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MURRUMBIDGEE ECOLOGICAL MONITORING PROGRAM

PART 1: ANGLE CROSSING

AUTUMN 2011

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Table of Contents

Table of Figures

List of Tables

List of Plates

Appendices

List of abbreviations

ACT – Australian Capital Territory
ACTEW – ACTEW Corporation Limited
AFDM – Ash Free Dry Mass (periphyton)
ALS – Australian Laboratory Services
ANOSIM – Analysis of similarities
ANOVA – Analysis of Variance (statistics)
ANZECC –Australian and New Zealand Environment and Conservation Council
APHA – American Public Health Association
ARMCANZ – Agriculture and Resource management Council of Australia and New Zealand
AUSRIVAS – Australian River Assessment System
BACI – Before After Control Impact
CMA – Catchment Management Authority
CRCFE – Cooperative Research Centre for Freshwater Ecology
EC – Electrical Conductivity
EIS – Environmental Impact Statement
EPA – Environmental Protection Authority
EPT – Ephemeroptera, Plecoptera and Trichoptera taxa
GL/a – Gigalitres per annum
GPS – Global positioning system
IBT- Inter-Basin Water Transfer
M2G – Murrumbidgee to Googong
MEMP – Murrumbidgee Ecological Monitoring Program
ML/d – Megalitres per day
NATA – National Association of Testing Authorities
NMDS – Non-metric Multidimensional Scaling (statistics)
NSW – New South Wales
NTU – Nephlelometric Turbidity Units
PERMANOVA – PERMutational Multiple Analysis Of Variance
QA – Quality Assurance
QC – Quality Control
SIMPER – Similarity Percentages
TN – Total Nitrogen
TP – Total Phosphorus

Executive Summary

To improve ACT water security for the future, ACTEW Corporation is constructing an additional pumping structure and pipeline to abstract water from the Murrumbidgee River near Angle Crossing (southern border of the ACT).

The proposed pumping system will transfer water from Angle Crossing through an underground pipeline into Burra Creek, and then transfer the water by run of river flows into the Googong Reservoir. The system is being designed to pump up to 100 ML/d, and is expected to be in operation by mid-2012. Abstraction will be primarily dictated by the level of demand and the availability of water and whether the Murrumbidgee River water quality complies with the EPA guidelines. The proposal is referred to as Murrumbidgee to Googong project (M2G).

This program aims to determine the baseline river condition prior to the additional water abstraction, which will include the period of pipeline construction and continue monitoring after commencement to determine what changes are taking place that are attributable to abstraction from Angle Crossing.

The key aims of this sampling run were to:

- *Collect current baseline condition macroinvertebrate community data, up- and downstream of Angle Crossing;*
- *Provide ACTEW with river health assessments based on AUSRIVAS protocols at key sites potentially affected by the construction and operation of pumping infrastructure at Angle Crossing;*
- *Collect current condition periphyton community baseline data to help monitor seasonal and temporal change and;*
- *Report on water quality up and downstream of Angle Crossing.*

This report presents the results from biological sampling and water quality monitoring of the Murrumbidgee River upstream and downstream of Angle Crossing in autumn 2011 and represents the 7th round of sampling carried out thus as part of a 3 year sampling program. Sampling was completed in May 2011 and macroinvertebrate sampling and associated habitat surveys were based on the AUSRIVAS sampling protocols, extended to include replicated sampling at each site and genus level identifications for selected taxa. The reasons for these variations were to: a) establish estimates of the within-site variability prior to the commencement of pumping; and; b) improve the ability of the monitoring program to detect subtle changes in the macroinvertebrate community that might occur in response to water abstraction impacts.

Macroinvertebrate community composition, periphyton assemblages and water quality were monitored from six sites on the Murrumbidgee River, three upstream and three downstream of Angle Crossing (~2km west of Williamsdale) with the aim of obtaining baseline ecological condition information following the ANZECC guidelines for ecological monitoring. River flows and rainfall for the sampling period were recorded at ALS gauging stations located at Lobb's Hole (downstream of Angle Crossing: 410761) and upstream of Angle Crossing (MURWQ09). Baseline physico-chemical water quality parameters including temperature, pH, electrical conductivity, turbidity and dissolved oxygen were recorded at each of the six sites at *the time of the biological sampling. Additionally, grab samples were taken from each site for Hydrolab verification and nutrient analysis.*

Macroinvertebrates were sampled in the riffle and edge habitats where available. Both habitats were sampled to provide a more comprehensive assessment of each site and potentially allow the program to isolate flow-related impacts from other disturbances. Riffle and edge habitats were sampled for macroinvertebrates and analysed in strict accordance with the ACT autumn riffle and edge AUSRIVAS (Australian River Assessment System) during autumn (May 5th and 6th) 2011. At each site, two samples were taken (where possible) from the riffle habitat. Two samples were also taken from the edge habitat and were collected by sweeping the collection net along the edge habitat at each site.

Periphyton samples were collected using the in-situ syringe method. At each of the six sampling sites, a 1m wide transect was established across the riffle zone. Along each transect, twelve samples were collected at regular intervals, using a syringe sampling device. In addition to this technique, qualitative assessments of the estimated substrate coverage by periphyton and filamentous green algae were also conducted at each site in accordance with the AUSRIVAS habitat assessment protocols to compliment the quantitative samples.

The key results from the autumn 2011 sampling of Angle Crossing show that:

1) *There was no difference in water quality parameters between the upstream and downstream sampling sites, based on continuous gauging station data. This suggests that the initial construction phase is not having an impact upon water quality downstream of Angle Crossing. The major influence on all of the gauged water quality parameters appears to be responses to changes in flow, which is apparent at both locations.*

2) *Continuous data from MURWQ09 (upstream of Angle Crossing) and 410761 (downstream of Angle Crossing) show a high degree of compliance with the ANZECC and ARMCANZ (2000) guidelines. Daily mean data show that, electrical conductivity, dissolved oxygen (% saturation) and pH were within the guidelines 100% of the time during autumn. Turbidity levels were within the guidelines 72% and 76% of the autumn period upstream and downstream of Angle Crossing respectively. High flows in mid and late March caused increased turbidity at both locations, however during periods of stable flow, turbidity values were within the 2-25 NTU guideline range.*

3) *The grab sample results are consistent with the gauged data and show very little differentiation between the upstream and downstream sites indicating that there was no impact from the construction work at Angle Crossing. Any short term impacts therefore, have either been missed because of the temporal scale of the sampling program (twice-yearly coinciding with autumn and spring), or the current base flow and preceding high flow events have alleviated or masked potential construction-associated impacts from detection. Nutrient analysis based on the grab sample data show that TP and TN exceeded the guideline values in all the sampled reaches in this project. However, it should be emphasised that these levels are consistent with those collected throughout this project, suggesting perhaps that the agricultural practices upstream of Angle Crossing and urban land use features downstream of the crossing maintain moderately high levels year round.*

4) *There was no evidence for differences in chlorophyll-a concentrations or Ash Free Dry Mass (AFDM) – measures of algal productivity - between upstream and downstream locations. Mean chlorophyll-a concentrations were higher than those recorded in spring 2010 upstream and downstream of Angle Crossing, but similar to those recorded in autumn 2010, suggesting a strong seasonal influence at both locations. The stable flows leading up to the May sampling run are likely to have been a strong influence on the concentrations observed in this study. Nutrient availability and flow stability are both influential on the development of periphyton communities, which in turn depend on the time since previous high floe event and retention times and delivery of nutrients.*

5) *Taxa richness, both at family and genus levels were comparable to previous sampling runs irrespective of season, as was the number of EPT families and genera. The key difference between the riffle macroinvertebrate communities in this sampling run compared to spring was a marked increase in the relative abundance of EPT taxa. While we have found that there is a strong seasonal influence, with spring samples generally having 20-40% lower relative abundance of EPT fauna, the autumn 2011 samples indicate a 20% increase compared to all other samples irrespective of season. This indicates that the multiple high intensity flows since September 2010 may have had the beneficial effects of removing fine sediment build up in the substrate and by doing so, improved habitat availability and quality for taxa that rely on clean and diverse substrates.*

6) *The AUSRIVAS assessment for the riffle habitat showed the four sites from the six sampled were "similar to reference condition" – i.e. BAND-A. Point Hut Crossing and the site immediately upstream of Angle Crossing were assigned BAND-B assessments, however, this was due to the absence of only 1 macroinvertebrate family(from one sample and that family was represented in other samples from these sites. The interpretation of these assessments should therefore take this into account because the outcome (i.e. BAND B) is to some extent misleading and not representative of the majority of the remaining subsamples. Generally however, AUSRIVAS results show an overall increase in both the O/E 50 across all sites compared to spring 2010. On a season by season basis, there were also improvements compared to autumn 2010, especially in the riffle habitat.*

7) *The edge habitat remained BAND B at MUR 23 since spring and indeed autumn 2010. MUR 19 shifted from a BAND C in spring to a BAND A in this sampling run and this also represents an improvement on the condition recorded in autumn 2010. The reasons are probably linked again to the flushing flows of spring and early March, and the higher base flow leading up to this sampling run.*

It is clear from our current sampling design that flow is highly influential in shaping the macroinvertebrate community structure. It is apparent that high flow events in spring can result in a reduction in the estimated abundances of specific groups of taxa such as Ephemeroptera: Plecoptera and Trichoptera (EPT) and free-living edge taxa that are otherwise ubiquitous throughout the sampled reaches. There has been little change in the number of taxa collected throughout this baseline period, which has encapsulated a range of flows in the range: 35 ML/d – 630ML/d.

It is predicted that during winter and spring, when the proportion of flow being abstracted is low compared to predicted seasonal base flows, that there are unlikely to be any long term effects on water quality, periphyton communities or the macroinvertebrate populations. Short term effects may include some reductions in individual indicator taxa and reactive changes in *water quality to hydrological disturbances, but as long as there is a period of stable flows following these disturbances, the system should return to a state similar to that seen before the disturbance. During summer and autumn, it is expected that detrimental changes in water quality may occur when flows are in the < 80 ML/d range due to reduced flushing of the riverine environment and greater nutrient uptake by algae during extended periods of low base flows. Water temperatures are also likely to increase during these periods of low flow, which will in turn influence D.O. and pH and influence algal growth.*

If flows in this range are artificially maintained through ongoing water abstractions, we could expect to see a further deterioration in water quality which would then begin to reduce the abundance and occurrence of sensitive macroinvertebrate taxa over the longer term and increase the relative abundance and frequency of pollution tolerant taxa.

This may have repercussions to fish populations which also rely on healthy macroinvertebrate populations as a food resource and may have particular preferences for certain macroinvertebrate taxa as a food source.

An additional challenge of the M2G project is to relate what we already know to what we can expect in terms of biological changes under the 80:90 pumping rules. To address these challenges we recommend the continuation of AUSRIVAS monitoring as suggested in the EIS. In doing so the data obtained from this program are likely to encompass a broader range of flow patterns which will allow firmer predictions to be established in relation to the operation of M2G.

1 Introduction

The Murrumbidgee Ecological Monitoring Program (MEMP) was set up by ACTEW Corporation to evaluate the potential impacts of water abstraction from the Murrumbidgee River. It is being undertaken as part of the ACT water supply security infrastructure upgrade.

The time-line for MEMP sampling covers autumn and spring sampling over a three year period that commenced in spring 2008 and will conclude in spring 2011.

There are four component areas being considered as part of the MEMP program:

- Part 1: Angle Crossing
- Part 2: Burra Creek (discharge point for Angle Crossing abstraction)
- Part 3: Murrumbidgee Pump Station
- Part 4: Tantangara to Burrinjuck

This report focuses on Part 1: Angle Crossing, specifically the results from the autumn 2011 sampling round

To improve ACT water security for the future, ACTEW Corporation is proposing to construct an additional pumping structure and pipeline to abstract water from the Murrumbidgee River near Angle Crossing (southern border of the ACT). The proposed pumping system will transfer water from Angle Crossing through a 12km underground pipeline into Burra Creek. The water will then be transported a further 13km by run of river flows into the Googong Reservoir.

The system has been designed to pump up to 100 ML/d and is expected to be in operation by mid-2012, with construction underway. Water abstraction from the Angle Crossing pump station will be dictated by the Googong Reservoir's capacity and by the availability of water in the Murrumbidgee River. The environmental flow rules for the Murrumbidgee to Googong project (M2G) have been adopted from the framework outlined in the 2006 Environmental Flow Guidelines (ACT Government, 2006). Under these flow rules, Murrumbidgee flows must be protected at the 80th percentile between November and May and the 90th percentile between June and October (Table 1).

Table 1. Flow rules for the Murrumbidgee to Googong project. These values are based on the period of record data (1974-2011) from Lobb's Hole gauging station (410761) and are current as of the 26th August 2011. All values are expressed in ML/d.

Jan*.	Feb*.	Mar*.	Apr*.	May*.	Jun†.	Jul†.	Aug†.	Sep†.	Oct†.	Nov*.	Dec*.
30.8	23.3	16.5	34.5	50	63.5	76	101.2	170.1	129.3	138.3	54.3

Notes:

* 80th percentile flow

† 90th percentile flow

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

1.1 Background: The Upper Murrumbidgee River

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

Land-use varies from National Park in the high country to agriculture and farming in the valley regions. Annual rainfall varies from greater than 1400 mm in the mountains, to 620 mm at Canberra, down to 300 mm in the west (B.O.M, 2010).

Drought has had the most significant impact on catchment quality within the upper Murrumbidgee catchments in recent times. More than 80% of catchments have been drought-affected since late 2002. Drought-induced land degradation in the upper Murrumbidgee catchments has been significant across all areas and adverse effects include increased stress on surface and groundwater resources, increased soil erosion and a shift from mixed farming and cropping, to grazing and reduced stock numbers. Drought has also led to increased pressure on native vegetation in the catchments, a heightened risk of fire in native forests, and an increase in the abundance of several weed species. This is highly relevant to the current study as the M2G Project will result in a reduction in flows downstream of the abstraction point relative to natural flow levels.

1.2 Project objectives

There are two key phases to this project, which incorporates two sets of objectives, representing long and short term aims (i.e. before and after abstraction) (Table 2). Phase 1 of this monitoring program involves the establishment of baseline macroinvertebrate community composition at selected sites up- and downstream of the proposed abstraction point. The focus of Phase 1 is on the documentation of spatial and seasonal changes in macroinvertebrate and periphyton assemblages as well as monitoring water quality patterns prior to abstraction, including the construction phase. Accordingly, this phase will provide data for before and after construction and before and after abstraction comparisons that will allow their potential impacts (direct or indirect) to be assessed.

Phase 2 incorporates long term objectives, with the aim of providing post-abstraction phase data that will help to delineate potential ecological effects that are related specifically to the abstraction of water from the Murrumbidgee River at Angle Crossing, outside of what is considered natural, temporal and spatial variation.

The specific aims of this monitoring program are:

1. To determine seasonal and annual variation in the composition and abundance of periphyton at control and test sites before water abstractions commence, and to assist in the monitoring of river ecosystem health once the abstractions begin.

2. To determine baseline macroinvertebrate communities at test and control sites before the water abstractions commence, and to assist in the monitoring of riverine ecosystem health once the abstractions begin.

Table 2. Project objectives and estimated time frames

	Key objectives	Time frame	Outcomes
Phase 1	Obtain baseline information to include: hydrological, biological and physico-chemical water quality information. Establish spatial and temporal trends up and downstream of the existing low-level crossing that is Angle Crossing.	2009-2011	Help establish flow rules for the operation of the pump in the M2G project. Identify key (indicator) species than can be used to identify flow thresholds. Establish biological signatures and inventories as references for changes over time.
Phase 2	Monitor the ecological responses related specifically to water abstractions from Angle Crossing. The ability to do this depends on establishing a comprehensive data set of spatial and temporal variability at all concerned sites.	2012-	Help minimise ecological impacts by using baseline and indicator taxa information in relation to proposed flow rules.

1.3 Project scope

The current ecological health of the sites monitored as part of the Murrumbidgee to Googong (M2G) monitoring program 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 autumn 2011 sampling. Specifically, as outlined in the MEMP proposal to ACTEW Corporation (Ecowise, 2009) this work includes:

- Sampling conducted in autumn 2011;

- Macroinvertebrate communities collected from riffle and edge habitats using AUSRIVAS protocols;

- Macroinvertebrate samples counted and identified to the taxonomic level of genus;

- Riffle and edge samples assessed through the appropriate AUSRIVAS model;

- *In-situ* water quality measurements collected and samples analysed for nutrients in ALS's NATA accredited laboratory.

1.4 Rationale for using biological indicators

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

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

Changes in total periphyton biomass and/or the live component of the periphyton (as determined by chlorophyll-*a*) can vary with changes in flow volume, so these variables are often used as indicators of river condition in relation to monitoring the effects of flow regulation, environmental flow releases or water abstraction impacts (Biggs, 1989; Biggs *et al.*, 1999; Whitton and Kelly, 1995). Water abstractions from Angle Crossing will not affect the timing or magnitude of higher flows, but could affect conditions during the seasonal low flow period, such as increasing the nutrient availability through increased residence time, reducing scouring impacts on benthic organism and reducing surface flows over riffle habitats and thus decreasing habitat quality and availability. As changes in flow volume are expected with the proposed changes in the Murrumbidgee River water abstraction regime, periphyton biomass and chlorophyll-*a* are included as biological indices.

2 Materials and Methods

2.1 Study sites

Macroinvertebrate community composition, periphyton assemblages and water quality were monitored from replicate sites on the Murrumbidgee River, up- and downstream of Angle Crossing (~2km west of Williamsdale) with the aim of obtaining baseline ecological condition information following the ANZECC guidelines for ecological monitoring (ANZECC & ARMCANZ, 2000).

The upper Murrumbidgee River is impacted by activities in its catchment, which include a large array of land-use practices. As such, it was important to select a sufficiently large number of sites to enable the program to provide a reasonable snap-shot of the current status of the macroinvertebrate community in the study area. Sites were chosen based on several criteria, which included:

- Safe access and approval from land owners;

- Sites have representative habitats (i.e. riffle / pool sequences). If both habitats were not present then riffle zones took priority as the they are the most likely to be affected by abstractions;

- Sites which have historical ecological data sets (eg. Keen, 2001) took precedence over “new sites” –allowing comparisons through time to help assess natural variability through the system. This is especially important in this program because there is less emphasis on the reference condition, and more on comparisons between and among sites of similar characteristics in the ACT and surrounds over time.

Potential sites were identified initially from topographic maps, they were visited prior to sampling and their suitability was subsequently considered. Six sites suited the criteria mentioned above (Table 2; Figures 1 and 2). These sites include three sites upstream of Angle Crossing (in NSW) and three sites downstream (all in the ACT).

Table 3. Sampling site locations and details

Site Code	Location	Landuse	Habitat sampled	Latitude	Longitude
MUR 15	Bumbalong Road	Grazing / Recreation	Riffle and Edge	35^0 51’ 51.6” S	149^0 08’ 7.81” E
MUR 16	The Willows - Near Michelago	Grazing	Riffle and Edge	35^0 41’ 18.72” S	149^0 06’ 32.80” E
MUR 18	U/S Angle Crossing	Grazing	Riffle and Edge	35^0 35’ 06.68” S	149^0 06’ 28.96” E
MUR 19	D/S Angle Crossing	Grazing / Recreation	Riffle and Edge	35^0 34’ 59.38” S	149^0 06’ 32.80” E
MUR 23	Point Hut Crossing	Recreation / Residential	Riffle and Edge	35^0 27’ 03.42” S	149^0 04’ 27.84” E
MUR 28	U/S Cotter River confluence	Grazing	Riffle and Edge	35^0 19’ 25.22” S	148^0 56’ 59.34” E

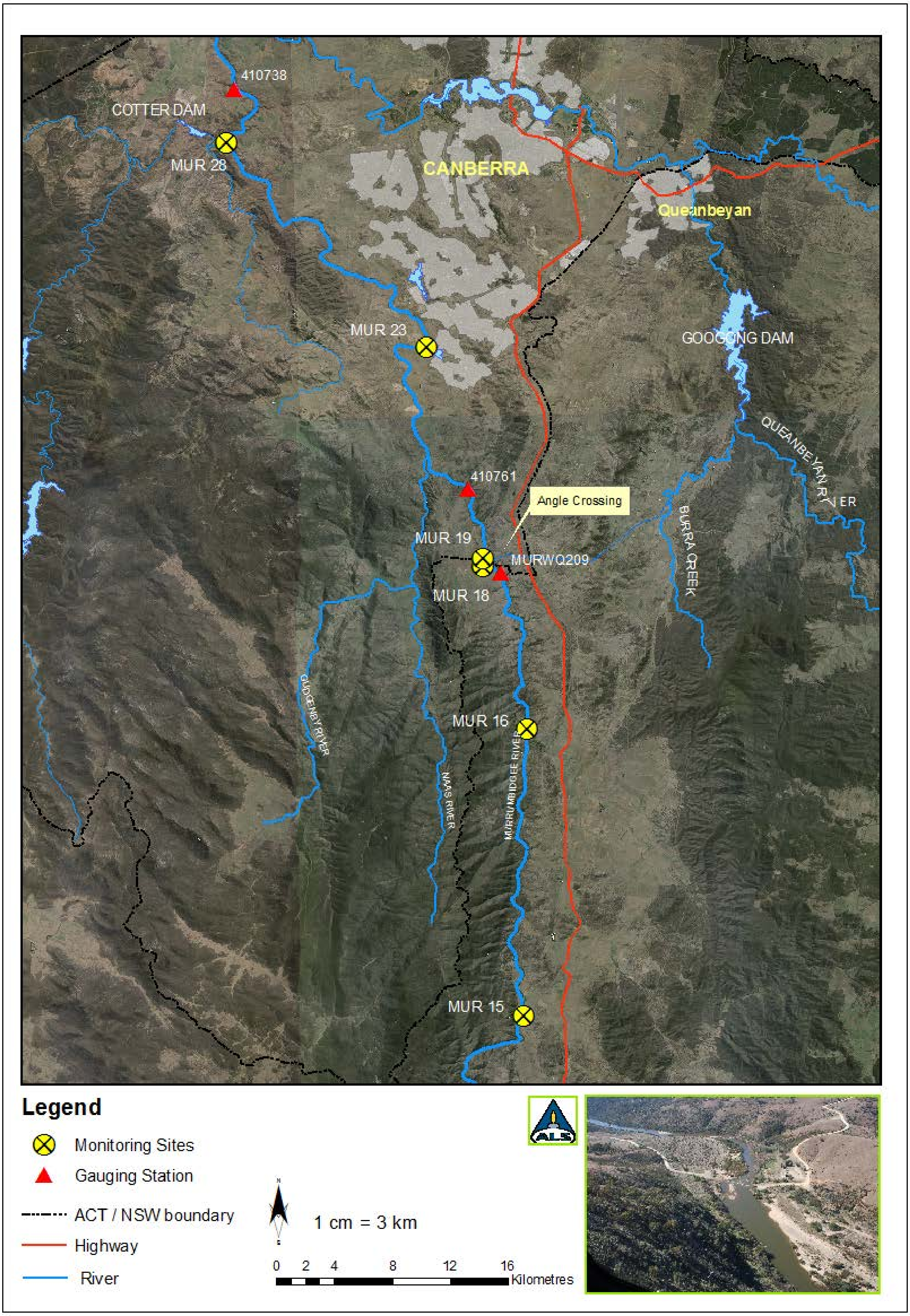
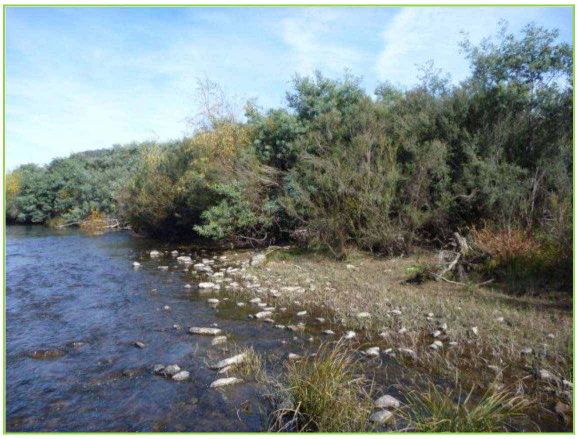
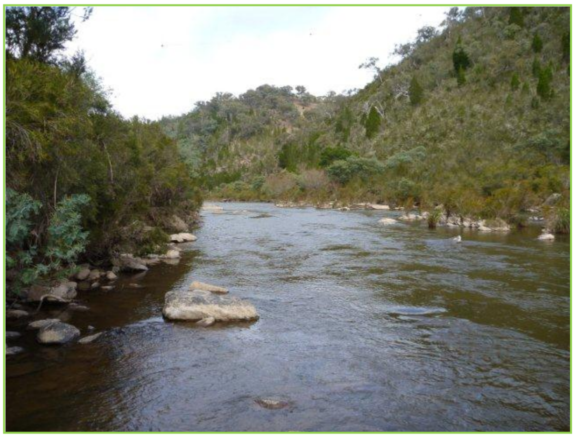


Figure 1. Angle Crossing sampling locations and gauging station

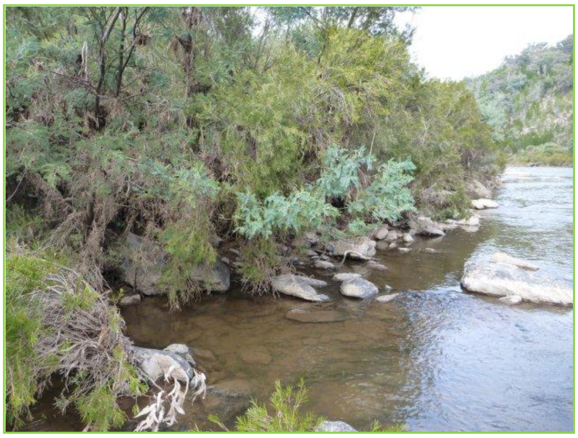
MUR 15. Looking upstream (238 ML/d)



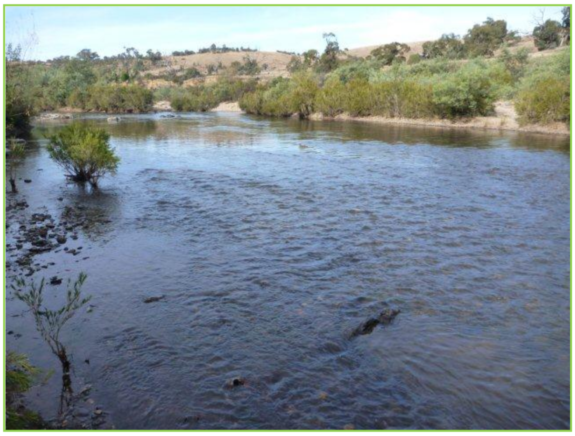
MUR 15. Riparian vegetation



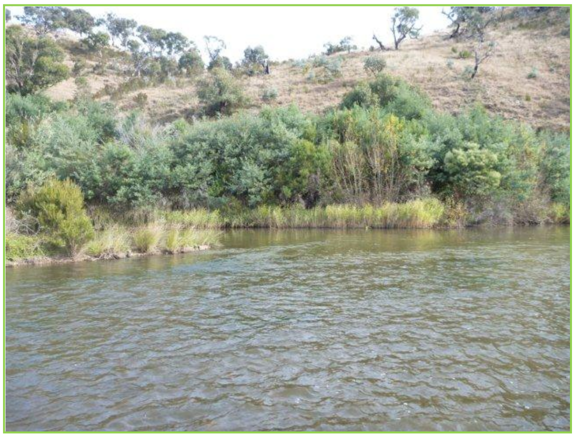
MUR 16. “The Willows” near Michelago (226 ML/d). Looking upstream



MUR 16. Riparian vegetation. Lack of edge habitat is evident

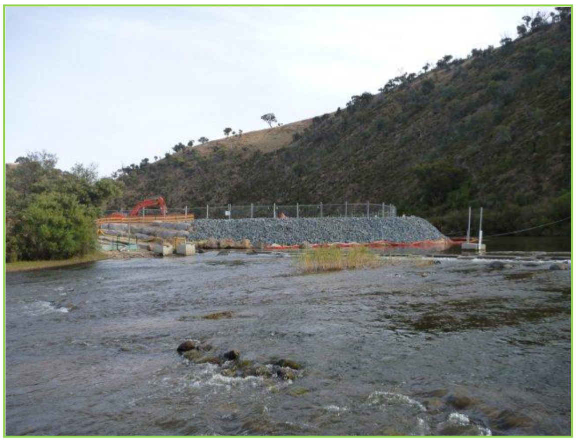


MUR 18. ~800m Upstream of Angle Crossing (255 ML/d)



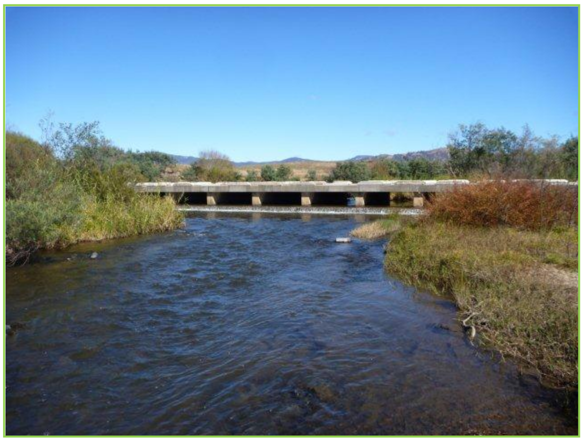
MUR 18. looking across to the edge habitat

PLATE 1. Photographs of sampling sites upstream of Angle Crossing

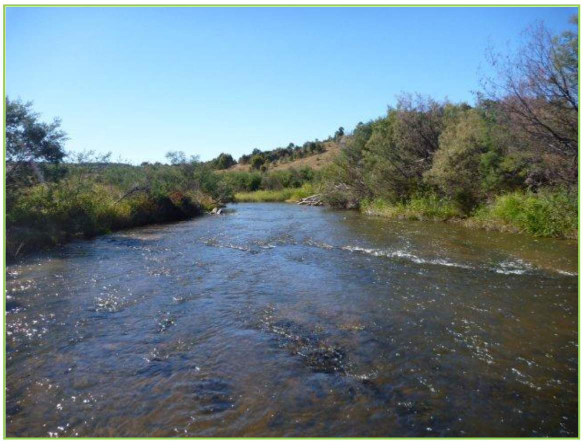


MUR 19. Downstream of Angle Crossing looking up to the coffer dam

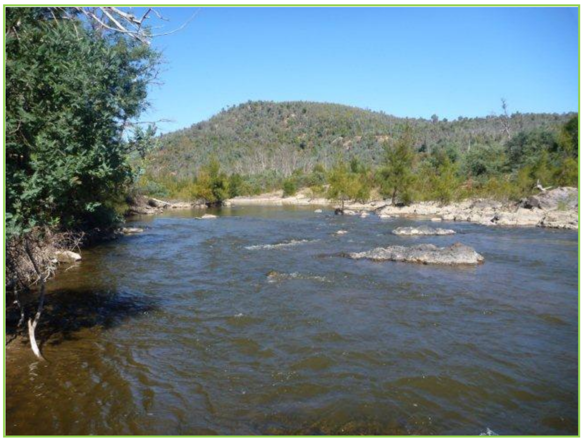
MUR 19. Looking downstream (255 ML/d)



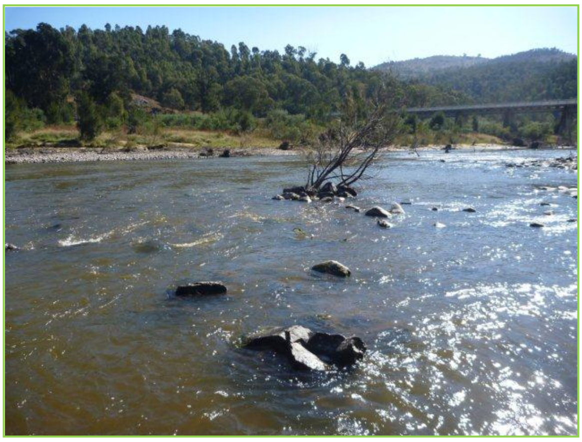
MUR 23. Point Hut Crossing



MUR 23. Looking downstream from bridge (217[1] ML/d)



MUR 28. Looking upstream



MUR 28. Looking downstream towards Cotter Bridge

PLATE 2. Photographs of sampling sites downstream of Angle Crossing

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[1] Recorded at Lobb's Hole Station (410761)

2.2 Hydrology and rainfall

River flows and rainfall for the sampling period were recorded at ALS gauging stations located at Lobb's Hole (downstream of Angle Crossing: 410761) and upstream of Angle Crossing (MURWQ09).

Site locations and codes are given in Table 4.

Stations are calibrated monthly and data are downloaded and verified before storage on the database where it is quality coded. Water level data is verified manually by comparing the logger value to the staff gauge value. If there are differences between logger and staff, the logger is adjusted accordingly. Rain gauges are calibrated and adjusted as required. Records are stored on the HYDSTRA© database software and downloaded for each sampling period.

Table 4. Location and details of continuous water quality and flow stations

Site Code	Location/Notes	Parameters*	Latitude	Longitude
410761	M'bidgee River @ Lobb's Hole (D/S of Angle Crossing)	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.5398	E 149.1015
MURWQ09	M'bidgee River U/S Angle Crossing	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.3533	E 149.0705

* WL = Water Level; Q = Rated Discharge; EC = Electrical Conductivity; DO = Dissolved Oxygen; Temp = Temperature; Turb = Turbidity; Rainfall = Rainfall (0.2 mm increments)

2.3 Water quality

Baseline physico-chemical parameters including temperature, pH, electrical conductivity, turbidity and dissolved oxygen were recorded using a multiprobe Hydrolab® minisonde 5a at sites indicated in Table 2. The Hydrolab® was calibrated following QA procedures and the manufactures requirements prior to sampling. Additionally, grab samples were taken from each site in accordance with the AUSRIVAS protocols (Coysh *et al.*, 2000) for Hydrolab verification and nutrient analysis. All samples were placed on ice, returned to the ALS laboratory, and analysed for nitrogen oxides (total NOx), total nitrogen and phosphorus in accordance with the protocols outlined in APHA (2005). Collectively, this information on the water quality parameters was used to assist in the interpretation of biological data and provide a basis on which to gauge ecosystem changes potentially linked to flow reductions at these key sites following water abstractions.

2.4 Macroinvertebrate sampling and processing

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

Riffle and edge habitats were sampled for macroinvertebrates and analysed in strict accordance with the ACT autumn riffle and edge AUSRIVAS (Australian River Assessment System) protocols (Coysh, *et al.*, 2000) during autumn (May 5th and 6th) 2011. At each site, two samples were taken (where possible) from the riffle habitat (flowing broken water over gravel, pebble, cobble or boulder, with a depth greater than 10 cm; (Coysh, *et al.*, 2000) using a framed net (350 mm wide) with 250 µm mesh size. Sampling began at the downstream end of each riffle. The net was held perpendicular to the substrate with the opening facing upstream. The stream directly upstream of the net opening was disturbed by vigorously kicking and agitating the stream bed, allowing any dislodged material to be carried into the net. The process continued, working upstream over 10 metres of riffle habitat. The samples were then preserved in the field using 70% ethanol, clearly labelled with site codes and date then stored on ice and refrigerated until laboratory sorting commenced.

The edge habitat was also sampled in strict accordance with the ACT AUSRIVAS protocols. Two samples were taken from the edge habitat. The nets and all other associated equipment were washed thoroughly between sampling events and sites to remove any macroinvertebrates retained on them. Samples were collected by sweeping the collection net along the edge habitat at the sampling site. The operator worked systematically over a ten metre section covering overhanging vegetation, submerged snags, macrophyte beds, overhanging banks and areas with trailing vegetation. Samples were preserved on-site as described for the riffle samples.

Processing of the macroinvertebrate samples followed the ACT AUSRIVAS protocols. Briefly, in the laboratory, the preserved macroinvertebrate samples were 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. The contents of randomly selected cells were removed and the macroinvertebrates within each cell were identified to genus level except for Chironomids (sub-family) and Oligochaeta (class). 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. For the AUSRIVAS model, taxa were analysed at family level except for: Chironomidae (sub-family), Oligochaeta (class) and Acarina (order) until 200 animals were identified (identification followed taxonomic keys published by Hawking (2000). If 200 animals were identified before a cell had been completely analysed, identification continued until the animals in the entire cell were identified. Data were entered directly into electronic spread sheets to eliminate errors associated with manual data transfer.

2.5 Periphyton

Estimates of algal biomass were made using complimentary data from both chlorophyll-*a* (which measures autotrophic biomass) and ash free dry mass (AFDM) which estimates the total organic matter in periphyton samples and includes the biomass of bacteria, fungi, small fauna and detritus in samples) of the periphyton samples (Biggs, 2000).

The six sites shown in Table 2 were sampled for periphyton in autumn in conjunction with the macroinvertebrate sampling. All periphyton - adnate and loose forms of periphyton, as well as organic/inorganic detritus in the periphyton matrix, were collected using the *in-situ* syringe method similar to Loeb (1981) as described in Biggs and Kilroy (2000). A 1m wide transect was established across riffles at each site. Along each transect, twelve samples were collected at regular intervals, using a syringe sampling device, based on two 60 ml syringes and a scrubbing surface of stiff nylon bristles, covering an area of ~637 mm^2. The samples were then divided randomly into two groups of six samples to be analysed for Ash Free Dry Mass (AFDM gm^{-2}), and chlorophyll-*a*. Samples for AFDM (gm^{-2}) and chlorophyll-*a* analysis were filtered onto glass filters and frozen. Sample processing follows the methods outlined in APHA (2005).

Qualitative assessments of the estimated substrate coverage by periphyton and filamentous green algae were also conducted at each site in accordance with the AUSRIVAS habitat assessment protocols (Coysh, *et al.*, 2000) to compliment the quantitative samples.

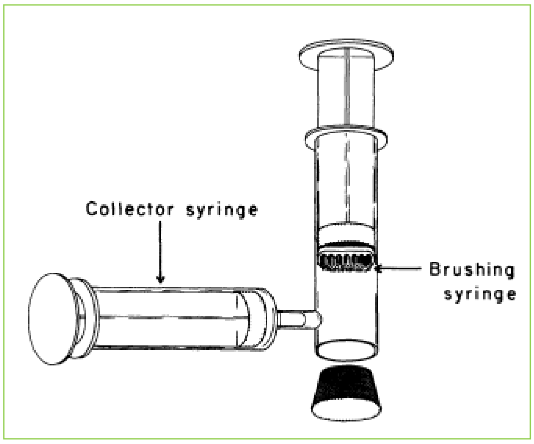

Plate 3. Diagram of the periphyton sampler (taken from Loeb, 1981)

Plate 4. Periphyton sampler in operation

2.6 Macroinvertebrate quality control procedures

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

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

All procedures were performed by AUSRIVAS accredited staff.

2.7 Licences and permits

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

ALS field staff maintains current ACT and NSW AUSRIVAS accreditation.

2.8 Data analysis

2.8.1 Water quality

Water quality parameters were examined for compliance with ANZECC water guidelines for healthy ecosystems in upland streams (ANZECC and ARMCANZ, 2000). Trend analyses of water quality parameters will be conducted at the end of the baseline collection period. This report only presents results based on autumn 2011 sampling.

2.8.2 Macroinvertebrate communities

The macroinvertebrate data were examined separately for riffle and edge habitats. Replicates were examined individually (i.e. not averaged) at all sites to examine within-site variation as much as it is to describe patterns among sites. The PERMDISP routine in PERMANOVA+ was used to test for homogeneity of multivariate dispersions based on Bray-Curtis similarities from the macroinvertebrate similarity matrix. The rationale for conducting this test was based on our previous observations from the Angle Crossing macroinvertebrate data set, which has revealed considerable within-site variation in community assemblages. Variation in multivariate dispersions can have two potential consequences on both the hypothesis testing component of the community analysis and the interpretation of the ordination plots. Because both the ANOSIM and PERMANOVA tests are sensitive to differences in multivariate dispersions (one of the design assumptions is homogenous dispersions of residuals and random effects), this test serves to test of one of the key assumptions of the macroinvertebrate community modelling. Furthermore, different degrees of variability (multivariate dispersions) among sites or grouping factors can be an important indicator of environmental stress on benthic communities (Warwick and Clarke, 1993); so may be an important component of this monitoring program in its own right (Anderson *et al.*, 2008). All multivariate analyses were performed using PRIMER version 6 (Clarke and Gorley, 2006) and PERMANOVA + (Anderson, *et al.*, 2008). Univariate statistics were performed using R version 2.12.1 (R Development Core Team, 2010).

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

The initial step in this process was to calculate a similarity matrix for all pairs of samples based on the Bray-Curtis similarity coefficient (Clarke and Warwick, 2001). For the macroinvertebrate data collected during this survey, the final number of dimensions was reduced to two. Stress values for each NMDS plot were examined before results were interpreted. The stress level is a measure of the distortion produced by compressing multidimensional data into a reduced set of dimensions and will increase as the number of dimensions is reduced and can be considered a measure of “goodness of fit” to the original data matrix (Kruskal, 1964). Stress values near zero suggest that NMDS patterns are very representative of the multidimensional data, while stress values greater than 0.2 indicate a poor representation and, therefore, the need to interpret NMDS plots with these sorts of stress values with caution (Clarke and Warwick 2001).

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

In addition to these analyses, variation in the macroinvertebrate data set was modelled against environmental, physical and water quality variables to explore which variable or combination of variable correlate to the macroinvertebrate resemblance matrix. This was performed using the BIO-ENV procedure in PRIMER V6. BIO-ENV which compares the biotic and environmental similarity matrices based on all possible combinations of the environmental variables; resulting in a rank-correlation coefficient (Spearman's Rho was selected) which can take on values between -1 and +1. The extreme Spearman Rho values indicate either complete disagreement or complete agreement respectively, between the two similarity matrices (Clarke and Warwick, 2006). Values around zero indicate no relationship between the biotic and abiotic data sets. Statistical significance of the global test (i.e. between all variables in the abiotic matrix and the macroinvertebrate data set) were obtained by 999 permutations to create a null-distribution to which our observed value of ρ is compared. The most parsimonious set of variables was selected on the basis of the best fit (i.e. smallest number of variables and highest ρ-value) since there are no formal tests available in this procedure for individual model selection.

2.8.3 AUSRIVAS assessment

In addition to assessing the composition and calculating biometrics from the macroinvertebrate data, riffle and edge samples, river health assessments based on the ACT AUSRIVAS spring riffle and edge models were conducted. AUSRIVAS is a prediction system that uses macroinvertebrate communities to assess the biological health of rivers and streams. Specifically, the model uses site-specific information to predict the macroinvertebrate fauna expected (E) to be present in the absence of environmental stressors. The expected fauna from sites with similar sets of predictor variables (physical and chemical characteristics which cannot be influenced due to human activities, e.g. altitude) are then compared to the observed fauna (O) and the ratio derived is used to indicate the extent of any impact (O/E). The ratio derived from this analysis is compiled into bandwidths (i.e. X, A-D; Table 5) which are used to gauge the overall health of particular site (Coysh *et al.* 2000). Data is presented using the AUSRIVAS O/E 50 ratio (Observed/Expected score for taxa with a >50% probability of occurrence) and the previously mentioned rating bands (Table 5).

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

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

2.8.4 SIGNAL-2 (Stream Invertebrate Grade Number – Average Level)

Stream Invertebrate Grade Number – Average Level (SIGNAL) is a biotic index based on pollution sensitivity values (grade numbers) assigned to aquatic macroinvertebrate families that have been derived from published and unpublished information on their tolerance to pollutants, such as sewage and nitrification (Chessman, 2003). Each family in a sample is assigned a grade between 1 (most tolerant) and 10 (most sensitive). Sensitivity grades are also given in the AUSRIVAS output which can then be used as complimentary information to these assigned bandwidths to aid the interpretation of each site assessment.

We conducted linear mixed effect ANOVA models separately for the riffle and edge samples to test for location differences in the univariate metrics: SIGNAL-2 scores and AUSRIVAS OE50 ratios. The factor, “site” (nested within location) was considered a random effect representing the river condition upstream and downstream of the proposed abstraction point; while location (up- and downstream) was considered a fixed, constant effect. Data transformations were not necessary because the model assumptions were met on all accounts. Models were constructed using lme4 (Bates *et al.*, 2011) a statistical package applied in the R environment (R Development Core Team, 2010)). For all analyses, the level of significance (alpha) was set to 5%.

Several metrics in addition to AUSRIVAS and SIGNAL-2 were used. The number of taxa (taxa richness) was counted for each site and other descriptive metrics such as the relative abundances of pollution-sensitive taxa (Ephemeroptera, Plecoptera and Trichoptera- EPT) and, pollution-tolerant taxa, (i.e. Oligochaeta and Chironomids) were examined at family and genus levels. Taxa richness was monitored as a means of assessing macroinvertebrate diversity. In assessing the taxonomic richness of a site, it is important to keep in mind that high taxa richness scores may, though does not always, indicate better ecological condition at a given location. In certain instances high taxa richness may indicate a response to the provision of new habitat or food resources that might not naturally occur as a result of anthropogenic activities.

Table 5. AUSRIVAS band-widths and interpretations for the ACT autumn riffle and edge models

	RIFFLE	EDGE	
BAND	**O/E Band width**	**O/E band width**	**Explanation**
X	>1.12	>1.17	More diverse than expected. Potential enrichment or naturally biologically rich.
A	0.88-1.12	0.83-1.17	Similar to reference. Water quality and / or habitat in good condition.
B	0.64-0.87	0.49-0.82	Significantly impaired. Water quality and/ or habitat potentially impacted resulting in loss of taxa.
C	0.40-0.63	0.15-0.48	Severely impaired. Water quality and/or habitat compromised significantly, resulting in a loss of biodiversity.
D	0-0.39	0-0.14	Extremely impaired. Highly degraded. Water and /or habitat quality is very low and very few of the expected taxa remain.

2.8.5 Periphyton

To test whether estimated biomass (AFDM) and live content (chlorophyll-*a*) were different between sites upstream and downstream of Angle Crossing, a mixed effects, analysis of variance was fitted to the Log-transformed data for AFDM and Chlorophyll-a. The factor “site”, was nested within location (upstream or downstream of the abstraction point). Consequently, site and location were treated as random and fixed effects, respectively in the ANOVA model. Log-transformation was necessary to meet the assumptions of normality. For the purposes of graphical visualisation, however, raw data are presented.

The relationship between the autumn periphyton data and a suite of environmental and physico-chemical water quality parameters was examined using Pearson’s product moment coefficients. Chlorophyll-a and AFDM data were log transformed to perform this analysis. The Pearson correlation coefficient measures the strength of the relationship between two variables (x and y). The correlation coefficient, denoted as “R”, can be positive or negative, with the values -1 or +1 indicating that the observations fall along a straight line (either negatively or positively) and 0 indicating no relationship between the variables. Univariate statistics were performed using R version 2.12.1 (R Development Core Team, 2010). Significance testing was not performed on these data because of low sample size (N=6 in all cases).

3 Results

3.1 Summary of sampling conditions

Autumn sampling was completed over two days in May (5th and 6th). Upstream sites were sampled on the 6th and downstream sites were sampled on the 5th of May. Mean daily flows recorded at the time of sampling at MURWQ09 (upstream of Angle Crossing) and 410761 (Lobb's Hole: downstream of Angle Crossing) were 252 ML/d and 225 ML/d respectively. In this round of sampling, flow conditions were stable for much of autumn due to low rainfall over the preceding months, although as a result there was limited edge habitat at MUR 16 and MUR 28 which meant only 1 edge sample was possible at these sites (Table 6). Air temperatures during the sampling period ranged between 11°C and 16°C and weather conditions were fine.

Table 6. Macroinvertebrate samples collected during the autumn sampling run

Site	Edge	Riffle
MUR 15	2	2
MUR 16	1	2
MUR 18	2	2
MUR 19	2	2
MUR 23	2	2
MUR 28	1	2

3.2 Field observations

During the autumn sampling period there was an observable increase in the amount of silt in the riffle and edges at MUR 19 (downstream of Angle Crossing) and at MUR 23 compared to the upstream sites. In previous reports we have suggested that the sources of siltation at these sites are likely to be the dirt roads flanking the low-level crossing at MUR 19 and the Point Hut Pond Spillway at MUR 23. There was an obvious lack of macrophytes across all sites, which were likely scoured out during the spring flood. Filamentous algae were also noticeably absent across most sites, but there was significant stands of new filamentous algal growth at MUR 18 and MUR 19 (immediately up and downstream of Angle Crossing respectively). Flows appeared to be dropping at all sampling sites. Iron bacteria deposits occurred along the margins at MUR 15, MUR 18 and MUR 23.

3.3 Hydrology and rainfall

There were two significant high flow events prior to autumn sampling (Figure 2). Both events occurred in May and happened approximately six weeks before sampling. The first event peaked at 5186 ML/d and while the second event was smaller, peaking at 2100 ML/d, representing an average annual recurrence interval of 1.5yr and 1yr respectively.

These events responded to two separate rainfall events, the first of which occurred over 5 days where 60.8mm of rain was received and the second, 1 week later where 24.8mm fell in 24 hours with a further 13.8mm falling over a four day period. The resulting average flows for March (Table 6) were the 6th highest on record (period of record: 1975-2011); and the 4th highest total rainfall recorded at Lobb's Hole. Total rainfall was highest in March at both stations (Table 7), with 11 wet days at Lobb's Hole and 9 recorded at the pluviometer upstream of Angle Crossing. In contrast to the March rainfall, rainfall in April was the 4th lowest on record (period of record: 1975-2011).

Despite these events early in the season, the flows leading up to the autumn sampling period were stable throughout April (Figure 2), and this pattern of stable flows continued throughout autumn. Mean flow for April was 230.7 ML/d upstream of Angle Crossing and 276.3 ML/d at Lobb's Hole (Table 7). Flows during March were more than three times the April average flow and more than four times the averages recorded in May at both gauging stations.

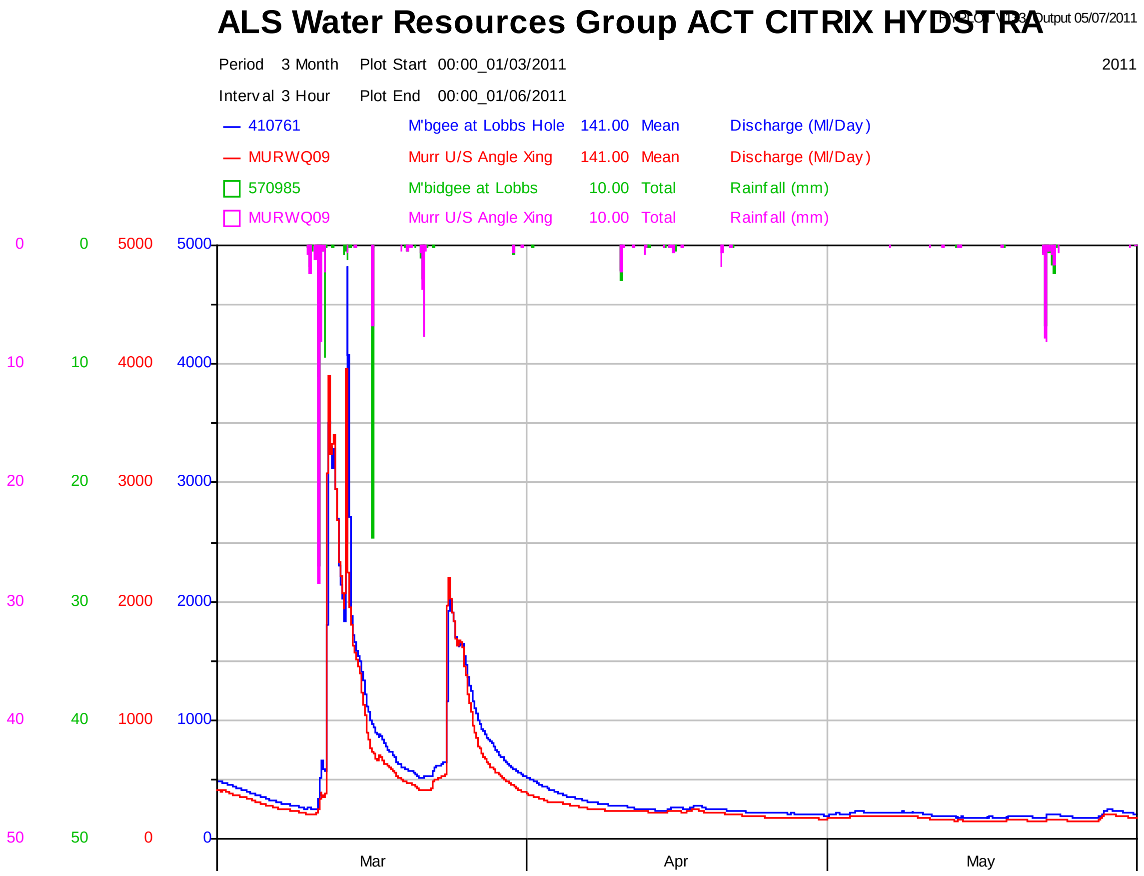

Figure 2. Autumn hydrograph of the Murrumbidgee River upstream of Angle Crossing (MURWQ09) and downstream of Angle Crossing at Lobb's Hole (410761)

Table 7. Autumn rainfall and flow summaries upstream and downstream of Angle Crossing. Flow values are daily means. Rainfall is total (mm).

Site	Upstream Angle Crossing (MURWQ09)		Lobb's Hole (410761)	
	Rainfall Total (mm)	Mean Flow (ML/d)	Rainfall Total (mm)	Mean Flow (ML/d)
March	74.6	774.7	99.2	869.5
April	9.4	230.7	7.2	276.3
May	22.2	169.0	20.4	201.0
Autumn (total (mean))	106.2 (35.4)	391.4	126.8 (42.2)	448.9

3.4 Water quality

3.4.1 Continuous records

Due to ongoing storm events between September 2010 and March 2011, pH data are missing from Lobb's Hole for most of the autumn period because of lightening damage to the pH sensor. Replacement probes were installed at Lobb's Hole following previous damage from the spring 2010 events, but these were also damaged from subsequent lightning strikes. Consequently, necessary repairs to the pH sensor on a number of hydrolabs meant that these data were not captured at Lobb's Hole in autumn 2011. pH data recorded upstream of Angle Crossing ranged between 6.95 and 8.05 during autumn. Based on daily means, pH was within the ANZECC and ARMCANZ (2000) guidelines (6.5-8.0; Table 8) for the entire period (Table 8).

Water temperatures between the upstream and downstream gauging stations were highly correlated throughout autumn (Table 8), with monthly means ranging from 10 – 20. 2°C. Overall, the time series shows a steady decline over the three month period at both gauging stations (Figures 3 & 4).

Dissolved oxygen ranges were broader upstream of Angle Crossing (range: 94-105) compared to Lobb's Hole (range: 94-97) (Tables 4 & 5), which as explained in previous reports (ALS, 2010a & 2010b) can be attributed to the shallower sensor depth, upstream of Angle Crossing. Despite the variation in ranges, mean daily dissolved oxygen minimums and maximums at both stations were within the ANZECC and ARMCANZ (2000) water quality guidelines 100% of the time in autumn (Table 8). In fact, all gauged parameters, except turbidity met the guidelines 100% of the time for the autumn period (Table 8). Turbidity increased in response to the two events discussed in section 3.3. The highest turbidity recorded was 965 NTU at Lobb's Hole following the first event in March (peaking at >5000 ML/d), maximum turbidity at MURWQ09 was 362 NTU during the same event.

Electrical conductivity (EC) decreased downstream as a function of increasing water volumes and dilution. Upstream of Angle Crossing, EC averaged 119µs/cm^{-2} for autumn, while downstream, EC was only slightly lower on average at 107µs/cm^{-2} (Table 8).

Water quality results based on the grab samples are in agreement with the continuous records in that all of the *physico-chemical* parameters were within the ANZECC and ARMCANZ (2000) guidelines (Table 9). Most of these parameters were comparable between sampling sites. EC and alkalinity exhibited mild downstream gradients, however the range of values (EC: range [97.4-111.6]; Alkalinity: range [43-48]) were lower than in previous sampling runs. pH was the most constant and only varied by 0.1 of a pH unit between sites.

Total nitrogen (TN) and Total phosphorus (TP) exceeded the guideline values at all monitoring sites during autumn (Table 10). The highest concentrations of TP were found at two sites upstream of Angle Crossing: MUR 15 and MUR 18(0.04 mg/L), which were 2 times higher than the recommended level of 0.02 mg/L, whereas TP recorded at MUR 23 was on the cusp of the recommended upper limit. Despite exceeding the recommended upper limit of 0.02mg/L, these TP values are the lowest recorded across all of the sampling sites since the program began in spring 2008. TN ranged between 0.26-0.28 mg/L and was highest at MUR 16.

Table 8. Monthly water quality statistics from upstream (MURWQ09) and downstream (410761) of Angle Crossing. All values are means, except D.O. % Sat. which is expressed as mean monthly minimums and maximums.

Analyte	Temp. °C		EC (us/cm)		pH		Turbidity (NTU) Max. in parentheses		D.O (% sat.)	
	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S
March	20.1	20.2	118.7	92.3	7.34	7.98*	56 (362)	188 (965)	94-101	93-97
April	15.2	15.3	114.2	109.7	7.67	N/A	16 (32)	5 (18)	96-107	96-98
May	10.3	10.3	124.1	120.4	7.74	N/A	8 (10)	5 (30)	94-107	95-98
Autumn	15.2	15.2	119	107.4	7.58	7.98	26 (362)	66 (965)	94-105	94-97

Table 9. Compliance (%) to ANZECC and ARMCANZ (2000) guideline values from the continuous gauging stations upstream (MURWQ09) and downstream (410761) of Angle Crossing.

Compliance values are expressed as the percentage of days throughout the autumn period (based on daily means) that values met the guidelines. Dissolved oxygen refers to mean daily minimum and mean daily maximums.

Analyte	EC (us/cm) 30-350		pH 6.5-8.0		Turbidity (NTU) 2-25		D.O (% sat.) 90-110	
	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S
March	100%	100%	100%	100%*	38%	25%	100%	100%
April	100%	100%	100%	N/A	80%	100%	100%	100%
May	100%	100%	100%	N/A	100%	100%	100%	100%
Autumn	100%	100%	100%	N//A	72%	76%	100%	100%

Notes: There are currently no guidelines available for water temperature

- * Two data points
- N/A = Not available

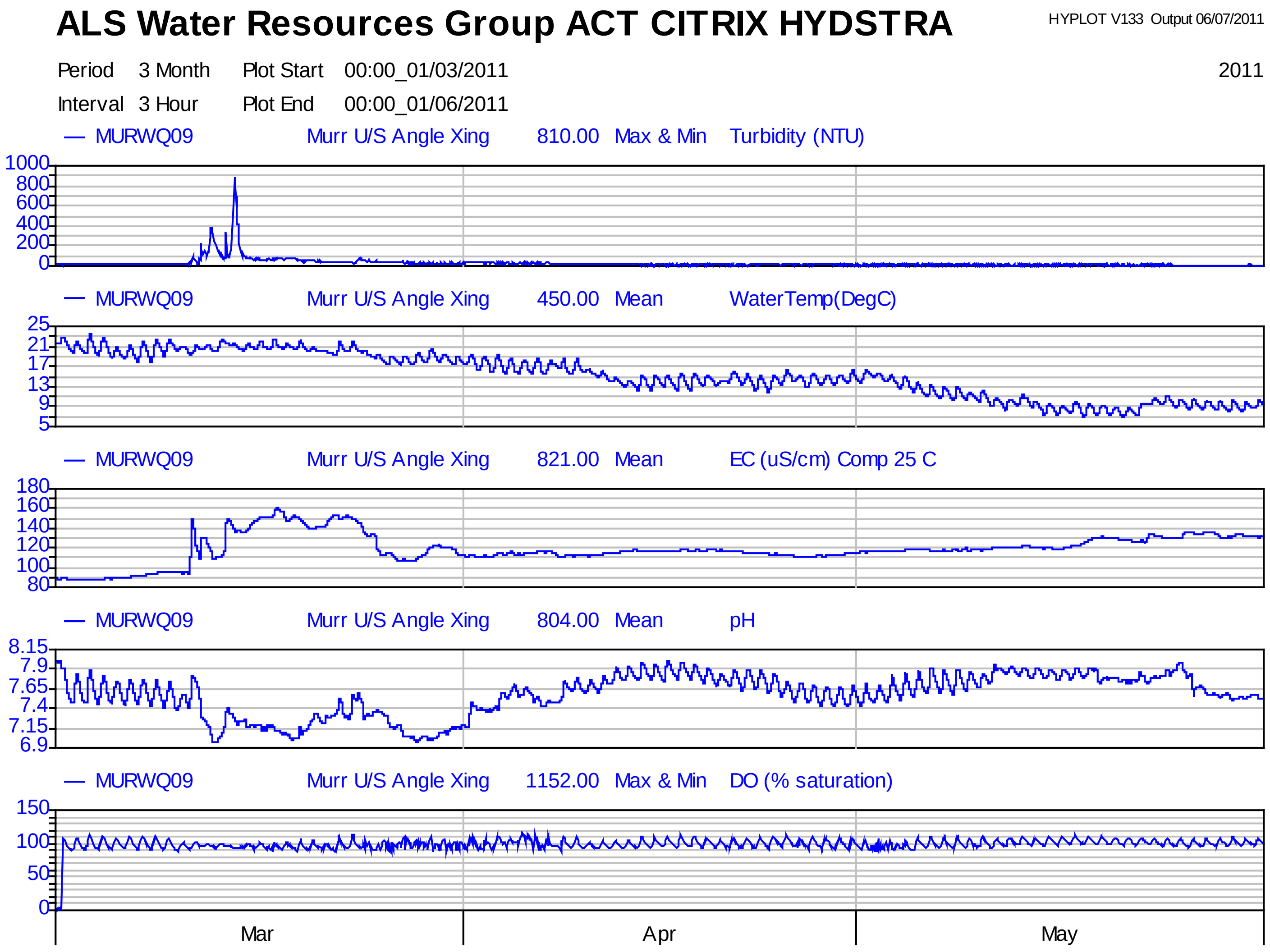

Figure 3. Continuous water quality records from upstream Angle Crossing (MURWQ09) for autumn 2011.

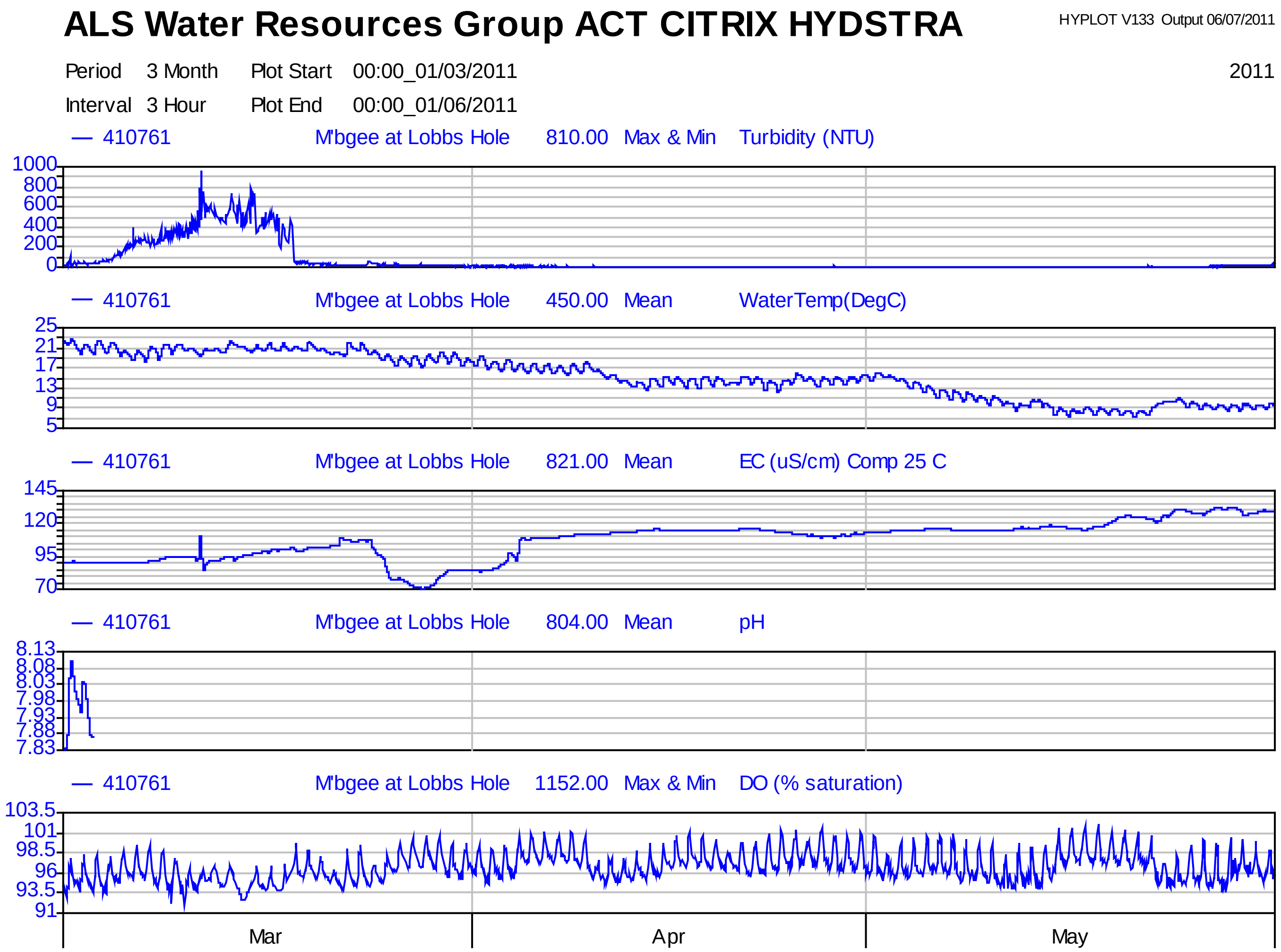

Figure 4. Continuous water quality records from Lobb's Hole (downstream Angle Crossing: 410761) for autumn 2011.

Table 10. In-situ water quality results from spring 2010 (ANZECC guidelines are in bold parentheses). Yellow cells indicate values outside of ANZECC and ARMCANZ (2000) guidelines. Orange cells indicate value is on the cusp of the guideline.

EC = Electrical conductivity; TSS = Total suspended solids; D.O = Dissolved oxygen; Alk. mg/L; TP = phosphorus; TN = total nitrogen

Location	Site	Time Date	Temp (°C)	EC (µs/cm) **(30-350)**	Turb. (NTU) **(2-25)**	TSS(mg/L)	pH **(6.5-8)**	D.O. (% Sat.) **(90-110)**	Dissolved Oxygen (mg/L)	Alk.	NOX (mg/L) **(0.015)**	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L) **(0.02)**	TN (mg/L) **(0.25)**
Control sites	MUR 15	11.00 6/5/11	12.9	97.4	6.2	10	7.7	96.6	10.4	43	<0.01	<0.01	<0.01	<0.01	0.04	0.26
	MUR 16	10.10 6/5/11	10.9	105.7	7.5	10	7.8	95.5	10.7	46	<0.01	<0.01	<0.01	<0.01	0.03	0.28
	MUR 18	14.00 6/5/11	12.2	107.9	5.4	10	7.8	98.8	10.7	47	<0.01	<0.01	<0.01	0.03	0.04	0.26
Downstream sites	MUR 19	15.30 5/5/11	12.3	108.7	5.2	9	7.8	99.3	10.8	46	<0.01	<0.01	<0.01	<0.01	0.03	0.27
	MUR 23	11.50 5/5/11	9.8	107.1	5.7	7	7.8	96.8	11.1	48	<0.01	<0.01	<0.01	0.02	0.02	0.26
	MUR 28	12.00 5/5/11	13.9	111.6	6.9	11	7.8	100.2	10.5	48	<0.01	<0.01	<0.01	0.04	0.03	0.27

3.5 Periphyton

The chlorophyll-a concentration ranged from 2583µg/m^{-2} at MUR 18 to 119242 µg/m^{-2} at MUR 28 (Figure 5). On average, these concentrations were higher downstream of Angle Crossing (mean =28077µg/m^{-2}) compared to upstream (mean = 18489µg/m^{-2}), however, these differences were not statistically different ($F_{1,4}$ =0.965; P>0.05; Table 11). These data show an apparent lack of spatial structure compared to previous sampling runs. Previously, there have been pronounced increases in both the range and median values from MUR 23 downstream which was not apparent from the autumn 2011data.

The organic content from the periphyton samples (AFDM) indicates a wider range of AFDM values at the farthest upstream sites (MUR 15 and 16) compared to sites further downstream (Figure 6). AFDM concentrations were higher on average upstream of Angle Crossing (mean=8280 mg/m^{-2}) compared to downstream of Angle Crossing (mean = 6403 mg/m^{-2}), but again these differences were not statistically significant ($F_{1,4}$ =0.035; P>0.05; Table 11).

Table 11. Nested analysis of variance results for chlorophyll-a and AFDM concentration

Response	Source	DF	F-value	P-value
Chlorophyll-*a* (log)	Location	1	0.965	0.38
	Site [Location]	4	1.788	0.15
	Residual	35		
AFDM (log)	Location	1	0.035	0.86
	Site [Location]	4	2.029	0.11
	Residual	35		

The relationship between periphytic AFDM and chlorophyll-a was weak (R=-0.39) indicating that the organic component of the periphyton samples were not dominated by a live algal component but were either dominated by secondary producers such as macroinvertebrates or detritus (including leaf litter and dead algae fragments for example) or a combination of both components. The relationship between AFDM and mean current velocity was weakly negative, suggesting some removal through increased velocities (Table 12). Pearson's correlation coefficient was weaker than in spring (spring 2010: R= -088) but was comparable to autumn 2010 (R= -0.17). AFDM appeared to increase as the percentage of trees <10m within the reach increased. AFDM also tended to increase with more stable substrates such as boulders (R=0.42) and cobbles (R=0.39) (although these relationships were moderate) and tended to decline as the substrate became more sandy (-0.53).

Chlorophyll-concentrations increased with mean velocity (R=0.91; Table 12) and while there were mildly positive increases in chlorophyll-a concentrations with boulders and total phosphorus, the main influence upon chlorophyll- a concentrations appeared to be water temperature (R=0.82) and dissolved oxygen (% saturation) (R=0.82).

Table 12. Pearson's correlation coefficients between mean AFDM, mean chlorophyll-a concentrations and the most important environmental parameters (based on the strength of the correlation)

Parameter	Mean log AFDM	Parameter	Mean log Chlorophyll-a
Mean velocity	-0.31	Mean velocity	0.91
Trees <10m	0.92	Water temp.	0.82
Boulder	0.42	D.O % sat.	0.82
Cobble	0.39	TP	0.37
Sand	-0.53	Boulder	0.31

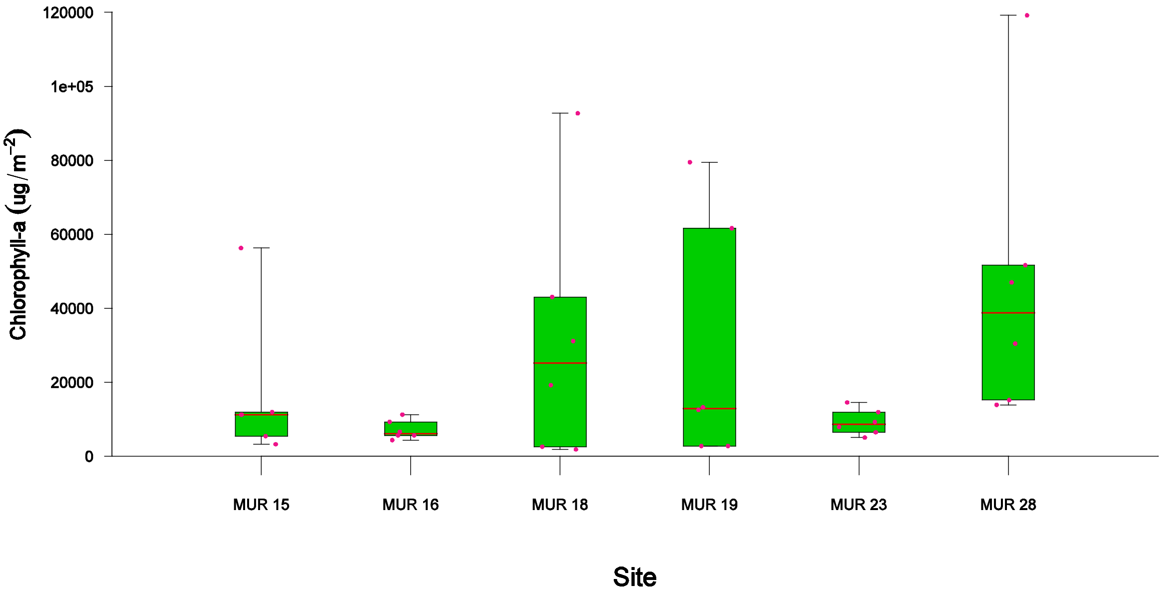

Figure 5. The distribution of Chlorophyll-a upstream and downstream of Angle Crossing. Strip chart values (in pink) represent the raw data values for each site.

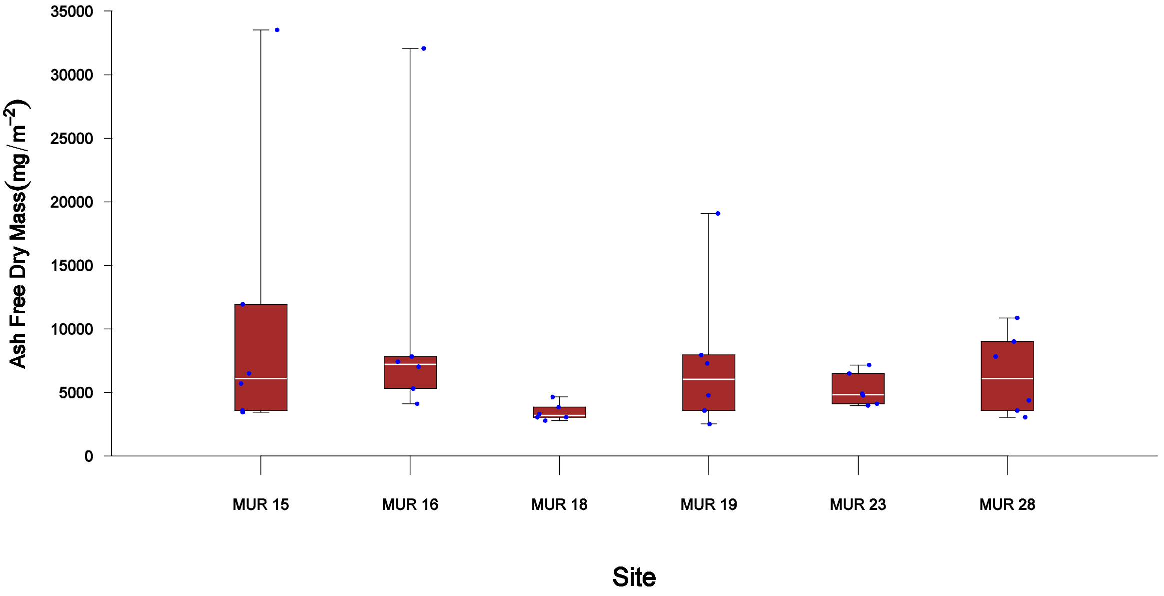

Figure 6. The distribution of Ash Free Dry Mass upstream and downstream of Angle Crossing. Strip chart values (in blue) represent the raw data values for each site.

See APPENDIX C for an explanation of how to interpret box and whisker plots.

3.6 Macroinvertebrate communities

3.6.1 Riffles

Results from the ANOSIM procedure indicate no location effect in the macroinvertebrate communities (R=-0.18; P=0.7). The negative R-value gives a strong indication that some samples within each location are more similar to samples from other sites than their own. This can be seen in the NMDS plot (Figure 7) particularly at MUR 19 and MUR 23, which both have samples with higher similarity percentages with other sites, namely MUR 16 and MUR 18. Sites downstream of Angle Crossing were more dispersed (i.e. more variable in relation to other sites within the downstream section) than sites upstream ($F_{1,36}$ = 7.38; P=0.014). This is reflected in the positioning of the sites in the ordination plot (Figure 7). The moderately high stress values warrant the inclusion of a cluster analysis for validation (Figure 8). In this case the NMDS ordination appears to project a similar grouping structure to the cluster analysis dendrogram suggesting it is a reasonable representation of the riffle macroinvertebrate communities, despite the stress value of 0.196.

There appears to be a general lack of structure in the NMDS plot, which is largely to do with the high degree of similarity between all of the sampling sites. The NMDS ordination is showing that at 65% similarity, the riffle samples were indistinguishable (Figure 7), indicating a high level of shared taxa between sites. In fact, 80% of the ten most dominant taxa among all sites were shared across all sites. In other words, only 20% of the most dominant taxa were unique to any given site. At 75% similarity, there was some separation of the riffle communities, and this separation tended to be driven by changes in the relative abundances of certain taxa rather than a shift in the composition of the communities. For example, Hydropsychidae (Trichoptera) tended to dominate MUR 15, 16 and 23, while at MUR 19, Simuliidae (Diptera) were the most dominant taxa followed by Hydropsychidae, Baetidae and Oligochaetes. The position of one of the samples from MUR 16 in relation to MUR 19 indicates that this sample is a potential outlier. The reason for this position of this sample is the absence of Acarina, Hydroptilidae and Orthocladiinae, which were otherwise common in the other samples.

At the family level, taxa richness ranged from 18 at MUR 16 to 21 at MUR 18 & MUR 23 (Figure 9). Genus level richness was highest at MUR 18, with 31 taxa and lowest at MUR 15 where 23 genera were documented. Of these taxa, 8 EPT families were collected at all sites, except MUR 28, where 9 families were found. Since the high flow events during spring, there has been an overall increase in the number of taxa collected in the EPT suite, leading to a dramatic increase in the relative abundance of sensitive taxa compared to tolerant taxa (Figure 10). Notably, while the spring samples were dominated by very high numbers of Simulids and Oligochaetes (which inflated the tolerant taxa relative abundances (ALS, 2010*b*)), there was a sharp increase in the number of EPT taxa (i.e. the sensitive taxa metric) in this round of sampling. The most obvious change was a ten-fold increase in the estimated abundances of Baetid mayflies (SIGNAL=5), Hydropsychidae (SIGNAL=6) and Leptophlebiidae (SIGNAL =8) compared to spring. The stonefly: *Dinotoperla sp.* (Gripopterygidae: SIGNAL=8) was collected at more locations during this round of sampling, but was only found in one sample at MUR 23 during spring 2010. At the remaining sites, individual numbers of *Dinotoperla sp.* were low (<100).

At Mur 18 and 23, the relative abundance of sensitive taxa was above 80% reflecting very high numbers (>1500) of *Cheumatopsyche sp.* (Hydropsychidae) and two unidentified genera from the Baetid family. MUR 19 was more evenly represented by both groups, which was a result of a sharp increase in Simulids and a decline in mayfly taxa.

The BIO-ENV results show a moderately strong relationship based on Spearman's rho statistic (ρ= 0.65; P=0.01) between the macroinvertebrate riffle communities and a combination of: current velocity; water temperature and alkalinity. The ten combinations of environmental variables which best explain the patterns shown in the macroinvertebrate data are shown in APPENDIX D.

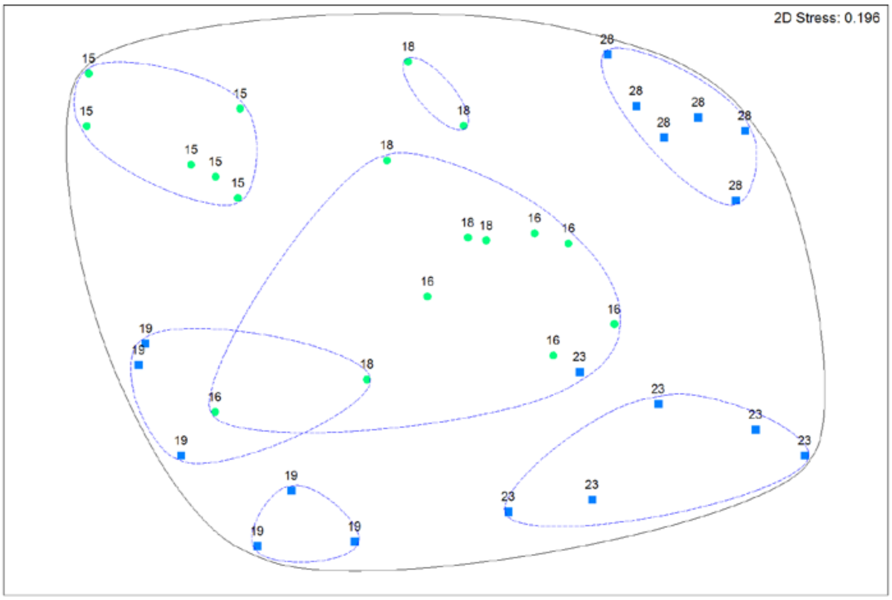

Figure 7. Non-metric multidimensional scaling of genus data from the spring riffle samples. The blue Ellipses represent the 75% similarity groups and the black ellipse shows the 65% similarity boundary superimposed from the cluster analysis (below)

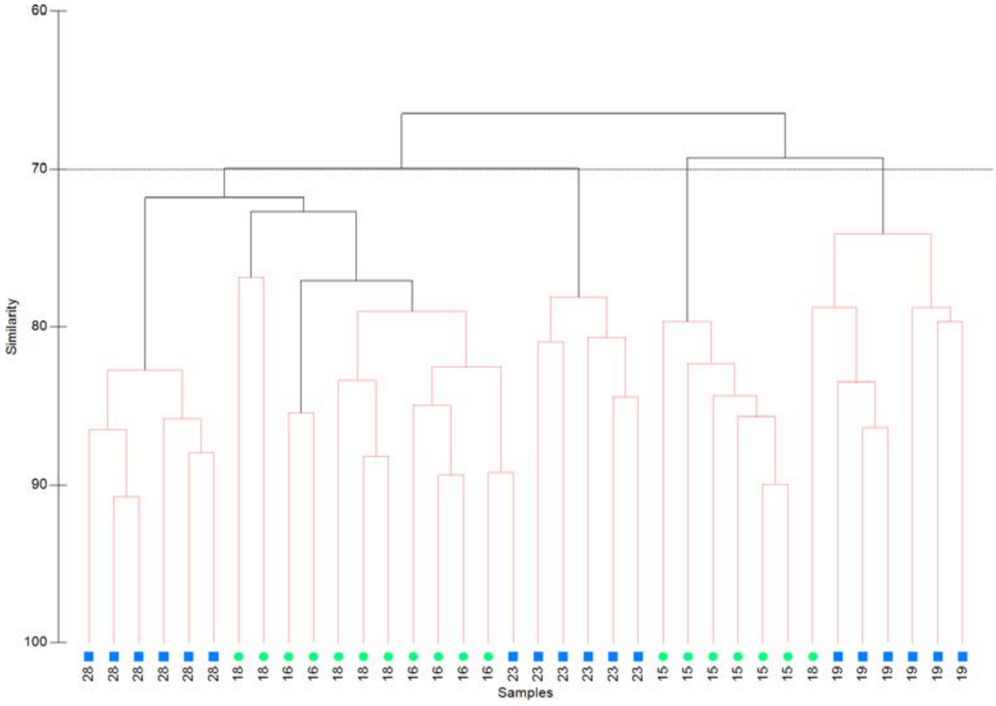

Figure 8. Cluster dendrogram of genus data from the autumn 2011 riffle samples.

Green circles represent upstream sites and blue squares are sites downstream of Angle Crossing

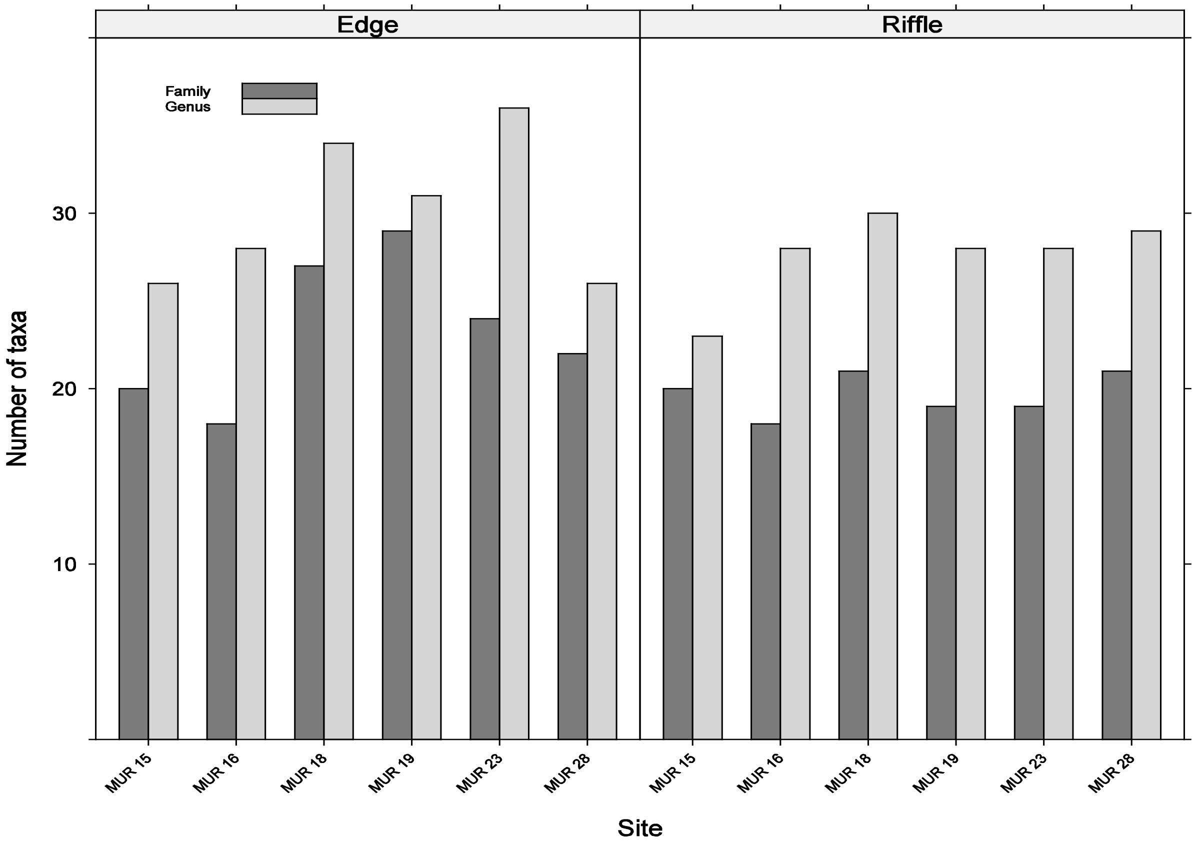

Figure 9. Total number of taxa at genus and family levels in the riffle and edge habitats

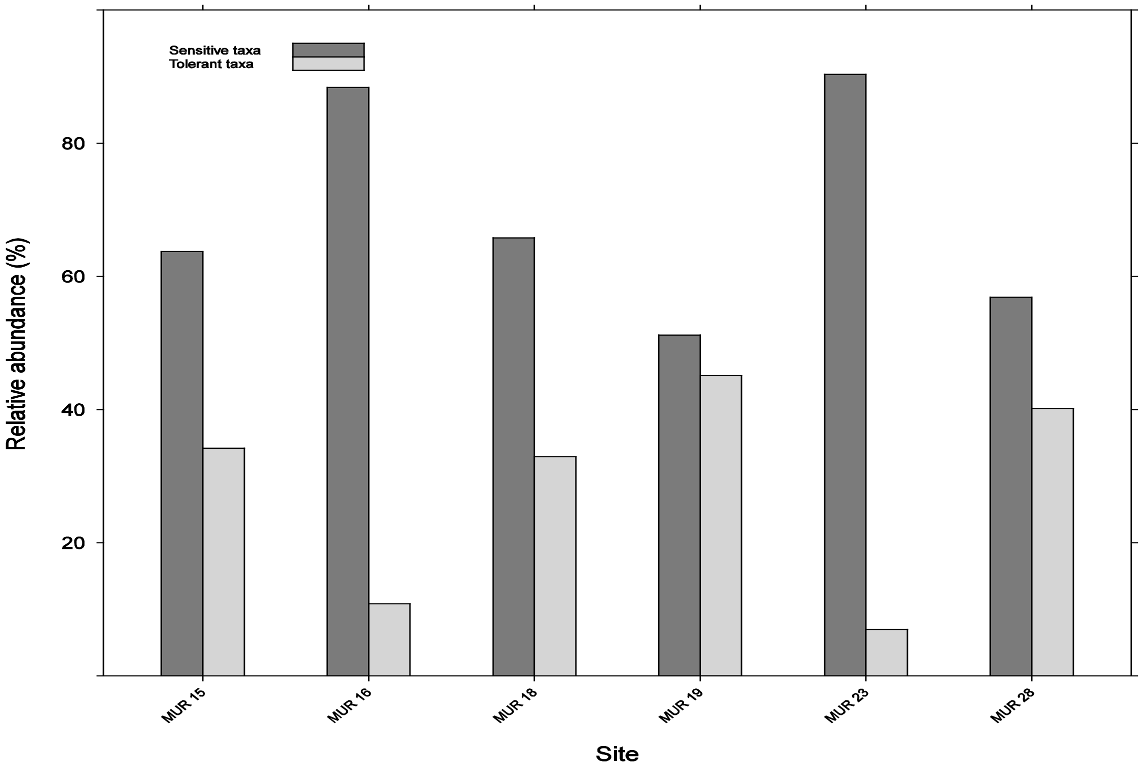

Figure 10. Average relative abundances of sensitive and tolerant taxa from sites upstream and downstream of Angle Crossing

3.6.1 Edges

Only one edge sample was possible from MUR 16 and MUR 28 due to a lack of available habitat (see Plates 1 and 2). Based on the available data, there was no evidence from the ANOSIM procedure to indicate a difference between the upstream and downstream edge communities (R=-0.18; P=0.8). However the PERMDISP procedure does indicate a dispersion effect between locations ($F_{1,15}$ = 10.75; P=0.002), suggesting there is higher variation among the upstream sites compared to the downstream sites . As with the riffle communities, there were higher similarities between sites from different locations for the riffle communities, with a negative (and almost identical) R-value observed. This is evident from the NMDS plot (Figure 11), particularly for the group containing MUR 16 & 23 (65% similarity). At 65% similarity, the samples are separated into three groups, with each group containing samples from both up and downstream locations.

The stress value of the NMDS plot (0.12) indicates the NMDS solution is a reasonable representation of the structure of the edge data. For consistency, the cluster analysis dendrogram is included (Figure 12), which is in agreement with the group structures in Figure 11.

Taxa richness ranged from 18 families at MUR 16 to 29 families at MUR 19 Figure 9. The highest genus richness was recorded at MUR 23 with 36, followed by MUR 18 with 34. These values marked an increase in diversity at MUR 18, 19 and 23 at the family level, while the number of genera increased since spring 2010 at MUR 19 and MUR 23. There was a decline in the number of families at MUR 15 from 27 in spring 2010 to 20 in the current round of sampling.

All sampling sites were dominated by tolerant to moderately sensitive taxa which, included high numbers of Chironominae (SIGNAL =3), Oligochaeta (SIGNAL =2), *Tasmanocoenis sp*. (Caenidae; SIGNAL =4) and *Cheumatopsyche sp*. (Hydropsychidae: SIGNAL =6). Two of the sensitive taxa that were absent from the edge samples in spring 2010 (i.e. Leptophlebiidae (SIGNAL=8) and Gripopterygidae (SIGNAL =8)) were collected in this sampling run albeit in low numbers. These groups were present at all sampling sites and featured in the five most abundant groups at a given site, indicating that the differences between sites was more a function of different abundances of these key groups than the presence or absence of specific taxa. However, the grouping of MUR 16 and MUR 23 together appears to be due to two unique (to those sites) genera in the form of families Hydroptilidae and Hydropsychidae and the absence of Corixidae (SIGNAL =2) from these sites.

The BIO-ENV results revealed a moderate relationship between the macroinvertebrate similarities and a combination of four environmental variables: water temperature; electrical conductivity; total nitrogen and total phosphorus, with a Spearman’s rho coefficient of 0.57 (P=0.01). A list of the ten best combinations with is given in APPENDIX D.

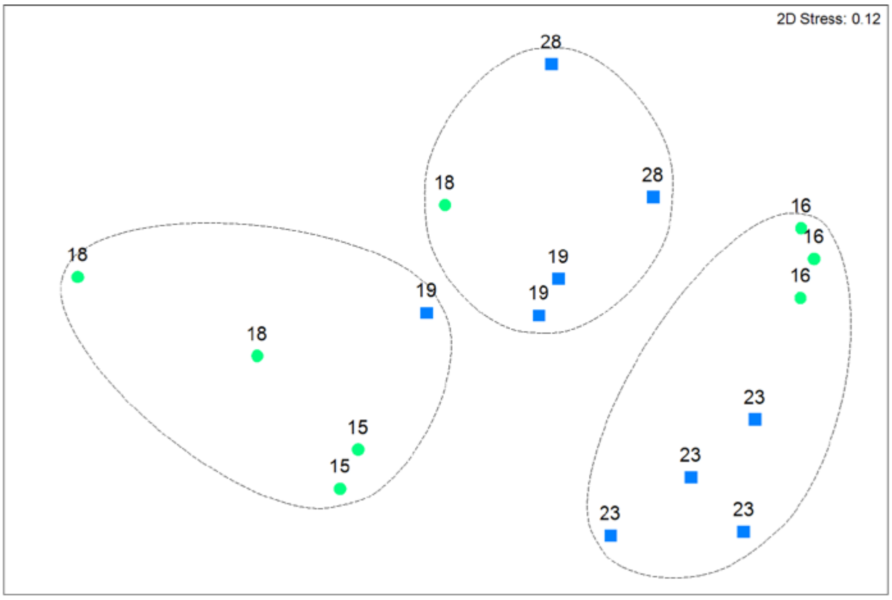

Figure 11. Non-metric multidimensional scaling of genus level data from spring edge samples. Ellipses represent the 60% similarity groups superimposed from the cluster analysis (above)

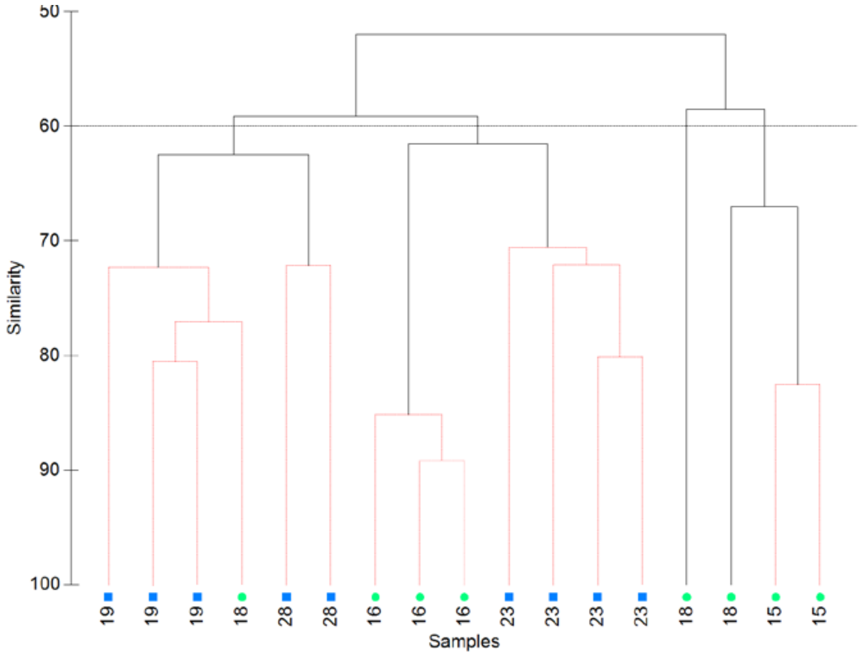

Figure 12. Cluster dendrogram of genus data from the autumn 2011 edge samples.

Green circles represent upstream sites and blue squares are sites downstream of Angle Crossing

3.7 AUSRIVAS Assessment

The two sites immediately upstream and downstream of Angle Crossing (MUR 18 and 19 respectively) were both nearly outside the experience of the AUSRIVAS model for this round of sampling. All necessary checks were made to the physical/chemical input data files, as recommended by Coysh *et al.*, (2000a), however there were no apparent input errors. The results from these two sites should therefore be treated with caution, since the site data are almost at the limitations of the predictive capabilities of the model (Coysh, *et al.*, 2000a)

Riffle assessments improved from Band C to Band A at MUR 23 and MUR 16 (Table 13) since spring 2010. High variability in spring 2010 meant that overall site assessments were not available for MUR 18 and MUR 15. However, the results for this round show that both sites returned Band B assessments. MUR 19, on the other hand, was assessed as Band A. All subsamples were constantly Band A in both habitats at this site indicating that the majority if taxa predicted to occur were collected. Among the three taxa missing from the riffle zone at MUR 19 two of these were the highly sensitive taxa Elmidae (SIGNAL=7) and Gripopterygidae (SIGNAL=8). It should be noted that 91% of the riffle samples we assessed as Band A for autumn 2011, the three exceptions included two samples from MUR 18 and one sample from MUR 23. Of these samples, the difference between the Band B and a Band A result was down to one taxon missing from each sample. In each of these cases, the missing family was present in each of the other samples (APPENDIX E).

Comparisons of the riffle habitat samples indicate no significant difference between upstream and downstream locations ($F_{1,4}$ =0.2; P=0.67; Table 13) in terms of OE/50 scores. Average OE/50 scores ranged from 0.94 – 0.96 upstream of Angle Crossing, while downstream they ranged from 0.89-1.01 amounting to highly consistent average scores amongst all sampling sites (Figure 13).

The highest weighted SIGNAL -2 scores of the observed riffle fauna (with >50% probability of occurrence) was seen at MUR 19 (immediately downstream of Angle Crossing) (mean=4.7), whereas the lowest (mean =4.4) was observed at MUR 16. Overall there appeared to be an upward trend in mean SIGNAL-2 scores from MUR 16 downstream to MUR 19 (Figure 13), which then declined again at MUR 23 and Mur 28. On the whole, however, there were no location effects ($F_{1,4}$ = 2.065; P=0.85) based on the SIGNAL-2 scores despite the average being slightly higher downstream (mean = 4.61) compared to the upstream sites (mean=4.53).

The AUSRIVAS assessment of the edge habitat samples were Band B at MUR 15, 16, 23 and 28. MUR 18 and 19 were both assessed as Band A (Table 13), which is an improved Band scale relative to the autumn 2010 and spring 2010 sampling rounds for both sites. Overall, there were no location differences over and above site to site variation ($F_{1,4}$ = 0.041; P=0.85; Table 14) in terms of OE/50 ratios (Figure 14). Similarly, there was no evidence to suggest that SIGNAL-2 scores for edge habitat differed significantly between locations ($F_{1,4}$ = 0.21; P=0.67; Table 15), despite the considerable variation in the site to site scores (range: 4.1-5; Figure 14).

Taxa missing from the edge samples that were predicted to be present by the AUSRIVAS model included families with a wide range of SIGNAL scores (2-8) (APPENDIX F). At the tolerant end of the scale were Planorbidae (SIGNAL =2), which were absent from all of the samples and Corixidae (SIGNAL =2), which were missing only from MUR 16 and MUR 23. At the more pollution-sensitive end, Synlestidae and Conoesucidae (SIGNAL=7) were absent from all sampling sites. Other sensitive families, such as Gripopterygidae (SIGNAL=8) were recorded in 64% of samples, but were missing entirely from MUR 16 and MUR 18, while Elmidae (SIGNAL -7) were absent from 83% of samples and were only found at MUR 28 and MUR 23.

Table 13. AUSRIVAS and SIGNAL scores for autumn 2011.

🟩 = *nearly outside the experience of the model*

SITE	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS band		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
Mur 15	1	4.63	4.20	0.89	0.78	A	B	A	B	B
Mur 15	2	4.25		0.89		A				
Mur 15	3	4.90		1.11		A				
Mur 15	4	4.63	4.20	0.89	0.78	A	B			
Mur 15	5	4.25		0.89		A				
Mur 15	6	4.90		1.11		A				
Mur 16	1	4.25	4.67	0.89	0.70	A	B	A	B	B
Mur 16	2	4.25	4.89	0.89	0.70	A	B			
Mur 16	3	4.67	4.80	1.00	0.78	A	B			
Mur 16	4	4.67		1.00		A				
Mur 16	5	4.67		1.00		A				
Mur 16	6	4.25		0.89		A				
Mur 18	1	4.63	4.50	0.89	0.93	A	A	B	A	B
Mur 18	2	4.14	4.45	0.78	0.85	B	A			
Mur 18	3	4.67		1.00		A				
Mur 18	4	4.90	4.18	1.11	0.85	A	A			
Mur 18	5	4.14		0.78		B				
Mur 18	6	4.90		1.11		A				
Mur 19	1	4.90	4.18	1.11	0.85	A	A	A	A	A
Mur 19	2	4.63	4.55	0.89	0.85	A	A			
Mur 19	3	4.56		1.00		A				
Mur 19	4	4.67	4.55	1.00	0.85	A	A			
Mur 19	5	4.90		1.11		A				
Mur 19	6	4.56		1.00		A				
Mur 23	1	4.56	4.89	1.00	0.70	A	B	B	B	B
Mur 23	2	4.88	4.80	0.89	0.78	A	B			
Mur 23	3	4.25		0.89		A				
Mur 23	4	4.25	4.70	0.89	0.78	A	B			
Mur 23	5	4.50	4.80	0.89	0.78	A	B			
Mur 23	6	5.00		0.78		B				
Mur 28	1	4.90	4.45	1.11	0.85	A	A	A	B	B
Mur 28	2	4.25	4.38	0.89	0.62	A	B			
Mur 28	3	4.25		0.89		A				
Mur 28	4	4.90		1.11		A				
Mur 28	5	4.56		1.00		A				
Mur 28	6	4.67		1.00		A				

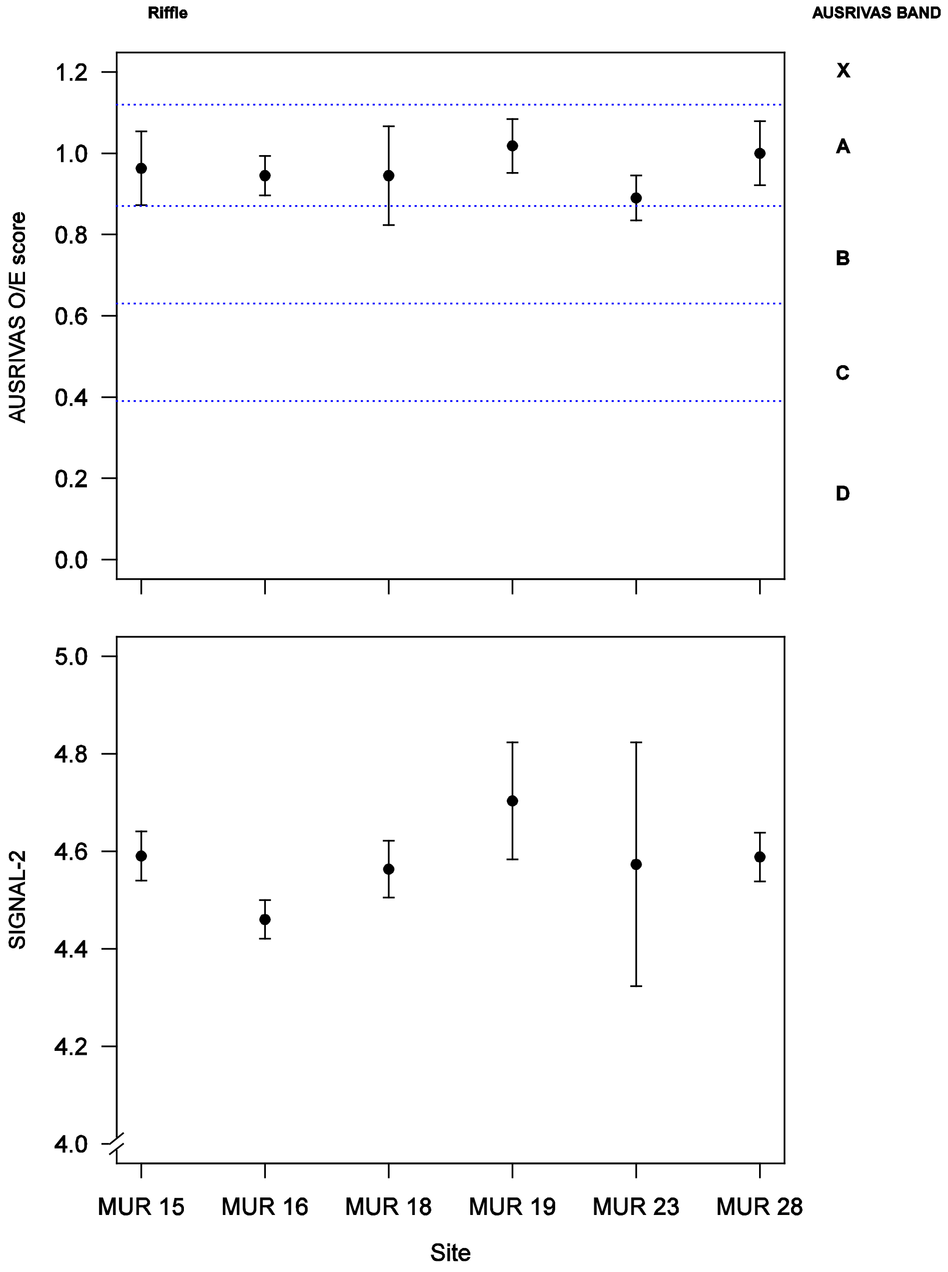

Figure 13. Average AUSRIVAS OE50 scores (top) and average SIGNAL-2 scores for RIFFLE samples upstream and downstream of Angle Crossing.

Error bars are 95% confidence intervals

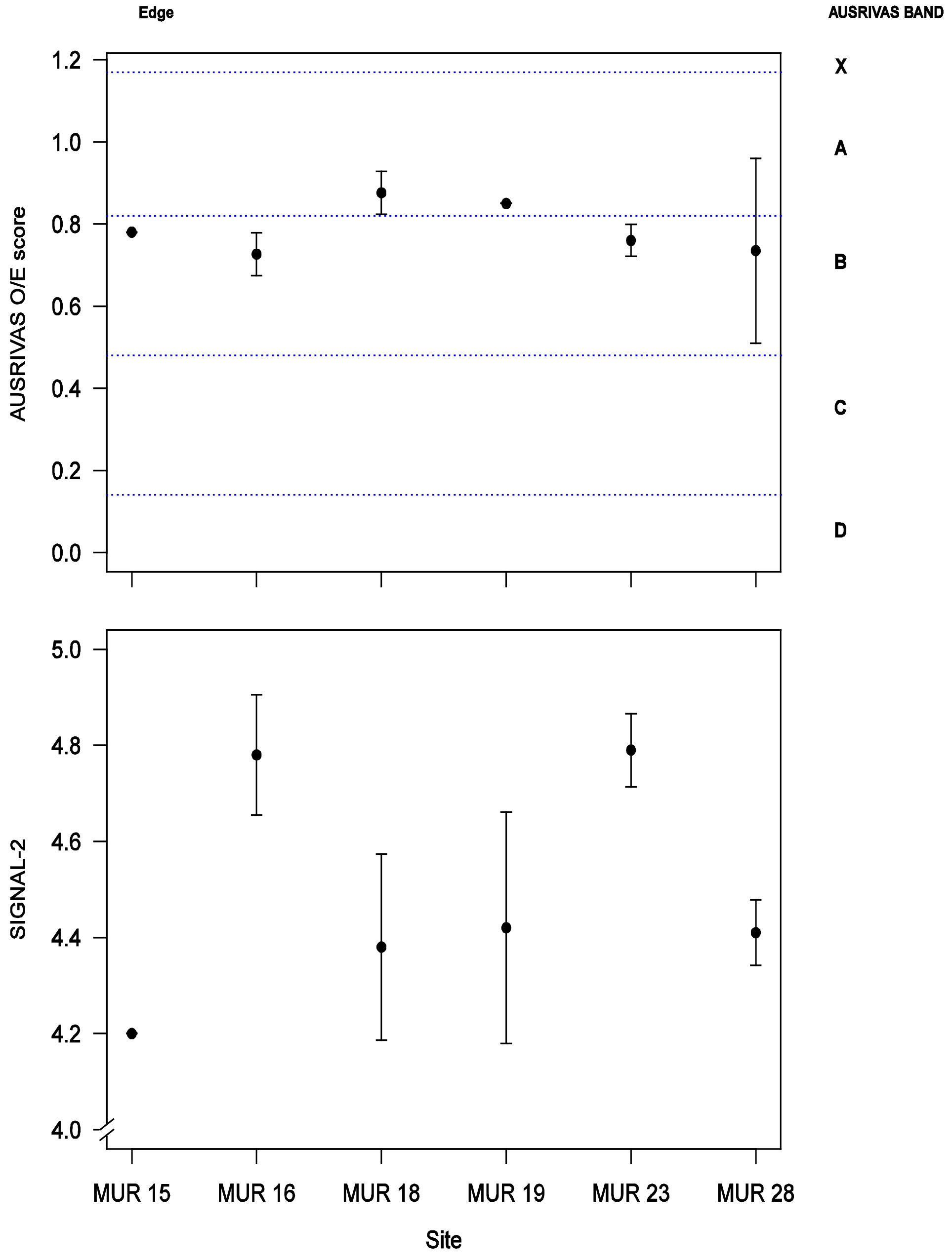

Figure 14. Average AUSRIVAS OE50 scores (top) and SIGNAL-2 scores for EDGE samples upstream and downstream of Angle Crossing.

Error bars are 95% confidence intervals

Table 14. Nested analysis of variance table from the riffle samples, based on OE50 and SIGNAL-2 scores

Response	Source	DF	F-value	P-value
OE 50	Location	1	0.204	0.67
	Site [Location]	4	1.457	0.23
	Residual	35		
SIGNAL -2	Location	1	2.065	0.22
	Site [Location]	4	0.383	0.81
	Residual	35		

Table 15. Nested analysis of variance table from the edge samples, based on OE50 and SIGNAL-2 scores

Response	Source	DF	F-value	P-value
OE 50	Location	1	0.041	0.85
	Site [Location]	4	3.776	0.03
	Residual	16		
SIGNAL-2	Location	1	0.212	0.67
	Site [Location]	4	11.02	<0.001
	Residual	16		

4 Discussion

The aim of this monitoring program is to obtain baseline information to include: hydrological, biological and physico-chemical water quality information, which will help establish spatial and temporal trends up and downstream of Angle Crossing (Table 2). An additional objective of this baseline monitoring period is to consider potential impacts of the construction phase of the M2G project which is now under way.

4.1 Water Quality

Overall, the water quality data both gauged and from our grab samples indicate a high level of compliance to the ANZECC and ARMCANZ (2000) guidelines (Tables 9 and 10). For the gauged data (MURWQ09 and 410761), the only parameter to exceed the guideline recommendations, was turbidity. Turbidity was within the recommended range of 2-25 NTU 72% of the time upstream of Angle Crossing and 76% downstream (Table 9). The slight differences are due to a period of siltation around the sensor at the upstream site following the second high flow event which came through in late March.

The *physico-chemical* results from the grab samples also were within the guideline values (Table 10); however the nutrient concentrations, despite being amongst the lowest collected during the term of this project still remained higher than the recommended guidelines (for TP the upper limit is 0.02 mg/L and for TN the upper limit is 0.25 mg/L). Stable flows and very little rainfall over a six week period leading up to autumn sampling, probably accounted for the low TN concentrations recorded in this sampling run.

There was no evidence from these results to suggest that the construction work at Angle Crossing is impacting the water quality downstream of the crossing. From the grab sample data, the parameter readings are almost identical at the closest upstream and downstream location (MUR 18 and 19 respectively) (Table 10). There are differences in EC and alkalinity, but these are normal longitudinal changes that are expected in a catchment of this size. There is also no indication of construction-related impacts from the continuous data (Table 8). Monthly summaries show data from both stations to be highly comparable and consistent throughout autumn. Spikes in turbidity and changes in EC, pH and altered diurnal dissolved oxygen ranges (Figures 3 & 4) in mid-March, were related to peaks in the hydrographs during rainfall events. These patterns were seen at both sampling sites (with the exception of pH due to missing data) indicating that the changes in the water quality parameters were related to seasonal and flow related changes as opposed to impacts from the construction work.

Overall, water quality was in compliance with guidelines apart from TN and TP which exhibited minor exceedances across all sites. Improved water quality in autumn probably relates to the recent flushing during high flows followed by a period of relatively stable but slightly elevated base flows.

4.2 Periphyton

There were no location effects observed in relation to chlorophyll-a or AFDM concentrations with respect to upstream and downstream of Angle Crossing (Table 11) in autumn 2011. Mean chlorophyll-a concentrations were higher than those recorded in spring 2010, both upstream and downstream of Angle Crossing, but were similar to those recorded in autumn 2010, suggesting a strong seasonal influence at both locations. The stable flows leading up to the May sampling run are likely to have been a strong influence on the concentrations collected in this study, even though the results from the correlation analysis suggest that chlorophyll-a tended to increase with increasing velocities (R=0.91).

This result is contrary to our previous findings, which have shown negative relationships between chlorophyll-a concentrations and current velocity. The strong positive relationship uncovered in this study is consistent with the findings of Biggs and Stokseth (1996) who showed that the uptake of nutrient was highest and gaseous exchanges were maximised at medium velocities where shear stress was not so severe that scouring rates exceeded accrual rates.

Chlorophyll-concentrations were considerably lower at MUR 23, which has tended to return the highest concentrations of all the sampling sites in previous sampling runs. The other site with notably lower concentrations compared to other sites is MUR 16 (Figure 5). The common environmental variable linking these two sites with the low chlorophyll-a concentrations was water temperature, which was about 2 °C lower at MUR 16 and MUR 23 compared to all other sites. Water temperature can restrict primary production under certain thresholds (Biggs, 2000) and in this study, provides one explanation for the observed patterns in the data set. Our field observations picked up some obvious bed movement, which suggest that MUR 23 was subject to high intensity scoring during the succession of multiple high flow events throughout spring, which would have reduced: a) the initial standing periphyton communities and b) limited accrual rates with subsequent high flow events. Thus, the particularly high level of bed scouring at this site is the most likely explanation for the reduced chlorophyll-a concentrations at MUR23 in autumn 2011. Site MUR 16 is dominated by bedrock and boulders, which provide a more stable environment for periphyton and macrophytes. However, MUR 16 narrows considerably through a steep gorge, which would have the effect of concentrating the flow during events and thus would excerpt high shear stress on benthic habitats. Hence scouring could also explain the trend for chlorophyll-a concentrations observed at this site in autumn 2011. Lower temperatures at MUR 16 and MUR 23 may have compounded this by being a limiting factor for periphyton re-establishment.

Periphyton biomass can be strongly dependant on nutrient supply following scouring events (Risengi *et al.*, 2004) which suggests (at least in the case of MUR 23) that a low supply of nutrients leading up to the autumn sampling run may have been the limiting factor following the scouring events as there were no run-off events for 40 days leading up to the collection of the samples.

4.2 Macroinvertebrate communities and AUSRIVAS assessment

The ANOSIM results (APPENDIX C) show no evidence of a downstream effect resulting from the current construction works, which has now entered the pipe installation phase. The non-significant ANOSIM test indicates that the riffle communities did not differ between upstream and downstream locations (Figure 7). In fact, the Bray-Curtis similarity metric used to compare the communities indicate a high degree of overlap and shared taxa among sites and location (Figure 7). For example, the five most abundant taxa from the riffle samples amongst all sites were: Simuliidae (SIGNAL=5); Hydropsychidae (SIGNAL =6); Baetidae (SIGNAL =5) and Oligochaeta (SIGNAL=2). The differences between sites in this study are mainly due to variations in the rank –order of relative abundances of these five key taxa as opposed to the complete absence of certain taxa. The exception to this was the absence of Elmidae (SIGNAL=7) at MUR 16. The absence of Elmidae is most likely due to habitat related properties at MUR 16 rather than factors relating to water quality, since this family was collected from all of the other sites.

The high similarity (>65%) among sites indicates a broad scale influence acting upon the sampling locations rather than localised or point source affects. The high flows throughout spring; followed by two events in early and late March (Figure 2) likely attributed to the similarities among sites by acting as a reset mechanism on the macroinvertebrate communities along the longitudinal profile. This is consistent with Ortiz and Puig (2007) who found that following a series of spates effecting two reaches, Bray–Curtis similarity between locations increased. Those authors suggested that high flow events in altered ecosystems can improve or have an overriding influence on the ecological status of altered ecosystems, suggesting that as long natural high flow events are maintained, any short term impacts associated with human-induced alterations may be negligible. The implications of this for the construction phase of M2G is that any short term impacts from the initial construction phase may have been masked by the flushing flows experienced over the last 5 months leading up to autumn sampling.

Simuliidae (SIGNAL=5) and Hydropsychidae (SIGNAL =6) are good indicators of early successional stages following flow disturbances. These taxa tend to have an antagonistic relationship where Simulids, in the very early stages of recolonisation, can rapidly colonise substrates recently removed of fine sediments and organic material (Hemphill and Cooper, 1983). Hydropsycids, on the other hand are generally slower colonists, but commonly out-compete Simulids in the later stages of succession (Death, 2008; Scrimgeour *et al.*, 1988; Wallace, 1990). In spring for example, samples were collected 12 days after a high flow event and the contribution of the Simulids to the total sample abundance ranged from 40% to upward of 60%, whereas in this sampling run samples were collected 37 days after run and Simulids contributed considerably less (5-25%). The high numbers of Oligochaetes provide a further line of evidence to support the idea that flows were the overriding factor shaping the autumn 2011 macroinvertebrate community structure. As sediment dwellers, they are less likely to be swept downstream by the increased shear stress excerpted by the increased velocities (Hynes, 1970).

Taxa richness, both at family and genus levels (Figure 9) were comparable to previous sampling runs irrespective of season as was the number of EPT families and genera. The key difference between the riffle macroinvertebrate communities in this sampling run compared to spring is a marked increase in the relative abundance of EPT taxa. While we have found that there is a strong seasonal influence, with spring samples generally have 20-40% lower relative abundance of EPT fauna, the autumn 2011 samples indicate a 20% increase compared to all other samples irrespective of season.

A break-down of the composition of the EPT fauna indicates that an increase in the estimated abundance of Hydropsychidae has contributed significantly to the increase in EPT composition, but there has also been a considerable increase in the individual numbers of Baetidae (SIGNAL =5) and Leptophlebiidae (SIGNAL=8), which tend to be susceptible to high flow events (Malmqvist, 2002) and siltation (Kaller and Hartman, 2004; Larsen *et al.*, 2011; Wood and Armitage, 1999) and their increased abundance in this study suggests that the intensity and frequency of the spring events may have removed fine sediments from the substrate such that the habitat conditions improved thus supporting higher numbers of these taxa.

The ordination analysis of the edge samples separates the sampling sites into three groups at 60% similarity (Figure 11). The NMDS displays three distinct groups (Figure 11) each containing samples from up and downstream of Angle Crossing. This grouping structure is consistent with the results of the ANOSIM procedure, which provides no evidence to suggest a location difference. The lower similarity measures between sites and groups from the edge samples are likely due within site habitat differences, which tend to be more complex than riffle habitats. Furthermore, because there was much more variation in riparian vegetation diversity and extent; pool depth and velocities between sites, it is not surprising to see more variation in the edge fauna.

Both MUR 18 and MUR 23 returned BAND B assessments for the riffle habitat due to the absence of one taxon missing, which were present in all other samples. Generally however, AUSRIVAS results show an overall increase in both the O/E 50 across all sites compared to spring 2010. On a season by season basis, there were also improvements compared to autumn 2010 (ALS, 2010a) especially in the riffle habitat, given that riffles are more susceptible to changing flow conditions and tend to respond faster to these changes. In this study, there was no location effect found based on the OE/50 AUSRIVAS scores or the SIGNAL -2 scores for either the riffle (Figure 13) or the edge samples (Figure 14).

The inventory of missing but predicted taxa (APPENDIX E) further highlights the similarities between sites because of the high occurrence of similar taxa missing across all of the sampling sites. From the riffle habitat, the two most sensitive taxa (Elmidae: SIGNAL =7 and Gripopterygidae: SIGNAL =8) were also missing from most samples (61% and 47% respectively). As mentioned earlier, water quality is unlikely to have resulted in the absence of these taxa since a) there were no obvious differences reported in any of the water quality parameters and b) aside from Elmidae at MUR 16, none of the missing taxa were entirely missing from a site, which suggests that differences in substrate availability and other environmental limitation, such as small scale differences in current velocity maybe resulting in patchy distributions within a given site (Brooks *et al.*, 2005). Tipulidae (SIGNAL=5) were also missing from several of the samples, but occurred more often than in previous sampling runs. It is unclear why Tipulidae have commonly been absent from the riffle samples. One possibility is that food resources have been scarce (Gooderham and Tsyrlin, 2005), or the Tipulidae were outcompeted by other taxa.

The edge habitat remained BAND B at MUR 23 since spring and indeed autumn 2010. MUR 19 shifted from a BAND C in spring to a BAND A in this sampling run and improved again since autumn 2010. The reasons are probably linked again to the flushing flows of spring and early March, and the higher base flow leading up to the sampling run. The higher base flows resulted in a deeper water column while the flushing flows probably helped alleviate some of sediment and organic build up in the edge. These processes have resulted in the return of Corixidae, Leptophlebiidae and Ceinidae to this site.

Following the high flow events of spring, the edge AUSRIVAS results were highly variable between sites which lead to the conclusion of “no reliable assessment” at two sampling sites at that time. The main differences between this sampling run and the results from the spring 2010 run is a marked increase in the relative abundance of EPT taxa, high similarity between the riffle samples (indicated by taxa composition, richness and abundance) and more consistency in the AUSRIVAS assessments within the edge samples. The increase of EPT taxa is likely related to the scouring action of the high flow events preceding autumn sampling; which, based on our field observations, removed some of the finer material from both the margins and main channel of the sampled habitat. The resulting cleaner substrate is thought to have increased the available habitat to this group of taxa, and in doing so permits the habitat to support high numbers of individuals (Gibbins *et al.*, 2007; Krumholz and Neff, 1970; Wood and Armitage, 1999).

5 Conclusions and Recommendations

The water quality results show no evidence of water quality being negatively impacted downstream of Angle Crossing due to the construction work currently underway immediately upstream of the crossing. Compliance of these water quality parameters to ANZECC and ARMCANZ (2000) guidelines were high overall (75-100%), however nutrient analysis conducted on the grab samples show that TP and TN are still slightly exceeding the guideline values in all the sampled reaches in this project (Table 9), suggesting that the agricultural practices upstream of Angle Crossing and urban land use features downstream of the crossing maintain nutrient levels at moderately high levels year round.

There is strong seasonal variation in the periphyton data collected to date. During spring, high flow events tend to exert high shear stress upon the periphyton communities and substrate mobilisation scours and displaces communities. In contrast, during low flow and periods of stable flows, periphyton has tended to increase in production, although this may depend on the availability of nutrients and water temperatures. Given that temperatures decline steadily throughout autumn and even if nutrients are delivered via runoff, the utilisation rates may be lowered or limited by decline surface water temperatures.

Over the past sampling occasions, the AUSRIVAS results have regularly been assigned BAND-B health assessments to the majority of the sampling sites. Following high flow events there has been evidence of some improvement in the AUSRIVAS assessments, such as in this study and this is probably related to the removal of fine sediment deposits in the riffle habitat from substrate mobilisation and increased near-bed velocities. It is clear from our current sampling design that flow is highly influential on shaping the macroinvertebrate community structure. It is apparent that high flow events in spring can result in a reduction in the estimated abundances of specific groups of taxa such as Ephemeroptera: Plecoptera and Trichoptera (EPT) and free-living edge taxa that are otherwise ubiquitous throughout the sampled reaches. In autumn, when base flows tend to be lower, but more stable, there is generally an increase in EPT abundances, but this is largely due to proliferation of moderately-tolerant Trichoptera taxa and a marked decrease in the number of sensitive mayfly taxa.

There has been little change in the number of taxa collected throughout this baseline period which has encapsulated a range of flows in the range: 35 ML/d – 630ML/d. The fact that taxonomic richness has been consistent throughout the course of this project suggests that irrespective of how the relative abundance of certain groups reacts to changes in flow, there is a considerable amount of resistance within the Murrumbidgee macroinvertebrate populations. And although after periods of high flow events, free living taxa such as Corixidae (SIGNAL=2) have been completely absent from some sites, they show high resilience, which is deemed to be a desirable quality of a healthy ecosystem (Davies *et al.*, 2010).

During periods of low flow, we have found a similar pattern, in that there appears to be a high degree of resilience in the Murrumbidgee River system during these periods of low flow. When the Murrumbidgee River was sampled in autumn 2009, at 72ML/d and in autumn 2010, at 36 ML/d there were reductions in the absolute numbers of the more sensitive taxa, but there was little evidence of taxa being removed completely. The exception to this was Elmidae (Coleoptera) which was notably absent during autumn during low flows, but was present under the current study at 220 ML/d suggesting, as Brooks *et al.* (2011) have suggested, that Elmidae may provide a useful indicator taxa for low flow impacts. Other taxa that could prove useful indicators of low flow impacts include Tipulidae, Leptophlebiidae and to lesser extent Gripopterygidae.

While the AUSRIVAS assessment did not pick up any difference between autumn 2009 and autumn 2010, there was evidence to suggest that during autumn 2009, the diurnal patterns in dissolved oxygen were changing, EC was increasing and pH and temperature were also rising. It is believed that these changes were the result of the longer period of time (112 d) since the last significant flow event in autumn combined with warmer ambient temperatures prior to the drought breaking in 2010. The implications of this are that while we have evidence to suggest that there is high resilience amongst the macroinvertebrate groups in relation to hydrological disturbances (and this could be due to spatial refugia, such as increasing drift, substrate heterogeneity or seeking shelter in edge/pool habitats), it is unclear how the secondary, or indirect impacts of low flows will impact macroinvertebrate communities because these refugia are unlikely to protect these macroinvertebrates from the effects of any indirect impacts such as changes to water temperature, pH changes in dissolved oxygen levels due to increased microbial activity under low flow conditions.

It is predicted that during winter and spring, when the proportion of flow being abstracted is low compared to base flows, that there are unlikely to be any long term effects on water quality, periphyton communities or the macroinvertebrate populations. Short term effects my see some reductions in individual indicator taxa and reactive changes in water quality to hydrological disturbances; but as long as there is a period of stable flows following these disturbances, the system should return to a state similar to that seen before the disturbance. During summer and autumn, it is expected that changes in water quality may occur when flows are < 80 ML/d for prolonged periods. If flows in this range are artificially maintained through ongoing water abstractions, we could expect to see a further deterioration in water quality which would then begin to influence the more sensitive macroinvertebrate taxa, which may eventually be eliminated. This will have repercussions to fish populations also which relay on healthy macroinvertebrate populations as a food resource, but are also sensitive to changes in water quality outside their natural thresholds (Ingram and De Silva, 2007; King, 2005; Tonkin *et al.*, 2006).

An additional challenge of the M2G project is to relate what we already know to what we can expect in terms of biological changes under the 80:90 pumping rules (ACT Government, 2006). To address these challenges we recommend the continuation of AUSRIVAS monitoring as suggested in the EIS. In doing so the additional data obtained from this program are likely to encompass a broader range of flow patterns which will provide a firmer foundation and lend support to these predictions as to the likely ecological impacts of operating M2G.

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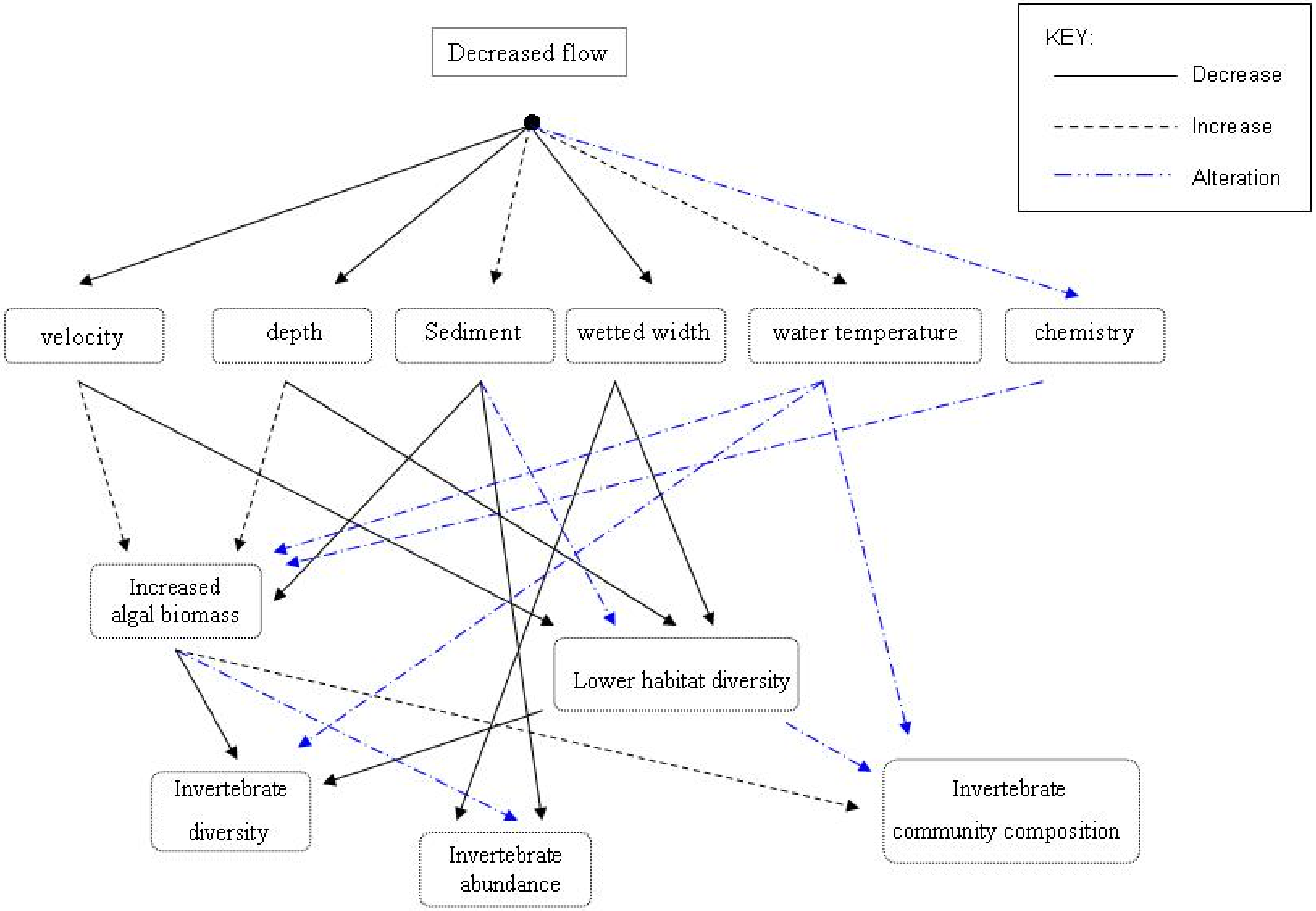
Appendix A –

Potential effects of reduced flow and their knock-on effects on habitat conditions and macroinvertebrate communities



Summary of the effects of reduced flows on various habitat conditions and macroinvertebrate communities from recent literature (Dewson et al. 2007)*.

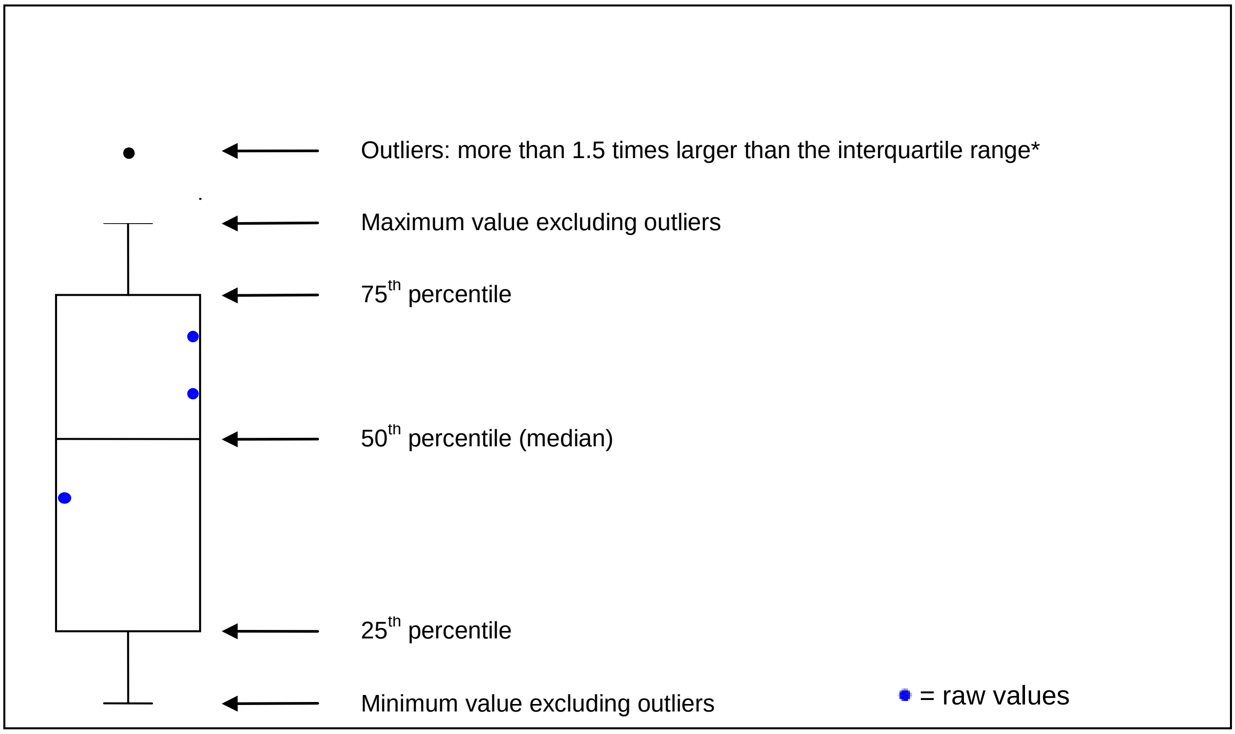
*Reproduced with permission from the authors.

Appendix B –

Interpreting box and whisker plots

Appendix B. Interpreting box and whisker plots

Box and whisker plots are intended as an exploratory tool to help describe the distribution of the data. The blue points on the inside of the plot area indicate the raw data values that make up the distribution portrayed in the boxplot. The plot below explains how the box and whisker plots should be read.



* The interquartile (IQR) range is the difference between the 25th and 75th percentile. This value is important when two sets of data are being compared. The closer the values are to the median, the smaller the IQR. Conversely, the more spread out the values are, the larger the IQR.

Appendix C –
ANOSIM output for riffle and edge samples

Analysis of Similarities

Two-Way Nested Analysis

RIFFLE

```
TESTS FOR DIFFERENCES BETWEEN # Site GROUPS
(across all # Location groups)
Global Test
Sample statistic (Global R): 0.876
Significance level of sample statistic: 0.01%
Number of permutations: 9999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

TESTS FOR DIFFERENCES BETWEEN # Location GROUPS
(using # Site groups as samples)
Global Test
Sample statistic (Global R): -0.185
Significance level of sample statistic: 80%
Number of permutations: 10 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 8
```

EDGE

```
TESTS FOR DIFFERENCES BETWEEN # Site GROUPS
(across all # Location groups)
Global Test
Sample statistic (Global R): 0.937
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 352800)
Number of permuted statistics greater than or equal to Global R: 0

TESTS FOR DIFFERENCES BETWEEN # Location GROUPS
(using # Site groups as samples)
Global Test
Sample statistic (Global R): -0.185
Significance level of sample statistic: 70%
Number of permutations: 10 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 7
```

Appendix D –

BIO-ENV output for riffle and edge samples

RIFFLE

```
BEST
Biota and/or Environment matching


Variables
  1 % riffl e
  2 Mode Stream width
  3 mean riffle depth
  4 mean velocity
  5 BEDROCK
  6 BOULDER
  7 COBBLE
  8 PEBBLE
  9 GRAVEL
 10 SAND
 11 Water temp.
 12 EC
 13 D.O (% Sat.)
 14 Turbidity
 15 Alkalinity
 16 TP
 17 TN

Global Test
Sample statistic (Rho): 0.654
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample)
Number of permuted statistics greater than or equal to Rho: 0

Best results
No.Vars    Corr. Selections
      3    0.654 4,11,15
      2    0.640 4,15
      4    0.636 4,12,15,16
      3    0.634 4,12,15
      4    0.633 4,11,12,15
      5    0.631 4,7,11,12,15
      3    0.627 4,15,16
      4    0.624 4,7,11,15
      4    0.620 4,7,12,15
      5    0.619 3,4,7,11,15
```

EDGE

```
BEST
Biota and/or Environment matching

Variables
  1 Water temp.
  2 EC
  3 D.O (% Sat.)
  5 Alkalinity
  6 TP
  7 TN
  8 % macrophyte
  9 mean edge depth
 10 mean velocity
 11 SHRUBS
 13 BOULDER
 14 COBBLE
 15 PEBBLE
 16 SAND



Global Test
Sample statistic (Rho): 0.567
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample)
Number of permuted statistics greater than or equal to Rho: 0


Best results
No.Vars    Corr. Selections
      4    0.567 1,2,6,7
      5    0.543 1,2,6-8
      5    0.541 1-3,6,11
      4    0.535 1,2,6,11
      3    0.531 1,2,6
      3    0.530 2,3,6
      5    0.530 1-3,6,7
      5    0.525 1-3,6,8
      4    0.525 1,6,7,14
      5    0.524 1,2,6,7,11
```

Appendix E –

Taxa predicted to occur with >50% probability but were not collected in the spring samples

APPENDIX E. Taxa expected, but not collected in the riffle habitat. The number in each cell is the probability of collection

Site	Taxa	Elmidae	Oligochaeta	Simuliidae	Tipulidae	Gripopterygidae	Total number of missing taxa
	SIGNAL	7	2	5	5	8	
Mur 15	Riffle	1			1		2
Mur 15		1				0.6	2
Mur 15							0
Mur 15		1			1		2
Mur 15		1				0.6	2
Mur 15							0
Mur 16	Riffle	1				0.6	2
Mur 16		1				0.6	2
Mur 16		1					1
Mur 16		1					1
Mur 16		1					1
Mur 16		1				0.6	2
Mur 18	Riffle	1			1		2
Mur 18		1			1	0.6	3
Mur 18		1					1
Mur 18							0
Mur 18		1			1	0.6	3
Mur 18							0
Mur 19	Riffle						0
Mur 19		1			1		2
Mur 19						0.6	1
Mur 19		1					1
Mur 19							0
Mur 19						0.6	1
Mur 23	Riffle					0.6	1
Mur 23			0.8			0.6	2
Mur 23		1				0.6	2
Mur 23		1				0.6	2
Mur 23				1		0.6	2
Mur 23		1	0.8	1			3
Mur 28	Riffle						0
Mur 28		1				0.6	2
Mur 28		1				0.6	2
Mur 28							0
Mur 28						0.6	1
Mur 28		1					1

APPENDIX E (cntd.). Taxa expected, but not collected in the edge habitat autumn 2011

Site	Taxa	Planorbidae	Oligochaeta	Elmidae	Tanypodinae	Baetidae	Leptophlebiidae	Caenidae	Corixidae	Synlestidae	Gripopterygidae	Hydroptilidae	Conoesucidae	Leptoceridae	Total number of missing taxa
	SIGNAL	2	2	7	4	5	8	4	2	7	8	4	7	6	
MUR 15	Edge	*0.55*		*0.62*						*0.66*	*0.69*	*0.93*	*0.59*		6
MUR 15		*0.55*		*0.62*	*0.9*					*0.66*	*0.69*		*0.59*		6
MUR 16	Edge	*0.55*		*0.62*	*0.9*				*0.62*	*0.66*			*0.59*	*0.96*	7
MUR 16		*0.55*		*0.62*	*0.9*				*0.62*	*0.66*			*0.59*		6
MUR 16		*0.55*		*0.62*	*0.9*				*0.62*	*0.66*			*0.59*		6
MUR 18	Edge	*0.55*		*0.62*						*0.66*			*0.59*		4
MUR 18		*0.55*		*0.62*		*0.9*				*0.66*			*0.59*		5
MUR 18		*0.55*		*0.62*			*0.97*			*0.66*			*0.59*		5
MUR 19	Edge	*0.55*		*0.62*						*0.66*	*0.69*		*0.59*		5
MUR 19		*0.55*		*0.62*	*0.9*					*0.66*			*0.59*		5
MUR 19		*0.55*		*0.62*	*0.9*					*0.66*			*0.59*		5
MUR 23	Edge	*0.55*		*0.62*					*0.62*	*0.66*		*0.93*	*0.59*		6
MUR 23		*0.55*		*0.62*	*0.9*				*0.62*	*0.66*			*0.59*		6
MUR 23		*0.55*			*0.9*				*0.62*	*0.66*	*0.69*		*0.59*		6
MUR 23		*0.55*		*0.62*	*0.9*				*0.62*	*0.66*			*0.59*		6
MUR 28	Edge	*0.55*			*0.9*					*0.66*	*0.69*		*0.59*		5
MUR 28		*0.55*	*0.97*		*0.9*		*0.97*	*1.0*		*0.66*	*0.69*		*0.59*		8

Appendix F–

Point Hut Pond Hydrograph: 2010

Appendix F. Point Hut Pond and Lobb’s Hole Hydrograph showing mean daily flows (in Cumecs) for autumn 2011