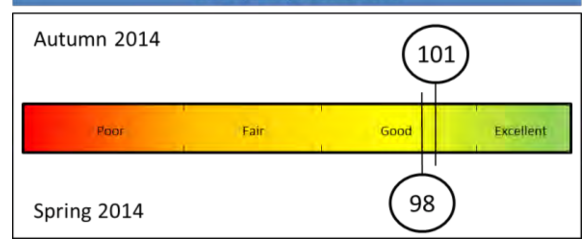
Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae

Additional Comments

- None

Site Quality Assessment



MUR28

Upstream Cotter River Confluence
12/11/2014 9:15 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
22.1	107	8.62	10	7.84	80.6	7.84

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
50	0.003	0.003	< 0.002	< 0.002	0.025	0.36

Daily Flow:

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

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

43 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.

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	B	B	B
Edge Habitat	NRA	C	A
Overall Site Assessment	NRA	C	B

Riffle Habitat

- Highly silted habitat
- Dominant substrate was boulder

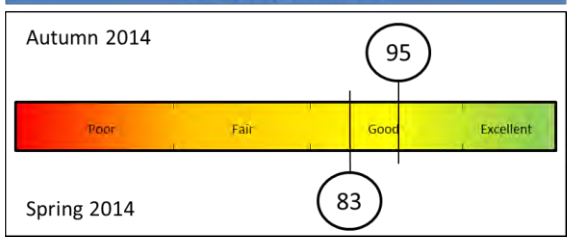
Dominant Taxa

- Simuliidae
- Chironomidae
- Caenidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae

Site Quality Assessment



Edge Habitat

- Poor quality habitat
- Only 1 samples collected due to limited habitat availability
- Dominant trailing bank vegetation was overhanging *Casuarina sp.* and blackberry

Dominant Taxa

- Atyidae
- Corixidae
- Leptoceridae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

Additional Comments

- Carp observed at the site

Part 2: Burra Creek

BUR1a

Burra Native
4/11/2014 9:30 am

Temp. (°C)	EC (µs/cm)	Turb. (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
16.4	112.9	14.0	2	6.91	76.4	7.26

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
30	< 0.002	< 0.002	< 0.002	< 0.002	0.016	0.36

Daily Flow: 1.6 ML/day

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

Compared to current flow:

Spring 2013:  Autumn 2014: 

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	A	C	NS
Edge Habitat	A	C	B
Overall Site Assessment	A	C	B

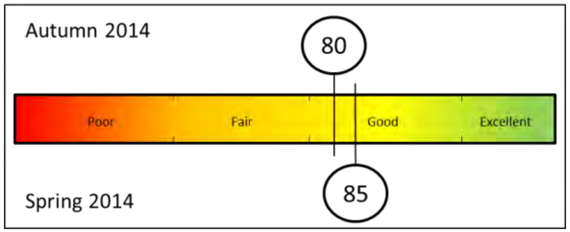
Riffle Habitat

- No riffle habitat, due to no flow

Additional Comments

- No flow through the riffle habitat
- Site was characterised by disconnected pools with no surface flow

Site Quality Assessment



Edge Habitat

- Dominant trailing bank vegetation was overhanging shrubs (mainly *Kunzea sp.*)
- Habitat was in good condition

Dominant Taxa

- Leptoceridae
- Leptophlebiidae
- Dysticidae
- Corixidae
- Chironomidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

BUR1c

Upstream Williamsdale Road
5/11/2014 9:00 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
16.5	388.2	5.2	15	8.14	85.3	8.29

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
171	< 0.002	< 0.002	< 0.002	< 0.002	0.015	0.31

Daily Flow: 1.5 ML/day

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

Compared to current flow:

Spring 2013:  Autumn 2014: 

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	B	B	A
Edge Habitat	X	B	A
Overall Site Assessment	B	B	A

Riffle Habitat

- Poor quality, highly silted habitat
- Only a single sample was collected due to limited habitat availability
- Dominant substrate was pebble

Dominant Taxa

- Chironomidae
- Baetidae
- Hydrobiosidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Hydrobiosidae
- Gripopterygidae

Edge Habitat

- Only a single sample was collected due to limited habitat availability
- Dominant trailing bank vegetation was macrophytes (mainly *Schoenoplectus sp.*)

Dominant Taxa

- Acarina
- Caenidae
- Notonectidae

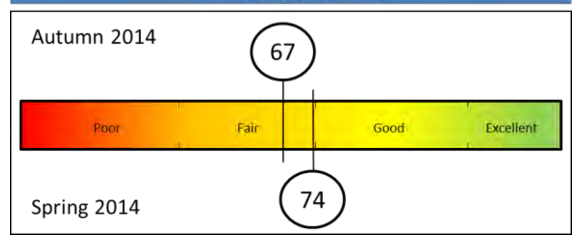
Sensitive Taxa (SIGNAL-2 ≥ 7)

- None

Additional Comments

- Very little flow
- A turtle was observed at the site

Site Quality Assessment



BUR2a

Downstream Williamsdale Road
4/11/2014 11:45 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
17.2	468.0	7.20	4	7.61	74.8	7.22

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
219	0.049	0.049	< 0.002	0.007	0.015	0.29

Daily Flow: 1.6 ML/day

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

Compared to current flow:

Spring 2013:  Autumn 2014: 

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	A	B	A
Edge Habitat	A	A	A
Overall Site Assessment	A	B	A

Riffle Habitat

- Only a single sample was collected due to limited habitat availability
- Highly silted habitat
- Dominant substrate is cobble and silt

Dominant Taxa

- Leptophlebiidae
- Baetidae
- Atyidae
- Simuliidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae

Additional Comments

- None

Edge Habitat

- Dominant trailing bank vegetation was macrophytes (mainly *Phragmites australis* and *Schoenoplectus sp.*)

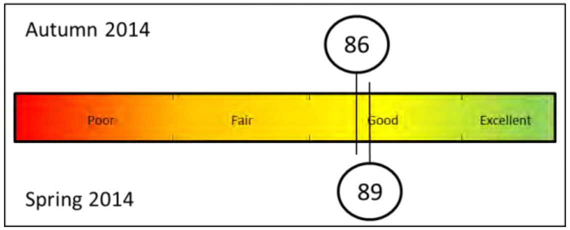
Dominant Taxa

- Atyidae
- Leptoceridae
- Leptophlebiidae
- Acarina
- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

Site Quality Assessment



BUR2b

Downstream Burra Road
4/11/2014 1:45 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
21.1	529.0	9.01	16	8.13	89.6	8.04

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
227	< 0.002	< 0.002	< 0.002	< 0.002	0.028	0.34

Daily Flow: 1.6 ML/day

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

Compared to current flow:

Spring 2013: ↑ Autumn 2014: ↑

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	A	B	B
Edge Habitat	A	B	B
Overall Site Assessment	A	B	B

Riffle Habitat

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

Dominant Taxa

- Baetidae
- Hydrobiosidae
- Chironomidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Hydrobiosidae
- Leptophlebiidae
- Gripopterygidae

Additional Comments

- None

Edge Habitat

- Abundance of floating algae in the habitat
- Dominant trailing bank vegetation is macrophytes (mainly *Phragmites australis*) and grasses

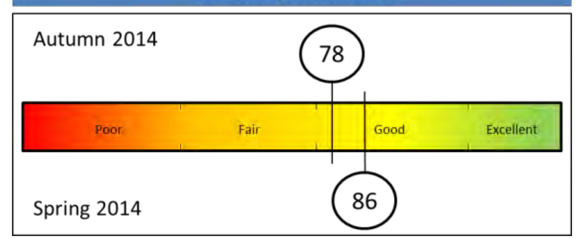
Dominant Taxa

- Dysticidae
- Corixidae
- Leptoceridae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

Site Quality Assessment



BUR2c

Upstream London Bridge
5/11/2014 11:15 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
18.2	465.7	2.82	6	8.23	86.8	8.93

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
218	0.010	0.010	< 0.002	< 0.002	0.007	0.25

Daily Flow: 1.5 ML/day

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

Compared to current flow:

Spring 2013: ↑ Autumn 2014: ↑

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	A	B	A
Edge Habitat	A	B	B
Overall Site Assessment	A	B	B

Riffle Habitat

- Dominant substrate was cobble

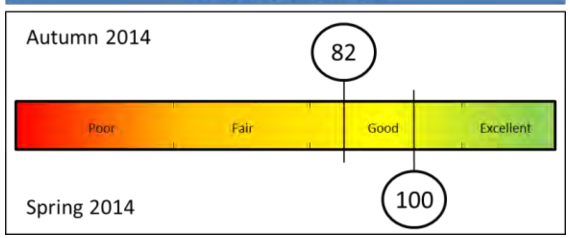
Dominant Taxa

- Leptophlebiidae
- Hydropsychidae
- Hydrobiosidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Hydrobiosidae

Site Quality Assessment



Edge Habitat

- Epiphyte coverage high
- Dominant trailing bank vegetation was macrophytes (mainly *Typha orientalis* and *Schoenoplectus sp.*)

Dominant Taxa

- Gyrinidae
- Baetidae
- Dysticidae
- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

Additional Comments

- None

QBYN1

Flynn's Crossing
5/11/2014 1:30 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
20.9	94.3	3.60	3	8.04	97.2	8.77

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
43	< 0.002	< 0.002	< 0.002	< 0.002	0.015	0.30

Daily Flow: 39 ML/day

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

Compared to current flow:

Spring 2013: ↑ Autumn 2014: ↑

AUSRIVAS Results

	Spring 2013	Autumn 2014	Spring 2014
Riffle Habitat	A	B	A
Edge Habitat	A	B	A
Overall Site Assessment	A	B	A

Riffle Habitat

- Some sections of riffle are less silted than others
- Dominant substrate was cobble

Dominant Taxa

- Gripopterygidae
- Hydrobiosidae
- Simuliidae
- Leptophlebiidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Leptophlebiidae
- Hydrobiosidae
- Megaloptera

Edge Habitat

- Edge habitat quality reduced due to low flows
- Dominant trailing bank vegetation overhanging shrubs (mainly *Kunzea sp.*)

Dominant Taxa

- Atyidae
- Corixidae
- Leptoceridae
- Chironomidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

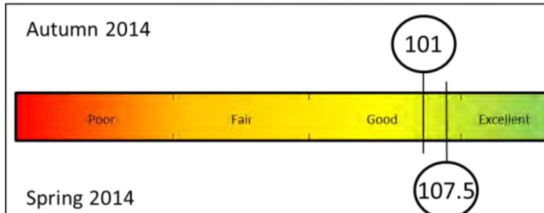
- Gripopterygidae

Additional Comments

- Very few submerged macrophytes
- Some new filamentous algal growth

Site Quality Assessment

Autumn 2014



Spring 2014

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 at Angle Crossing sites from the riffle habitat

Site	Taxa	Oligochaeta	Acarina	Elmidae	Psephenidae	Tipulidae	Tanypodinae	Chironominae	Baetidae	Leptophlebiidae	Caenidae	Gripopterygidae	Hydrobiosidae	Glossosomatidae	Hydropsychidae	Conoesucidae	Total number of missing taxa
	SIGNAL-2	2	6	7	6	5	4	3	5	8	4	8	8	9	6	7	
MUR 15	Riffle			0.94	0.52		0.69	0.93				0.89	0.51	0.57		0.52	8
MUR 15		1.00	0.78	0.94	0.52	0.53	0.69	0.93					0.51	0.57		0.52	10
MUR 15				0.94	0.52	0.53							0.51	0.57		0.52	6
MUR 15				0.94	0.52	0.53		0.93						0.57		0.52	6
MUR 15		1.00		0.94	0.52	0.53	0.69						0.51	0.57		0.52	8
MUR 15		1.00		0.94	0.52	0.53	0.69						0.51	0.57	0.55	0.52	9
MUR 16	Riffle			0.94	0.52								0.51	0.57		0.52	5
MUR 16				0.94	0.52								0.51	0.57		0.52	5
MUR 16				0.94	0.52								0.51	0.57		0.52	5
MUR 16					0.52		0.69		0.65				0.51	0.57		0.52	6
MUR 16				0.94	0.52	0.53	0.69						0.51	0.57		0.52	7
MUR 16		1.00		0.94	0.52		0.69	0.93					0.51	0.57		0.52	8
MUR 18	Riffle	1.00		0.95	0.58		0.64							0.66		0.63	6
MUR 18					0.58									0.66		0.63	3
MUR 18					0.58		0.64						0.55			0.63	4
MUR 18					0.58									0.66		0.63	3
MUR 18					0.58		0.64						0.55	0.66		0.63	5
MUR 18					0.58		0.64							0.66		0.63	4
MUR 19	Riffle			0.95	0.60		0.63						0.56	0.68		0.64	6
MUR 19				0.95	0.60								0.56	0.68		0.64	5
MUR 19				0.95	0.60		0.63						0.56	0.68		0.64	6
MUR 19				0.95	0.60	0.62	0.63	0.91	0.63	0.91			0.56	0.68		0.64	10
MUR 19				0.95	0.60		0.63		0.63	0.91	0.89			0.68		0.64	8
MUR 19				0.95	0.60	0.62	0.63	0.91		0.91	0.89			0.68		0.64	9
MUR 23	Riffle			0.94	0.54								0.52	0.60		0.56	5
MUR 23				0.94	0.54		0.67			0.87			0.52	0.60		0.56	7
MUR 23				0.94	0.54		0.67							0.60		0.56	5
MUR 23				0.94	0.54		0.67						0.52	0.60		0.56	6
MUR 23		1.00		0.94	0.54								0.52	0.60		0.56	6
MUR 23		1.00		0.94	0.54					0.87			0.52	0.60		0.56	7
MUR 28	Riffle			0.96	0.65		0.59					0.95	0.60	0.76		0.73	7
MUR 28				0.96	0.65		0.59						0.60	0.76		0.73	6
MUR 28					0.65		0.59						0.60	0.76		0.73	5
MUR 28				0.96	0.65		0.59			0.94		0.95	0.60	0.76		0.73	8
MUR 28				0.96	0.65		0.59					0.95	0.60	0.76		0.73	7
MUR 28				0.96	0.65		0.59					0.95	0.60	0.76		0.73	7

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

Site	Taxa	Ceratopogonidae	Baetidae	Leptophlebiidae	Corixidae	Gripopterygidae	Leptoceridae	Total number of missing taxa
	SIGNAL-2	4	5	8	2	8	6	
MUR 15	Edge	*0.65*						1
MUR 15		*0.65*	*0.62*				*0.88*	3
MUR 15			*0.62*				*0.88*	2
MUR 15		*0.65*	*0.62*					2
MUR 15		*0.65*						1
MUR 15								0
MUR 16	Edge	*0.65*		*0.82*		*0.62*	*0.88*	4
MUR 16			*0.62*				*0.88*	2
MUR 16		*0.65*						1
MUR 16				*0.82*			*0.88*	2
MUR 18	Edge	*0.65*						1
MUR 18					*0.53*	*0.62*		2
MUR 18		*0.65*						1
MUR 18		*0.65*						1
MUR 18		*0.65*	*0.62*					2
MUR 18		*0.65*	*0.62*				*0.88*	3
MUR 19	Edge	*0.65*					*0.88*	2
MUR 19		*0.65*						1
MUR 19							*0.88*	1
MUR 19							*0.88*	1
MUR 19		*0.65*		*0.82*			*0.88*	3
MUR 23	Edge	*0.65*		*0.82*				2
MUR 23		*0.65*						1
MUR 23		*0.65*		*0.82*				2
MUR 23								0
MUR 23		*0.65*						1
MUR 23		*0.65*		*0.82*				2
MUR 28	Edge	*0.65*	*0.62*			*0.62*		3
MUR 28		*0.65*				*0.62*		2

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

Site	Taxa	Sphaeriidae	Oligochaeta	Acarina	Elmidae	Ceratopogonidae	Simuliidae	Baetidae	Caenidae	Gripopterygidae	Total number of missing taxa
	SIGNAL-2	5	2	6	7	4	5	5	4	8	
BUR 1C	Riffle				*0.92*					*0.86*	2
BUR 1C					*0.92*						1
BUR 1C					*0.92*						1
BUR 2A	Riffle			*0.75*	*0.92*						2
BUR 2A					*0.92*						1
BUR 2A				*0.75*	*0.92*	*0.50*					3
BUR 2B	Riffle		*1.00*		*0.92*						2
BUR 2B			*1.00*		*0.92*	*0.50*	*0.77*		*0.87*		5
BUR 2B			*1.00*		*0.92*	*0.50*			*0.87*	*0.85*	5
BUR 2B					*0.92*						1
BUR 2B											0
BUR 2B										*0.85*	1
BUR 2C	Riffle	*0.50*								*0.84*	2
BUR 2C		*0.50*									1
BUR 2C		*0.50*						*0.67*		*0.84*	3
BUR 2C											0
BUR 2C		*0.50*									1
BUR 2C											0
QBYN 1	Riffle	0.52				*0.51*	*0.79*				3
QBYN 1		0.52				*0.51*	*0.79*	*0.67*			4
QBYN 1		0.52	*1.00*				*0.79*				3
QBYN 1		0.52				*0.51*					2
QBYN 1		0.52				*0.51*					2
QBYN 1		0.52				*0.51*					2

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

Site	Taxa	Acarina	Ceratopogonidae	Tanypodinae	Baetidae	Leptophlebiidae	Caenidae	Gripopterygidae	Leptoceridae	Total number of missing taxa
	SIGNAL-2	6	4	4	5	8	4	8	6	
BUR 1A	Edge	*0.56*			*0.63*	*0.87*	*0.94*	*0.75*		*5*
BUR 1A		*0.56*			*0.63*		*0.94*	*0.75*		*4*
BUR 1A		*0.56*			*0.63*		*0.94*	*0.75*		*4*
BUR 1A							*0.94*	*0.75*		*2*
BUR 1A						*0.87*	*0.94*	*0.75*		*3*
BUR 1A		*0.56*			*0.63*	*0.87*	*0.94*	*0.75*		*5*
BUR 1C	Edge								*0.89*	*1*
BUR 1C							*0.94*		*0.89*	*2*
BUR 1C								*0.77*	*0.89*	*2*
BUR 2A	Edge	*0.50*						*0.71*		*2*
BUR 2A		*0.50*					*0.94*			*2*
BUR 2A		*0.50*								*1*
BUR 2A		*0.51*							*0.89*	*2*
BUR 2A		*0.51*		*0.96*						*2*
BUR 2A		*0.51*							*0.89*	*2*
BUR 2B	Edge	*0.60*						*0.78*		*2*
BUR 2B		*0.60*						*0.78*		*2*
BUR 2B		*0.60*						*0.78*		*2*
BUR 2B				*0.95*				*0.78*	*0.90*	*3*
BUR 2B								*0.78*		*1*
BUR 2B		*0.60*					*0.94*	*0.78*	*0.90*	*4*
BUR 2C	Edge		*0.60*							*1*
BUR 2C								*0.78*		*1*
BUR 2C										*0*
BUR 2C			*0.60*					*0.78*		*2*
BUR 2C			*0.60*					*0.78*		*2*
BUR 2C		*0.60*	*0.60*					*0.78*		*3*
QBYN 1	Edge									*0*
QBYN 1					*0.62*					*1*
QBYN 1		0.45								*1*
QBYN 1										*0*
QBYN 1						*0.84*				*1*
QBYN 1										*0*

Appendix F - Taxonomic Inventory

Appendix F1. Taxonomic inventory of macroinvertebrates collected from the riffle habitat at the Angle Crossing sites

CLASS / Order	Family	Genus	MUR 15	MUR 16	MUR 18	MUR 19	MUR 23	MUR 28
ACARINA			■	■	■	■	■	■
BIVALVIA	Corbiculidae	*Corbicula*	■			■	■	■
	Sphaeriidae	*Pisidium*			■			
		sp.		■				■
Coleoptera	Elmidae	*Austrolimnius*		■	■			
		sp.			■			■
	Gyrinidae	*Macrogyrus*	■					
	Hydrophilidae					■		
	Scirtidae				■			
Decapoda	Atyidae	*Paratya*	■					■
Diptera	Ceratopogonidae	*Ceratopoginae*	■	■	■			
	Chironominae		■	■	■	■	■	■
	Dolichopodidae			■				
	Empididae				■	■	■	■
	Orthocladiinae		■	■	■	■	■	■
	Psychodidae							■
	Simuliidae	*Austrosimulium*	■	■	■	■	■	■
		Simulium	■	■	■			
		sp.	■	■	■	■	■	■
	Tanypodinae		■	■	■	■	■	
	Tipulidae		■	■	■	■	■	■
Ephemeroptera			■		■			
	Baetidae	*Baetidae Genus 1*						■
		Baetidae Genus 2	■	■	■		■	■
		sp.	■	■	■	■	■	■
	Caenidae	*Irapacaenis*		■	■	■		■
		Tasmanocoenis	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
	Coloburiscidae	*Coloburiscoides*	■	■	■			
	Leptophlebiidae	*Atalophlebia*						■
		Jappa	■	■	■	■	■	■
		Nousia					■	
		sp.	■	■	■	■	■	■
Odonata	Gomphidae	*Austrogomphus*					■	
OLIGOCHAETA			■	■	■	■	■	■
Plecoptera					■			
	Gripopterygidae	*Dinotoperla*	■	■	■	■		■
		Illiesoperla	■	■	■	■	■	■
		sp.	■	■	■	■	■	
Trichoptera			■		■			
	Ecnomidae	*Ecnomus*		■				
		sp.		■				
	Glossosomatidae	*Agapetus*			■			
	Hydrobiosidae	*Psyllobetina*			■			
		Ulmerochorema				■		
		sp.	■		■		■	
	Hydropsychidae	*Asmicridea*		■	■	■	■	■
		Cheumatopsyche	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
	Hydroptilidae	*Hellyethira*				■		■
		Hydroptila	■	■	■	■	■	■
		Oxyethira	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
	Leptoceridae	*Oecetis*					■	
	Philopotamidae	*Chimarra*				■		
Turbellaria	Dugesiidae	*Dugesia*			■			

Appendix F2. Taxonomic inventory of macroinvertebrates collected from the edge habitat at the Angle Crossing sites

CLASS / Order	Family / Sub-Family	Genus	MUR 15	MUR 16	MUR 18	MUR 19	MUR 23	MUR 28
ACARINA			■	■	■	■	■	■
BIVALVIA	Corbiculidae	*Corbicula*	■		■			
Coleoptera	Dytiscidae	*Necterosoma*					■	
		sp.	■					
	Gyrinidae	*Macrogyrus*				■		
	Hydrophilidae	*Coelostoma*				■		
		Helochares						■
		sp.						■
Decapoda	Atyidae	*Paratya*	■	■	■	■	■	■
Diptera								■
	Ceratopogonidae	*Ceratopoginae*	■	■	■	■	■	
	Chironominae		■	■	■	■	■	■
	Empididae		■				■	
	Orthocladiinae		■	■	■	■	■	■
	Psychodidae		■					
	Simuliidae	*Austrosimulium*	■	■	■	■	■	■
		Simulium				■		
		sp.	■	■	■	■	■	■
	Tanypodinae		■	■	■	■	■	■
	Tipulidae		■	■	■			■
Ephemeroptera							■	
	Baetidae	*Baetidae Genus 1*		■		■	■	
		Baetidae Genus 2				■	■	
		Cloeon					■	
		sp.	■	■	■	■	■	■
	Caenidae	*Irapacaenis*	■	■	■	■	■	■
		Tasmanocoenis	■	■	■	■	■	■
		sp.	■		■	■	■	■
	Leptophlebiidae	*Atalophlebia*			■	■	■	■
		Jappa	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
GASTROPODA							■	
	Lymnaeidae						■	
	Physidae	*Physa*	■			■	■	
	Planorbidae (Ancylidae)	*Ferrissia*			■		■	
Hemiptera	Gerridae	*Rheumatometra*			■	■		■
		sp.		■				
	Micronectidae	*micronecta*	■	■	■	■	■	■
	Notonectidae	*Enithares*		■				■
		Paranisops	■		■			
		sp.	■	■	■	■	■	
	Veliidae	*Microvelia*			■			
		Mircrovelopsis	■					
Lepidoptera	Crambidae		■					
Odonata	Coenagrionidae	*Ischnura*	■					
	Epiprocta							■
	Telephlebiidae	*Austroaeschna*				■		
OLIGOCHAETA			■	■	■	■	■	■
Plecoptera	Gripopterygidae	*Dinotoperla*	■	■	■	■	■	
		Illiesoperla					■	
		sp.	■		■	■	■	
Trichoptera							■	
	Ecnomidae	*Ecnomus*					■	
		sp.			■			
	Hydrobiosidae		■					
	Hydropsychidae	*Asmicridea*			■			

CLASS / Order	Family / Sub-Family	Genus	MUR 15	MUR 16	MUR 18	MUR 19	MUR 23	MUR 28
		Cheumatopsyche						
		sp.						
	Hydroptilidae	*Hellyethira*						
		Hydroptila						
		Oxyethira						
		sp.						
	Leptoceridae	*Notalina*						
		Oecetis						
		Triaenodes						
		Triplectides						
		sp.						

Appendix F3. Taxonomic inventory of macroinvertebrates collected from the riffle habitat at the Burra Creek sites

CLASS / Order	Family / Sub-Family	Genus	BUR 1C	BUR 2A	BUR 2B	BUR 2C	QBYN 1
ACARINA							
Amphipoda	Ceinidae						
BIVALVIA	Sphaeriidae	*Musculium (Sphaerium)*					
		Pisidium					
		sp.					
Coleoptera	Dytiscidae	*Laccophilus*					
		Necterosoma					
	Elmidae	*Austrolimnius*					
		Notriolus					
		Simsonia					
		sp.					
	Gyrinidae						
	Psephenidae	*Sclerocyphon*					
	Scirtidae						
Decapoda	Atyidae	*Paratya*					
Diptera	Ceratopogonidae	*Ceratopoginae*					
		Forcipomyiinae					
	Chironominae						
	Dixidae						
	Empididae						
	Orthocladiinae						
	Simuliidae	*Austrosimulium*					
		Simulium					
		sp.					
	Stratiomyidae	*Odontomyia*					
	Tanypodinae						
	Tipulidae						
Ephemeroptera	Baetidae	*Baetidae Genus 1*					
		Baetidae Genus 2					
		sp.					
	Caenidae	*Irapacaenis*					
		Tasmanocoenis					
		sp.					
	Leptophlebiidae	*Jappa*					
		sp.					
GASTROPODA	Lymnaeidae	*Pseudosuccinea*					
	Physidae	*Physa*					
	Planorbidae (Ancylidae)	*Ferrissia*					
Hemiptera	Gerridae						
	Micronectidae	*micronecta*					
	Veliidae						
Hydrozoa	Hydridae	*Hydra*					
Megaloptera	Corydalidae	*Archichauliodes*					
		sp.					
Odonata							
	Aeshnidae						
	Gomphidae	*Hemigomphus*					
		sp.					
OLIGOCHAETA							
Plecoptera							
	Gripopterygidae	*Dinotoperla*					
		Illiesoperla					
		sp.					
Temnocephalida	Temnocephalidae	*Temnocephala*					
Trichoptera							

CLASS / Order	Family / Sub-Family	Genus	BUR 1C	BUR 2A	BUR 2B	BUR 2C	QBYN 1
	Ecnomidae	*Ecnomus*					
		sp.					
	Glossosomatidae	*Agapetus*					
	Hydrobiosidae	*Apsilochorema*					
		Taschorema					
		Ulmerochorema					
		sp.					
	Hydropsychidae	*Asmicridea*					
		Cheumatopsyche					
		sp.					
	Hydroptilidae	*Hellyethira*					
		Hydroptila					
		Orthotrichia					
		Oxyethira					
		sp.					
	Leptoceridae	*Notalina*					
		Oecetis					
		sp.					
	Philopotamidae	*Chimarra*					
		sp.					
Turbellaria	Dugesiidae	*Dugesia*					

Appendix F4. Taxonomic inventory of macroinvertebrates collected from the edge habitat at the Burra Creek sites

CLASS / Order	Family / Sub-Family	Genus	BUR 1A	BUR 1C	BUR 2A	BUR 2B	BUR 2C	QBYN 1
ACARINA			■	■		■	■	■
Amphipoda	Ceinidae				■	■		
BIVALVIA	Corbiculidae	*Corbicula*					■	
	Sphaeriidae	*Musculium (Sphaerium)*				■		
		Pisidium						■
		sp.						■
Coleoptera	Dytiscidae	*Antiporus*	■			■		
		Laccophilus			■			
		Liodessus				■		
		Necterosoma	■	■	■	■	■	■
		Sternopriscus		■				
		sp.		■			■	
	Elmidae	*Simsonia*						■
		sp.						■
	Gyrinidae	*Macrogyrus*					■	
		sp.					■	
	Hydraenidae	*Hydraena*	■					
	Hydrochidae	*Hydrochus*	■		■	■		
	Hydrophilidae	*Sternolophus*						■
		sp.		■	■			
	Psephenidae	*Sclerocyphon*					■	■
	Scirtidae					■		■
Decapoda						■		
	Atyidae	*Paratya*	■		■	■		■
		sp.			■			
	Parastacidae	*Cherax*						■
Diptera					■			
	Ceratopogonidae	*Ceratopoginae*	■	■	■	■	■	■
	Chironominae		■	■	■	■	■	■
	Culicidae	*Aedes*	■					■
		sp.	■		■	■		
	Dixidae		■		■	■		■
	Dolichopodidae				■			
	Empididae				■		■	
	Orthocladiinae		■	■	■	■	■	■
	Psychodidae			■	■		■	
	Simuliidae	*Austrosimulium*					■	
		Simulium						■
		sp.					■	
	Stratiomyidae	*Odontomyia*		■	■	■	■	
	Tanypodinae		■	■	■	■	■	■
	Tipulidae		■					
Ephemeroptera	Baetidae	*Baetidae Genus 1*			■	■		
		Baetidae Genus 2			■			
		Cloeon	■		■			■
		sp.	■	■	■	■	■	■
	Caenidae	*Irapacaenis*		■		■		■
		Tasmanocoenis		■	■	■	■	■
		sp.				■	■	■
	Leptophlebiidae	*Atalophlebia*		■	■	■	■	■
		Jappa			■		■	
		Koornonga			■	■	■	■
		sp.	■	■	■	■	■	■
	Nesameletidae	*Ameletoides*						■
	Oniscigastridae	*Tasmanophlebia*						■
GASTROPODA	Lymnaeidae	*Pseudosuccinea*	■	■	■	■		

CLASS / Order	Family / Sub-Family	Genus	BUR 1A	BUR 1C	BUR 2A	BUR 2B	BUR 2C	QBYN 1
		sp.						
	Physidae	*Physa*						
	Planorbidae (Ancylidae)	*Ferrissia*						
Hemiptera								
	Gerridae	*Rheumatometra*						
		sp.						
	Micronectidae	*micronecta*						
	Notonectidae	*Anisops*						
		Enithares						
		Notonecta						
		Paranisops						
		sp.						
	Veliidae	*Drepanovelia*						
		Microvelia						
		sp.						
Hirudinea	Erpobdellidae							
	Richardsonianidae							
Hydrozoa	Hydridae	*Hydra*						
Odonata	Aeshnidae	*Adversaeschna*						
		sp.						
	Coenagrionidae	*Austroagrion*						
		Ischnura						
	Cordulephyidae	*Cordulephya*						
	Corduliidae							
	Epiprocta							
	Gomphidae	*Austrogomphus*						
		sp.						
	Lestidae	*Austrolestes*						
	Libellulidae							
	Zygoptera							
OLIGOCHAETA								
Plecoptera								
	Gripopterygidae	*Dinotoperla*						
		Illiesoperla						
		sp.						
Trichoptera								
	Calamatoceridae	*Anisocentropus*						
	Ecnomidae	*Ecnomus*						
	Hydrobiosidae	*Taschorema*						
	Hydropsychidae	*Cheumatopsyche*						
		sp.						
	Hydroptilidae	*Hellyethira*						
		Hydroptila						
		Oxyethira						
		sp.						
	Leptoceridae	*Notalina*						
		Oecetis						
		Triaenodes						
		Triplectides						
		sp.						
	Odontoceridae							
Turbellaria	Dugesiidae	*Dugesia*						

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