Icon Water

Murrumbidgee Ecological Monitoring Programme
Sentinel Monitoring - Spring 2015

February 2016

Executive summary

The Murrumbidgee Ecological Monitoring Programme commenced in 2008. The project is being undertaken by the GHD Water Science Group for Icon Water to establish information and collect data regarding relevant biological and water quality information during the standby mode of the Murrumbidgee to Googong (M2G) water transfer project and Murrumbidgee Pump Station (MPS).

Over the course of this monitoring programme, there have been a number of changes and modifications to the programme, which have been in line with the adaptive management philosophy adopted in the design phase of the MEMP. The most recent and major change to the MEMP followed the recent peer review of the programme by Jacobs Group (Australia) (Jacobs, 2014). The review resulted in a number of recommendations to adapt the programme so that Icon Water may continue to have a robust monitoring programme, capable of detecting potential ecological impacts, while at the same time accounting for the lowered ecological risk during periods of standby and maintenance modes of operation.

Three modes of operation were defined for the M2G and MPS to help target the monitoring programme during different stages. These are defined for the ***M2G*** *as:*

- ***Standby (maintenance)*** *– ready to run, all components in place and being operated routinely for maintenance purposes. Peak pump volumes are typically 49 ML/d and transferring approximately 50 ML in total.*
- ***Operating (full pump) –*** *operating in earnest under normal flow conditions, with continuous transfer of bulk water to Googong reservoir for a period of greater than 30 consecutive days.*
- ***Operating (drought conditions, full pump, drought flows)*** *– operating in earnest under drought flow conditions with continuous transfer of bulk water to Googong reservoir for a period of greater than 30 consecutive days.*

For the ***MPS,*** *the modes of operation are defined as:*

- ***Standby*** *– abstraction from the Murrumbidgee River is not occurring. Ready to run, all components in place and being operated routinely for maintenance purposes.*
- ***Recirculating Pump Operation -*** *flow up to 40 ML/d transferred to the base of the Cotter Dam to provide environmental flows to the lower Cotter River. Water to the Cotter River re-enters the Murrumbidgee River just upstream of the MPS.*
- ***Operating (full pump) –*** *abstraction of up to 150 ML/d of water for raw water supply to Stromlo Water Treatment Plant for greater than 30 consecutive days. While this is the maximum capacity of the Murrumbidgee Pump Station, this extraction volume rarely occurs due to water quality in the Murrumbidgee River. Hence smaller volumes are likely to be taken and shandied with cleaner Cotter River water from the Bendora Main.*

With this in mind, the revised MEMP will adopt a two-stage approach which incorporates sentinel monitoring during ***standby*** *operation modes and* ***impact*** *monitoring assessment during the various operation modes.*

The purpose of the sentinel monitoring is to detect if major catchment-scale changes to the aquatic ecology occur during the standby mode. Sentinel monitoring will therefore occur during standby periods when the risk to the ecosystem is deemed to be very low. Monitoring will occur in autumn and spring every three years beginning in autumn 2015 with a reduced number of monitoring sites (1 upstream and 1 downstream of Angle Crossing (M2G), Burra Creek discharge structure (M2G) and the Murrumbidgee Pump Station (MPS)). Periphyton sampling is not required in the sentinel monitoring and qualitative methods, such as photogrammetry and AUSRIVAS habitat assessments are used to track the conditions of these sites on a broad spatial and temporal scale. Under this scenario, testing of hypotheses and targeted monitoring are not required.

The trigger for impact monitoring to go ahead is the decision to operate the M2G or MPS infrastructure. This monitoring scenario requires a before and after approach, and relies on replicated sampling protocols. Under this monitoring protocol several univariate indicators of river health and condition with be analysed before and after the operation period at both upstream and downstream locations. Periphyton photogrammetry will be assessed at both time periods and compared between monitoring locations. The key difference between this, and the sentinel monitoring is the number of sites, replicates and sampling events (impact monitoring requires at least one before and one after sampling event) and the level of detail used in the analysis.

Following the operation period, a consecutive spring and autumn monitoring schedule must also be carried out; and should pumping occur across a spring and/ or autumn period, sampling will be carried out during those times.

Component 1 – Angle Crossing Overview

Icon 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.

Component 1 – Angle Crossing Spring 2015

***Water quality** at Angle Crossing had the same characteristics, both upstream and downstream of the M2G intake and most of the physico-chemical parameters were within the ANZECC and ARMCANZ guidelines (2000). Nutrients (total nitrogen and total phosphorus) were above the guideline values at both the upstream and downstream sites, indicating (as has been the case previously), that the background nutrient concentrations are high in this reach of the river, and is likely unrelated to the M2G project.*

The gauging station located upstream of Angle Crossing has had ongoing issues with data quality and collection since it was installed. These issues, which were related to siltation near and around the water quality probe and damage due to lightning strikes, are expected to be resolved because the site has been moved (post – spring sampling), which should remove the problems associated with silt accumulation and vulnerability to lightning strikes.

*Photogrammetry of **periphyton** cover shows no obvious difference in cover between the upstream and downstream sites. Estimates of areal cover for the reach and riffle was lower in the current monitoring period (35-65%) than it was in spring 2014 (65-90%), which was a direct result of the high flow event that occurred in August.*

*While the **geomorphology** at Angle Crossing has shown that over recent years it is a dynamic reach which can have significant changes from individual high flow events during the period since autumn 2015 there has been very little change within this reach. While there was some erosion in a small section of river bank adjacent to the riffle at MUR 19 (downstream of the low level crossing); there was no instream deposition or bar formation which could be observed from the Photo Points. The two seasons of Photo Points from autumn and spring this year will be used for comparison during the next geomorphology monitoring scheduled for 2018 to determine the natural changes to the Murrumbidgee River, or following the operation of the Murrumbidgee to Googong Pipeline requiring impact assessment.*

*The **macroinvertebrate** results from spring 2015 suggest that there has been an increase in the ecological condition, based on AUSRIVAS at the two Angle Crossing sites; with both sites registering their highest scores since the inception of the MEMP. Both edge habitats were assessed as Band X ("more diverse than expected"), which is the first time both sites have received this Band. The fact that there was a synchronous increase in condition indicates environmental cause rather than factors relating to M2G.*

Component 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 followed by monitoring of 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.

Component 2– Burra Creek Spring 2015

There were no significant difference in ***Water quality*** *parameters between the upstream "control" site (BUR 1a) and the site downstream of the discharge weir (BUR 2a). Furthermore, the water quality results in Burra Creek during spring 2015 indicated high levels of compliance to the ANZECC & ARMCANZ (2000) guidelines. pH levels were within guidelines values at both upstream and downstream sites for the first time since spring 2012.*

Elevated nutrient levels were recorded during spring 2015 with both total nitrogen (TN) and NO_x *concentrations exceeding the ANZECC & ARMCANZ (2000) trigger levels. TN levels have fluctuated during the MEMP with higher concentration usually associated with periods of lower flows and an increase in the length of time since the most recent high flow event.*

The elevated NO_x *values at BUR 1c is surprising as previous seasons have found that these levels are usually elevated at BUR 2a and have been shown to be sourced from Holden's Creek (immediately upstream of the M2G discharge structure). These elevated nitrates are likely sourced from the upstream and surrounding agricultural areas either by direct runoff or indirectly via groundwater after leaching through the topsoils.*

Periphyton *coverage was high at both sites, with >90% coverage across the reach and 65-90% in the riffle habitat at both sites, which is slightly lower compared to spring 2014. Both sites showed high macrophyte growth through their respective reaches, which is characteristic of Burra Creek during this time of year. These records, providing the pipeline is not operated, will provide an indication of changes in the periphyton community between now and the next sentinel monitoring period during 2018.*

In the MEMP ***geomorphology*** *report (GHD, 2015c) it was pointed out that the area of greatest concern along Burra Creek is the downstream reach at BUR 2c. This is the only monitored site which has shown movement since the previous monitoring occurred during autumn 2015. Increased areas of erosion and bank slumping has occurred along the left bank at the site during that time, possibly as a result of high flow events occurring between the two monitoring periods (i.e. autumn and spring). These will continue to be monitored during the 2017 monitoring period.*

There was an increase in the edge habitat at BUR 1c from Band A to Band X since spring 2014, based on the ***macroinvertebrate****, AUSRIVAS model. The increase of the edge habitat to Band X ("more diverse than expected") is surprising considering the poor habitat quality of the habitat documented at the site during sampling. It is suggested that sites which receive a Band X are either a biodiversity 'hot-spot' or receive mild nutrient* *enrichment. Taking into consideration the poor habitat quality it is possible that the increased AUSRIVAS results are being driven by some level of nutrient enrichment, potentially resulting from decomposition and the high organic load within the stream channel. At the downstream site (BUR 2a) AUSRIVAS scores were consistent with spring 2014 and near reference condition (Band A) in both habitats.*

Component 3- Murrumbidgee Pump Station Overview

The Murrumbidgee Pump Station (MPS) is located just downstream of the Cotter River confluence with the Murrumbidgee River. The MPS underwent a significant upgrade which increased its pumping capacity to the Mount Stromlo Water Treatment Plant from 50ML/d to approximately 150ML/d. The framework for this programme responds primarily to the Icon Water abstraction licence reporting requirements. Water abstraction at the MPS, requires an assessment of the response of the river through monitoring methods that can quantify subtle impacts.

Component 3- Murrumbidgee Pump Station Spring 2015

Water quality *at the Murrumbidgee Pump Station sites showed exceedances of the ANZECC & ARMCANZ (2000) guidelines with pH, dissolved oxygen, total nitrogen and total phosphorus, although based on the historic records, none of these exceedances are out of the ordinary and all of the values lie within the range of values recorded for these sites.*

The **macroinvertebrate** *results from spring 2015 showed very similar results to spring 2014 (for MUR 28) and spring 2012 (for MUR 935). Habitat and overall site Bandings were the same between spring 2015 and spring 2014 and 2012, with small changes in the SIGNAL-2 and O/E scores in this time. The exception to this is the edge habitat at MUR 28 which has reduced to Band B ("significantly impaired") from Band A ("similar to reference") during spring 2014. The edge habitat at MUR 28 during spring 2015 was assessed as being in fairly poor condition and low flows prevailed leading up to sampling which reduced the available habitat for macroinvertebrates.*

Conclusions

The purpose of the sentinel monitoring programme is to provide a broad scale assessment of control and impact sites related to the Angle Crossing abstraction point, the discharge weir in Burra Creek and the Murrumbidgee pump station, located just downstream of the Cotter Road bridge. Specifically this programme aims to "provide confidence that the condition of the potential impact sites is broadly similar to non-impact sites across time".

There were a number of changes in AUSRIVAS bands since spring 2014. For example, at Angle Crossing the edge habitat at both locations was assessed as band X, which was an increase from band A in the previous spring. The site upstream discharge point in Burra Creek (BUR1c) had an overall assessment of band X, which was an increase from band A in spring 2014; while downstream of the discharge point there was no change as both habitats were assessed as band A, which is the same site assessment as spring 2014. The elevation from band A to band X at Bur 1c is likely a reflection of increased nutrients and high levels of detritus providing additional resources and thereby increased diversity, since the habitat quality was poor at this site at the time of the spring 2015 assessment.

There were no obvious differences in any of the measured parameters between all of the upstream / downstream site pairs for each of the components of this sampling run. These results were also consistent with those of previous spring sampling periods (see Appendix B) throughout the MEMP which suggests that in the absence of the operation of M2G or MPS, these sites are generally showing similar temporal and spatial variation.

The upshot of this is that we can be confident that at each site and location there are no other site specific influences that may impose additional stresses to the aquatic environment. If that were the case (i.e. there were significant changes to one site but not the other during standby mode) then this would imply that site specific stressors may exists, which may reduce our ability to detect change if there is any, during the operational phases of M2G or MPS projects.

Recommendations

The only additional recommendation to those put forward in autumn 2015 (GHD, 2015e) is to install erosion pins at BUR 2c. In light of the recent bank movement at this site, it would be a seen as a complimentary, quantitative method to determine actual rates of decline from this bank. Moreover, using this technique, measurements would be able to be made before and after natural events and before and after APPLE maintenance runs to isolate movement associated with those natural events compared to movement associated with the aforementioned APPLE maintenance runs. This method is cost effective and has been successfully developed for use in other catchments in the ACT.

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List of abbreviations

ACT – Australian Capital Territory

ACTEW – ACTEW Corporation Limited

ALS – Australian Laboratory Services

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

EC – Electrical Conductivity

ECD – Enlarged Cotter Dam

EIS – Environmental Impact Statement

EPA – Environmental Protection Authority

EPT – Ephemeroptera, Plecoptera and Trichoptera taxa

GL/a – Gigalitres per annum

GPS – Global positioning system

M2G – Murrumbidgee to Googong

MEMP – Murrumbidgee Ecological Monitoring Programme

ML/d – Megalitres per day

MPS – Murrumbidgee Pump Station

NATA – National Association of Testing Authorities

NSW – New South Wales

NTU – Nephlelometric Turbidity Units

QA – Quality Assurance

QC – Quality Control

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. Icon Water (formally 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.

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 Reservoir 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. The enlargement of Cotter Dam to 78 GL called the Enlarged Cotter Dam (ECD) just downstream of the existing 4 GL Cotter Dam[1].

To assess the influence of the construction and operations of these major projects Icon Water developed a detailed monitoring programme to establish a comprehensive baseline data set which could then be compared to the conditions during and following construction and also during the operation of M2G and MPS.

Since the completion of the MPS upgrade and the M2G infrastructure, both have been used infrequently because Icon Water has opted to use available water from other catchments which offer raw water with lower production costs. Furthermore, given the breaking of the drought in 2010 there has been no operational need to operate M2G or MPS because of improved water storage levels. Modelling by Icon Water has shown that it may be several years before full scale operation of either infrastructure is required which means that the MPS and M2G are both essentially on standby mode; implying that ecological impacts relating to these projects may be minimal.

1.1 Background and Adaptive management: changes to the MEMP since 2008

The Murrumbidgee Ecological Monitoring Programme (MEMP) was initially set up by Icon Water to evaluate the potential impacts of water abstraction from the Murrumbidgee River and the influence of increased water volumes in Burra Creek on ecological communities. The MEMP was implemented prior to the commencement of the M2G project, allowing Icon Water to collect pre-abstraction baseline data to compare against the post-abstraction data once the M2G project began operation. Sampling has been conducted in spring and autumn each year between spring 2008 and spring 2015.

Over the course of this monitoring programme, there have been a number of changes and modifications which have been in line with the adaptive management philosophy of the MEMP. The history of the MEMP is shown schematically in Figure 1-1.

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

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

[1] Note that the MEMP does not include monitoring related to the Enlarged Cotter Dam.

However, following the autumn 2013 monitoring period Icon Water reviewed the MEMP which resulted in the discontinuation of Component 3 (the Murrumbidgee Pump Station component) and Component 4 (the Tantangara to Burrinjuck component).

Following this review the MEMP continued to assess Component 1 and Component 2 from spring 2013 to spring 2014. During 2014 Icon Water commissioned a full independent review of the MEMP project. This review was completed by Jacobs (2014) and produced a number of recommendations which are outlined below.

Commencing in autumn 2015, these changes are:

- Sentinel monitoring – completion of autumn and spring seasonal analysis every 3 years;
- The re-inclusion of Component 3: Murrumbidgee Pump Station;
- Reduction of sites assessed for macroinvertebrates for each Component from 6 sites to 2 sites;
- Reduction from 2 riffle and 2 edge habitat samples to 1 riffle and 1 edge habitat sample;
- Removal of quantitative periphyton assessment;
- Introduction of photogrammetry monitoring for periphyton, vegetation and geomorphology at relevant locations.

1.2 Project review and requirements

The most recent and major change to the MEMP followed the recent peer review of the programme by Jacobs Group (Australia) (Jacobs, 2014). The review resulted in a number of recommendations to adapt the programme so that Icon Water may continue to have a robust monitoring programme, capable of detecting potential ecological impacts, while at the same time accounting for the lowered ecological risk during periods of standby and maintenance modes of operation.

Three modes of operation were defined for the M2G and MPS to help target the monitoring programme. These are defined for the **M2G** as:

- **Standby (maintenance) –** ready to run, all components in place and being operated routinely for maintenance purposes. Peak pump volumes are typically 49 ML/d and transferring approximately 50 ML in total.
- **Operating (Full pump) –** operating in earnest under normal flow conditions, with continuous transfer of bulk water to Googong Reservoir for a period of greater than 30 consecutive days.
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For the **MPS,** the modes of operation are defined as:

- **Standby –** abstraction from the Murrumbidgee River is not occurring. Ready to run, all components in place and being operated routinely for maintenance purposes.
- **Recirculating Pump Operation -** flow up to 40 ML/d transferred to the base of the Cotter Dam to provide environmental flows to the lower Cotter River. Water to the Cotter River re-enters the Murrumbidgee River just upstream of the MPS.
- **Operating (full pump) –** abstraction of up to 150 ML/d of water for raw water supply to Stromlo Water Treatment Plant for greater than 30 consecutive days. While this is the maximum capacity of the Murrumbidgee Pump Station, this extraction volume rarely occurs due to water quality in the Murrumbidgee River. Hence smaller volumes are likely to be taken and shandied with cleaner Cotter River water from the Bendora Main.

During periods of standby for M2G and MPS the risks from these projects to the ecological condition of the Murrumbidgee River and Burra Creek is minimal. Alternatively, it is anticipated that any risks to the Murrumbidgee River and Burra Creek are most likely to manifest during periods of full operation.

With this in mind, the revised MEMP will adopt a two-stage approach which incorporates sentinel monitoring during **standby** operation modes and **impact** monitoring assessment during the various operation modes. These two types of monitoring are described in sections 1.2.1 and 1.2.2 respectively.

1.2.1 Sentinel Monitoring (MPS and M2G)

The purpose of the sentinel monitoring is to understand if major catchment-scale changes to the aquatic ecology are taking place. Sentinel monitoring will occur during standby periods when the risk to the ecosystem is deemed to be very low. Sentinel monitoring will occur in autumn and spring every three years which begun in autumn 2015 with a reduced number of monitoring sites (1 upstream and 1 downstream of Angle crossing (M2G); Burra Creek discharge structure (M2G) and at the Murrumbidgee Pump Station (MPS)). Periphyton sampling is not required in the sentinel monitoring and qualitative methods, such as photogrammetry and AUSRIVAS habitat assessments are used to track the conditions of these sites on a broad spatial and temporal scale. Under this scenario testing of hypotheses and targeted monitoring are not required.

1.2.2 Impact Monitoring (MPS and M2G)

The trigger for impact monitoring to go ahead is the decision to operate the M2G or MPS infrastructure. This monitoring scenario requires a before and after approach, and relies on replicated sampling protocols. Under this monitoring protocol several univariate indicators of river health and condition with be analysed before and after the operation period at both upstream and downstream locations. Periphyton photogrammetry will be assessed at both time periods and compared between monitoring locations. The key difference between this, and the sentinel monitoring is the number of sites, replicates and sampling events (impact monitoring requires at least one before and one after sampling event) and the level of detail used in the analysis.

Following the operation period, a consecutive spring and autumn monitoring schedule must also be carried out; and should pumping occur across a spring and/or autumn period, sampling will be carried out during those times.

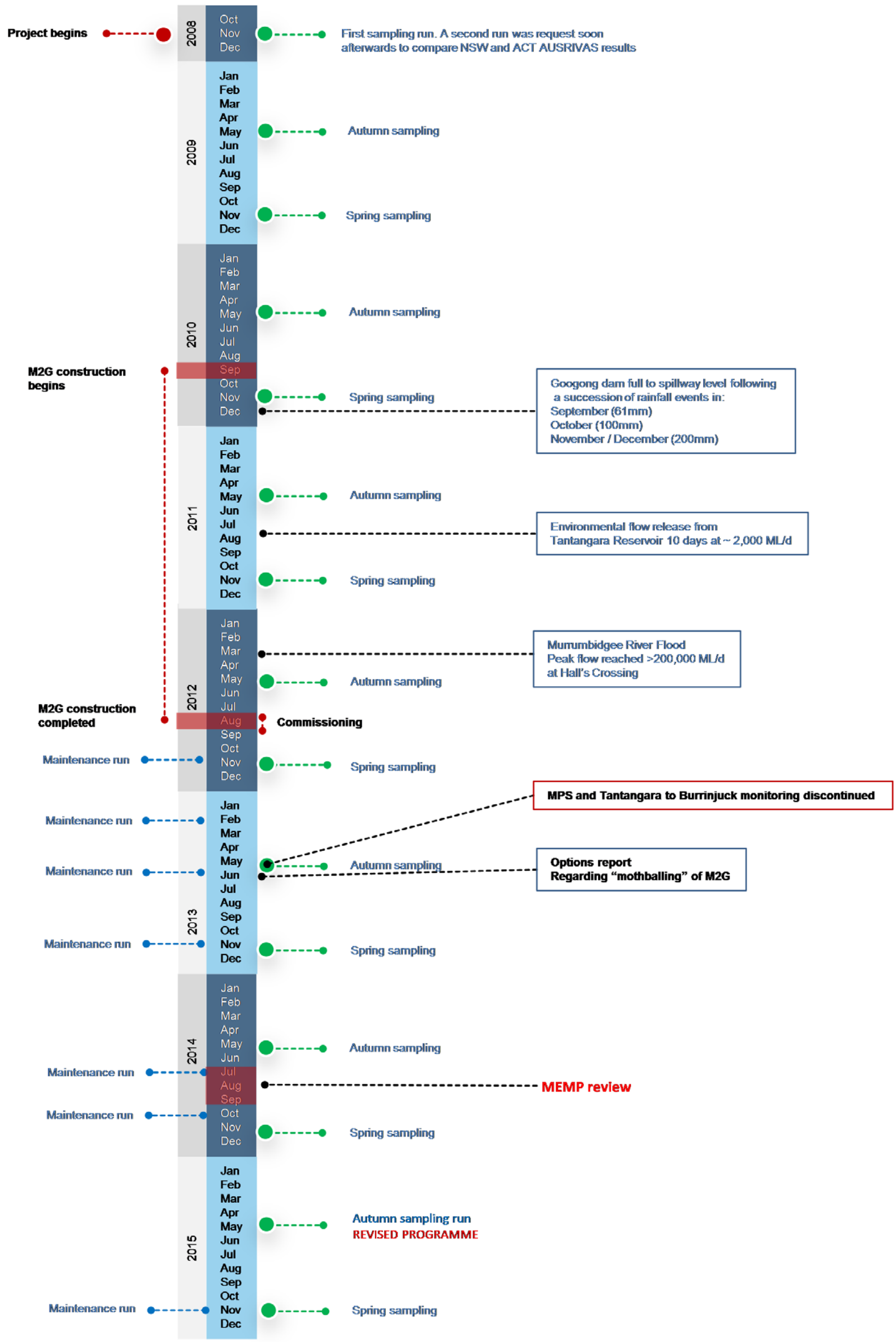


Figure 1-1. Schematic time line of the Murrumbidgee Ecological Monitoring Programme

1.2.3 Environmental flows and the 80:90 percentile rule

The environmental flow rules for the Murrumbidgee to Googong (M2G) component have been adopted from the framework outlined in the Environmental Flow Guidelines (ACT Government, 2013). Under the current licence agreement (Icon Water's Licence to take water, 2015 under the Water Resources ACT 2007), flows in the Murrumbidgee River at the Murrumbidgee Pump Station must be maintained at 20 ML/d during any stage of water restrictions. When these restrictions do not apply, flows must be maintained using the 80:90 rule.

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 1-2).

As can be seen from Figure 1-2, 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.

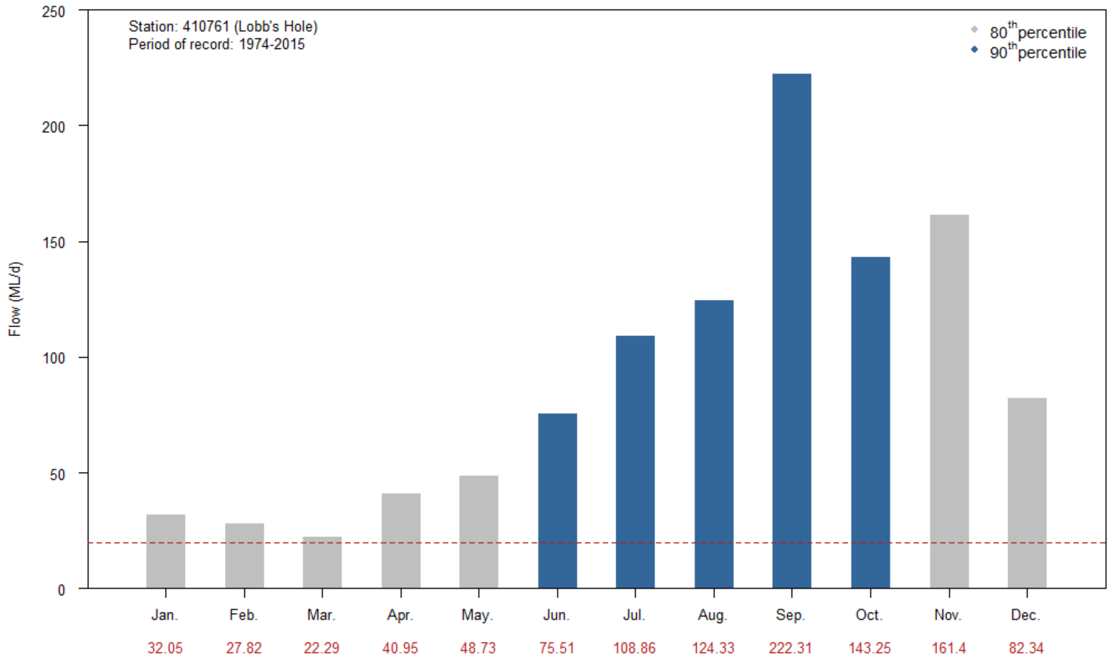


Figure 1-2. Environmental flow values for the operation of the M2G pipeline

Note: Flow data values to 30/11/2015. 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. Dashed line shows 20 ML/d

1.2.4 Parts 1 & 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 to be transported a further 13 km by run of river flows into Googong Reservoir. Water abstraction from the Angle Crossing pump station will be dictated by 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 Environmental Management Plan (Icon Water, 2015).

Murrumbidgee River

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 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;
- changes to water depth.

All of these changes have potential knock-on effects to the biota within the river's ecosystem. The current monitoring programme forms the basis of an Ecological Monitoring Programme to satisfy the EIS and compliance commitments for the M2G Project.

Burra Creek

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 M2G pipeline 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 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;
- 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). 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 (2009-2015)
Water Quality	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 indices of macroinvertebrate community composition and quality 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. 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 two.
	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 observed changes to 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, changes to 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 of M2G operations including fish species (GHD, 2015a). 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.	GHD, 2015c	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.
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, 2015c). Ongoing vegetation monitoring is coinciding with seasonal biological sampling.
Riparian vegetation	Changes in the natural flow regime could potentially lead to changes in species composition and dominance of select species leading to a reduction in diversity. An increase in bare ground due to more frequent high flow events could also lead to an increase in weed coverage and diversity, or encroachment of terrestrial species. Increases in flow level could lead result in changes to instream macrophyte cover and diversity.	GHD, 2010	Current flows from the M2G pipeline are restricted to maintenance flows which are short in duration and infrequent. The current M2G flow regime does not pose a threat to fringing riparian vegetation or instream macrophytes due to short duration that the flow level is increased (GHD, 2014).

1.2.5 Part 3 – Murrumbidgee Pump Station (MPS)

The Murrumbidgee Pump Station (MPS) is located just downstream of the Cotter River confluence with the Murrumbidgee River. It is adjacent to the Cotter Pump Station which can abstract up to 100 ML/d, contributing to the water supply for the ACT. New infrastructure has increased the abstraction amount from the Murrumbidgee River to approximately 150 ML/d via the MPS. The upgraded infrastructure also provides a recirculating flow from the Murrumbidgee River to the base of the Enlarged Cotter Dam (ECD), providing environmental flows to the lower Cotter River below the dam. This project is referred to as the Murrumbidgee to Cotter (M2C) transfer. The MEMP project does not include monitoring related to the M2C transfer, but rather provides a characterisation of the Murrumbidgee River condition upstream and downstream of the MPS.

The upgraded pump station was commissioned in 2010. Pumping is dependent on demand, licence requirements, and water quality. The framework for this programme responds primarily to requirements of Icon Water's abstraction licence.

The increase in abstraction at the MPS may place additional stress on the downstream river ecosystem. Originally part of the MEMP, the MPS component was removed following a review by Icon Water after the autumn 2013 reporting period. However, following the Jacobs (2014) review Component 3 has been re-established with sentinel monitoring of the Murrumbidgee River at the key upstream and downstream sites.

1.3 Project Objectives

The Murrumbidgee Ecological Monitoring Programme (MEMP) was set up by Icon Water to evaluate the potential impacts of water abstraction from the Murrumbidgee River at Angle Crossing and the Murrumbidgee Pump Station (Components 1 & 3) and the subsequent changes that might occur in Burra Creek (Component 2).

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

The aim of the sentinel monitoring presented in this report is to compare the ecological conditions of control sites to those of the impacted sites over time to determine if there is any major catchment scale changes to the aquatic ecology in either the Murrumbidgee River or Burra Creek during the projects standby phase.

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. This has been demonstrated through the adjustments to the programme following the autumn 2013 reporting period and also the project review completed by Jacobs (2014). The information derived from this programme will also support Icon Waters' adaptive management approach to water abstraction and environmental flow provision in the ACT.

1.4 The Upper Murrumbidgee River

The Murrumbidgee River flows for 1,600 km from its headwaters in the Snowy Mountains to its junction with the Murray River. The catchment area to Angle Crossing is 5,096 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 referred to as the Upper Murrumbidgee.

Land use varies from National Park in the high country to agricultural use 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, 2015).

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 the following twelve months, resulting in an upward trend in the mean monthly base flows (Figure 1-3). 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 31st May 2015, base flows in the Murrumbidgee River are following an increasing trend following another particularly dry summer in 2014/15 (Figure 1-3).

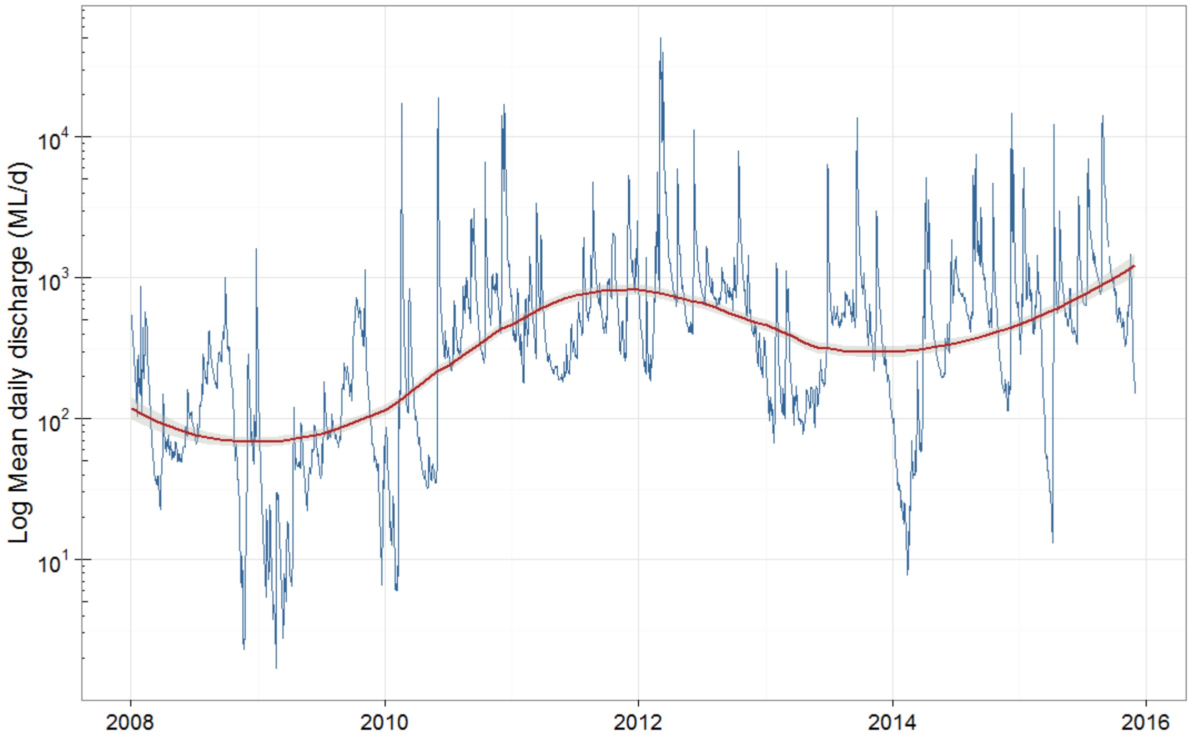


Figure 1-3. Hydrograph of the Murrumbidgee River at Lobb's Hole (410761) from 2008 to November 2015

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

1.5 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 submerged macrophyte beds with limestone bedrock and frequent pool-riffle sequences throughout its length. During low flow periods the main channel is commonly choked with macrophytes. Burra Creek is within a large macro channel in the lower reaches both upstream and downstream of London Bridge (a 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 2009 to the 30th November 2015) was 13.14 ML/d. Since flow records began in 1985 a mean monthly flow of 100 ML/d has been exceeded 8 times, while daily flows in excess of 100 ML/d have only occurred 1.6% of the time.

Flow conditions have varied considerably since the inception of the MEMP in late 2008 (Figure 1-4). 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 1-4). Summer in 2013/14 was the driest since 2010 although autumn rainfall balanced out the smoothing curve resulting in positive trend since September 2013. The overall trend since the beginning of 2014 has shown a gradual increase in daily mean flows (Figure 1-4). Summer flows in 2014/15 were considerably higher in Burra Creek compared to summer 2013/14 where average flows for the season were 5.95 ML/d and 1.22 ML/d respectively. Summer flows are an ecologically important consideration because summer is potentially a particularly stressful period for macroinvertebrates, especially in intermittent streams and these flows have the potential to strongly influence the dynamics and structure of macroinvertebrate communities.

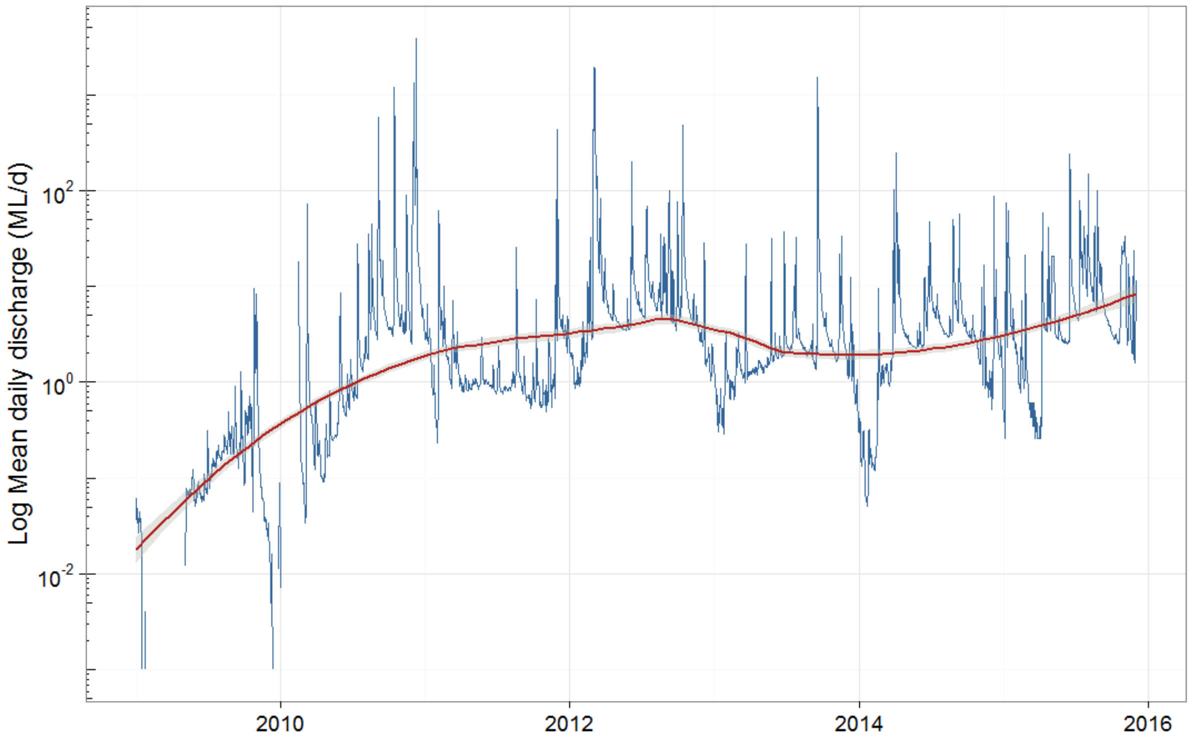


Figure 1-4. Hydrograph of Burra Creek at the Burra Road weir (410774) from 2009 to November 2015

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

1.6 Scope of work

Part 1 – 3: Angle Crossing, Burra Creek & Murrumbidgee Pump Station

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 2015 sentinel monitoring. Specifically, as outlined in the MEMP proposal to Icon Water (GHD, 2015b) this work includes:

- Macroinvertebrate samples collected from riffle and edge habitats using AUSRIVAS protocols at the relevant sites;
- Macroinvertebrate samples counted and identified to the taxonomic level of genus[2];
- Riffle and edge samples assessed through the appropriate AUSRIVAS model;
- The use of photogrammetry to monitor periphyton[3], vegetation and geomorphology at the relevant sites;
- *In-situ* water quality measurements; and
- Water quality grab samples analysed for nutrients in the Australian Laboratory Services (ALS) Canberra NATA accredited laboratory.

The monitoring elements for each component of the revised monitoring programme are outlined in Table 1-2.

Table 1-2. General suite of monitoring elements and monitoring scenario to which they will be undertaken

Monitoring element	Provider	M2G sentinel	M2G impact	MPS sentinel	MPS impact
Water Quality (online)	Icon Water	✓	✓	✓	✓
Water Quality (grab samples)	GHD	✓	✓	✓	✓
Macroinvertebrates	GHD	✓	✓	✓	✓
Periphyton	GHD	Not required	✓	Not required	✓
Geomorphology	GHD	✓	✓	Not required	Not required
Riparian vegetation	GHD	✓	✓	Not required	Not required
Fish	ACT Government	✓	✓	✓	✓

[2] The reason for the genus resolution stems from the extensive and high quality data set which precedes the adjusted program. By including genus level identification, the long term integrity of the data record can be maintained.

[3] Not required for sentinel monitoring but it was felt that given the extra effort was negligible in the field, that it would be a useful inclusion to assist in the interpretation of macroinvertebrate data and to continue the data record.

2. Methodology

2.1 Study Sites

One site upstream and one site downstream of the respective infrastructure formed the basis of this sentinel monitoring component of the MEMP. These sites are a subset of existing sites which were previously sampled as part of the original MEMP programme (2009-2014). These sites were initially 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.

The number of sites to be sampled during sentinel monitoring was specified in the MEMP project review (Jacobs, 2014). The sentinel monitoring component therefore consists of six sites (details of these sites are given in Table 2-1) and are shown in Figure 2-1. Macroinvertebrate and water quality sampling, and photogrammetry for periphyton, vegetation and geomorphology were conducted at the relevant sites on the Murrumbidgee River and Burra Creek. Aquatic macroinvertebrates were sampled from two habitats (riffle and pool edges) and organisms identified to genus level (where practical) to characterise each site in terms of river health and community composition.

Table 2-1. Sampling locations and details

Component of the MEMP		Site Code	Location	Alt. (m)	Landuse	Latitude	Longitude
PART 1	Angle Crossing	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**
PART 2	Burra Creek	BUR 1c	Upstream Williamsdale Road	762	Grazing / residential	**-35.556511**	**149.221238**
		BUR 2a	Downstream Williamsdale Road	760	Grazing	**-35.554345**	**149.224477**
Part 3	Murrumbidgee Pump Station	MUR 28	Upstream Cotter River Confluence	468	Grazing	**-35.324382**	**148.950381**
		MUR 935	Casuarina Sands	471	Grazing	**-35.319483**	**184.951667**

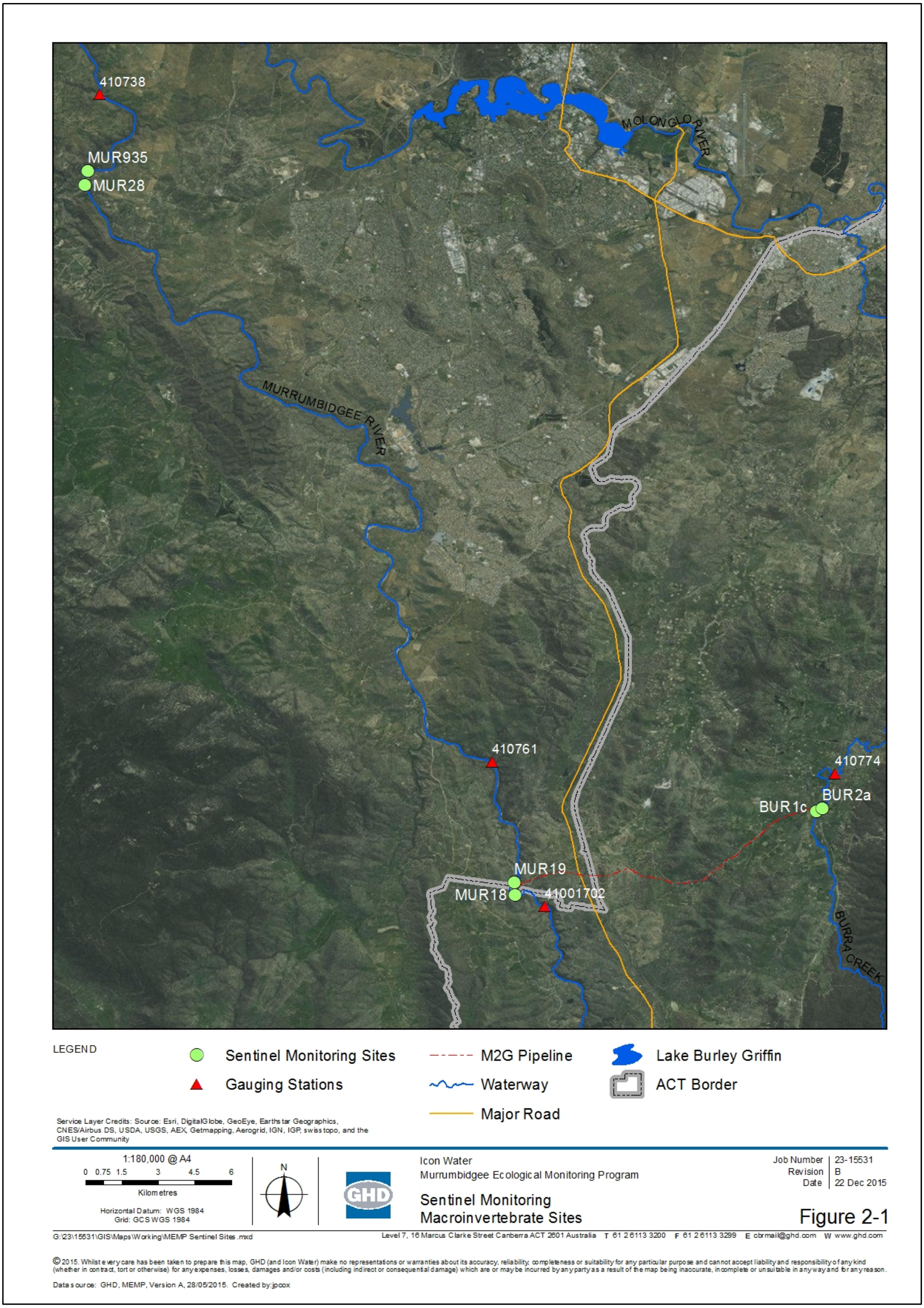


Figure 2-1. Map of macroinvertebrate site locations on the Murrumbidgee River and Burra Creek for the current sentinel monitoring

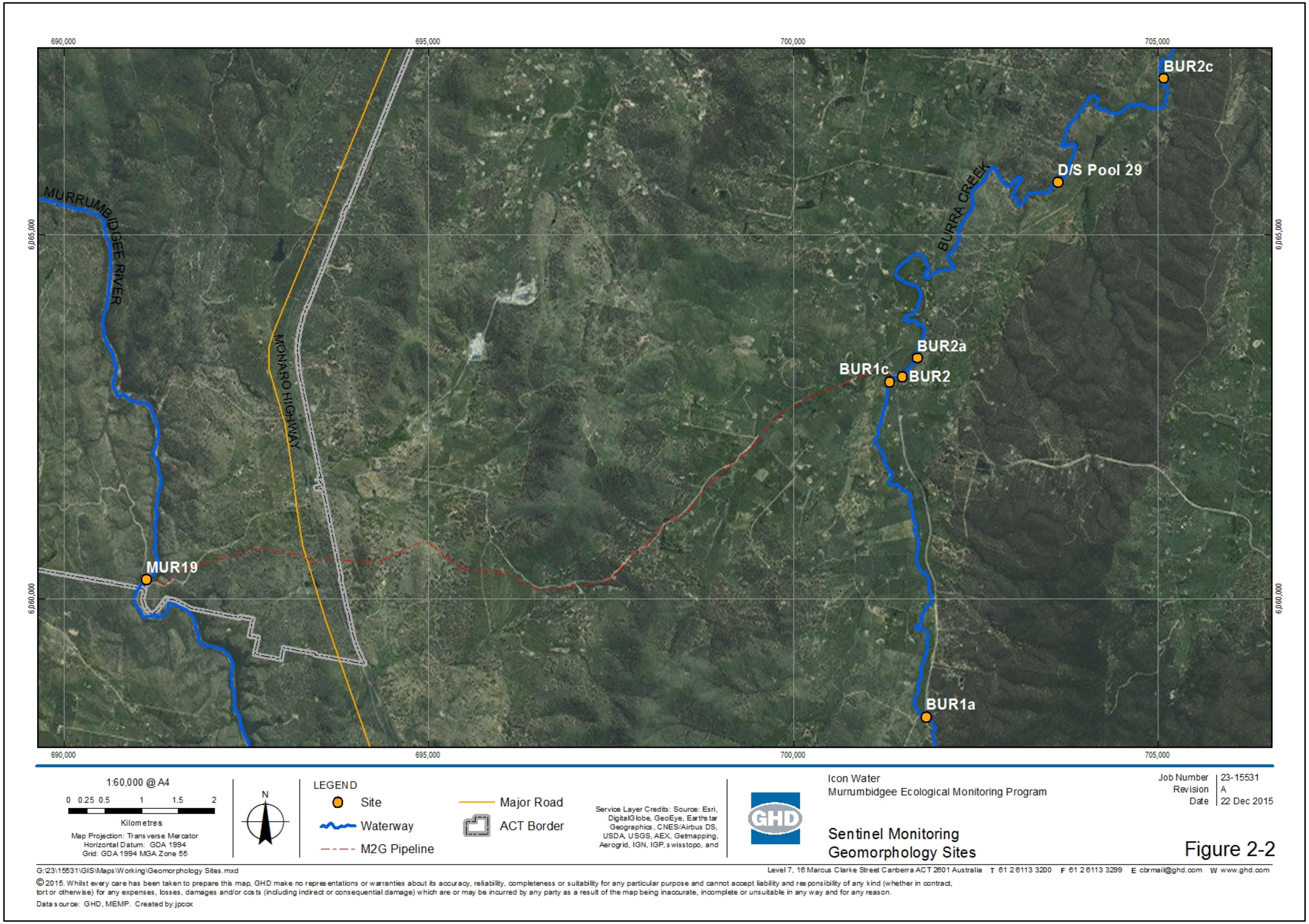


Figure 2-2. Map of the geomorphology site locations on the Murrumbidgee River and Burra Creek for the current sentinel monitoring

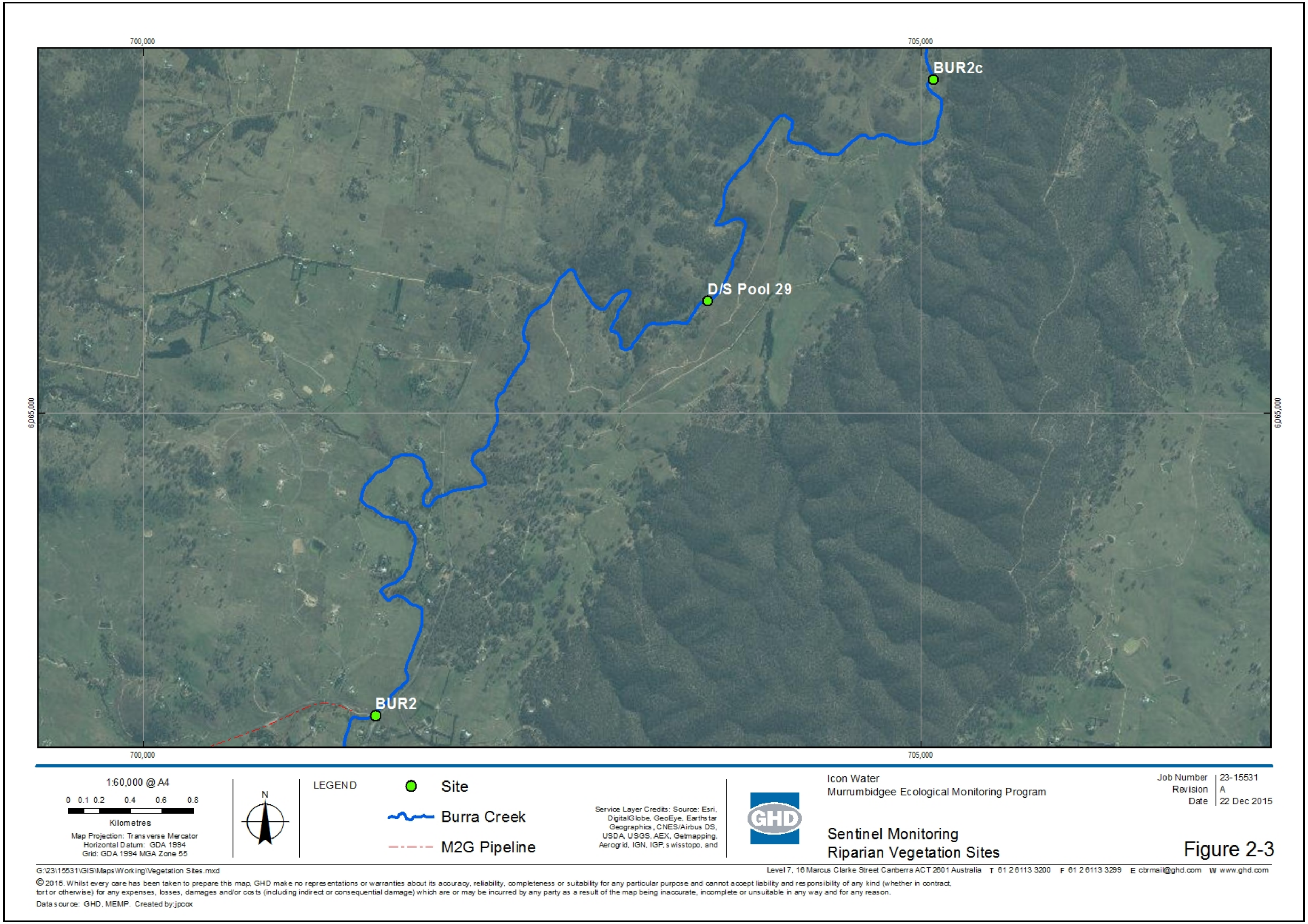


Figure 2-3. Map of the riparian vegetation site locations on Burra Creek for the current sentinel monitoring

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 (41001702); at Lobb's Hole (downstream of Angle Crossing: 410761); Mt. MacDonald (downstream of the MPS; 410738) and Burra Creek (upstream of BUR 2b: 410774). 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 data from the gauging station 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 / Murrumbidgee Pump Station
410738	Murrumbidgee River @ Mt. MacDonald	WL, Q	-35.2916	148.9552	Murrumbidgee Pump Station
410774	Burra Creek D/S road bridge	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	-35.5425	149.2279	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

Water temperature, turbidity, dissolved oxygen (DO), electrical conductivity (EC) and pH were measured *in situ* using a laboratory calibrated YSI 556 multi-parameter water quality meter as a part of the ACT AUSRIVAS field sheets.

Grab samples were collected at all sites in accordance with AUSRIVAS protocols (Nichols, *et al.* 2000), and submitted to ALS for analysis. Samples were analysed for alkalinity, SS, TKN, total NO_x, TP, TN, total iron and total manganese.

2.3.1 Data analysis

Water quality parameters were examined for compliance with ANZECC water guidelines for healthy ecosystems in upland streams (ANZECC and ARMCANZ, 2000). Summary statistics were calculated for the parameters collected at the gauging stations and time series plots were created to assist with the interpretation.

2.4 Macroinvertebrate monitoring

Rapid bio-assessment (RBA) methods (i.e. AUSRIVAS) will occupy the main component of the sentinel monitoring programme. The Australian Rivers Assessment System (AUSRIVAS) is a rapid, standard method for assessing the ecological health of freshwaters through biological monitoring and habitat assessment (Nichols *et al.*, 2000). This assessment will provide an overview of the system that will indicate on a broad scale whether there are notable changes based on the ratio of the number of observed to expected taxa which are recorded at each site. The observed / expected ratio is an indication of the current ecological condition at a given site. These data will be used for comparison with data collected during operational periods (i.e. during impact monitoring) in the Murrumbidgee River and Burra Creek, so relative seasonal and annual changes over time can be monitored against any potential changes directly resulting from the Icon Water projects.

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 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. A single sample was collected from each of the two habitats (edge and riffle - where available) at all sites. 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. The ACT AUSRIVAS field sheets were also completed at each site.

Processing of the aquatic macroinvertebrate bulk samples followed the ACT AUSRIVAS protocols (Nichols *et al*., 2000). 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 preserve the long term integrity of the data record within the experimental design, laboratory processing of each sample was repeated 3 times to align with the data collected between 2009-2014 which will allow these data and the existing data to be amalgamated with limited disruption to the project methodology.

For similar reasons, macroinvertebrates were identified to genus level (where possible) using taxonomic keys outlined in Hawking (2000) and later publications. Specimens that could not be identified to the specified taxonomic level (i.e. immature or damaged taxa) were removed from the data set prior to analysis. Genus identification was recommended by Chessman (2008) from his review of the MEMP project design. To enable comparison with previous sample seasons where genus level data was utilised, Icon Water has continued the use of this method, based on recommendations from GHD.

2.4.1 Data analysis

The broader, less intensive nature of the sentinel monitoring component (Jacobs, 2014) means that all formal hypothesis testing, which was a significant feature of the original MEMP is either not required or has limited power due to the low sample sizes. In light of this, the statistical component of this report is presented in the form of descriptive methods including univariate indices and metrics.

The univariate techniques performed on the macroinvertebrate data include:

- Taxa Richness and EPT taxa index (richness);
- SIGNAL-2 Biotic Index;

- ACT AUSRIVAS O/E scores and Bandings.

These metrics are often used in a lines-of-evidence approach to river assessments and have solid foundations in biomonitoring. Each index is used to assess slightly different aspects of river health. SIGNAL -2 for example usually relates to changes in water quality while AUSRIVAS is mainly an indicator of habitat changes. Taxa richness is an indicator of changes in composition and needs to be assessed carefully because it does not indicate where in the community changes such as increases or losses of sensitive taxa occur. EPT is used to do just this, which is why it is used together with taxa richness since both provide complimentary information.

Taxa Richness

The number of taxa (taxa richness) was counted for each site and richness of pollution-sensitive taxa (Ephemeroptera, Plecoptera and Trichoptera - EPT) were examined at family and genus levels. Taxa richness was calculated 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 and are the 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 has been assigned a grade between 1 (most tolerant) and 10 (most sensitive). 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 other sites, with higher values indicating higher community sensitivity. 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.

AUSRIVAS

In addition to assessing the composition and calculating biometrics based on the macroinvertebrate data, river health assessments based on the ACT AUSRIVAS autumn 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 by human activities, e.g. altitude) are then compared to the observed fauna (O) and the ratio derived (O/E) is used to indicate the extent of any impact. The ratio derived from this analysis is compiled into Bandwidths (i.e. X, A-D; Table 2-3) which are used to gauge the overall health of that 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 Bandwidths or Bands (Table 2-3).

The site assessments are based on the results from both the riffle and edge samples. Using a precautionary approach as recommended by Coysh *et al.* (2000), the overall site condition was based on the farthest Band from reference in a particular habitat at a particular site. For example, a site assessed as a Band-A in the edge and a Band-B in the riffle would be given an overall site assessment of Band-B (Coysh *et al*., 2000). In cases where the Bands deviate significantly between habitat (e.g. D – A) then an overall site-level assessment was avoided due to the unreliability of the results, leading to no reliable assessment.

The use of the O/E 50 scores is standard in AUSRIVAS. 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).

Table 2-3. AUSRIVAS Band widths and interpretations for the ACT spring riffle and edge habitats

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.

2.4.2 Quality control

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

- Organisms that were heavily damaged were not selected during sorting. To overcome losses associated with damage to intact organisms during sample handling 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 5% of samples were re-identified by another senior taxonomist and these QA/QC results are found in Appendix A;
- 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.

2.5 Photogrammetry (Periphyton, Geomorphology and Vegetation)

Photogrammetry is introduced in this component of the MEMP as a means to monitor potential changes in response to the full pumping operation of M2G and MPS over and above those occurring naturally.

Photogrammetry is a cheap and robust alternative to quantitative techniques (O'Connor and Bond, 2007). Using this method, photo points are established at each monitoring location using markers and GPS coordinates. Photographs are taken at the same point on a pre-determined temporal scale or at times triggered by natural or other unforeseen events. The aspect of the photograph is determined by either using secondary or tertiary markers or by using land scape features. Photo points have been established at all of the existing MEMP sites.

The resulting photographs provide a robust and valuable resource to help understand the temporal dynamics of the system; and provide a good visual reference of habitat in relation to the qualitative macroinvertebrates results as a measure of river health. This method will be used to monitor periphyton, vegetation and geomorphology at the relevant sites as listed in Table 2-4.

Table 2-4. Locations of photogrammetry for each assessment type and number of photo points

Site	Periphyton	Vegetation	Geomorphology
Burra Creek			
BUR 1c	✓		2 Photo Point
BUR 2a	✓		4 Photo Points
BUR 1a			3 Photo Points
BUR 2		4 Photo Points	4 Photo Points
BUR 2c		4 Photo Points	4 Photo Points
D/S Pool 29		3 Photo Points	3 Photo Points
Murrumbidgee River			
MUR 18	✓		
MUR 19	✓		5 Photo Points
MUR 28	✓		
MUR 935	✓		

Note: Ticks indicate sites at which periphyton monitoring occurs.

2.5.1 Periphyton

Representative photographs were taken at each macroinvertebrate site of the substrate using a 1m x 1m quadrat for scale (Table 2-4). These photographs were considered to be representative of the habitat and site. Quantitative assessments of the proportion of cover were recorded using the ACT AUSRIVAS field sheet methodology (Nichols, *et al.*, 2000).

2.5.2 Vegetation

Photographs were taken at 3 or 4 (site dependent) existing photo points to record the current extent of riparian and instream vegetation at relevant sites (Table 2-4). Three photos were taken at each point, one facing upstream, one facing downstream and another directly across the channel. GPS coordinates have been recorded for all photo points, while some sites also have survey pegs inserted to assist in locating the exact location. Sites will be revisited in 2 years' time, when photographs will be taken again and field notes recorded.

2.5.3 Geomorphology

Photographs were taken at each of the geomorphology sites (Table 2-4) with 2 to 5 photo points used at each site. Geomorphological features of interest have already been established (GHD, 2015c) and this represents a continuation of the methods that have already been used in monitoring geomorphology in the context of the MEMP. To capture changes in the morphology as effectively as possible, the photos were taken from the existing photo points. Both survey pegs and GPS co-ordinates have been used to accurately record the position of each photo point. Three photos were taken at each point, one facing upstream, one facing downstream and another directly across the channel, with these photo points chosen to ensure all geomorphological features identified at each site have been adequately recorded.

2.6 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 ACT and NSW AUSRIVAS accreditation.

3. Angle Crossing

3.1 Summary of sampling and river conditions

Sampling of the Angle Crossing sites was conducted on the 24th November 2015. The weather on the day was fine and the maximum temperatures reached over 27°C (at Canberra Airport (BoM, 2015)). The flow in the Murrumbidgee River was receding following a small flow event in mid-November, and the mean daily flow on the day was 290 ML/d at the Lobb's Hole gauging station (410761). A single riffle and a single edge sample were collected at both the upstream and downstream sites (MUR 18 and MUR 19 respectively). Site photographs are presented in Plate 3-1. Like previous seasons, submerged macrophyte cover was high at both sites, but particularly at MUR 19, where the dominant macrophyte species was *Myriophyllum* sp.; small patches of filamentous algae were also present at MUR 19. Site summaries are presented in Appendix B and general habitat data is shown in Appendix C.


MUR 18: Looking upstream (left) and downstream (right)


MUR 19: Looking upstream (left) and downstream (right)

Plate 3-1. Photographs of the Angle Crossing monitoring sites at the time of sampling - spring 2015

3.2 Hydrology and Rainfall

Rainfall during spring 2015 was highest during November (Table 3-1), when total rainfall was greater than both September and October combined. November rainfall exceeded the median spring rainfall for the monitoring period, but was significantly below the median value in September and October.

Full Rainfall and flow summaries for upstream and downstream of Angle Crossing for spring 2015 are presented in Table 3-1.

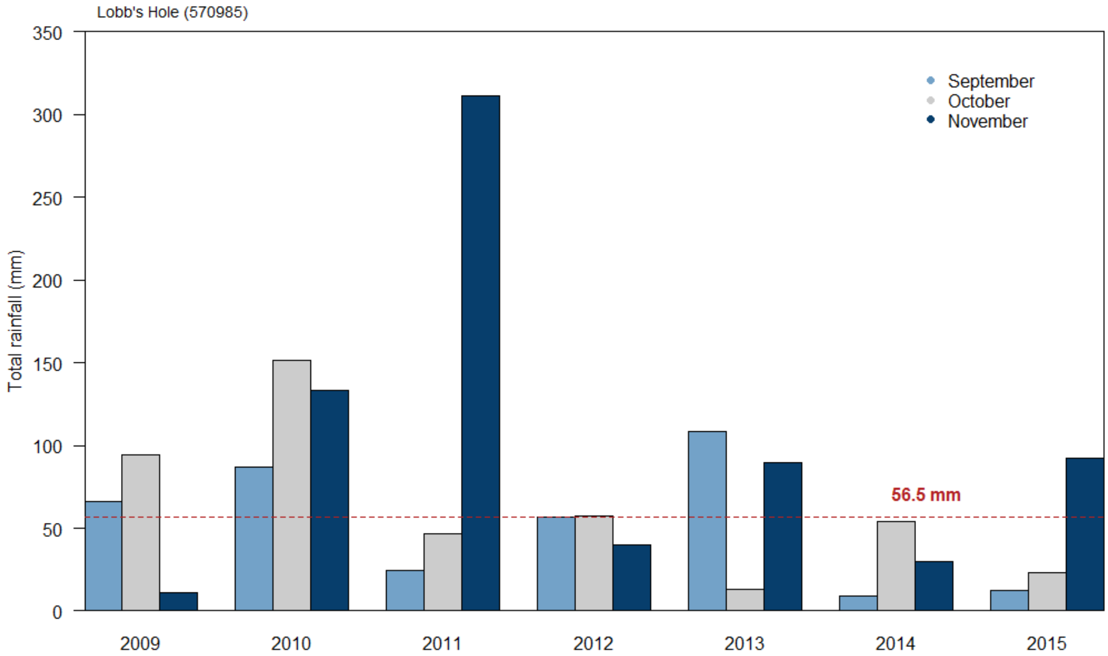


Figure 3-1. Annual comparison of spring rainfall (mm) recorded at Lobb's Hole (570985)

Note: Red dotted line and text shows the median rainfall for spring (2009-2015)

Table 3-1. Spring rainfall and flow summaries, upstream and downstream of Angle Crossing

	Upstream Angle Crossing (41001702)		Lobb's Hole (410761)	
	Rainfall Total (mm)	Mean Flow (ML/d)	Rainfall Total (mm)	Mean Flow (ML/d)
September	6.9	1,700	12.4	2,000
October	27.4	450	23.0	540
November	91.2	500	92.6	540
Spring (mean)	125.5 (41.8)	890	128.0 (42.7)	1,000

Flow during the spring period was characterised by a high flow event at the beginning of the season which peaked above 10,000 ML/d and receded over a three week period in September; which was followed by approximately three weeks of steady flow resulting from low rainfall during October. A small flow event of approximately 1,500 ML/d occurred in mid-November following the higher rainfall during the first half of the month (Figure 3-2). Flows during the final week of November (when sampling occurred) were the lowest of the entire spring period (mean flow of 200 ML/d during the final week of November at 410761). This follows a similar pattern to spring 2014 when there was a high flow event during August with flows generally receding throughout spring and through to the beginning of summer (Figure 3-3). Flow data at upstream Angle Crossing (41001702) was missing for a week during mid-October.

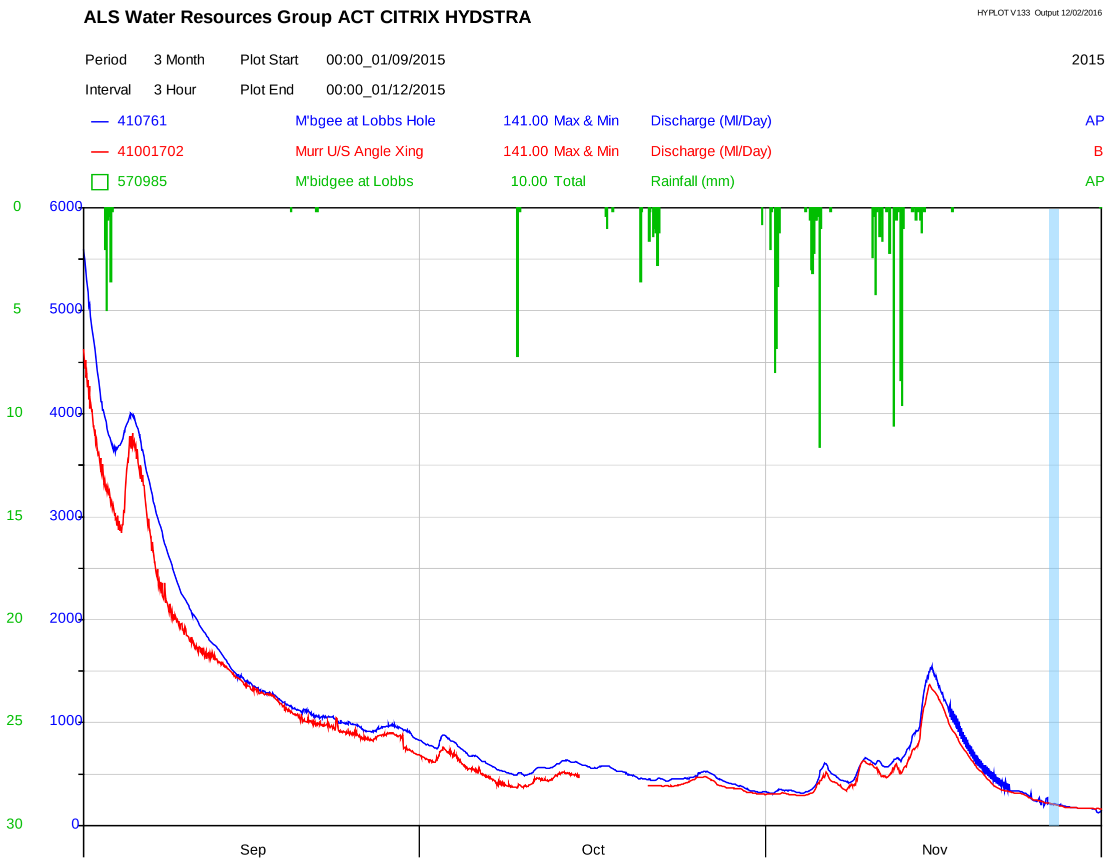


Figure 3-2. Spring 2015 hydrograph of the Murrumbidgee River upstream (41001702) and downstream (410761) of Angle Crossing

Note: Sampling day highlighted by light blue shading.

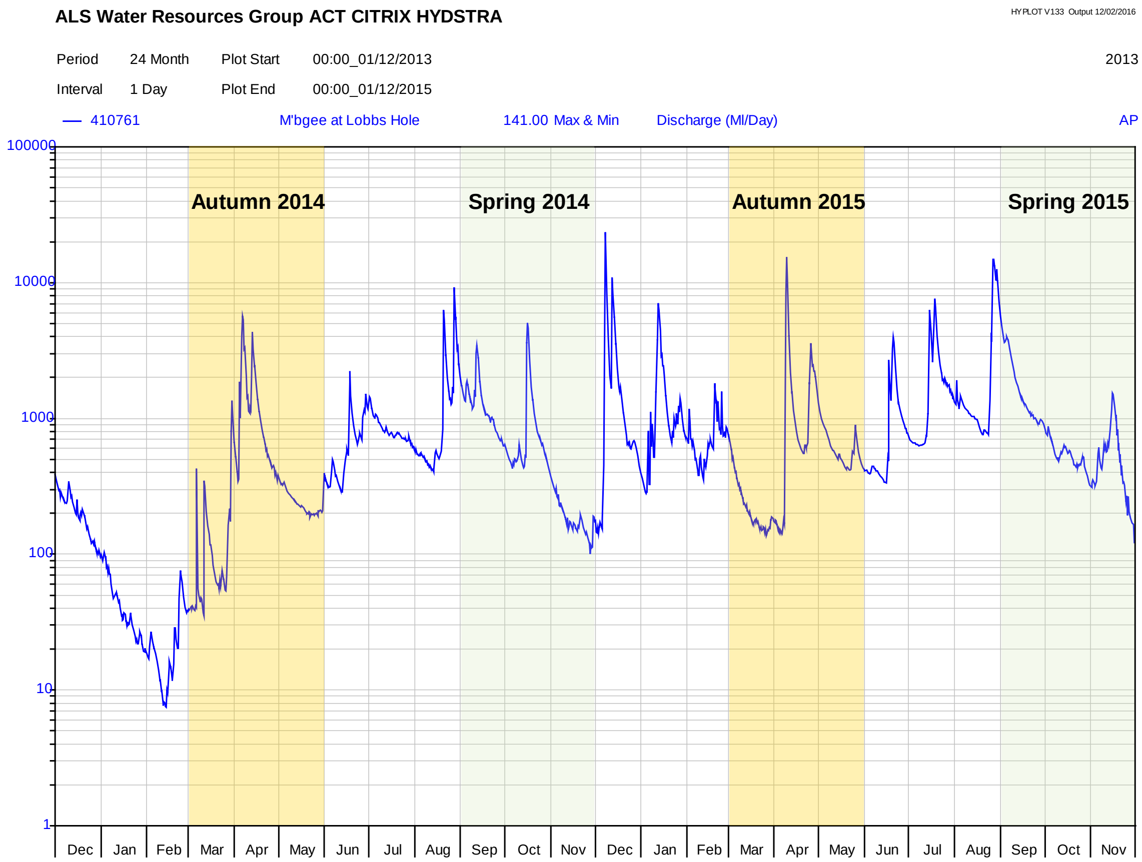


Figure 3-3. Hydrograph from Lobb's Hole highlighting the past four sampling periods between December 2013 and November 2015

3.3 Water Quality

3.3.1 Grab samples and *in-situ* parameters

In-situ water quality parameters and grab sample results are presented in Table 3-2. The majority of the recorded parameters were within the ANZECC & ARMCANZ (2000) guidelines, including electrical conductivity, turbidity, dissolved oxygen and NO_x. However, pH was above the ANZECC & ARCMANZ (2000) upper limit at both sites; downstream of Angle Crossing (MUR 19) recorded a slightly more alkaline result than MUR 18 (Table 3-2). Comparatively, during spring 2014 MUR 18 was within the recommended range (by 0.01 pH unit) while MUR 19 exceeded the upper limit (GHD, 2015d).

Nutrient levels at the Angle Crossing sites have been above the trigger values during all spring sampling occasions for the duration of the MEMP. Spring 2015 is no different, as both total phosphorus and total nitrogen both exceeded the ANZECC & ARCMANZ (2000) trigger values to both MUR 18 & 19. NO_x values at both upstream and downstream sites were below the trigger value.

3.3.2 Continuous water quality monitoring

The continuous water quality monitoring from Lobb's Hole (410761) and upstream Angle Crossing (41001702) are presented in Figure 3-4 and Figure 3-5 respectively[4]. Water quality monitoring data from the upstream Angle Crossing site were not available during November due to lightning damaging the probe.

[4] Both sites are yet to have their data quality checked and verified.

The site was being relocated to a more appropriate location in the first week of December and as such the decision was made to leave the site as is and replace the damaged sensor upon the completion of the site relocation. The data prior to the lightning damage at upstream Angle Crossing appears to be poor quality, with siltation from the high flow event during late August most likely the cause. This highlights the issues which were frequent at this site prior to its relocation during December.

Turbidity was low for most of the season with 55% of daily mean values being below the ANZECC & ARMCANZ (2000) guidelines during the period; however some spikes were recorded including during a period of increased flow during mid-November. Temperature increased throughout the season, while electrical conductivity increased throughout the season but remained within the recommended range. During the beginning of spring the pH levels were initially within the recommended range, however became elevated during the second half of the season with daily means exceeding the guidelines from 19th October until the end of the season. Dissolved oxygen levels during spring 2015 were consistently around 90%, with variation in the diurnal trend increasing towards the end of the season dropping the DO levels slightly. Mean daily dissolved oxygen (% sat.) remained consistent with all daily means for the season between 85-93%.

Table 3-2. *In-situ* water quality results from Angle Crossing during spring 2015

	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)	TKN (mg/L)	TP (mg/L) (0.02)	TN (mg/L) (0.25)	Total Iron (mg/L)	Total Manganese (mg/L) (1.9)
Upstream	MUR 18	24/11/2015	11:10	22.2	178.5	7.37	10	8.13	102.4	8.19	74	< 0.002	0.42	0.030	0.42	0.60	0.067
Downstream	MUR 19	24/11/2015	12:20	22.9	177.9	5.25	9	8.19	104.4	8.11	74	0.002	0.40	0.028	0.41	0.57	0.065

Note: ANZECC and ARMCANZ (2000) guidelines are in yellow parentheses, yellow cells indicate values outside of the guidelines; guideline value for Total Manganese is the 95% species level protection for slightly-moderately disturbed systems.

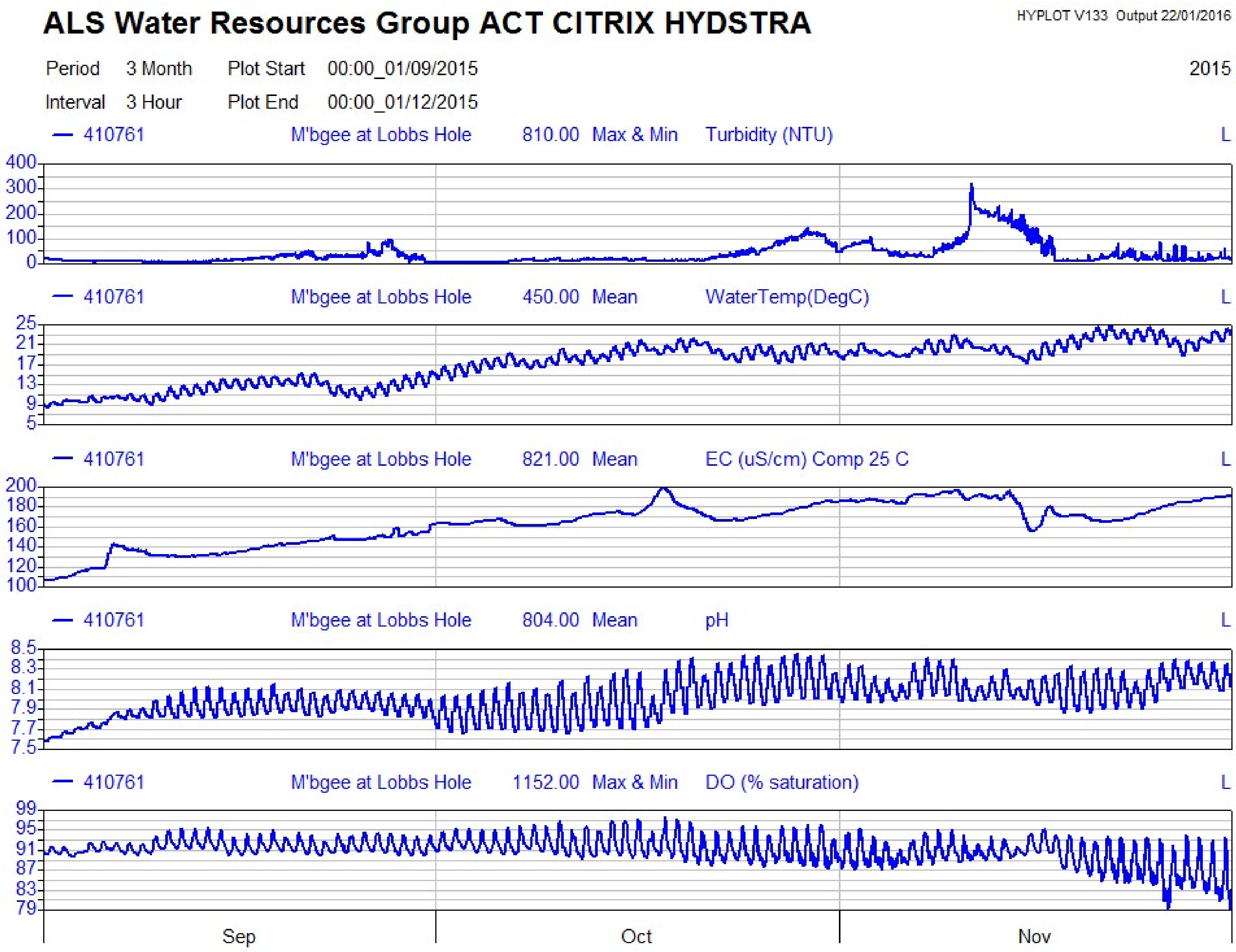


Figure 3-4. Continuous water quality records from Lobb's Hole (410761) for spring 2015

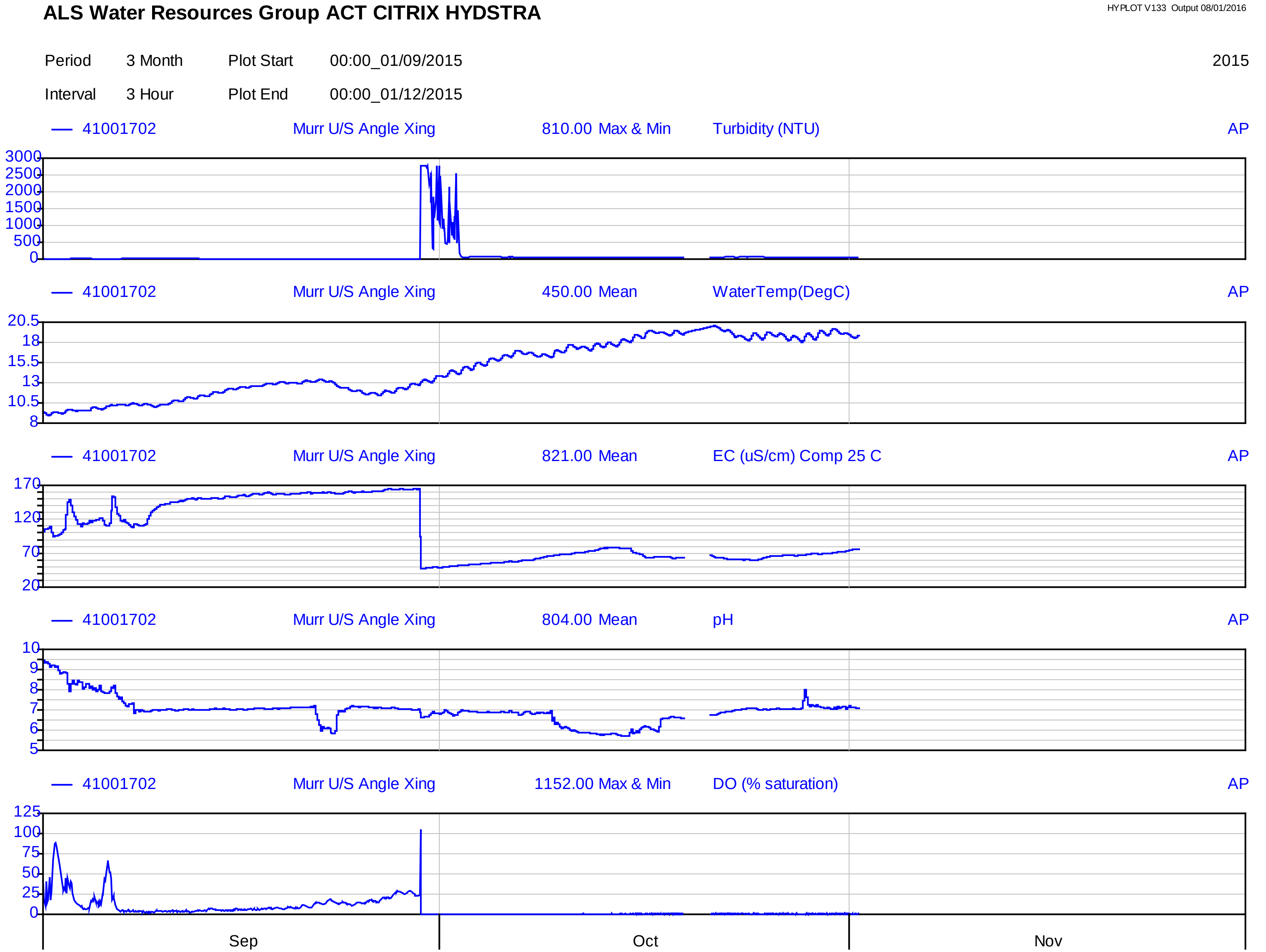


Figure 3-5. Continuous water quality records from upstream Angle Crossing (41001702) for spring 2015

3.4 Photogrammetry

3.4.1 Periphyton

MUR 18

The periphyton coverage at MUR 18 was approximately 65-90% for the reach and 35-65% for the riffle habitat using the AUSRIVAS assessment method (Plate 3-2). There were large stands of the submerged macrophyte *Myriophyllum* sp. growing throughout the reach (as shown below in Plate 3-2 [bottom right]). The dominant substrate in the riffle habitat was cobble.

Plate 3-2. Photos showing the periphyton and macrophyte coverage in the reach and riffle at MUR 18

Note: Quadrat area is 1m^2.

MUR 19

The periphyton coverage was approximately 35-65% at MUR 19 for both the reach and riffle habitat using the AUSRIVAS assessment (Plate 3-3). *Myriophyullum* sp. was dominant throughout the riffle habitat, and the dominant substrate, like MUR 18, was cobble.

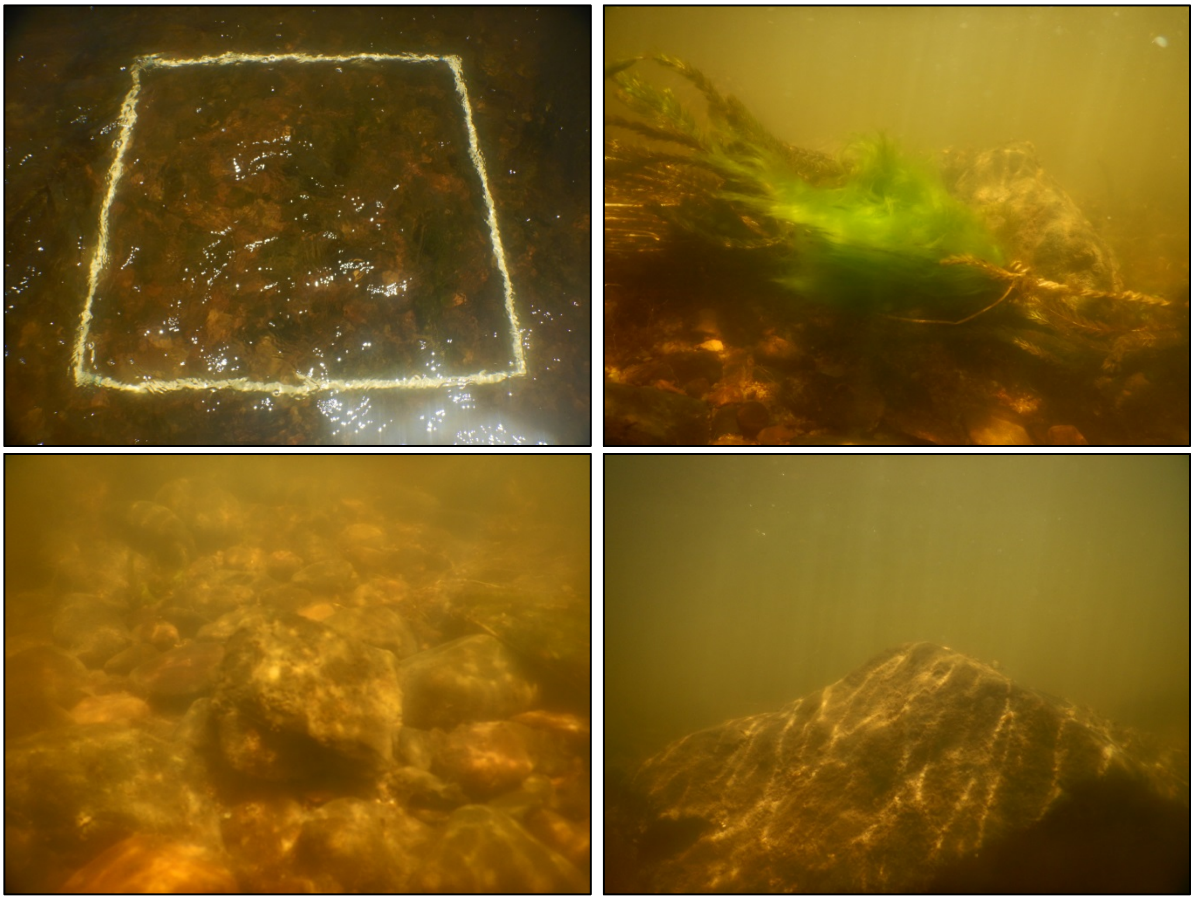


Plate 3-3. Photos showing the periphyton coverage in the riffle at MUR 19

Note: Quadrat area is 1m^2.

3.4.2 Geomorphology

Angle Crossing

Geomorphological features at Angle Crossing have remained relatively unchanged compared to autumn 2015 (GHD, 2015). There appears to be small sections of increased erosion on the right bank next to the riffle habitat which is visible in Photo Point 2 (Plate 3-5). Outside of this small adjustment, not other changes were evident. The large longitudinal bar at Photo Point 5 (Plate 3-8) appears to have increased in size however, this is more likely due to the lower flow during sampling in spring 2015 compared to autumn 2015. A total of five photographs from five photo points were captured at Angle Crossing during spring 2015 and are presented in Plate 3-4 through to Plate 3-8.

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 3-4. Geomorphology photo point 1 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 3-5. Geomorphology photo point 2 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 3-6. Geomorphology photo point 3 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 3-7. Geomorphology photo point 4 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 3-8. Geomorphology photo point 5 at Angle Crossing showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

3.5 Macroinvertebrates

Taxa richness was higher at the downstream site when compared the upstream site during spring 2015 in the riffle habitat (Table 3-3). Comparatively, the upstream site recorded a high richness compared to the downstream site in the edge habitat. Samples generally had higher taxa richness compared to spring 2014 (ranging from 3-4 more families and up to 3 more genera), with the riffle sample at MUR 18 the notable exception (recording 3 fewer families and 6 fewer genera) (GHD, 2015d).

EPT richness scores follow the same pattern as the total richness, with MUR 18 having higher tax richness in the edge habitat while MUR 19 had higher richness in the riffle habitat (Table 3-4). However, the richness values were still similar with the difference between family richness only a single family in both habitats, while the genera differed by two in the riffle habitat and three in the edge habitat (Table 3-4).

Table 3-3. Number of taxa at family and genus level from riffle and edge habitats

Total Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
MUR 18	19	25	26	32
MUR 19	22	27	25	30

Table 3-4. Number of EPT taxa at family and genus level from riffle and edge habitats

EPT Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
MUR 18	7	11	9	15
MUR 19	8	13	8	12

3.5.1 AUSRIVAS & SIGNAL-2

Mean SIGNAL-2 scores in the riffle habitat were very similar between MUR 18 and MUR 19 during spring 2015 scoring 5.11 and 5.15 respectively (Table 3-5). MUR 19 also had a mean SIGNAL-2 of 5.15 during spring 2014, while MUR 18 has decreased since spring 2014 when it scored 5.44. The mean SIGNAL-2 score in the edge habitat during spring 2015 at MUR 18 & 19 was 4.55, which was an increase on spring 2014 means at both sites.

The AUSRIVAS results showed that ecological health of the two sites was very similar across both habitats. Mean O/E scores differed by 0.03 in the riffle habitat scoring 0.95 at MUR 18 and 0.92 at MUR 19 resulting in two overall habitat assessments receiving Band A (‘similar to reference’) (Table 3-5). The last time MUR 19 received an overall riffle habitat assessment of Band A was in spring 2011, while this is the first time MUR 18 has received a Band A for the overall habitat assessment. The O/E scores for the edge habitat were, like the SIGNAL-2 scores, identical with both sites scoring 1.22. This

O/E score gives both sites overall edge habitat assessments of Band X ('more diverse than expected' - for more information on Band X see Barmuta *et al*. (2003)) (Table 3-5).

This is the first time that either of these sites have received an overall habitat assessment of Band X. This unexpected result is due to all Angle Crossing edge replicates having no missing taxa in the AUSRIVAS model (Appendix F).

The overall site assessments of Band A, show an increase in Banding over spring 2014 at MUR 18, which was assessed as Band B while MUR 19 maintains Band A (Table 3-6). The observed/expected results from the AUSRIVAS model are presented in Appendix F, while a full taxonomic inventory can be found in Appendix G.

Table 3-5. AUSRIVAS and SIGNAL-2 scores for spring 2015

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 18	**1**	5.15	4.55	1.00	1.22	A	X	**A**	**X**	**A**
	2	4.92	4.55	0.92	1.22	A	X			
	3	5.25	4.55	0.92	1.22	A	X			
MUR 19	**1**	5.15	4.55	1.03	1.22	A	X	**A**	**X**	**A**
	2	4.80	4.55	0.79	1.22	B	X			
	3	5.50	4.55	0.95	1.22	A	X			

Note: The MUR 19 edge replicates were "nearly outside the experience of the model" (see Coysh et al. (2000) for details).

Table 3-6. Overall site assessments for Angle Crossing sites since 2012

	Autumn 2012	Spring 2012	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014	Autumn 2015	Spring 2015	Change since spring 2014
MUR 18	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**A**	↑
MUR 19	**B**	**B**	**B**	**B**	**B**	**A**	**B**	**A**	↔

3.6 Discussion

3.6.1 Water quality

The water quality results from the Angle Crossing site indicate that the similarity between the upstream and downstream sites which has been previously identified is continuing (GHD, 2015e). Exceedances of the ANZECC & ARMCANZ (2000) guidelines were limited throughout the spring season. pH values identified in both the continuous water quality data and the grab samples were in exceedance of the upper limit. These elevated pH levels are considered to be normal in this reach of the Murrumbidgee River, with a majority of values in the range of 7.9-8.2.

Elevated nutrient concentrations at both the upstream and downstream site have been frequently recorded during spring along this reach since the inception of the MEMP. Previous MEMP reports have identified that these elevated concentrations originate from upstream of the ACT, with the likely sources a combination of agricultural land use and erosion (see GHD, 2013).

The poor quality and missing data at the gauging station upstream of Angle Crossing (41001702; Figure 3-5) meant that use of this data within the report was not possible. The relocation of this site to a more appropriate location aims to reduce the issues associated related to sedimentation and electrocution from lightning, and provide better quality data more reliably for use over future seasons.

3.6.2 Photogrammetry

Periphyton

Periphyton has been included in the monitoring programme for Angle Crossing sites as a means of assessing the influence of flow upon the algal communities downstream of the abstraction point compared to upstream. The aim of this monitoring is to determine during operational pumping whether algal and periphyton communities downstream of Angle Crossing are increasing compared to upstream sites due to the reduction in flow through abstraction. While not required for the sentinel monitoring component, the inclusion of these images will increase the baseline information for the impact monitoring which will occur if the pumping conditions are satisfied.

The photos of the substrate presented in section 3.4.1 using both the quadrat and underwater aspects, provides a good overview of the periphyton coverage at both upstream and downstream sites. The coverage of periphyton in the riffle habitat during spring 2015 was lower than that recorded during spring 2014, changing from 65-90% to 35-65%. This change in coverage is due to the high flow event during late August. High flow events are known to reduce periphyton biomass, which was likely still recovering during our sampling run (Jowett & Biggs, 1997). When compared to the event which occurred during a similar timeframe prior to spring 2014 sampling (approximately 9,000 ML/d) the event in August 2015 (approximately 15,000 ML/d) was roughly two thirds larger suggesting it would have a higher velocity leading to more scouring of the periphyton.

Geomorphology

While the geomorphology at Angle Crossing has shown that over recent years it is a dynamic reach which can have significant changes from individual high flow events (GHD, 2014b; GHD, 2015c), during the period since autumn 2015 there has been very little change within this reach. While there was some erosion in a small section of river bank, there was no instream deposition or bar formation which could be observed from the Photo Points. The two seasons of Photo Points from autumn and spring this year will be used for comparison during the next geomorphology monitoring scheduled for 2018 to determine the natural changes to the Murrumbidgee River, or following the operation of the Murrumbidgee to Googong Pipeline requiring impact assessment.

3.6.3 Macroinvertebrate communities and river health assessment

The macroinvertebrate AUSRIVAS results from spring 2015 suggest that there has been an increase in the ecological condition, based on AUSRIVAS at these two sites, with both recording the highest scores since the inception of the MEMP. Both edge habitats were assessed as Band X ("more diverse than expected"), which is the first time both sites have received this Band. This increase in the AUSRIVAS bands in the edge habitat is due to the presence of all taxa which were predicted by the AUSRIVAS model, with no missing taxa recorded (Appendix F).

Three taxa which have been frequently absent during spring over the previous few years, Leptoceridae (SIGNAL-2 = 6), Ceratopogonidae (SIGNAL-2 = 4) and Tanypodinae (SIGNAL-2 = 4) were recorded in all replicates. Because of the criteria used to assess the final AUSRIVAS band when multiple samples or subsamples are used (Barmuta et al., 2003) even two or one missing taxa from any sample can result in a lower score for that site because of the conservative approach taken under this methodology. Therefore, by reducing the number of replicates collected at a given site, the probability of missing taxa and a lower AUSRIVAS band is essentially halved. This result also shows that one replicate does not fully account for the variability that can be expected within each of these defined sites, since previously, at certain times, there has been considerable variation between replicate samples at MUR 18 and MUR 19. Also, while these taxa have been present previously, they were only recorded in some replicates, which could indicate the abundances of these and other missing taxa may have increased leading to their presence in all replicates at both sites.

There was also a change in the AUSRIVAS bands in the riffle habitat, particularly at MUR 19. The mean O/E score from spring 2014 was 0.74 (which equates to Band B), has now increased to 0.92 (Band A). This was a result of less variation across the sub-samples (5-7 missing taxa compared to 5-10 missing taxa in spring 2014) in the presence and absence of a range of taxa as opposed to being the result of specific taxa.

Mean riffle O/E scores at MUR 18 have remained very similar from spring 2014 to 2015 (0.04 decline). However, during spring 2014 the overall riffle habitat assessment was Band B, while during spring 2015 it was assessed as Band A even though the mean O/E score was lower. This is a good example of why the new methodology of using the mean O/E score for Banding was recommended versus the standard AUSRIVAS methodology of using the farthest Band from Band A (Barmuta *et al.* 2003).

One of the six replicates during spring 2014 was assessed as Band B resulting in the overall habitat assessment of Band B, despite the high mean O/E score. The SIGNAL-2 score also reduced compared to the previous year, with the absence of Leptophlebiidae (SIGNAL-2 = 8) during spring 2015 the major cause. While Leptophlebiidae prefer habitats with faster flowing waters (Gooderham & Tsyrlin, 2005), the riffle habitat at MUR 18 matches this description and Leptophlebiidae are usually collected at this site. It is surprising that similarly sensitive taxa such as Coloburiscidae (SIGNAL-2 = 8) which were observed to be relatively abundant within the sample and Gripopterygidae (SIGNAL-2 = 8) were also present, however Leptophlebiidae were absent entirely.

4. Burra Creek

4.1 Summary of sampling conditions

Sampling of Burra Creek sites was completed on the 23rd November 2015. The weather on the day was fine with a maximum temperature of 26°C recorded at the Canberra Airport (BoM, 2015). The mean daily flow in Burra Creek on the 23rd was 1.98 ML/d recorded at the Burra Weir (410774). Macroinvertebrate samples were collected at both BUR 1c and BUR 2a, consisting of one riffle sample and one edge sample. Site photos of BUR 1c and 2a are presented in Plate 4-1.

Macrophyte growth was prolific at both Burra Creek sites during spring 2015. Great Bullrush (*Schoenoplectus validus*) was dominant at BUR 1c while there were a number of large stands of Common Reed (*Phragmites australis*) at BUR 2a. The riffle habitats at both sites were highly silted and provided very poor habitat quality compared to previous seasons. Site summaries can be found in Appendix B, while site habitat data is given in Appendix C.

BUR 1c: Looking upstream (left) and looking downstream (right)

BUR 2a: Looking upstream (left) and looking downstream (right)

Plate 4-1. Photographs of the Burra Creek sites during spring 2015 sampling

4.2 Hydrology and rainfall

Surface flow in Burra Creek during spring 2015 was low, typically ranging between 2-4 ML/d (Figure 4-1). There were two periods of naturally increased flow during early-mid November where flow peaked between 20 and 30 ML/d. Outside of these natural events, flow increased during late October and twice in late November as a result of the APPLE runs of the M2G pipeline as highlighted in Figure 4-1. The period of sampling immediately prior to the second APPLE run is also highlighted in Figure 4-1. Rainfall during spring increased over the season and ranged from 10.4mm in September to 118.8mm in November, which was more than three times the rainfall which fell during September and October combined (Table 4-1). This is the highest November rainfall recorded since 2011 (Figure 4-3). The hydrograph for the previous two years (Figure 4-2) shows that flows leading into spring 2015 were considerably higher than those leading into spring 2014 (during July and August).

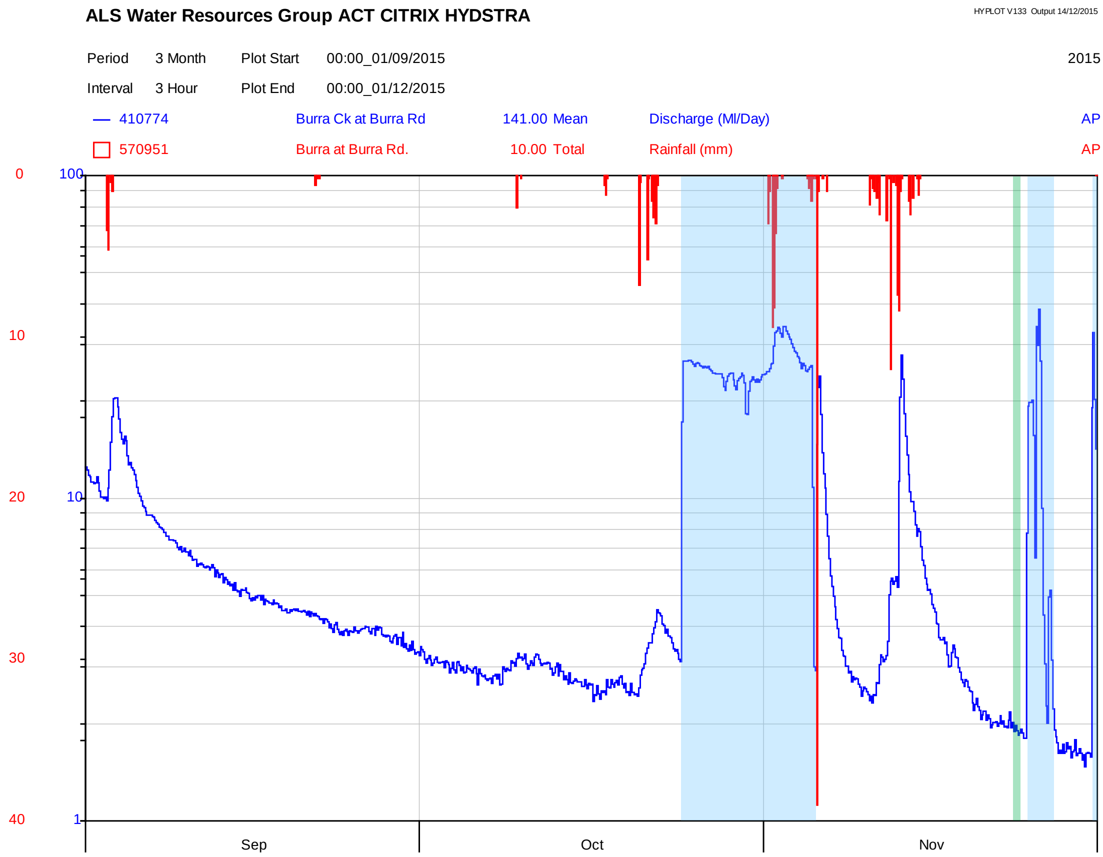


Figure 4-1. Hydrograph and rainfall from Burra Creek (410774) during spring 2015

Note: The green shading indicates time of sampling, blue highlight indicates APPLE run.

Table 4-1. Rainfall and flow summaries for Burra Creek for spring 2015

	Burra Creek (410774)	
	Total Rainfall (mm)	Mean Flow (ML/d)
September	10.4	6.5
October	26.6	8.0
November	118.8	9.0
Spring (mean)	155.8 (51.9)	7.8

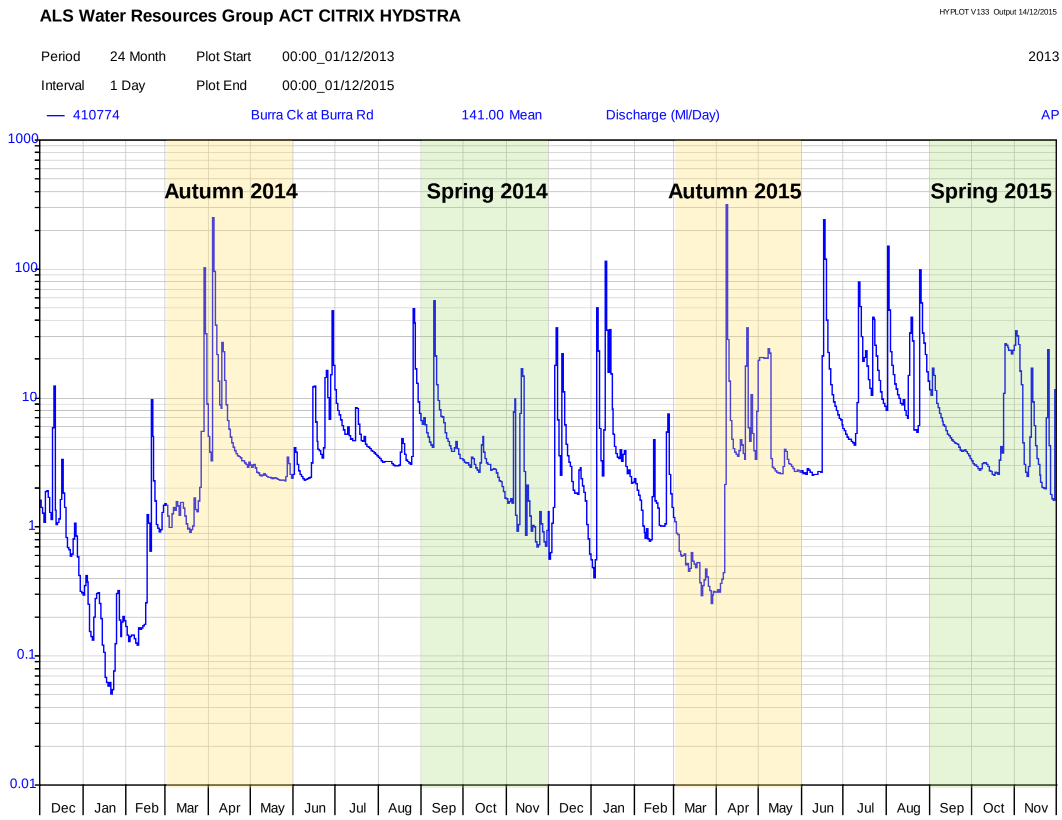


Figure 4-2. Burra Creek hydrograph highlighting the past four sampling periods between March 2014 and November 2015

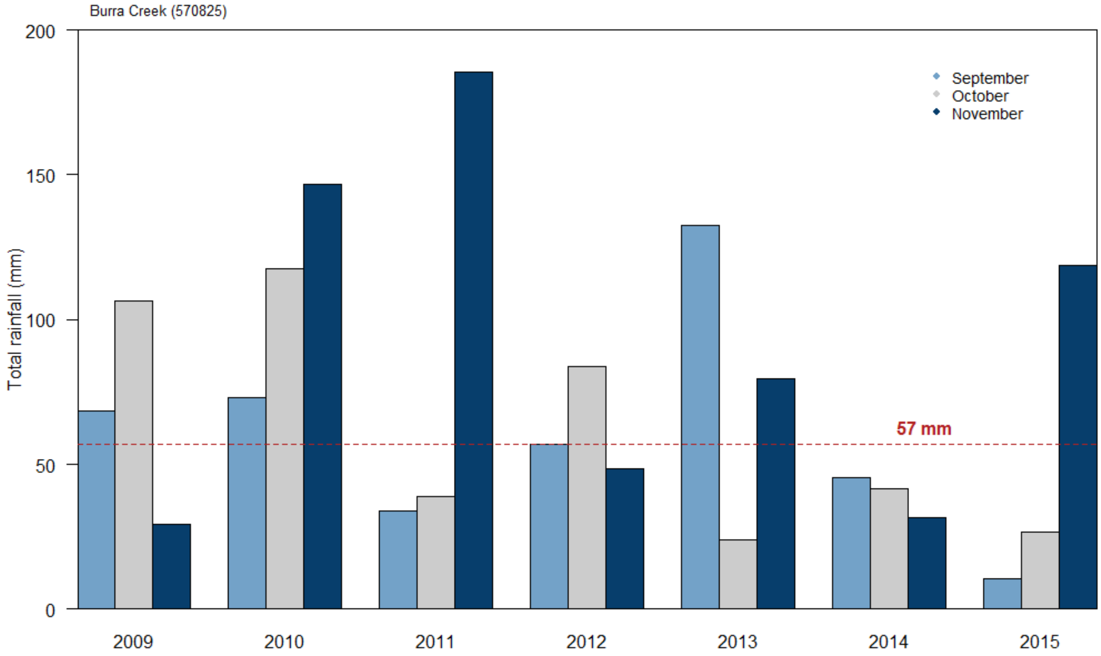


Figure 4-3. Annual comparisons of spring rainfall (mm) recorded at Burra Creek (570951)

4.3 Water Quality

4.3.1 Grab Samples and *in-situ* parameters

The *in-situ* water quality parameters were consistent with previous season's results in terms of ANZECC & ARMCANZ (2000) conformity (Table 4-2). Both sites exceeded the upper range for electrical conductivity (EC), recording similar results to that of spring 2014. Dissolved oxygen (D.O % sat.) was 10% higher at BUR 2a compared to spring 2014; however both sites were still below the lower range of the guidelines.

At sites BUR 1c and 2a pH values were within the recommended range (6.5-8.0) which is the first time that both of these sites have been recorded within the guideline range since spring 2012.

The results of the grab samples analysed at ALS Canberra showed exceedances of the ANZECC & ARMCANZ (2000) trigger values for both NO_x and total nitrogen (TN) (Table 4-2). BUR 1c exceeded the NO_x trigger value for the first time since spring 2012, while BUR 2a was recorded below the trigger value for the first time since spring 2010. Both sites were recorded above the trigger value for TN, consistent with the results of previous spring sample results. Table 4-2 shows the results for all parameters.

4.3.2 Continuous water quality monitoring

The continuous water quality data recorded at the Burra Weir (410774) is presented in Figure 4-4. The diurnal trend evident in the DO values indicate that while the daily peaks are within the ANZECC & ARMCANZ (2000) recommended range the troughs between the peaks fell below the lower limit, with all daily means after the 1st October falling below the recommended range. The pH data showed high levels of guideline exceedance at the start of spring (all daily means exceeded the guidelines until 9th October), however slowly declined throughout the season to within the guideline range, while temperature increased throughout the spring period towards the beginning of summer. These three parameters showed little response to the changes in flow, either natural or artificial pumping, which is not surprising considering the magnitude of flows which occurred.

Turbidity spiked in response to the initial APPLE run at the beginning of November. Turbidity levels were approximately 50% of the initial flush when two natural events came through the system; however the second and third APPLE runs produced very minimal to no response in turbidity. Comparatively, electrical conductivity (EC) increased over the spring period starting within the recommended range and increasing to over 500 µS/cm. There was little to no response of EC to the initial APPLE run, however distinct falls in EC were recorded at each of the natural flow events and the second and third APPLE runs. Outside of these reductions in EC, levels were in exceedance of the ANZECC & ARMCANZ (2000) upper limit.

Table 4-2. *In-situ* water quality results from Burra Creek during spring 2015 sampling

	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)**	TKN (mg/L)	TP (mg/L) **(0.02)**	TN (mg/L) **(0.25)**	Total Iron (mg/L)	Total Manganese (mg/L) **(1.9)**
Upstream	BUR 1c	23/11/2015	12:20	21.9	436	5.85	4	7.86	82.1	6.49	174	0.105	0.27	0.017	0.38	0.89	0.148
Downstream	BUR 2a	23/11/2015	13:15	20.8	515	11.0	17	7.98	84.9	6.65	214	0.003	0.30	0.013	0.30	0.56	0.113

Note: ANZECC and ARMCANZ (2000) guidelines are in yellow parentheses; yellow cells indicate values outside of the guidelines; guideline value for Total Manganese is the 95% species level protection for slightly-moderately disturbed systems.

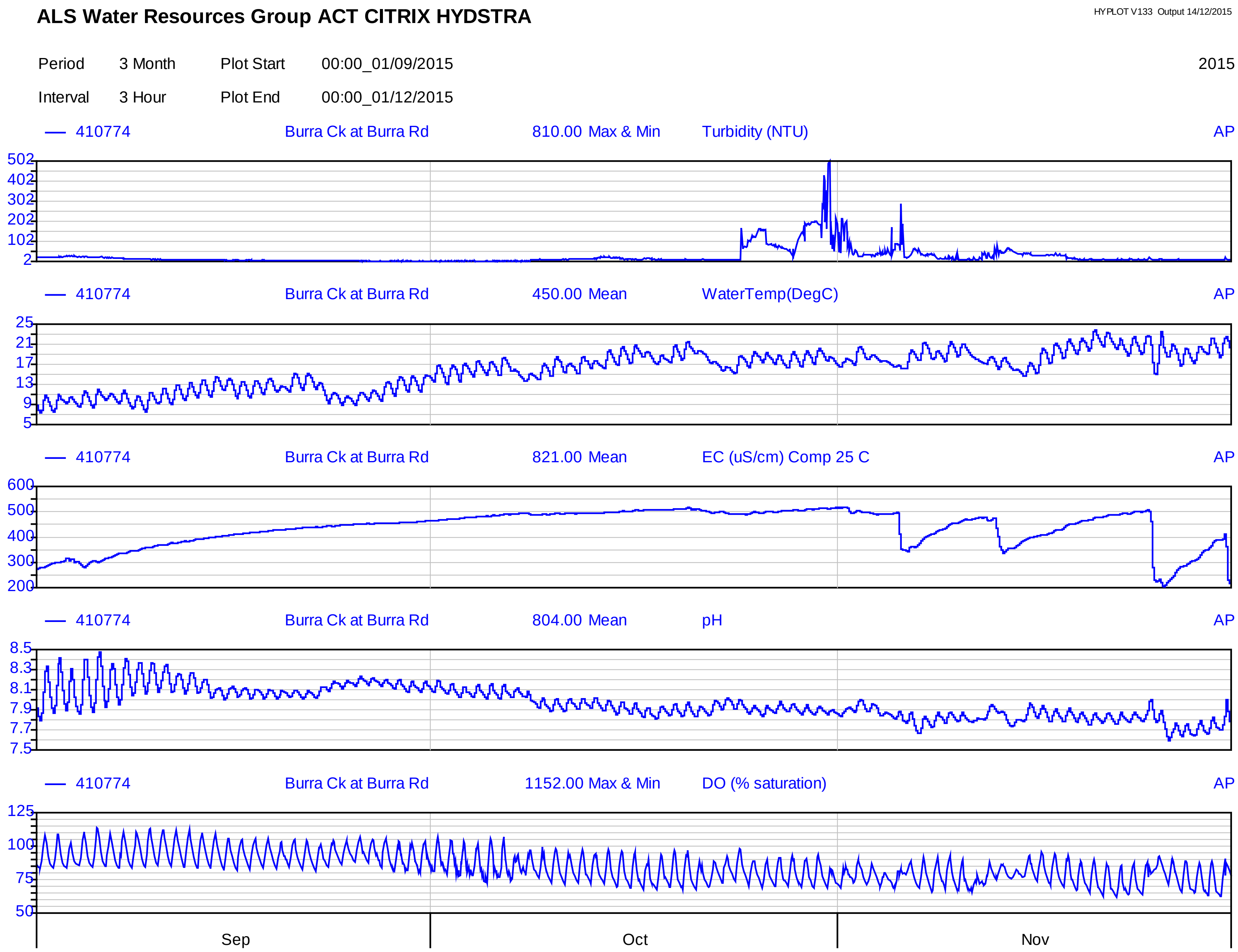


Figure 4-4. Continuous water quality records from Burra Creek (410774) during spring 2015

4.4 Photogrammetry

4.4.1 Periphyton

BUR 1c

The periphyton coverage at BUR 1c was estimated at >90% for the reach scale and 65-90% for the riffle habitat using the AUSRIVAS assessment (Plate 4-2). There were some small sections of *Myriophyllum sp.* and *Isolepis habra* growth along the edge of the riffle habitat, while *Schoenoplectus validus* was dominant throughout the reach, choking the channel in places. The dominant substrate in the riffle habitat was silt. The degree of inundation by *Schoenoplectus validus* caused some problems in capturing quality periphyton photographs during this sampling run.

Plate 4-2. Periphyton coverage at BUR 1c

BUR 2a

Periphyton coverage at BUR 2a was >90% at the reach scale and 65-90% in the riffle habitat using the AUSRIVAS assessment (Plate 4-3). There were *Schoenoplectus validus* stands along the riffle margins, with minimal stands of *Myriophyllum* sp. present. Large stands of *Phragmites australis* were present in the upstream and downstream pool areas. The dominant substrate was cobbles and silt.

Plate 4-3. Periphyton coverage at BUR 2a

4.4.2 Vegetation

BUR 2

There are a number of trees present at BUR 2. The large *Populus* sp. (Poplar) located immediately downstream of the causeway and a couple of young *Populus* sp. (approx. 3m tall) across the site were all displaying new growth from the spring period. There were high levels of macrophyte growth across the site, where *Phragmites australis* (Common Reed) was dominant throughout. There were large stands both upstream and downstream of the Williamsdale Road causeway, as can be seen in all of the photo points. Four vegetation photo points were collected at BUR 2 in spring 2015 and are presented in Plate 4-4 through to Plate 4-7.

Downstream of Pool 29

The site downstream of Pool 29 has few large vegetated areas to provide shade. Three trees were present at the site, a native *Acacia dealbata* (Silver Wattle) on the right bank and introduced *Populus* sp. (Poplar) and *Salix* sp. (Willow) on the left bank. There are a considerable number of juvenile *Populus* sp. on the vegetated laterally attached bar on the left bank, approximately 30-40 cm high. The large vegetated bank-attached point bar on the right bank is dominated by weeds with dense patches of *Rubus fruiticosus* (Blackberry) along the water's edge, and other common weeds across the bar including *Hypericum perforatum* (St. John's Wort), *Conyza* sp.(Fleabane), *Verbascum* sp. (Mullein) and various thistles. There is also considerable coverage by grasses, including native *Poa* spp. and introduced *Phalaris* sp. (Canary Grass) and *Paspalum dilatatum* (Caterpillar Grass), throughout the macro channel. Aquatic macrophytes showed significant growth within the reach with *Mentha* x *piperita* **var.** *'piperita'* (Peppermint) common throughout the shallow riffle zone and small infrequent stands of *Typha orientalis* (Broad leaf Cumbungi) across the reach. *Schoenoplectus validus* (Great Bulrush) was common along the edges of the channel lining most of the creek. Three vegetation photo points were collected at the site downstream of Pool 29 during spring 2015 and are presented in Plate 4-8 through to Plate 4-10.

BUR 2c

While BUR 2c is surrounded by numerous large *Eucalyptus* spp. on the floodplain, there is minimal vegetation close to the creek to provide shading. Within the macro channel there are large sections covered by grasses, mostly *Poa* spp., while weeds such as *Verbascum* sp. (Mullein), *Hypericum perforatum* (St. John's Wort), *Rubus fruiticosus* (Blackberry) and various thistle species are also frequent. Several small *Populus* sp. (Poplar) and *Salix* sp. (Willow) are present within the macro channel while two larger *Populus* sp. (approximately 3-4 m tall) are the largest vegetation within the channel. Instream vegetation is dominated by *Typha orientalis* (Broad leaf Cumbungi) with numerous large stands visible from all photo points, while *Schoenoplectus validus* (Great Bulrush) is also present in smaller patches. Four vegetation photo points were collected at BUR 2c during spring 2015 and are presented in Plate 4-11 through to Plate 4-14.

BUR 2

a)

b)

c)

Plate 4-4. Vegetation extent photo point 1 at BUR 2 showing upstream (a), downstream (b) and across the channel (c)


a)


b)


c)

Plate 4-5. Vegetation extent photo point 2 at BUR 2 showing upstream (a), downstream (b) and across the channel (c)

a)

b)

c)

Plate 4-6. Vegetation extent photo point 3 at BUR 2 showing upstream (a), downstream (b) and across the channel (c)


a)


b)


c)

Plate 4-7. Vegetation extent photo point 4 at BUR 2 showing upstream (a), downstream (b) and across the channel (c)

Downstream Pool 29

a)

b)

c)

Plate 4-8. Vegetation extent photo point 1 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c)

a)

b)

c)

Plate 4-9. Vegetation extent photo point 2 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c)

a)

b)

c)

Plate 4-10. Vegetation extent photo point 3 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c)

BUR 2c

a)

b)

c)

Plate 4-11. Vegetation extent photo point 1 at BUR 2c showing upstream (a), downstream (b) and across the channel (c)

a)

b)

c)

Plate 4-12. Vegetation extent photo point 2 at BUR 2c showing upstream (a), downstream (b) and across the channel (c)

a)

b)

c)

Plate 4-13. Vegetation extent photo point 3 at BUR 2c showing upstream (a), downstream (b) and across the channel (c)

a) 

b) 

c) 

Plate 4-14. Vegetation extent photo point 4 at BUR 2c showing upstream (a), downstream (b) and across the channel (c)

4.4.3 Geomorphology

BUR 1a

The conditions at BUR 1a have remained relatively unchanged since autumn 2015 with the site characterised by a large macro channel with a small inset low flow channel set along the right side of the macro channel. Large sections of the site show evidence of erosion and bank slumping however no significant changes have been recorded since autumn 2015. Three photo points were collected during spring 2015 at BUR 1a and are presented in Plate 4-15 through to Plate 4-17.

BUR 1c

The banks at BUR 1c are highly vegetated; however this vegetation is almost exclusively restricted to grasses, with very few trees and no shrubs along the reach. The creek has a very low sinuosity throughout this reach, while a small laterally attached sand bar is located immediately downstream of the riffle habitat. This reach is a depositional zone with high macrophyte coverage restricting flows and causing blanketing of silt across all habitats. Two photo points at BUR 1c were collected during spring 2015 and are presented in Plate 4-18 and Plate 4-19.

BUR 2

While no changes large scale have been observed since autumn 2015, the pool downstream of the drop off has a vertical bank on the right hand side which shows evidence of small scale erosion and potential for bank slumps, particularly vulnerable during periods of high flow. The other areas downstream of the causeway are well protected by the large established *Salix* sp. (Willow). The discharge pool has shown no geomorphological changes since autumn 2015. Four photo points were collected at BUR 2 during spring 2015 and are presented in Plate 4-20 through to Plate 4-23.

BUR 2a

Consistent with previous monitoring (GHD, 2015c) the steep right bank at BUR 2a has shown no signs of erosion. Similar to BUR 1c, this reach is a depositional zone with blanketing silt across all habitats. Four photo points were collected at BUR 2a during spring 2015 and are presented in Plate 4-24 through to Plate 4-27.

Downstream of Pool 29

The large eroding sections of bank downstream of pool 29 show no signs of bank slumps or large scale movement since autumn 2015. The large macro channel has had no major changes to its morphology since the previous visit during autumn 2015, while the vegetated point bar upstream of the riffle habitat and lateral bank attached bar adjacent to the riffle appear to have neither increased or decreased in size. The formed vegetated island in the riffle habitat also appears stable. Three photo points were collected downstream of pool 29 during spring 2015 and are presented in Plate 4-28 through to Plate 4-30.

BUR 2c

Compared to all other geomorphology sites during spring 2015, BUR 2c was the only site which showed noticeable signs of change since autumn 2015. The large steep left banks have previously been identified as an area for high erosion potential (GHD, 2015c) and are visible in Photo Point 2 (Plate 4-32) where bank slumping and erosion has occurred since the previous monitoring period. Other than the changes along these steep bank sections the rest of the site has remained relatively unchanged. Four photo points were collected at BUR 2c during spring 2015 and are presented in Plate 4-31 through to Plate 4-34.

BUR 1a

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-15. Geomorphology photo point 1 at BUR 1a showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-16. Geomorphology photo point 2 at BUR 1a showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-17. Geomorphology photo point 3 at BUR 1a showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

BUR 1c

a)

b)

c)

Plate 4-18. Geomorphology photo point 1 at BUR 1c showing upstream (a), downstream (b) and across the channel (c) during spring 2015

Note: This is the first time this photo point has been collected, so no autumn 2015 comparison photos were available.

Autumn 2015 || Spring 2015


a)


b)

c)

Plate 4-19. Geomorphology photo point 2 at BUR 1c showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Note: No autumn 2015 across channel photo is available.

BUR 2

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-20. Geomorphology photo point 1 at BUR 2 showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-21. Geomorphology photo point 2 at BUR 2 showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-22. Geomorphology photo point 3 at BUR 2 showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-23. Geomorphology photo point 4 at BUR 2 showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

BUR 2a

a)

b)

c)

Plate 4-24. Geomorphology photo point 1 at BUR 2a showing upstream (a), downstream (b) and across the channel (c) during spring 2015

Note: This is the first time this photo point has been collected, so no autumn 2015 comparison photos are available.

a)

b)

c)

Plate 4-25. Geomorphology photo point 2 at BUR 2a showing upstream (a), downstream (b) and across the channel (c) during spring 2015

Note: This is the first time this photo point has been captured, so no autumn 2015 comparison photos are available.

Autumn 2015 || Spring 2015


a)


b)


c)

Plate 4-26. Geomorphology photo point 3 at BUR 2a showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-27. Geomorphology photo point 4 at BUR 2a showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Downstream pool 29

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-28. Geomorphology photo point 1 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-29. Geomorphology photo point 2 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-30. Geomorphology photo point 3 downstream of pool 29 showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

BUR 2c

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-31. Geomorphology photo point 1 at BUR 2c showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-32. Geomorphology photo point 2 at BUR 2c showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-33. Geomorphology photo point 3 at BUR 2c showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

Autumn 2015 || Spring 2015

a)

b)

c)

Plate 4-34. Geomorphology photo point 4 at BUR 2c showing upstream (a), downstream (b) and across the channel (c) during autumn 2015 (left) and spring 2015 (right)

4.5 Macroinvertebrates

Taxa richness was relatively high across the Burra Creek sites during spring 2015. With the exception of the edge habitat at BUR 2a all samples showed higher richness compared to spring 2014 (GHD, 2015d). In spring 2014, taxa richness in the edge habitat at BUR 2a was 34 families and 44 genera compared to 25 families and 28 genera in spring 2015, the lowest of any spring 2015 Burra Creek sample (Table 4-3). EPT richness during spring 2015 was very similar to spring 2014. The exception to this was the edge genus EPT richness at BUR 2a which dropped by half during spring 2015 compared to the previous spring (from 14 to 7 genera; Table 4-4).

Table 4-3. Number of taxa at family and genus level from riffle and edge habitats

Total Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
BUR 1c	31	37	26	31
BUR 2a	25	33	25	28

Table 4-4. Number of EPT taxa at family and genus level from riffle and edge habitats

EPT Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
BUR 1c	9	13	7	12
BUR 2a	9	15	6	7

4.5.1 AUSRIVAS & SIGNAL-2

Mean SIGNAL-2 scores for the riffle habitat during spring 2015 were similar between the upstream and downstream sites with a mean difference of 0.01, with BUR 1c and 2a scoring 4.92 and 4.91 respectively (Table 4-5). This corresponds with the results from spring 2014 when mean SIGNAL-2 results were very similar also (GHD, 2015d). SIGNAL-2 scores within the edge habitat were lower at the downstream site with mean scores of 4.81 at BUR 1c and 4.46 at BUR 2a (Table 4-5). This is an increase in the SIGNAL-2 scores at BUR 1c compared to spring 2014 while BUR 2a has seen reduction in the edge habitats sensitivity.

The mean O/E scores at BUR 1c were 1.16 in both the riffle and edge habitats which resulted in an overall habitat assessment of Band X and overall site assessment as Band X (Table 4-6). This indicates an increase in both the diversity and sensitivity of the taxa at BUR 1c over the previous spring period during 2014. Mean O/E scores at BUR 2a during spring 2015 were 1.13 in the riffle habitat and 1.01 in the edge habitat resulting in both habitats being assessed as Band A, producing an overall site assessment of Band A (Table 4-6). This corresponds to the previous three spring seasons where BUR 2a has been assessed with an overall site result of Band A.

The predicted/collected results from the AUSRIVAS model are presented in Appendix F, while a full taxonomic inventory can be found in Appendix G.

Table 4-5. AUSRIVAS and SIGNAL-2 scores for spring 2015

Site	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS Band		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
BUR 1c	**1**	4.92	4.91	1.16	1.20	X	X	**X**	**X**	**X**
	2	4.92	4.60	1.16	1.09	X	A			
	3	4.92	4.91	1.16	1.20	X	X			
BUR 2a	**1**	4.92	4.50	1.16	0.93	X	A	**A**	**A**	**A**
	2	5.00	4.44	1.16	1.05	X	A			
	3	4.82	4.44	1.06	1.05	A	A			

Table 4-6. Overall site assessments for Burra Creek sites since 2012

	Autumn 2012	Spring 2012	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014	Autumn 2015	Spring 2015*	Change since spring 2014
BUR 1c	**B**	**B**	**B**	**B**	**B**	**A**	**B**	**X**	↑
BUR 2a	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	↔

Note: * = calculated from mean O/E scores as recommended by GHD (2015)

4.6 Discussion

4.6.1 Water quality

Water quality results in Burra Creek during spring 2015 indicated high levels of compliance to the ANZECC & ARMCANZ (2000) guidelines. pH levels were within guidelines values at both upstream and downstream sites for the first time since spring 2012. This is likely the result of the good spread of rainfall for the month prior to the sampling date, which maintained the lower pH, similar to the patterns resulting in the lower values in spring 2012. Electrical conductivity levels were elevated above guideline levels as has been recorded throughout the MEMP, and has previously been associated with the geology and groundwater contribution in the catchment (GHD, 2012).

Elevated nutrient levels were recorded during spring 2015 with both total nitrogen (TN) and NO_x concentrations exceeding the ANZECC & ARMCANZ (2000) trigger levels. TN levels have fluctuated during the MEMP with higher concentration usually associated with periods of lower flows and an increase in the length of time since the most recent high flow event. Spring 2015 is consistent with this format, having been over three months since the most recent event which reached over 100 ML/d and consistently low flows since. The high flow event is important as it appears to have a flushing effect on the creek, clearing out the nutrients which have built up since the previous event.

The elevated NO_x values at BUR 1c is surprising as previous seasons have found that these levels are usually elevated at BUR 2a and have been shown to be sourced from Holden's Creek (immediately upstream of the M2G discharge structure). These elevated nitrates are likely sourced from the upstream and surrounding agricultural areas either by direct runoff or indirectly via groundwater after leaching through the topsoils (Di & Cameron, 2002). Riparian zones have been found to be highly effective denitrification areas prior to sources entering streams (Hill, 1995), however BUR 1c has a very poor, shallow rooted riparian zone which is dominated by grasses and is likely not removing much nitrate before it enters the Creek.

4.6.2 Photogrammetry

Periphyton

Periphyton has been included in the monitoring programme for Burra Creek to monitor the effect which flow is having upon the algal communities downstream of the M2G discharge weir. The aim of this monitoring is to determine during operational pumping whether algal communities downstream of the discharge are changing compared to upstream sites due to the alteration of the natural flow regime.

Periphyton coverage was high at both sites, with >90% coverage across the reach and 65-90% in the riffle habitat at both sites, which is slightly reduced compared to spring 2014. Both sites showed high macrophyte growth through their respective reaches, which is characteristic of Burra Creek during this time of year. These records, providing the pipeline is not operated, will provide an indication of changes in the periphyton community between now and the next sentinel monitoring period during 2018.

Vegetation

The use of photogrammetry for monitoring the change in the vegetation communities and coverage at the Burra Creek sites is considered to be an efficient method for assessing whether the maintenance pumping is having a significant impact (Hall, 2001). These photo points will be used for comparison to future photo points (in two years' time - 2017), or with photos and observations recorded before and after the use of the M2G pipeline for operational purposes, should this occur within the next two years.

Significant new growth of vegetation was present across all sites monitored during spring 2015,. Plant communities and composition observed in spring 2015 was similar to previous assessments (GHD, 2015e; GHD, 2015f), with no noticeable increase in exotic species coverage.

Geomorphology

During the current maintenance phase of the M2G pipeline, the use of photogrammetry at the previously identified cross sections along Burra Creek are considered to be a robust method for the monitoring of potential changes in bank erosion and slumping. The photo points collected during spring 2015 will be used for comparison to future photo points (in two years' time - 2017), or with photographs and observations recorded before and after the use of the M2G pipeline for operational purposes, should this occur within the next two years.

As indicated in the MEMP Geomorphology report (GHD, 2015c) the area of greatest concern along Burra Creek is the downstream reach at BUR 2c. This is the only monitored site which has shown movement since the previous monitoring occurred during autumn 2015. Increased areas of erosion and bank slumping has occurred along the left bank at the site during that time, possibly as a result of natural high flow events. These will continue to be monitored during the 2017 monitoring period.

4.6.3 Macroinvertebrates and AUSRIVAS

The increase of the edge habitat at the Burra Creek upstream site to Band X ("more diverse than expected") is surprising considering the poor quality of the habitat documented at the site during sampling. Barmuta *et al.* (2003) suggest that sites which receive a Band X are either a biodiversity 'hot-spot' or receive mild nutrient enrichment. Taking into consideration the poor habitat quality it is possible that the increased AUSRIVAS results are being driven by some level of nutrient enrichment, potentially resulting from decomposition and the high organic load within the stream channel.

The water quality results from spring 2015 indicate that elevated nitrogen concentration were present, with total nitrogen and NO_x levels in exceedance of the ANZECC & ARMCANZ (2000) guidelines. As discussed in section 4.6.1, there were no flows for over three months prior to sampling to flush the system, there may potentially have been a build-up of nutrients at the site, either directly from the surrounding and upstream agricultural area via direct leaching or indirectly through groundwater (Di & Cameron, 2002; Smolders *et al.*, 2009).

The decline in SIGNAL-2 score in the edge habitat at BUR 2a is due mainly to the absence of Gripopterygidae (SIGNAL-2 = 8). Gripopterygidae is a diverse family which can inhabit many parts of the stream and different substrates (Gooderham & Tsyrlin, 2005). While this sensitive taxa is usually present at this site, during spring 2015 it was absent from all three replicates. However, the overall assessment for the edge habitat at BUR 2a was assessed at Band A, with the O/E score of 1.01 which is the same as spring 2014, meaning additional, more tolerant taxa which were absent during the previous season have been recorded this season to keep the O/E score stable.

5. Murrumbidgee Pump Station

5.1 Summary of sampling and river conditions

Sites for the Murrumbidgee Pump Station were sampled on the 24th November 2015. The weather on the day was fine with a slight breeze, and the maximum temperature reached over 27°C (recorded at the Canberra Airport (BoM, 2015)). Mean daily flow on the was recorded at 290 ML/d at the Lobb's Hole gauging station (410761) and 480 ML/d at the Mt. MacDonald gauging station (410738). Single riffle and edge samples were collected from both MUR 28 and MUR 935. Site photographs are presented in Plate 5-1. Site summaries can be found in Appendix B, while the AUSRIVAS habitat data is available in Appendix C.

MUR 28: Looking upstream (left) and looking downstream (right)

MUR 935: Looking upstream (left) and looking downstream (right)

Plate 5-1. Photographs of the Murrumbidgee Pump Station sites during spring 2015 sampling

5.2 Hydrology and rainfall

Flow was receding in the Murrumbidgee River at the beginning of spring following a high flow event during late August as shown in the hydrograph in Figure 5-1. Following recession, the hydrograph remained relatively stable throughout October, maintaining a high base-flow level. During early November, in response to some rainfall during this period, the hydrograph shows some high flow peaks at around 3000 ML/d at the Mt. MacDonald gauging station (410738). Flow at Mt. MacDonald during this period was consistently higher during this period with some short duration high flows, compared to the slower rise and fall seen at Lobb's Hole. This is due to the urban discharges downstream of the Lobb's Hole station, as well as flow contributed by Gudgenby River. Flow from the Cotter River was restricted to water released from the Enlarged Cotter Dam with flows peaking at over 300 ML/d during September (Figure 5-2). Flow and rainfall summaries for the season are presented in Table 5-1.

Plate 5-2 and Plate 5-3 show the upstream and downstream views from the bridge at MPS, during spring 2015 sampling compared to the previous spring sampling period which occurred in 2012.

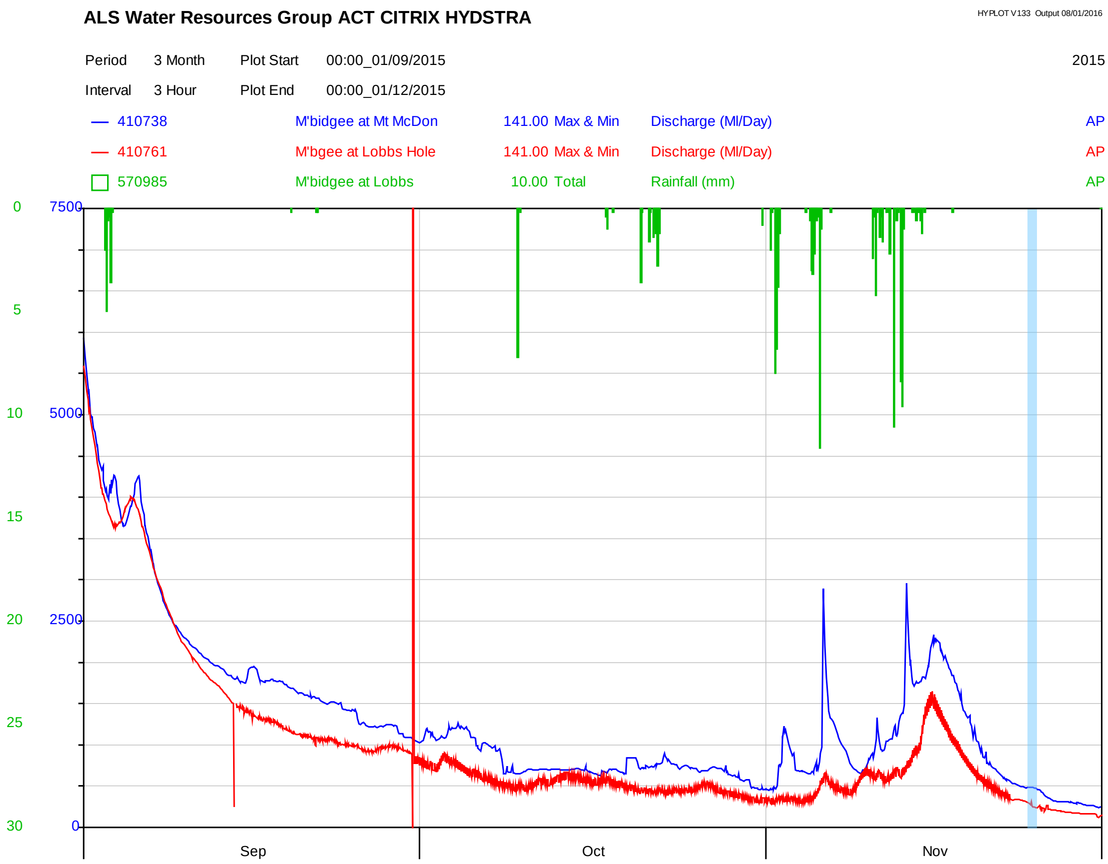


Figure 5-1. Autumn hydrograph of the Murrumbidgee River at Lobb's Hole (410761) and Mt. MacDonald (410738), including total rainfall for the Lobb's Hole gauge (570985) from spring 2015

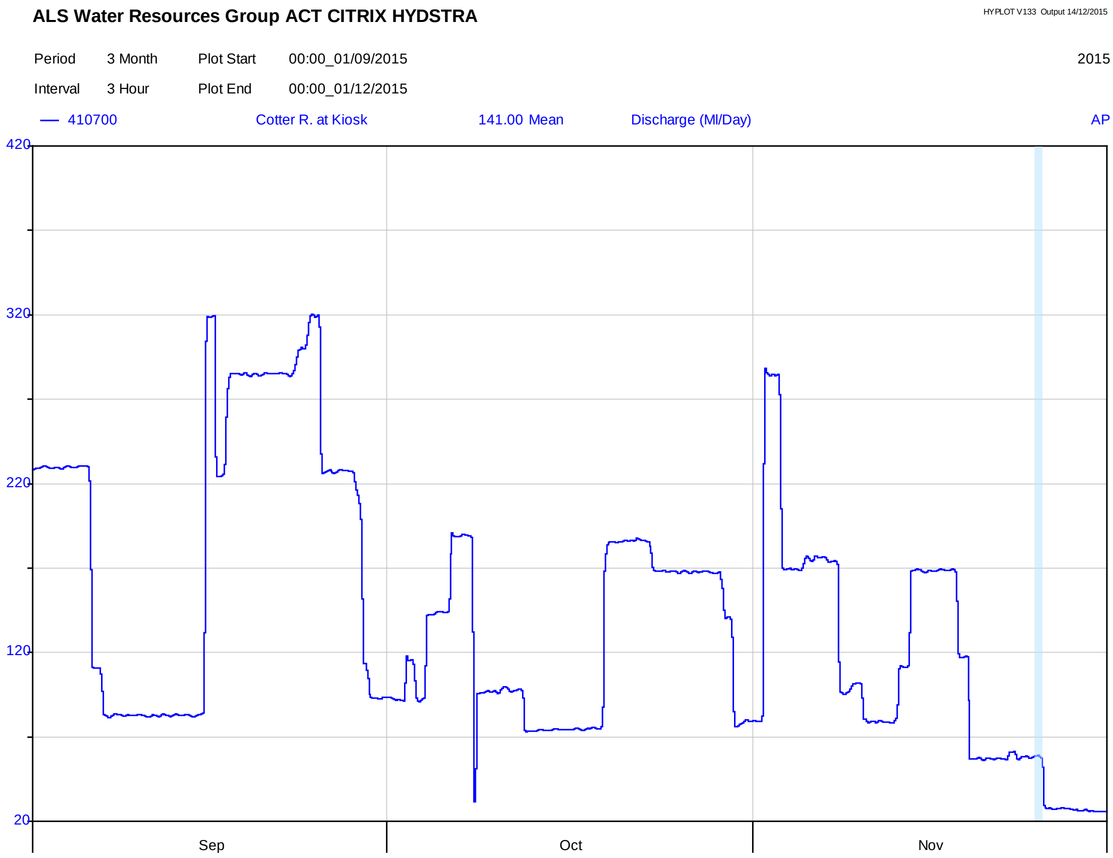


Figure 5-2. Hydrograph for the Cotter River downstream of the Cotter Dam (410700) for spring 2015

Table 5-1. Spring rainfall and flow summaries upstream and downstream of the MPS

	Lobb's Hole (410761)		Mt. MacDonald (410738)
	Rainfall Total (mm)	Mean Flow (ML/d)	Mean Flow (ML/d)
September	12.4	2,000	2,200
October	23.0	540	78
November	92.6	540	940
Spring (mean)	128.0 (42.7)	1,000	1,300

2012 – 1,200 ML/d (14/11/2012)

2015 – 470 ML/d (24/11/2015)

Plate 5-2. The Murrumbidgee River upstream of the Cotter Road bridge and the MPS in spring 2012 (top) and 2015 (bottom)

Note: Flow is mean daily flow recorded at Mt. MacDonald (410738)

2012 – 1,200 ML/d (14/11/2012)

2015 – 470 ML/d (24/11/2015)

Plate 5-3. The Murrumbidgee River downstream of the Cotter Road bridge, MPS on the right bank, in spring 2012 (top) and 2015 (bottom)

Note: Flow is mean daily flow recorded at Mt. MacDonald (410738)

5.3 Water Quality

5.3.1 Grab samples and *in-situ* parameters

The *in-situ* and grab sample water quality results are presented in Table 5-2. Results for electrical conductivity, turbidity and total manganese were within the ANZECC & ARMCANZ (2000) guidelines at both sites. The *in-situ* pH readings were in exceedance of the guidelines upper limit of 8.0, reading 8.38 at MUR 28 and 8.40 at MUR 935. This is a large increase at MUR 28 compared to spring 2014 which was within the recommended range at 7.84, while also an increase since the last record for MUR 935 (spring 2012) the reading of 8.17 was still in exceedance of the upper limit.

Nutrient levels at both sites were in exceedance of the ANZECC & ARMCANZ (2000) trigger levels for total phosphorus (TP) and total nitrogen (TN) (Table 5-2). This is consistent with previous seasons where both TP and TN have also been recorded in exceedance of the guidelines. NO_x was within the guidelines at both sites. Additional water quality grab samples were collected by ALS during the spring season with the results of these presented in Appendix D.

5.3.2 Continuous water quality monitoring

Continuous water quality data recorded during spring 2015 at the Lobb's Hole gauging station is presented in Figure 5-3. Turbidity was low for most of the season with 50 daily means below the ANZECC & ARMCANZ (2000) guidelines during the period; however some spikes were recorded including during a period of increased flow during mid-November. Temperature increased throughout the season, while electrical conductivity increased throughout the season but remained within the recommended range. During the beginning of spring the pH levels were initially within the recommended range, however became elevated during the second half of the season with daily means exceeding the guidelines from 19th October until the end of the season. Dissolved oxygen levels during spring 2015 were consistently around 90%, with variation in the diurnal trend increasing towards the end of the season dropping the DO levels slightly. Mean daily DO saturations remained consistent with all daily means for the season between 85-93%.

Table 5-2. *In-situ* water quality results from MPS sites during spring 2015

	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)**	TKN (mg/L)	TP (mg/L) **(0.02)**	TN (mg/L) **(0.25)**	Total Iron (mg/L)	Total Manganese (mg/L) **(1.9)**
Upstream	MUR 28	24/11/2015	15:35	25.7	170.9	7.57	9	8.38	110.0	8.09	72	< 0.002	0.44	0.029	0.44	0.49	0.048
Downstream	MUR 935	24/11/2015	14:40	25.7	169.5	5.45	8	8.40	120.2	8.95	71	< 0.002	0.42	0.028	0.42	0.47	0.045

Note: ANZECC and ARMCANZ (2000) guidelines are in yellow parentheses; yellow cells indicate values outside of the guidelines while orange cells indicate values on the cusp of the guideline; trigger value for Total Manganese is the 95% species level protection for slightly-moderately disturbed systems.

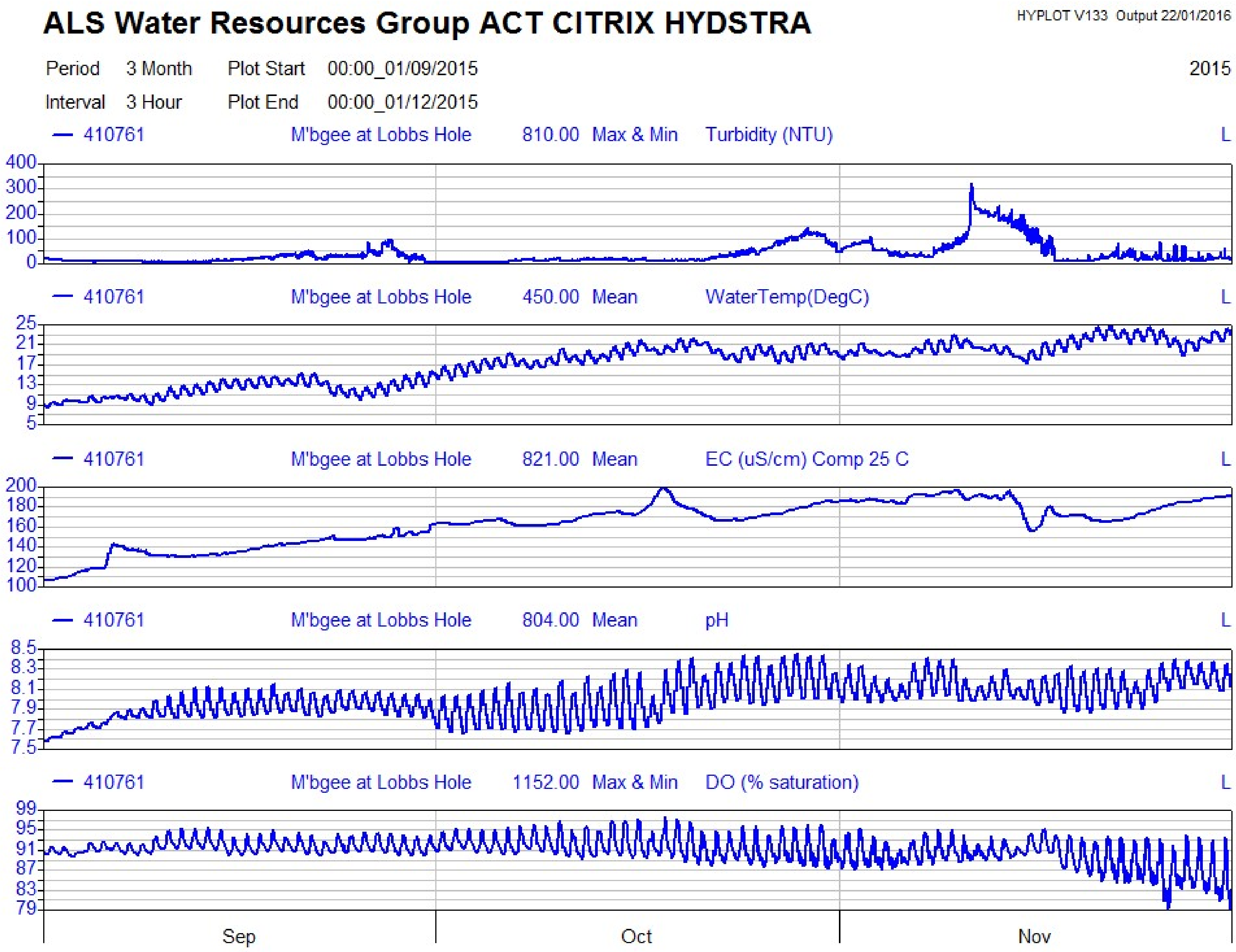


Figure 5-3. Continuous water quality records from Lobb's Hole (410761) for spring 2015

5.4 Photogrammetry

5.4.1 Periphyton

MUR 28

Periphyton coverage of the substrate was 65-90% for both the reach and the riffle habitat at MUR 28 during spring 2015, assessed using the AUSRIVAS assessment (Plate 5-4). No submerged macrophytes were observed at the site this season while the dominant substrate was cobble.

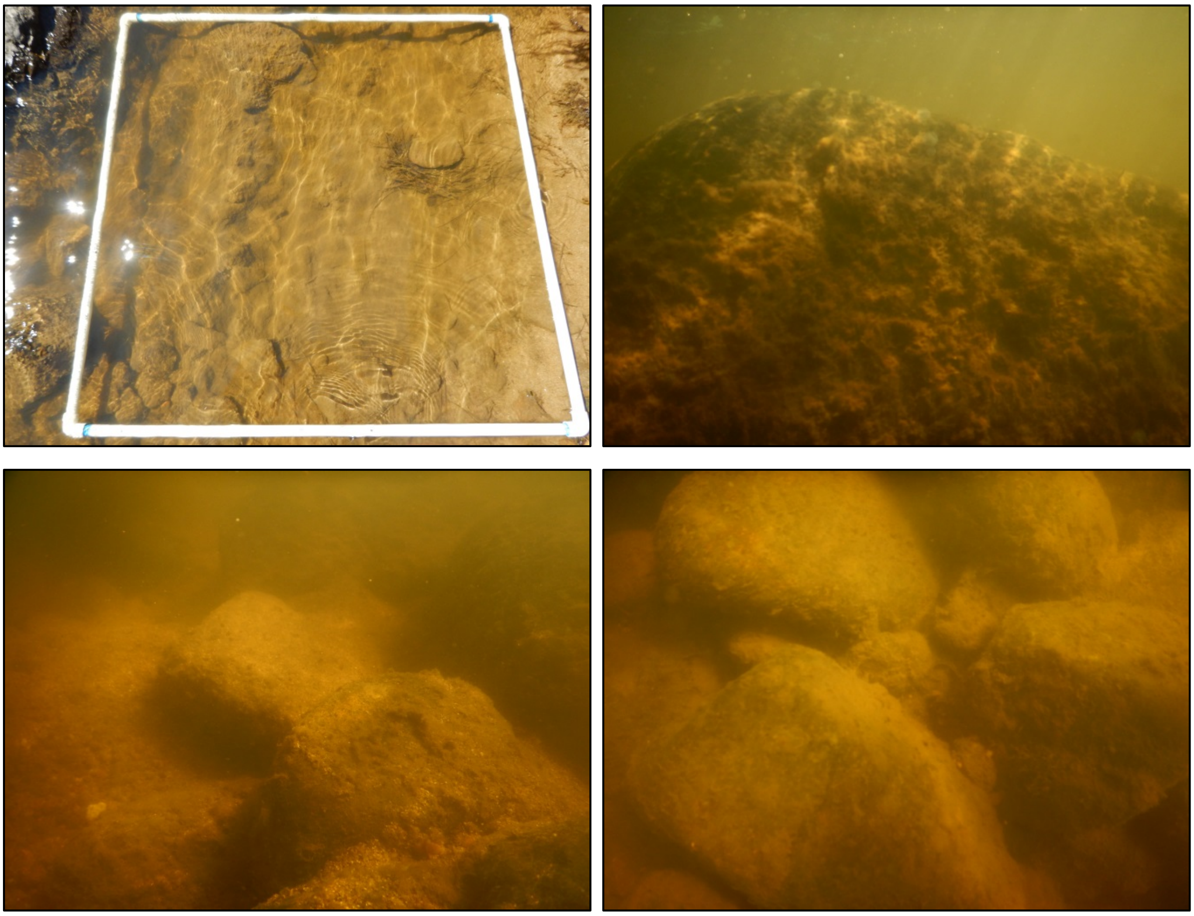


Plate 5-4. Photos showing periphyton coverage in the reach and riffle at MUR 28

MUR 935

Periphyton coverage at MUR 935 during spring 2015 was 65-90% for the reach and 35-65% for the riffle habitat, using the AUSRIVAS assessment methods (Plate 5-5). Similar to the upstream site (MUR 28) no submerged macrophytes were observed during spring 2015, while the dominant substrate was cobbles.

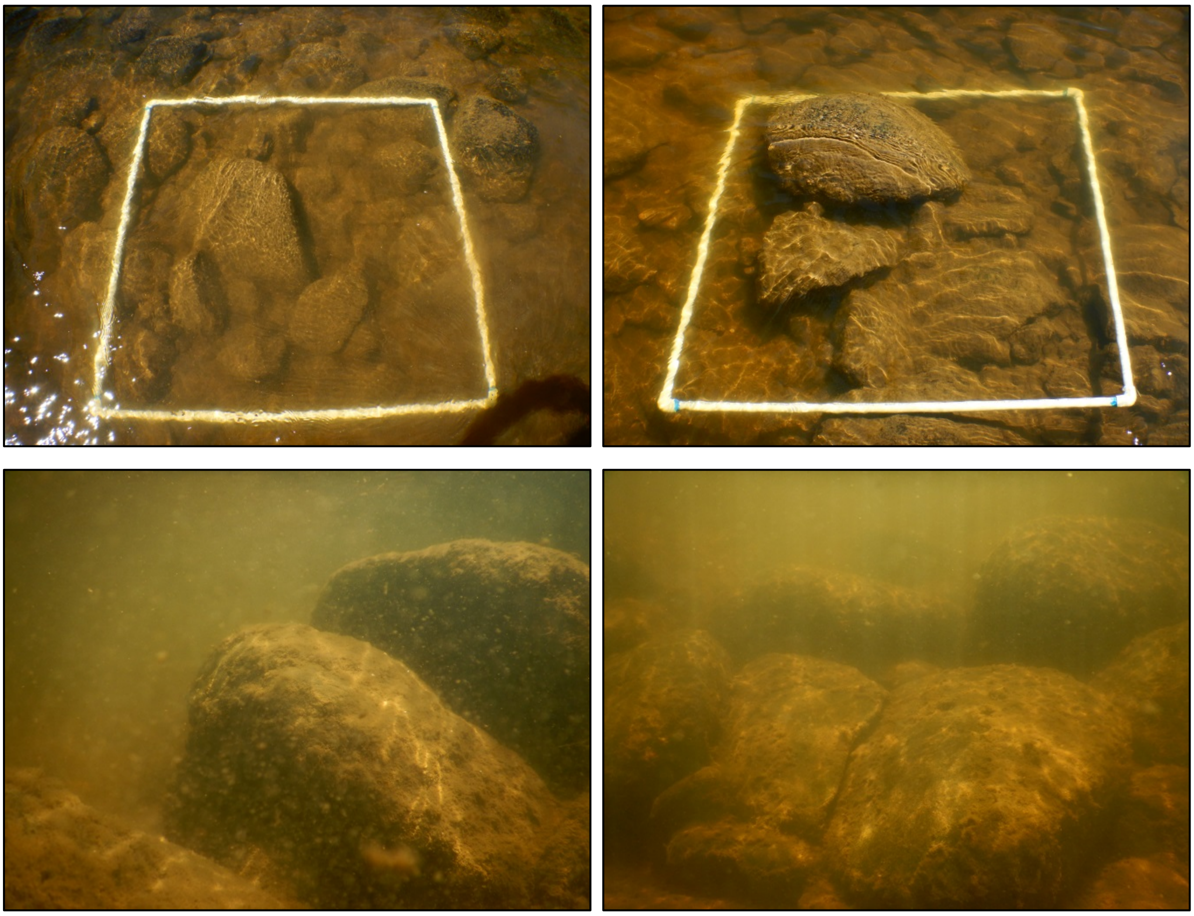


Plate 5-5. Photos showing periphyton coverage in the reach and riffle at MUR 935

5.5 Macroinvertebrates

Taxa richness was higher in the riffle habitat at the upstream site, compared to the downstream site (Table 5-3). This pattern was reversed in the edge habitat, with the more diverse community recorded at the downstream site. In comparison to the most recent spring samples (2014 for MUR 28, 2012 for MUR 935), diversity has increased in the edge habitats, while the riffle habitat tended to be more variable. For example, MUR 28 recorded a higher number of families, but fewer genera compared to spring 2014.

The EPT richness scores followed the same patterns as the taxa richness, with MUR 28 more diverse in the riffle habitat and MUR 935 more diverse in the edge habitat (Table 5-4). Again, edge richness was greater when compared with the most recent spring sampling event, while the riffle habitat recorded a reduction in EPT diversity, with the exception of the number of families at MUR 28.

Table 5-3. Number of taxa at family and genus level from riffle and edge habitats

Total Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
MUR 28	20	24	21	27
MUR 935	17	19	30	36

Table 5-4. Number of EPT taxa at family and genus level from riffle and edge habitats

EPT Richness	Riffle		Edge	
Site	Family	Genus	Family	Genus
MUR 28	7	10	7	13
MUR 935	6	8	9	15

5.5.1 AUSRIVAS & SIGNAL-2

In the riffle habitat, both SIGNAL-2 and O/E scores were similar between the two sites; although MUR 28 had marginally higher scores on average. Mean SIGNAL-2 scores were 4.92 and 4.81 at MUR 28 and MUR 935 respectively, while O/E scores were 0.83 at MUR 28 and 0.72 at MUR 935 (Table 5-5). This was an increase at MUR 28, compared to the scores from spring 2014, however only slightly. Comparatively, the scores at MUR 935 were lower than those from the most recent spring sampling in 2012, but again, only slightly. The overall habitat scores for both sites was Band B, which is consistent with all previous spring seasons.

SIGNAL-2 scores were higher at the downstream site, MUR 935, in the riffle habitat scoring 4.46, compared to 4.17 at MUR 28. This indicates a higher level of sensitivity in the macroinvertebrate community at this downstream site which is also reflected in the O/E scores (Table 5-5). The overall edge habitat score at MUR 935 was Band A, compared to Band B at MUR 28. The results at MUR 935 signify a slight increase from those recorded during spring 2012, while the SIGNAL-2 score at MUR 28 was almost identical (a decline of 0.01) however there was a reduction in the O/E score from spring 2014.

The overall site assessment for both MUR 28 and MUR 935 was Band B, which is consistent with all previous spring sampling seasons (Table 5-6). The predicted/collected results from the AUSRIVAS model are presented in Appendix F, while a full taxonomic inventory can be found in Appendix G.

Table 5-5. AUSRIVAS and SIGNAL-2 scores for spring 2015

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 28	**1**	4.89	4.22	0.68	1.00	B	A	**B**	**B**	**B**
	2	5.00	4.14	0.90	0.78	A	B			
	3	4.92	4.14	0.90	0.78	A	B			
MUR 935	**1**	4.44	4.50	0.67	1.11	B	A	**B**	**A**	**B**
	2	4.70	4.20	0.75	1.11	B	A			
	3	5.30	4.67	0.75	1.00	B	A			

Note: All MPS edge replicates were “nearly outside the experience of the model” (see Coysh et al. (2000) for details).

Table 5-6. Overall AUSRIVAS assessments for MPS sites since 2011

	Autumn 2011	Spring 2011	Autumn 2012	Spring 2012	Autumn 2013		Autumn 2015	Spring 2015	Change since spring 2012
MUR 28	**B**	**B**	**B**	**B**	**B**		**A**	**B**	↔
MUR 935	**B**	**B**	**NRA**	**B**	**B**		**A**	**B**	↔

5.6 Discussion

5.6.1 Water quality

Water quality at the Murrumbidgee Pump Station sites showed exceedances of pH, DO, TN and TP with respect to the ANZECC & ARMCANZ (2000) guidelines, although based on the historic records, none of these values are out of the ordinary.

The increased dissolved oxygen (DO) levels recorded from the *in-situ* data also correspond to the increase in DO at the gauging station. These increased levels are usually associated with increased algae or macrophyte abundances through increased photosynthesis rates, however very minimal algae and macrophytes were observed at both the MPS sites. The higher DO at MUR 935 was likely a combination of photosynthesis and rapid aeration owing to the cascade at this site.

The elevated nutrient concentrations at both the upstream and downstream site have been historically recorded along this reach as part of the MEMP. Previous MEMP reports have attributed these elevated concentrations to sources upstream of the ACT, with the likely sources a combination of agricultural land use and erosion (GHD, 2013).

5.6.2 Photogrammetry

Periphyton

Periphyton has been included in the monitoring programme for MPS to monitor the effect which flow is having upon the algal communities downstream of the abstraction point. The aim of this monitoring is to see, during operational pumping whether algal communities downstream of the MPS are increasing compared to upstream sites due to the reduction in flow through abstraction.

The photographs provided in section 5.4.1 provide an overview of the periphyton coverage using both quadrat and underwater aspects at both sites. The coverage at MUR 28 of 65-90% for both the reach and riffle habitat is consistent with that observed during spring 2014 (GHD, 2015d). The coverage at MUR 935 of 65-90% for the reach and 35-65% in the riffle habitat is also the same as the coverage observed during spring 2012 (the last time this site was sampled; GHD, 2013). These assessments will be used to compare to future levels for comparison and changes should operation of the MPS occur above the trigger level for impact assessment.

5.6.3 Macroinvertebrates and AUSRIVAS

The macroinvertebrate results from spring 2015 showed very similar results to spring 2014 (for MUR 28) and spring 2012 (for MUR 935). Habitat and overall site Bandings were the same between spring 2015 and spring 2014 and 2012, with small changes in the SIGNAL-2 and O/E scores in this time.

The exception to this is the edge habitat at MUR 28 which has reduced to Band B (“significantly impaired”) from Band A (“similar to reference”) during spring 2014. While the relatively small decrease in O/E score (0.10) has resulted in the lowering of the Band score, this is only due to the absence of a single additional taxa. The absence of Tanypodinae is surprising as this family of predators is widespread and fairly tolerant with a SIGNAL-2 score of four (Gooderham & Tsyrlin, 2005).

The edge habitat at MUR 28 during spring 2015 was assessed as being in fairly poor condition, with the relatively low flows reducing the available habitat for macroinvertebrates which may have impacted the presence of Tanypodinae at this site.

6. Conclusions

The purpose of the sentinel monitoring programme is to provide a broad scale assessment of control and impact sites related to the Angle Crossing abstraction point, the discharge weir in Burra Creek and the Murrumbidgee pump station, located just downstream of the Cotter Road bridge. Specifically this programme aims to *"provide confidence that the condition of the potential impact sites is broadly similar to non-impact sites across time".*

There were a number of changes in AUSRIVAS bands since spring 2014. For example, at Angle Crossing the edge habitat at both locations was assessed as band X, which was an increase from band A in the previous spring. The site upstream discharge point in Burra Creek (BUR1c) had an overall assessment of band X, which was an increase from band A in spring 2014; while downstream of the discharge point there was no change as both habitats were assessed as band A, which is the same site assessment as spring 2014. The elevation from band A to band X at Bur 1c is likely a reflection of increased nutrients and high levels of detritus providing additional resources and thereby increased diversity, since the habitat quality was poor at this site at the time of the spring 2015 assessment.

There were no obvious differences in any of the measured parameters between all of the upstream / downstream site pairs for each of the components of this sampling run. These results were also consistent with those of previous spring sampling periods (see Appendix B) throughout the MEMP which suggests that in the absence of the operation of M2G or MPS, these sites are generally showing similar temporal and spatial variation.

The upshot of this is that we can be confident that at each site and location there are no other site specific influences that may impose additional stresses to the aquatic environment. If that were the case (i.e. there were significant changes to one site but not the other during standby mode) then this would imply that site specific stressors may exists, which may reduce our ability to detect change if there is any, during the operational phases of M2G or MPS projects.

7. Recommendations

The only additional recommendation to those put forward in autumn 2015 (GHD, 2015e) is to install erosion pins at BUR 2c.

In light of the recent bank movement at this site, it would be a seen as a complimentary, quantitative method to determine actual rates of decline from this bank. Moreover, using this technique, measurements would be able to be made at before and after natural events and before and after APPLE maintenance runs to isolate movement associated with those natural events compared to movement associated with the aforementioned APPLE maintenance runs. This method is cost effective and has been successfully developed by ALS staff (now GHD) for use in other catchments in the ACT.

8. Literature Cited

ACT Government (2013). Environmental Flow Guidelines.

ACTEW Corporation (2010) Murrumbidgee to Googong Water Transfer: Ecological Monitoring Sub Plan.

ACTEW Corporation (2012) *Murrumbidgee to Googong Water Transfer: Operation Environmental Management Plan.*

ALS (2010) Upper Murrumbidgee (Angle Crossing) Ecological Monitoring Programme: Vegetation Assessment. Water Science Group, Penrith.

ANZECC & ARMCANZ (2000) National water quality management strategy: Paper No. 4. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1. The Guidelines. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Barmuta, L. A., Chessman, B. C. & Hart, B. (2003) Australian River Assessment System: Interpretation of the Outputs from AUSRIVAS (Milestone Report). Monitoring River Health Initiative Technical Report Number 24. Land and Water Resources Research and Development Corporation.

Biggs, B.J.F. & Stokseth, S. (1996) Hydraulic habitat suitability for periphyton in rivers. *Regulated Rivers-Research & Management*, **12** (2-3), 251-261.

Bureau of Meteorology (2015) Canberra, Australian Capital Territory: May 2015 Daily Weather Observations. Bureau of Meteorology, Canberra.

Brunke, M. & Gonser, T. (1997) The ecological significance of exchange processes between rivers and groundwater. Freshwater Biology, 37, 1-33.

Bunn, S. E. and Arthington, A. H. (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, **30** (4), 492-507.

Cao, T., Larsen, D. P. and ST-J. Thorne, R. (2001) Rare species in multivariate analysis for bioassessment: some considerations. *Journal of the North American Benthological Society*, **20** (1), 144- 153.

Chessman, B. C. (2003) New sensitivity grades for Australian river macroinvertebrates. *Marine and Freshwater Research*, 54 95-103.

Chessman, B. (2008) Review of the Murrumbidgee Ecological Monitoring Programme study design. Report to Ecowise Australia Pty Ltd.

Coysh, J., Nichols, S., Ransom, G., Simpson, J., Norris, R.H., Barmuta, L.A. & Chessman, B. (2000) AUSRIVAS Macroinvertebrate bioassessment: Predictive modelling manual. Canberra.

Davies, B.R., Thoms, M. & Meador, M. (1992) An assessment of the ecological impacts of inter-basin water transfers, and their threats to river basin integrity and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems,* **2,** 325-349.

Dewson, Z.S., James, A.B.W. & Death, R.G. (2007) A review of the consequences of decreased flow for instream habitat and macroinvertebrates. *Journal of the North American Benthological Society,* **26,** 401-415.

Di, H.J. & Cameron, K.C. (2002) Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems*, **64** (3), 237-256.

GHD (2012) Murrumbidgee Ecological Monitoring Programme – Part 2: Burra Creek ~ Autumn 2012. Water Science Group, Canberra. 23/14302/67987.

GHD (2013) Murrumbidgee Ecological Monitoring Programme: Spring 2012. Water Science Group, Canberra. 23/14616/69744.

GHD (2014) Murrumbidgee Ecological Monitoring Programme: Burra Creek geomorphology and vegetation assessment. Water Science Group, Canberra. 2314302/68616-h.

GHD (2015*a*) Murrumbidgee Ecological Monitoring Programme: Fish Survey March 2014. Report to Icon Water. Water Science Group, Canberra. 2315101/FS15.

GHD (2015*b*) Proposal for the Provision of Ecological Monitoring Sites in the Upper Murrumbidgee River and Burra Creek. Proposal to Icon Water. Water Science Group, Canberra. RFT No. 14-2012.

GHD (2015*c*) Murrumbidgee Ecological Monitoring Programme: Burra Creek Geomorphology Update. Water Science Group, Canberra. 2315101/68616.

GHD (2015*d*) Murrumbidgee Ecological Monitoring Programme: Spring 2014. Water Science Group, Canberra. 23/15101/74156.

GHD (2015*e*) Murrumbidgee Ecological Monitoring Programme: Sentinel Monitoring – autumn 2015. Water Science Group, Canberra. 23/15531/76023.

GHD (2015*f*) Murrumbidgee Ecological Monitoring Programme: Vegetation Assessment. Water Science Group, Canberra. 23/15101/73978.

Gooderham, J. & Tsyrlin, E. (2005) The Waterbug Book: A guide to the freshwater macroinvertebrates in temperate Australia. CSIRO Publishing, Collingwood.

Hall, Frederick C. 2001 Ground-based photographic monitoring. Gen. Tech. Rep. PNW-GTR-503. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 340 p.

Harrod, J.J. (1964) The distribution of invertebrates on submerged aquatic plants in a chalk stream. *Journal of Animal Ecology,* **33,** 335-348.

Hawking, J.H. (2000) Key to Keys: A guide to keys and zoological information to identify invertebrates from Australian inland waters. Cooperative Research Centre for Freshwater Ecology, Albury.

Hill, A.R. (1996) Nitrate Removal in Stream Riparian Zones. *Journal of Environmental Quality*, **25** (4), 743-755.

Jacobs (2014) Review of the Murrumbidgee Environmental Monitoring Programmeme. Report to ACTEW Water. VW07641.

Jansen, A., Robertson, A., Thompson, L., Wilson, A. & Flanery, F. (2007) Rapid Appraisal of Riparian Condition: Technical guideline for the southern tablelands of New South Wales. Land & Water Australia, Canberra.

Jowett, I.G. & Biggs, B.J.F. (1997) Flood and velocity effects on periphyton and silt accumulation in two New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research*, **31** (3), 287-300.

Keen, G. (2001) Australia-Wide Assessment of River Health: Australian Capital Territory Bioassessment Report. Department of Urban Services, Canberra.

Marchant, R. (1989) A subsampler for samples of benthic invertebrates. *Bulletin of the Australian Society of Limnology*, 12 49-52.

Martin, T. & Rutlidge, A. (2009) Murrumbidgee to Googong Water Transfer Project: Aquatic Impact Assessment. Biosis Research Pty. Ltd., Queanbeyan.

Nichols, S., Sloane, P., Coysh, J., Williams, C. & Norris, R.H. (2000) AUStralian RIVer Assessment System - Australian Capital Territory: Sampling and Processing Manual. Cooperative Research Centre for Freshwater Ecology, Canberra.

O'Connor, P. & Bond, A.J. (2007) Maximizing the effectiveness of photopoint monitoring for ecological management and restoration *Ecological Management & Restoration,* **8,** 228-233.

Smolders, A.J.P., Lucassen, E.C.H.E.T., Bobbink, R., Roelofs, J.G.M. & Lamers, L.P.M. (2009) How nitrate leaching from agricultural lands provokes phosphate eutrophication in groundwater fed wetlands: the sulphur bridge. *Biogeochemistry*, **98** (1), 1-7.

Upper Murrumbidgee Waterwatch (2015) Upper Murrumbidgee Waterwatch monitoring site, https://root.ala.org.au/bdrs-core/umww/home.htm. 28/07/2015.

Appendices

Appendix A - QA/QC Results

Appendix A1. QA/QC results for from spring 2015

		Habitat	Riffle		Riffle	
		Sample	MUR 18		MUR 935	
		Replicate	1	QA	2	QA
CLASS / Order	Family / Sub-Family	Genus				
ACARINA			1	1	3	2
Bivalvia			1	1		
Coleoptera	Elmidae	*Simsonia*	4	4	1	1
Diptera	Ceratopogonidae	Ceratopoginae	1	1		
	Chironominae	*sp.*	1	1	5	6
	Orthocladiinae	*sp.*	33	35	24	16
	Simuliidae	*Austrosimulium*	79	87	117	122
		Simulium	3	1		
	Tanypodinae	*sp.*	1	1		
	Tipulidae	*sp.*	7	7	2	2
Ephemeroptera	Baetidae	*Offedens*			3	4
		sp.	2	1	19	19
	Caenidae	*Irapacaenis*	2	2		
		Tasmanocoenis	6	6	1	0
	Leptophlebiidae	*sp.*	0	1	0	0
Hemiptera	Micronectidae	*Micronecta*			1	1
Lepidoptera	Crambidae	*sf Nymphulinae*			1	1
Megaloptera	Corydalidae	*Archichauliodes*			1	1
Oligochaeta			1	1	1	1
Plecoptera	Gripopterygidae	*Dinotoperla*		3		
		Euntoperla	4			
		Illiesoperla		4		
		Neboissoperla	1			
Trichoptera	Hydropsychidae	*Ulmerochorema*	0	1		
		Asmicridea	11	18	4	4
		Cheumatopsyche	23	20	27	27
		sp.	17	11	6	7
	Hydrobiosidae	*sp.*	1			
		Ulmerochorema		1		
	Hydroptilidae	*Orthotrichia*			1	1
		Error	11.9%		2.8%	
		Pass Rate	< 5%		< 5%	
		Pass / Fail	**FAIL**		**Pass**	

Note: Pink boxes = count error; Blue boxes = identification error.

MUR 18 failed due to mis-identifications of three genera in the families: Gripopterygidae and Hydrobiosidae. These errors have been corrected in the data base and it should be noted that this has no bearing on the analysis or interpretation of data present in the current report.

Appendix B - Site Summaries

Note: The scores for the site quality assessments presented in the site summary sheets result from the habitat scoring system in the ACT (AUSRIVAS) field sampling sheet (see Appendix H).

Part 1: Angle Crossing

MUR18

Upstream Angle Crossing
24/11/2015 11:10 am

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
22.2	178.5	7.37	10	8.13	102.4	8.19

Alkalinity (mg/L)	NO_x (mg/L)	TKN (mg/L)	TP (mg/L)	TN (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)
74	< 0.002	0.42	0.030	0.42	0.60	0.067

Daily Flow: 290 ML/day

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

Compared to current flow:

Spring 2014: 

Autumn 2015: 

Riffle Habitat

- Dominant substrate was cobble

Dominant Taxa

- Coloburiscidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Hydrobiosidae
- Coloburiscidae
- Gripopterygidae

Edge Habitat

- Dominant trailing bank vegetation was overhanging native shrubs and roots

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae

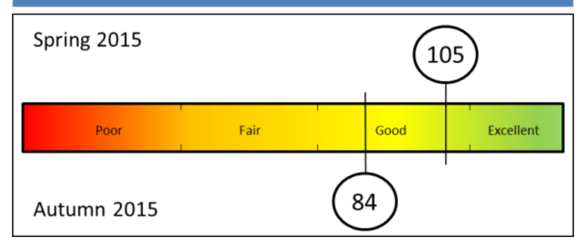
AUSRIVAS Results

	Spring 2014	Autumn 2015	Spring 2015
Riffle Habitat	B	NRA	A
Edge Habitat	A	B	X
Overall Site Assessment	B	B	A

Additional Comments

- *Myriophyllum* sp. was highly abundant
- Presence of some dead *Salix* sp. and other shrubs along the banks

Site Quality Assessment



MUR19

Downstream Angle Crossing
24/11/2015 12:20 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
22.9	177.9	5.25	9	8.19	104.4	8.11

Alkalinity (mg/L)	NO_x (mg/L)	TKN (mg/L)	TP (mg/L)	TN (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)
74	0.002	0.40	0.028	0.41	0.57	0.065

Daily Flow: 290 ML/day

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

Compared to current flow:

Spring 2014:

Autumn 2015:

AUSRIVAS Results

	Spring 2014	Autumn 2015	Spring 2015
Riffle Habitat	NRA	B	A
Edge Habitat	A	B	X
Overall Site Assessment	A	B	A

Riffle Habitat

- *Myriophyllum* sp. highly abundant throughout the habitat
- Some small tufts of filamentous algae
- Dominant substrate was cobble

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Hydrobiosidae
- Coloburiscidae

Additional Comments

- None

Edge Habitat

- Dominant trailing bank vegetation was overhanging trees and wood debris

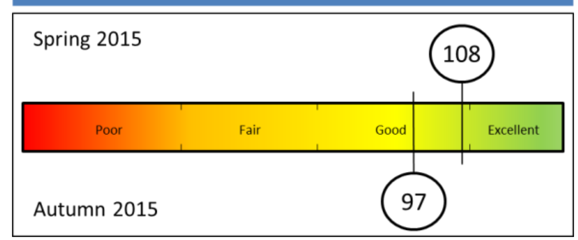
Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae

Site Quality Assessment



Part 2: Burra Creek

BUR1c

Upstream Williamsdale Road
23/11/2015 12:20 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
21.9	436	5.85	4	7.86	82.1	6.49

Alkalinity (mg/L)	NO_x (mg/L)	TKN (mg/L)	TP (mg/L)	TN (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)
174	0.105	0.27	0.017	0.38	0.89	0.148

Daily Flow: 2.0 ML/day

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

Compared to current flow:

Spring 2014:  Autumn 2015: 

Riffle Habitat

- Poor quality, highly silted habitat
- Limited habitat available due to low flows
- Dominant substrate was silt

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae

Edge Habitat

- Shallow habitat amongst fringing macrophytes
- Dominant trailing bank vegetation was macrophytes (*Schoenoplectus validus*)

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

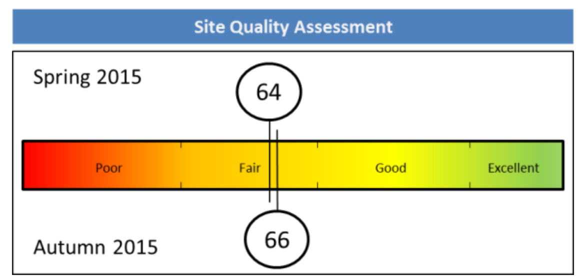
- Leptophlebiidae
- Gripopterygidae

AUSRIVAS Results

	Spring 2014	Autumn 2015	Spring 2015
Riffle Habitat	A	B	X
Edge Habitat	A	A	X
Overall Site Assessment	A	B	X

Additional Comments

- Increased shading of the site due to dense macrophyte coverage



BUR2a

Downstream Williamsdale Road
23/11/2015 1:15 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
20.8	515	11.0	17	7.98	84.9	6.65

Alkalinity (mg/L)	NO_x (mg/L)	TKN (mg/L)	TP (mg/L)	TN (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)
214	0.003	0.30	0.013	0.30	0.56	0.113

Daily Flow: 2.0 ML/day

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

Compared to current flow:

Spring 2014: 

Autumn 2014: 

AUSRIVAS Results

	Spring 2014	Autumn 2015	Spring 2015
Riffle Habitat	A	B	A
Edge Habitat	A	B	A
Overall Site Assessment	A	B	A

Riffle Habitat

- Slow flowing habitat
- Dominant substrate is cobble and silt

Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae
- Hydrobiosidae
- Leptophlebiidae

Edge Habitat

- Deep edge habitat with abundance of fringing macrophytes
- Dominant trailing bank vegetation was macrophytes (mainly overhanging grasses and *Schoenoplectus validus*)

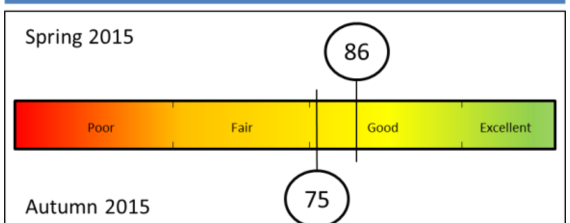
Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

Site Quality Assessment



Additional Comments

- Slow flow through the site

Part 3: Murrumbidgee Pump Station

MUR28

Upstream Cotter River Confluence
24/11/2015 3:35 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
25.7	170.9	7.57	9	8.38	110.0	8.09

Alkalinity (mg/L)	NO_x (mg/L)	TKN (mg/L)	TP (mg/L)	TN (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)
72	< 0.002	0.44	0.029	0.44	0.49	0.048

Daily Flow:

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

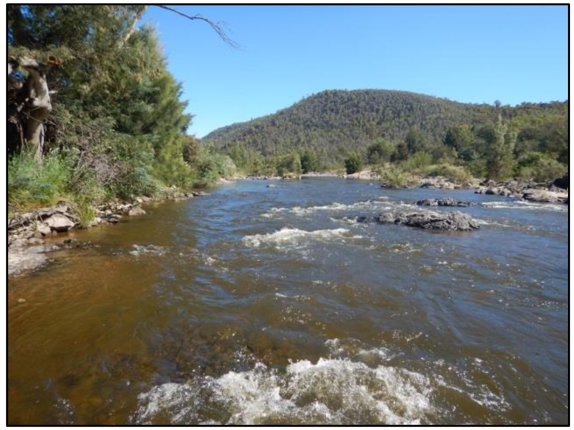
470 ML/day
Recorded at station 410738, located on the Murrumbidgee River at Mt. MacDonald.

60 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 and the Murrumbidgee to Cotter water recirculation system.

AUSRIVAS Results

	Spring 2014	Autumn 2015	Spring 2015
Riffle Habitat	B	A	B
Edge Habitat	A	A	B
Overall Site Assessment	B	A	B



Riffle Habitat

- Highly silted with high periphyton coverage
- Dominant substrate was cobble

Dominant Taxa

- Hydrobiosidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Hydrobiosidae

Edge Habitat

- Shallow, flowing, poor quality habitat
- Dominant trailing bank vegetation was overhanging *Acacia* sp.

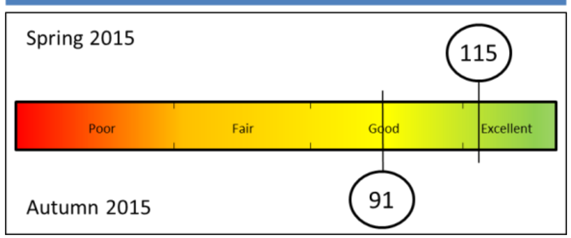
Dominant Taxa

- None

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Gripopterygidae

Site Quality Assessment



Additional Comments

- Periphyton coverage was high (see photo)

MUR935

Casuarina Sands
24/11/2015 2:40 pm

Temp. (°C)	EC (µs/cm)	Turbidity (NTU)	SS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
25.7	169.5	5.45	8	8.40	120.2	8.95

Alkalinity (mg/L)	NO_x (mg/L)	TKN (mg/L)	TP (mg/L)	TN (mg/L)	Total Iron (mg/L)	Total Manganese (mg/L)
71	< 0.002	0.42	0.028	0.42	0.47	0.045

Daily Flow:

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

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

60 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 and the Murrumbidgee to Cotter water recirculation system.

Riffle Habitat

- Dominant substrate was cobble

Dominant Taxa

- Hydropsychidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Hydrobiosidae
- Corydalidae

Edge Habitat

- Poor quality habitat
- Dominant trailing bank vegetation was overhanging *Casuarina* sp.

Dominant Taxa

- None

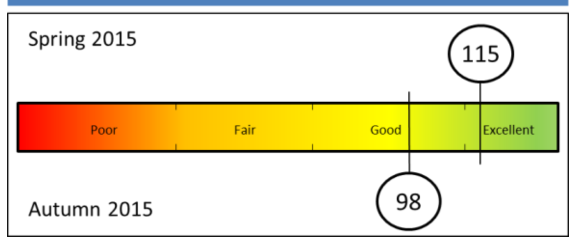
Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

AUSRIVAS Results

	Spring 2014	Autumn 2015	Spring 2015
Riffle Habitat	NS	A	B
Edge Habitat	NS	A	A
Overall Site Assessment	NS	A	B

Site Quality Assessment



Additional Comments

- Some new areas of erosion were visible on the left bank

Appendix C - AUSRIVAS habitat information

Appendix C1. AUSRIVAS habitat information collected on site during spring 2015

Site Code	BUR1c	BUR2a	MUR18	MUR19	MUR28	MUR935
Date	23/11/2015	23/11/2015	24/11/2015	24/11/2015	24/11/2015	24/11/2015
Time	12:20	13:15	11:10	12:20	15:35	14:40
Season	Spring	Spring	Spring	Spring	Spring	Spring
River	Burra Creek	Burra Creek	Murrumbidgee River	Murrumbidgee River	Murrumbidgee River	Murrumbidgee River
Location	upstream Williamsdale Road	downstream Williamsdale Road	upstream Angle Crossing	downstream Angle Crossing	upstream Cotter River Confluence	Casuarina Sands
Weather	fine	fine, hot	fine	fine	fine	fine, slight breeze
Cloud cover (%)	3	3	0	0	0	0
Rain during the previous week?	no	no	no	no	no	no
Bank Height (m)	1.5	2.5	1.5	2	2	2
Bank Full Width (m)	18	28	100	100	100	80
Mode Stream Width (m)	2	3	22	30	24	36
Length of Reach	180	280	1000	1000	1000	800
Habitat in Reach						
% Riffle	1	3	10	30	10	15
% Pool	90	80	40	20	15	15
% Run	9	17	50	50	75	70
% Edge	10	20	10	10	5	5
% Macrophyte	95	50	20	15	1	3
Mean Riffle Depth (cm)	11	20	28.33	21.67	26	21.33
Mean Riffle Velocity (m/s)	0.028	0.2013	1.3367	0.8357	0.5783	0.606
Mean Edge Depth (cm)	25	36.67	81.67	85	14.67	52.33
Mean Edge Velocity (m/s)	0.019	0.019	0.0513	0.019	0.041	0.0507
Riparian Vegetation						
Mean Riparian Width (m)	1	3	6.5	7	12.5	7.5
% Trees >10m	0	10	10	5	5	5
% Trees <10m	10	10	30	15	35	45

Site Code	BUR1c	BUR2a	MUR18	MUR19	MUR28	MUR935
% Shrubs	5	0	30	50	30	20
% Grasses/Ferns/Sedges	90	90	30	30	30	30
% Shading	26 - 50	6 - 25	< 5	< 5	< 5	< 5
% Native	30	30	20	50	60	50
% Exotic	70	70	80	50	40	50
Observations						
Water Odours	normal	normal	normal	normal	normal	normal
Water Oils	none	none	none	none	none	none
Turbidity	clear	clear	slight	clear	slight	clear
Plume	lots	lots	some	some	little	some
Sediment Oils	absent	absent	absent	absent	absent	absent
Sediment Odours	normal	normal	normal	normal	normal	normal
Flow Level	low	low	moderate	moderate	moderate	moderate
Sediment Deposits	none	none	sand, cobble, gravel	none	none	none
Local Erosion	none	some	some	some	none	some
Point Source Pollution	no	M2G, road	no	crossing, M2G	no	bridge, MPS, Bendora scour valve, cotter confluence
Non Point Source Pollution	agriculture	agriculture	agriculture	agriculture	agriculture	agriculture, recreation
Dams/Barriers	no	no	no	no	no	no
River Braiding	no	no	no	no	no	no
Site Classification	broad valley	broad valley	steep valley	steep valley	steep valley	steep valley
Left Bank Land Use	grazing	grazing	grazing, native grassland (no grazing)	native forest	native forest	native forest
Right Bank Land Use	grazing, residential	grazing	native forest, native grassland (no grazing)	native forest, industrial	native forest, industrial	native forest, industrial, recreational

Site Code	BUR1c	BUR2a	MUR18	MUR19	MUR28	MUR935
% Bar Cover	0	0	15	1	5	5
Reach - Substratum Description						
% Bedrock	0	10	10	5	20	20
% Boulder	0	15	10	10	20	30
% Cobble	20	20	30	30	20	25
% Pebble	10	10	5	15	10	5
% Gravel	10	10	5	10	15	5
% Sand	20	5	30	20	10	10
% Silt	40	20	10	10	5	5
% Clay	0	10	0	0	0	0
% Detritus	20	15	10	15	10	10
% Muck/Mud	35	20	10	10	10	5
% Periphyton	65 - 90	> 90	65 - 90	35 - 65	65 - 90	65 - 90
% Moss	< 10	< 10	< 10	< 10	< 10	< 10
% Filamentous Algae	< 10	< 10	< 10	< 10	< 10	< 10
% Macrophytes	> 90	35 - 65	10 - 35	10 - 35	< 10	< 10
Riffle - Substratum Description						
% Bedrock	0	10	5	0	10	10
% Boulder	0	15	10	5	15	20
% Cobble	5	30	50	40	35	40
% Pebble	5	0	15	15	15	10
% Gravel	0	15	15	10	15	5
% Sand	0	0	10	25	5	10
% Silt	80	30	5	5	5	5
% Clay	10	0	0	0	0	0
% Detritus	10	15	15	10	5	10
% Muck/Mud	20	15	5	5	0	5
% Periphyton	65 - 90	65 - 90	35 - 65	35 - 65	65 - 90	35 - 65
% Moss	< 10	< 10	< 10	< 10	< 10	< 10
% Filamentous Algae	< 10	< 10	< 10	< 10	< 10	< 10
% Macrophytes	> 90	10 - 35	10 - 35	35 - 65	< 10	< 10
Edge - Substratum Description						

Site Code	BUR1c	BUR2a	MUR18	MUR19	MUR28	MUR935
% Bedrock	0	10	0	0	40	5
% Boulder	0	10	5	5	10	20
% Cobble	10	10	10	5	10	35
% Pebble	5	5	15	0	5	5
% Gravel	5	5	15	10	5	5
% Sand	0	10	35	65	15	20
% Silt	75	50	15	15	15	10
% Clay	5	0	5	0	0	0
% Detritus	30	10	20	30	10	25
% Muck/Mud	40	20	10	15	10	10
% Periphyton	> 90	> 90	> 90	> 90	> 90	> 90
% Moss	< 10	< 10	< 10	< 10	< 10	< 10
% Filamentous Algae	< 10	< 10	< 10	< 10	< 10	< 10
% Macrophytes	65 - 90	35 - 65	< 10	10 - 35	< 10	< 10
Macrophytes						
Submergent / Floating	yes	no	yes	yes	no	no
Emergent	yes	yes	yes	yes	yes	yes
Habitat score	64	86	105	108	115	115

Appendix D - Additional water quality results

Appendix D1. Additional water quality grab sample results collected during spring 2015 by ALS on behalf of Icon Water

		Site	MUR 213			MUR 890		
		Location	Angle Crossing Murrumbidgee River			Pump Station Murrumbidgee River (East Side)		
		Date	13/08/15	20/10/15	24/11/15	13/08/15	20/10/15	24/11/15
		Time	0855	1500	1000	1039	0835	1100
Test	Analyte	Units						
A2_COLERT	E.Coli	MPN/100mL	8	17	22	2	8	10
	Total coliforms	MPN/100mL	770	1400	870	820	1600	2400
ALKAL_TOT	Bicarb	mg/L	54.1		72.2		73.1	
	Carb	mg/L	<0.1		<0.1		<0.1	
	Hydrox	mg/L	<0.1		<0.1		<0.1	
	Total	mg/L	54		72		73	
AW_SO4	Sulphate	mg/L SO4		0.03			0.06	
B_ALGAE	Bacillariophyceae	No/mL	1008	977	361	504	439	516
	Chlorophyta	No/mL	120	202	44	72	0	78
	Chrysophyceae	No/mL	0	0	0	24	0	0
	Cryptophyceae	No/mL	48	0	0	48	0	0
	Cyanophyta	No/mL	1176	194	0	1272	138	77
	Euglenophyta	No/mL	24	9	9	24	0	17
	Pyrrophyta	No/mL	0	0	0	0	0	0
	Total Algae	No/mL	2380	1380	414	1940	577	688
	Unknown	No/mL	0	0	0	0	0	0
	Xanthophyceae	No/mL	0	0	0	0	0	0
B_CHL_A2	Chlorophyll	ug/L	1.68	8.48	6.84	5.13	8.55	7.17
BACTEROID	Animal Bact QPCR	copies/L				540000	38000	8800000
	Bacteroides PCR					Detected	Detected	Detected
	Human Bact QPCR	copies/L				Not Detected	Not detected	1700000
C_GIARD_TC	Crypto Recovery	%	84	90	70	76	85	78
	Cryptosporidium	oocysts/L	<0.05	<0.05	<0.05	<0.05	<0.1	<0.05
	Giardia	cysts/L	<0.05	<0.05	<0.05	0.05	<0.1	<0.05
	Giardia Recovery	%	77	71	63	73	40	71
	Volume Analysed	L	20.0	20.0	20.0	20.0	10.0	20.0

		Site	MUR 213			MUR 890		
		Location	Angle Crossing Murrumbidgee River			Pump Station Murrumbidgee River (East Side)		
		Date	13/08/15	20/10/15	24/11/15	13/08/15	20/10/15	24/11/15
		Time	0855	1500	1000	1039	0835	1100
Test	Analyte	Units						
	Volume Concentrated	L	20.0	20.0	20.0	20.0	10.0	20.0
COL_TRUE	True	Pt-Co	32	23	40	46	21	41
DOC	DOC	mg/L	5	6	7	6	5	7
HARD_CA	Calcium	mg/L					11.8	
HARD_TOT	Total	mg/L					59	
MWIM_T_SCR	Aluminium	ug/L	293		50			
	Antimony	ug/L					211	
	Arsenic	ug/L					<3	
	Barium	ug/L					<1	
	Beryllium	ug/L					15.7	
	Cadmium	ug/L					<0.1	
	Chromium	ug/L					<0.05	
	Cobalt	ug/L					<2	
	Copper	ug/L					<0.2	
	Lead	ug/L					<1	
	Manganese	ug/L					<0.2	
	Nickel	ug/L					1	
	Selenium	ug/L					<1	
	Silver	ug/L					<1	
	Zinc	ug/L					<5	
NW_H_TN	Total_N	mg/L N	0.22	0.34	0.42		0.31	
NW_L_NH3	Ammonia	mg/L N	0.010	0.003	0.004		<0.002	
NW_L_NO2	Nitrite	mg/L N	<0.002	<0.002	<0.002		<0.002	
NW_L_NO3	Nitrate	mg/L N	0.004	<0.002	0.002		<0.002	
NW_L_NOX	Oxidised_N	mg/L N	0.004	<0.002	0.002		<0.002	0.004
NW_L_PO4	Ortho_P	mg/L P	0.008	0.003	0.004		0.002	
NW_L_TP	Total_P	mg/L P	0.021	0.026	0.029		0.019	
OC_PEST_L	4.4`-DDD	ug/L		<0.010			<0.010	
	4.4`-DDE	ug/L		<0.010			<0.010	
	4.4`-DDT	ug/L		<0.010			<0.010	
	Aldrin	ug/L		<0.010			<0.010	

		Site	MUR 213			MUR 890		
		Location	Angle Crossing Murrumbidgee River			Pump Station Murrumbidgee River (East Side)		
		Date	13/08/15	20/10/15	24/11/15	13/08/15	20/10/15	24/11/15
		Time	0855	1500	1000	1039	0835	1100
Test	Analyte	Units						
	alpha-BHC	ug/L		<0.010			<0.010	
	alpha-Endosulfan	ug/L		<0.010			<0.010	
	beta-BHC	ug/L		<0.010			<0.010	
	beta-Endosulfan	ug/L		<0.010			<0.010	
	cis-Chlordane	ug/L		<0.010			<0.010	
	delta-BHC	ug/L		<0.005			<0.005	
	Dieldrin	ug/L		<0.010			<0.010	
	Endosulfan sulfate	ug/L		<0.010			<0.010	
	Endrin	ug/L		<0.010			<0.010	
	Endrin aldehyde	ug/L		<0.010			<0.010	
	Endrin ketone	ug/L		<0.010			<0.010	
	gamma-BHC	ug/L		<0.010			<0.010	
	Heptachlor	ug/L		<0.010			<0.010	
	Heptachlor epoxide	ug/L		<0.010			<0.010	
	Hexachlorobenzene (HCB)	ug/L		<0.010			<0.010	
	Methoxychlor	ug/L		<0.010			<0.010	
	Oxychlordane	ug/L		<0.010			<0.010	
	trans-Chlordane	ug/L		<0.010			<0.010	
PHN_A_HB_L	2.4.5-T	ug/L		<0.01			<0.01	
	2.4.5-TP	ug/L		<0.01			<0.01	
	2.4.6-T	ug/L		<0.1			<0.1	
	2.4-D	ug/L		<0.1			<0.1	
	2.4-DB	ug/L		<0.01			<0.01	
	2.4-DP	ug/L		<0.05			<0.05	
	2.6-D	ug/L		<0.01			<0.01	
	4-Chlorophenoxyacetic Acid	ug/L		<0.05			<0.05	
	Clopyralid	ug/L		<0.01			<0.01	
	Dicamba	ug/L		<0.01			<0.01	
	Fluroxypyr	ug/L		<0.01			<0.01	
	MCPA	ug/L		<0.05			<0.05	

		Site	MUR 213			MUR 890		
		Location	Angle Crossing Murrumbidgee River			Pump Station Murrumbidgee River (East Side)		
		Date	13/08/15	20/10/15	24/11/15	13/08/15	20/10/15	24/11/15
		Time	0855	1500	1000	1039	0835	1100
Test	Analyte	Units						
	MCPB	ug/L		<0.01			<0.01	
	Mecoprop	ug/L		<0.01			<0.01	
	Picloram	ug/L		<0.01			<0.01	
	Triclopyr	ug/L		<0.1			<0.1	
PROFILE1	Conductance	uS/cm	126	173	169	122	173	164
	Diss_Oxygen	mg/L	11.3	9.3	7.8	11.9	8.6	8.4
	pH	pH units	7.4	8.3	7.8	8.1	7.8	7.9
	Temp	deg C	6.0	21.7	21.8	6.8	20.6	22.6
SOL_TDS1	TDS	mg/L	96	101	104		106	
TBT	Tributyltin	ngSn/L		<2			<2	
TOC	TOC	mg/L	5	6	7	6	5	8
TURB	Turbidity	NTU	96	101	104		106	
	Anabaenopsis	No/mL	0	0	0	0	0	0
	Aphanizomenon	No/mL	0	0	0	0	0	0
	Aphanocapsa	No/mL	816	106	0	1080	0	0
	Aphanothece	No/mL	0	0	0	0	0	0
	Chroococcus	No/mL	0	35	0	0	52	0
	Cylindrospermopsis	No/mL	0	0	0	0	0	0
	Merismopedia	No/mL	0	0	0	0	0	0
	Microcystis	No/mL	0	0	0	0	0	0
	Nodularia	No/mL	0	0	0	0	0	0
	Oscillatoria	No/mL	0	0	0	0	0	0
	Other	No/mL	192	53	0	192	86	0
	Phormidium	No/mL	0	0	0	0	0	0
	Planktolyngbya	No/mL	168	0	0	0	0	0
	Planktothrix	No/mL	0	0	0	0	0	0
	Pseudanabaena	No/mL	0	0	0	0	0	77
	Radiocystis	No/mL	0	0	0	0	0	0
	Spirulina	No/mL	0	0	0	0	0	0
	Total Cyanophyta	No/mL	1180	194	<1	1270	138	77
	Tychonema	No/mL	0	0	0	0	0	0

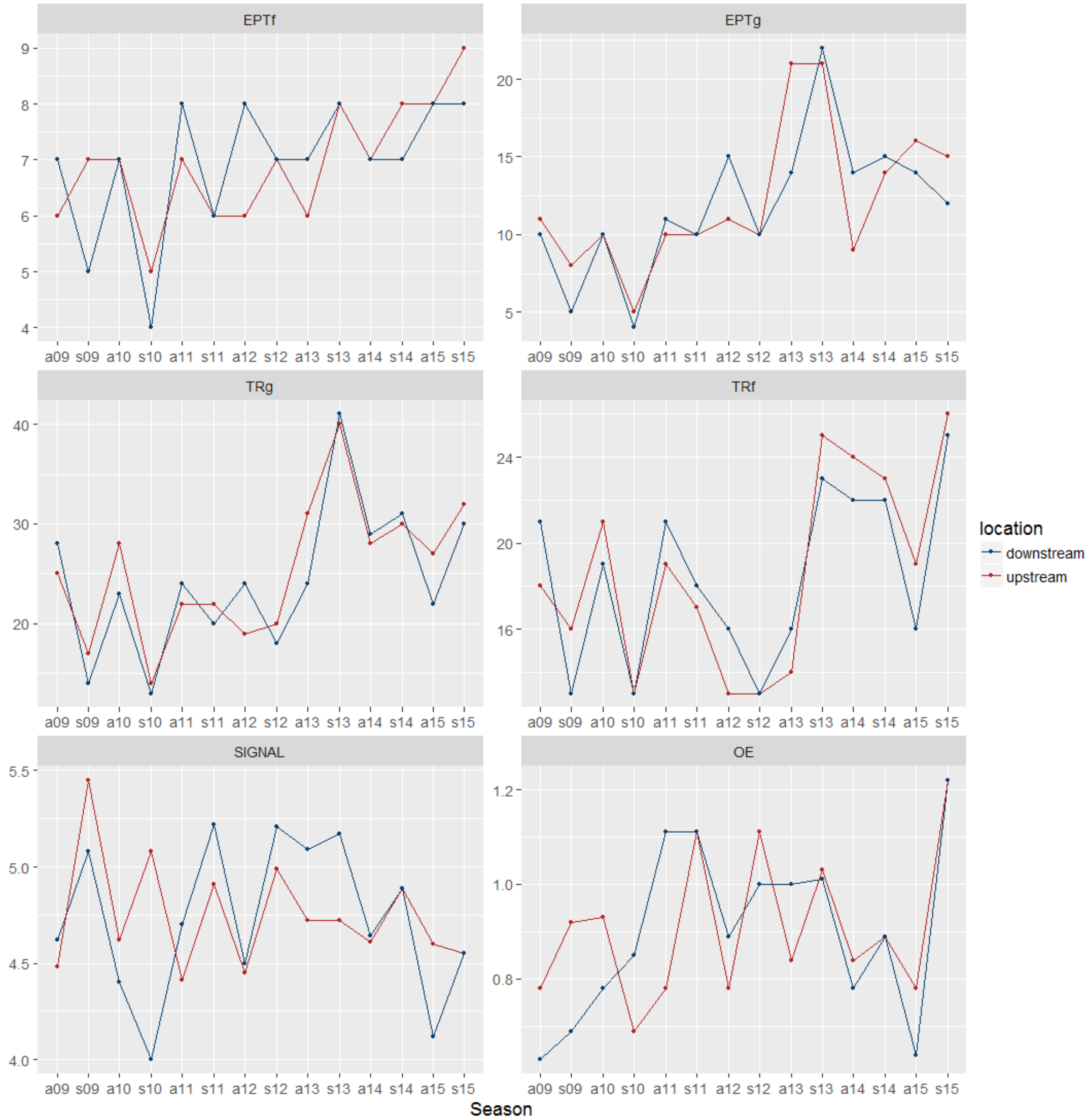
Appendix E - Historical macroinvertebrate indices

NOTE - MPS is not included at this stage due to the large data gaps. Values are means for each location.

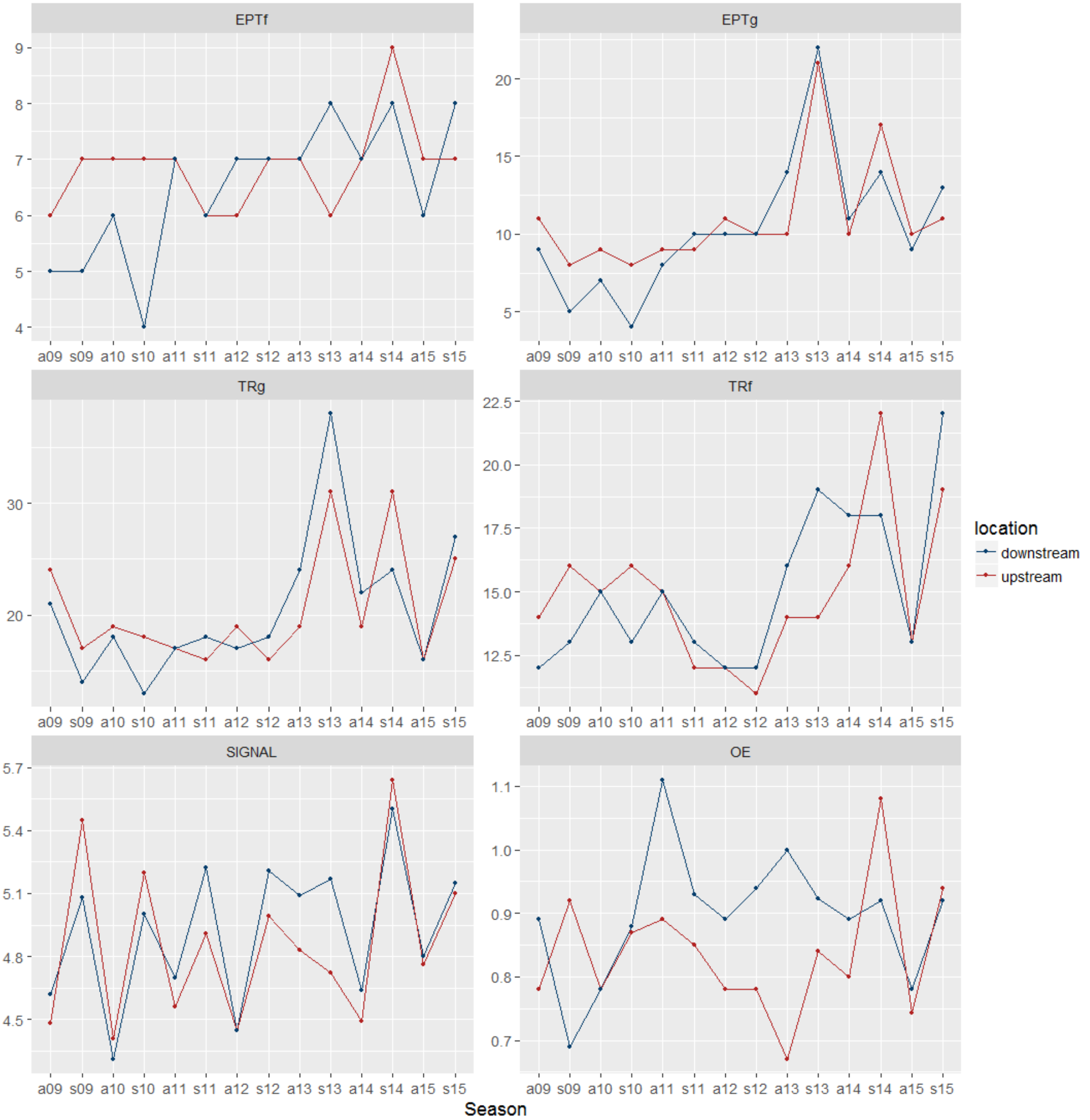
TR = taxa richness; EPT = Ephemeroptera + Plecoptera + Trichoptera

Suffix “g” refers to genus level data; suffix “f” refers to family

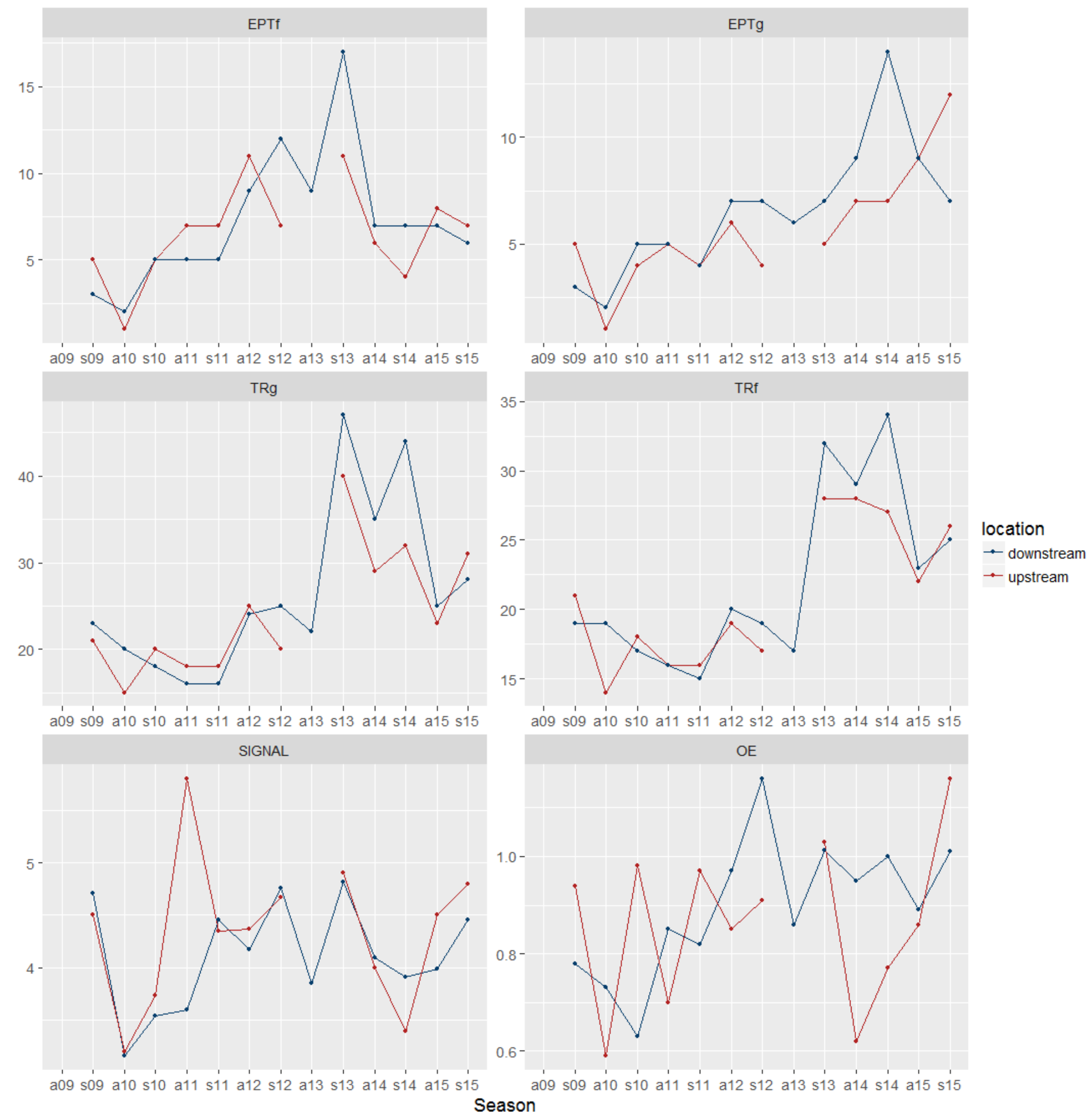
Angle Crossing EDGE - Macroinvertebrate indices between autumn 2009 and spring 2015



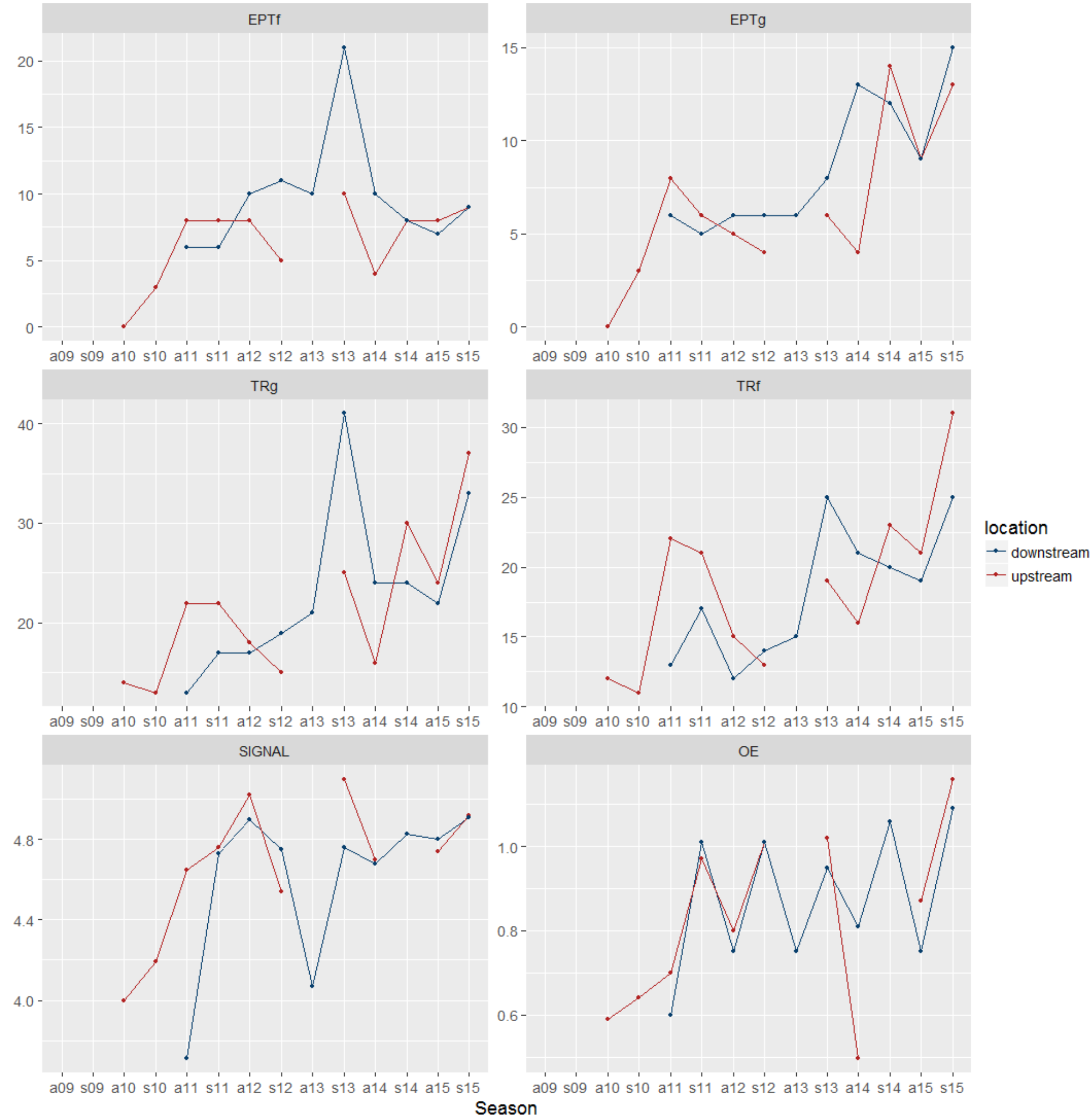
Angle Crossing RIFFLE - Macroinvertebrate indices between autumn 2009 and autumn 2015



Burra Creek EDGE - Macroinvertebrate indices between autumn 2009 and autumn 2015



Burra Creek RIFFLE- Macroinvertebrate indices between autumn 2009 and spring 2015



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

Appendix F1. Taxa predicted to occur with >50% probability but not collected in the riffle habitat

Site	Taxa	Oligochaeta	Acarina	Elmidae	Psephenidae	Tanypodinae	Leptophlebiidae	Caenidae	Gripopterygidae	Hydrobiosidae	Glossosomatidae	Hydropsychidae	Conoesucidae	Total Number of Missing Taxa
	SIGNAL-2	2	6	7	6	4	8	4	8	8	9	6	7	
BUR 1c				*0.92*										1
BUR 1c	Riffle			*0.92*										1
BUR 1c				*0.92*										1
BUR 2a				*0.92*										1
BUR 2a	Riffle											*0.53*		1
BUR 2a			*0.75*	*0.92*										2
MUR 18					*0.60*		*0.91*				*0.68*		*0.64*	4
MUR 18	Riffle				*0.60*		*0.91*			*0.56*	*0.68*		*0.64*	5
MUR 18					*0.60*	*0.63*	*0.91*				*0.68*		*0.64*	5
MUR 19					*0.54*		*0.87*				*0.60*		*0.56*	4
MUR 19	Riffle			*0.94*	*0.54*	*0.67*	*0.87*			*0.53*	*0.60*		*0.56*	7
MUR 19		*1.00*		*0.94*	*0.54*						*0.60*		*0.56*	5
MUR 28				*0.96*	*0.64*	*0.59*		*0.89*	*0.95*	*0.59*	*0.75*		*0.72*	8
MUR 28	Riffle			*0.96*	*0.64*				*0.95*		*0.75*		*0.72*	5
MUR 28					*0.64*				*0.95*	*0.59*	*0.75*		*0.72*	5
MUR 935				*0.97*	*0.64*	*0.60*	*0.95*		*0.96*	*0.60*	*0.76*		*0.74*	8
MUR 935	Riffle				*0.64*	*0.60*	*0.95*		*0.96*	*0.60*	*0.76*		*0.74*	7
MUR 935		*1.00*			*0.64*	*0.60*	*0.95*			*0.60*	*0.76*		*0.74*	7

Appendix F2. Taxa predicted to occur with >50% probability but not collected in the edge habitat

Site	Taxa	Ceratopogonidae	Tanypodinae	Baetidae	Caenidae	Gripopterygidae	Total Number of Missing Taxa
	SIGNAL-2	4	4	5	4	8	
BUR 1c	Edge						0
BUR 1c						*0.74*	1
BUR 1c							0
BUR 2a	Edge				*0.94*	*0.69*	2
BUR 2a						*0.69*	1
BUR 2a						*0.69*	1
MUR 18	Edge						0
MUR 18							0
MUR 18							0
MUR 19	Edge						0
MUR 19							0
MUR 19							0
MUR 28	Edge	*0.65*				*0.62*	2
MUR 28		*0.65*	*0.97*	*0.62*		*0.62*	4
MUR 28		*0.65*	*0.97*	*0.62*		*0.62*	4
MUR 935	Edge			*0.62*			1
MUR 935						*0.62*	1
MUR 935		*0.65*	*0.97*				2

Appendix G - Taxonomic Inventory

Appendix G1. Taxonomic inventory of taxa collected in the riffle habitat during spring 2015

CLASS / Order	Family / Sub-Family	Genus	BUR 1c	BUR 2a	MUR 18	MUR 19	MUR 28	MUR935
ACARINA								
BIVALVIA	Corbiculidae	*Corbicula*						
	Sphaeriidae	*Pisidium*						
Coleoptera	Dytiscidae	*Necterosoma*						
		Platynectes						
		sp.						
	Elmidae	*Austrolimnius*						
		Coxelmis						
		Simsonia						
		sp.						
	Hydrochidae	*Hydrochus*						
	Hydrophilidae							
	Scirtidae							
Decapoda	Parastacidae	*Cherax*						
Diptera	Ceratopogonidae	*Ceratopoginae*						
	Chironominae							
	Dixidae							
	Empididae							
	Orthocladiinae							
	Simuliidae	*Austrosimulium*						
		Simulium						
		sp.						
	Tanypodinae							
	Tipulidae							
Ephemeroptera	Baetidae	*Baetidae Genus 1*						
		Baetidae Genus 2						
		sp.						
	Caenidae	*Irapacaenis*						
		Tasmanocoenis						
		sp.						
	Coloburiscidae	*Coloburiscoides*						

CLASS / Order	Family / Sub-Family	Genus	BUR 1c	BUR 2a	MUR 18	MUR 19	MUR 28	MUR935
	Leptophlebidae	*Austrophlebioides*						
		Atalophlebia						
		Jappa						
		sp.						
GASTROPODA	Planorbidae	*Ferrissia*						
	Lymnaeidae	*Lymnaea*						
		sp.						
	Physidae	*Physa*						
Hemiptera	Micronectidae	*micronecta*						
	Notonectidae							
	Veliidae							
Lepidoptera	Crambidae	sf Nymphulinae sp.						
Megaloptera	Corydalidae	*Archichauliodes*						
Odonata	Gomphidae	*Hemigomphus*						
	Zygoptera							
OLIGOCHAETA								
Plecoptera								
	Gripopterygidae	*Euntoperla*						
		Illiesoperla						
		Neboissoperla						
		sp.						
Trichoptera	Ecnomidae	*Ecnomus*						
		sp.						
	Hydrobiosidae	*Taschorema*						
		sp.						
	Hydropsychidae	*Asmicridea*						
		Cheumatopsyche						
		sp.						
	Hydroptilidae	*Hellyethira*						
		Hydroptila						
		Orthotrichia						
		Oxyethira						
		sp.						
	Leptoceridae	*Notalina*						
		Oecetis						

CLASS / Order	Family / Sub-Family	Genus	BUR 1c	BUR 2a	MUR 18	MUR 19	MUR 28	MUR935
		Triplectides						
		sp.						
Turbellaria	Dugesiidae	*Dugesia*						
	Temnocephalidae							

Appendix G2. Taxonomic inventory of taxa collected in the edge habitat during spring 2015

CLASS / Order	Family / Sub-Family	Genus	BUR 1c	BUR 2a	MUR 18	MUR 19	MUR 28	MUR935
ACARINA								
Amphipoda	Ceinidae							
BIVALVIA	Sphaeriidae	*Pisidium*						
Coleoptera	Dytiscidae	*Barretthydrus*						
		Megaporus						
		Necterosoma						
		sp.						
	Gyrinidae	*Macrogyrus*						
	Hydraenidae	*Hydraena*						
	Hydrochidae	*Hydrochus*						
	Hydrophilidae	*Coelostoma*						
		sp.						
Decapoda	Atyidae	*Paratya*						
	Parastacidae	*Cherax*						
Diptera	Ceratopogonidae	*Ceratopoginae*						
	Chironominae							
	Dixidae							
	Empididae							
	Orthocladiinae							
	Simuliidae	*Austrosimulium*						
		sp.						
	Stratiomyidae	*Odontomyia*						
	Tanypodinae							
	Tipulidae							
Ephemeroptera	Baetidae	*Baetidae Genus 1*						
		Baetidae Genus 2						
		Cloeon						
		sp.						
	Caenidae	*Irapacaenis*						
		Tasmanocoenis						
		sp.						
	Leptophlebidae	*Austrophlebioides*						
		Atalophlebia						
		Jappa						

CLASS / Order	Family / Sub-Family	Genus	BUR 1c	BUR 2a	MUR 18	MUR 19	MUR 28	MUR935
		sp.						
GASTROPODA								
	Planorbidae	*Ferrissia*						
	Lymnaeidae	*Lymnaea*						
		sp.						
	Physidae	*Physa*						
Hemiptera	Corixidae							
	Gerridae	*Aquarius*						
		Rheumatometra						
		sp.						
	Micronectidae	*micronecta*						
	Notonectidae	*Paranisops*						
		sp.						
	Veliidae							
Lepidoptera	Crambidae	sf Nymphulinae sp.						
Odonata	Epiprocta							
	Telephlebiidae	*Dendroaeschna*						
		sp.						
OLIGOCHAETA								
Plecoptera	Gripopterygidae	*Euntoperla*						
		Neboissoperla						
		sp.						
Porifera	Spongillidae							
Trichoptera	Ecnomidae	*Ecnomus*						
		sp.						
	Hydrobiosidae							
	Hydropsychidae	*Asmicridea*						
		Cheumatopsyche						
		sp.						
	Hydroptilidae	*Hellyethira*						
		Hydroptila						
		Orthotrichia						
		Oxyethira						
		sp.						
	Leptoceridae	*Notalina*						

CLASS / Order	Family / Sub-Family	Genus	BUR 1c	BUR 2a	MUR 18	MUR 19	MUR 28	MUR935
		Oecetis						
		Triaenodes						
		Triplectides						
		sp.						
	Philopotamidae	*Chimarra*						
Turbellaria	Dugesiidae	*Dugesia*						
	Temnocephalidae							

Appendix H – Habitat assessment scoring system

Appendix H. Habitat assessment scoring system from the ACT AUSRIVAS field sheets

	Category			
Habitat variable	Excellent	Good	Fair	Poor
1. Bottom substrate/available cover	Greater than 50% rubble, gravel, submerged logs, undercut banks and other stable habitat	30-50% rubble, gravel or other stable habitat. Adequate habitat	10-30% rubble, gravel or other stable habitat. Habitat availability less than desirable	Less than 10% rubble, gravel or other stable habitat. Lack of habitat is obvious
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Embeddedness	Gravel, cobble and boulder particles are between 0 & 25% surrounded by fine sediment	Gravel, cobble and boulder particles are between 25 & 50% surrounded by fine sediment	Gravel, cobble and boulder particles are between 50 & 75% surrounded by fine sediment	Gravel, cobble and boulder particles are over 75% surrounded by fine sediment
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Velocity / depth category	Slow deep (<0.3 m/s & >0.5m); Slow shallow; Fast deep; Fast shallow; habitats all present	Only 3 of the four habitat categories present (missing riffles or runs receive lower score than missing pools)	Only 2 of the four habitat categories present (missing riffles/ runs receive lower score)	Dominating by one velocity/depth category (usually pool)
	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Channel alteration	Little or no enlargement of islands or point bars and/or no channelisation	Some new increase in bar formation, mostly from coarse gravel; and/or some channelisation present	Moderate deposition of new gravel, coarse sand, on old and new bars; pools partly filled w/silt; and/or embankments on both banks	Heavy deposits of fine materials, increased bar development; most pools filled with silt; and/or extensive channelisation
	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
5. Bottom scouring and deposition	Less than 5% of the bottom affected by scouring and deposition	5-30% affected. Scours at constrictions and where grades steepen, some deposition in pools.	30-50% affected. Deposits and scours at obstruction and bends. Some deposition in pools.	More than 50% of the bottom changing nearly year-long. Pools almost absent due to deposition. Only large rocks in riffle exposed
	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
6. pool/riffle, run/bend ratio	0-7 Variety of habitat. Deep riffles and pools	7-15 Adequate depth in pools and riffles. Bends provide habitat	15-25 Occasional riffle or bend. Bottom contours provide some habitat.	>25 Essentially a straight stream. Generally all flat water or shallow riffle. Poor habitat.
	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
7. Bank stability	Stable. No evidence of erosion or bank failure. Side slopes generally <30%. Little potential for future problem.	Moderately stable. Infrequent, small areas of erosion mostly healed over. Side slopes up to 40% on one bank. Slight potential in extreme floods	Moderately unstable. Moderate frequency and size of erosional areas. Side slopes up to 60% on some banks. High erosion potential during extreme/high flows	Unstable. Many eroded areas. Side slopes > 60% common. "Raw" areas frequent along straight sections and bends.
	10 9	8 7 6	5 4 3	2 1 0
8. bank vegetative structure	Over 80% of the streambank surfaces covered by vegetation or boulders and cobble	50-79% of the streambank surfaces covered by vegetation, gravel or larger material	25-49% of the streambank surfaces covered by vegetation, gravel or larger material	Less than 25% of the streambank surfaces covered by vegetation, gravel or larger material
	10 9	8 7 6	5 4 3	2 1 0
9. Streamside vegetation cover	Dominant vegetation is of tree form	Dominant vegetation shrub	Dominant vegetation is grass, sedge, ferns	Over 50% of the streambank has no vegetation and dominant material is soil, rock, bridge materials, culverts, or mine tailings
	10 9	8 7 6	5 4 3	2 1 0
Total score				

GHD

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

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