ACTEW CORPORATION

MURRUMBIDGEE ECOLOGICAL MONITORING PROGRAM

PART 1: ANGLE CROSSING

AUTUMN 2010

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CERTIFICATE OF APPROVAL FOR ISSUE OF DOCUMENTS

Client:	ACTEW Corporation
Project Title:	Murrumbidgee Ecological Monitoring Program
Report Title:	Angle Crossing assessment autumn 2010
Document No:	AC_A10_R5
Document Status:	Final
Date of Issue:	**December 2010**

	POSITION	NAME	SIGNATURE	DATE
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Document Revision Control

VERSION	DESCRIPTION OF REVISION	PERSON MAKING ISSUE	DATE	APPROVAL
1	DRAFT	NM	10/08/2010	

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List of abbreviations

ACT – Australian Capital Territory
ACTEW – ACTEW Corporation Limited
AFDM – Ash Free Dry Mass (periphyton)
ALS – Australian Laboratory Services
ANOSIM – Analysis of similarities
ANOVA – Analysis of Variance (statistics)
ANZECC –Australian and New Zealand Environment and Conservation Council
APHA – American Public Health Association
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
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 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 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 in 2011. Abstraction will be dictated by the level of demand for water, and by the availability of water in the Murrumbidgee River. 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 and then 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 monitoring of the Murrumbidgee River upstream and downstream of Angle Crossing in autumn 2010. Sampling was completed in May 2010 and was based on the AUSRIVAS sampling protocols, but was extended to include replicated sampling at each site and genus level identifications for selected taxa. The reasons for these variations were to: a) establish within-site variability prior to the commencement of pumping; and

b) improve the potential ability of the monitoring program to detect subtle changes in the macroinvertebrate community in response to water abstraction impacts.

The key results from the autumn 2010 sampling of Angle Crossing show that:

1) The continuous water quality records for all gauged physico-chemical parameters were within the ANZECC and ARMCANZ (2000) guidelines (assessments based on daily means) for the autumn period. Fluctuations in the individual water quality parameters are related to hydrological variation and changing ambient temperatures and are closely correlated between the two stations. There are slight differences in the daily cycles between these stations, which is probably related to the different depths of the loggers at each site.

2) Grab samples collected in conjunction with the biological sampling show that total nitrogen concentrations were above the ANZECC and ARMCANZ (2000) guideline of 0.26 mg/L at all of the sampling sites. The highest concentrations were recorded at Point Hut Crossing with 0.4 mg/L, and our site upstream of the Cotter confluence had a concentration of 0.39 mg/L. The remaining sites ranged between 0.32 and 0.35 mg/L. Total phosphorus (TP) guideline concentration of 0.02 mg/L was only exceeded at Point Hut Crossing (0.03 mg/L), while at the remaining sites, TP concentrations were on the cusp of the recommended ANZECC & ARMCANZ value. Nitrogen oxides were below detectable levels for all sites. The remaining physico-chemical parameters were similar across all sites and were within the recommended guidelines.

3) Chlorophyll-a concentrations were elevated at sites downstream of Point Hut Crossing, but on average the downstream sites were not statistically different between upstream and downstream locations. Chlorophyll-a and AFDM were highly correlated suggesting that the chlorophyll was probably algal derived. Furthermore, there were strong positive correlations between these concentrations with TP and TN and substrate size indicating that nutrients might be the limiting factor for increased algal biomass (inferred from the periphyton data), but require larger, more stable substrate to withstand scouring during high flow periods.

4) All sites were classified as "significantly impaired" (BAND B) by the AUSRIVAS assessment, which is similar to our previous assessments of these sites. SIGNAL -2 scores and O/E scores did not differ between locations or habitats. There were subtle changes in the community composition downstream of Angle Crossing – with the dominant Chironomids (SIGNAL=3) being replaced with high abundances of Hydropsychidae (SIGNAL=6), which have been shown to proliferate and dominate slightly enriched sites. These findings are consistent with our nutrient data which show increased abundances of these taxa with increasing TN and TP concentrations.

5) All sampling sites were dominated by a similar suite of taxa that were seen on both previous sampling runs, which include tolerant taxa with low to intermediate SIGNAL-2 scores. The main difference between sampling runs is the sharp increase in the diversity of EPT taxa which may be because the two high flow events have assisted in removing fine sediment build up from the riffles and edges and thus improving habitat quality and surface water quality. Overall taxa richness was considerably higher since spring supporting our predictions from the spring 2009 report. These results are probably a reflection of the time since the last high flow event (92d) compared to the short time frame in spring (8-10d).

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 proposed time-line is to undertake sampling in spring and autumn over a three year period that commenced in spring 2008.

There are four component areas being considered:

- 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

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 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 to be in operation in late 2011. Abstraction will be dictated by the level of demand for the water, and by the availability of water in the Murrumbidgee River. The proposal is referred to as Murrumbidgee to Googong project (M2G).

Due to the combined effects of climate change and increased demands from industry and households, the impacts of water abstraction on aquatic ecosystems, river health and water quality have been extensively researched (see Dewson *et al.*, 2007 for a recent review). It is expected there will be changes to the aquatic ecosystem within the Murrumbidgee River and Burra Creek 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 (**APPENDIX A**). This current monitoring program will form the basis of an Ecological Monitoring Program to satisfy EIS requirements.

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.

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.

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 1). 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 will be on the documentation of spatial and seasonal changes in macroinvertebrate and periphyton assemblages as well as monitoring water quality patterns. This will also include monitoring potential effects associated with (either directly or indirectly) the construction of the new pump station at Angle Crossing.

Phase 2, incorporates long term objectives, which aim 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 1. 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.	2-3 years	Help establish flow rules for the operation of the pump in the M2G project 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.	3+ years	Help minimise ecological impacts by better understanding biological responses to water abstraction.

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 2010 sampling. Specifically, as outlined in the MEMP proposal to ACTEW Corporation (Ecowise, 2009) this work includes:

- Sampling conducted in autumn 2010;
- 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), are used during this survey 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 (Talsma and Hallam, 1982; Biggs, 1989;; Whitton and Kelly, 1995; Biggs *et al.*, 1999;). Water abstractions from Angle Crossing will not affect the timing or magnitude of higher flows, but it 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 large catchment, which includes 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 (e.g. 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 2. Sampling site locations and details

Site Code	Location	Landuse	Habitat sampled
MUR 15	Near Colinton - Bumbalong Road	Grazing / Recreation	Riffle and Edge
MUR 16	The Willows - Near Michelago	Grazing	Riffle and Edge
MUR 18	U/S Angle Crossing	Grazing	Riffle and Edge
MUR 19	D/S Angle Crossing	Grazing / Recreation	Riffle and Edge
MUR 23	Point Hut Crossing	Recreation / Residential	Riffle and Edge
MUR 28	U/S Cotter River confluence	Grazing	Riffle and Edge

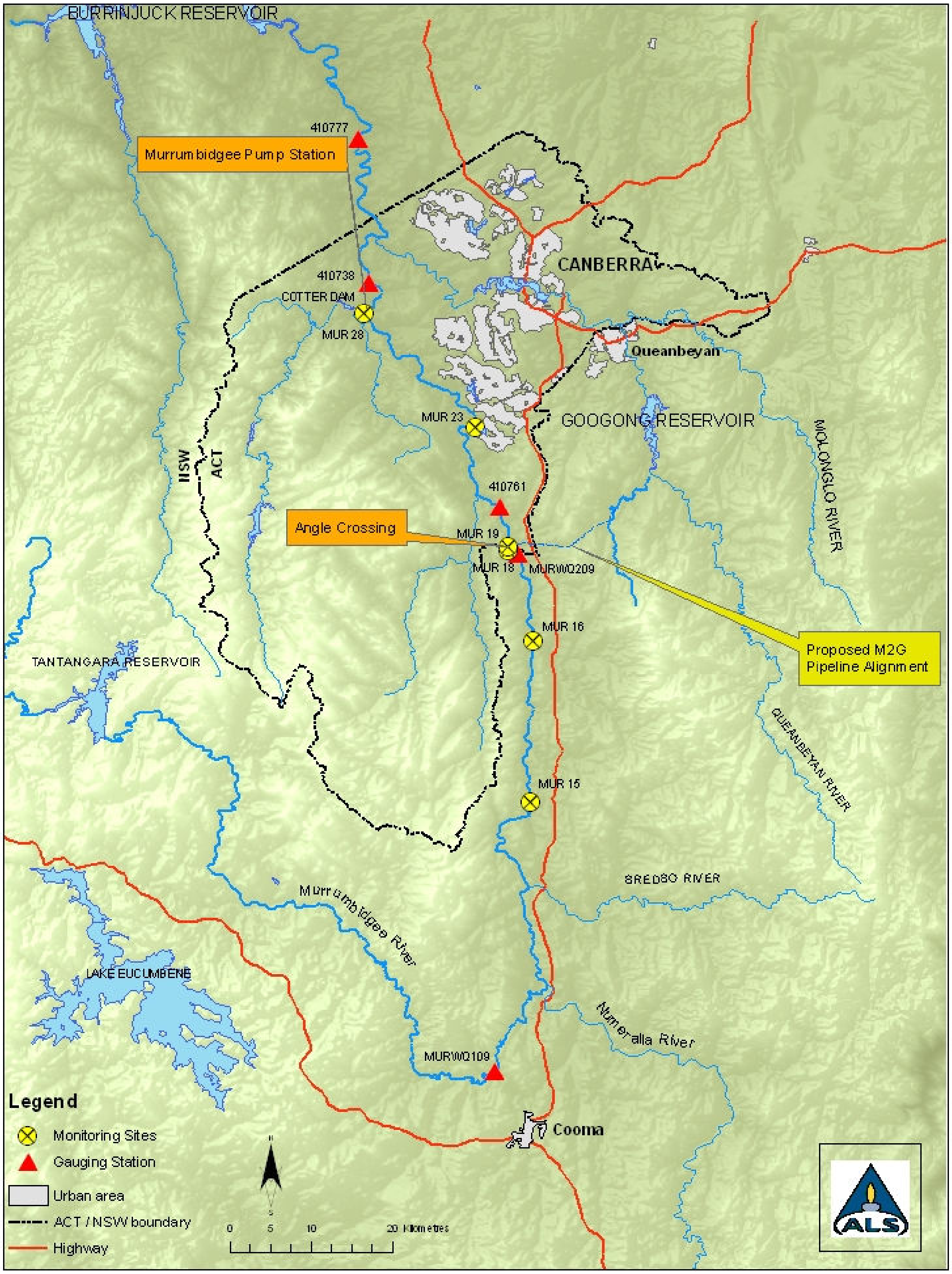

Figure 1. Angle Crossing sampling locations and gauging stations

MUR 15. Looking upstream (36 ML/d)

MUR 15. Looking downstream

MUR 16. “The Willows” near Michelago (36 ML/d)

MUR 16. Looking downstream

Mur 18. ~800m Upstream of Angle Crossing

Mur 18 looking upstream (39 ML/d) (INSET: with exposed riffle in the foreground)

PLATE 1. Photographs of sampling sites upstream of Angle Crossing

Mur 19. Downstream of Angle Crossing

Mur 19. Looking downstream (35.7 ML/d)

Mur 23. Point Hut Crossing

Mur 23. Looking upstream towards bridge

Mur 28. Upstream Cotter River confluence

PLATE 2. Photographs of sampling sites downstream of Angle Crossing

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 Angle Crossing (MURWQ09).

Site locations and codes are given in Table 3. Stations are calibrated monthly and data is 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 3. 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 *in-situ* 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.*, 2000b) 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 will 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.*, 2000a); 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.*, 2000b) during autumn (May 25th and 26th) 2010. 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.*, 2000b) 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 spreadsheets 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 Ash Free Dry Mass (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.*, 2000b) to compliment the quantitative samples.

2.6 Data analysis

2.6.1 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.

2.6.2 Macroinvertebrate communities

The macroinvertebrate data were examined separately for riffle and edge habitats. Replicates were examined individually (i.e. not averaged) at all sites because the aim is to examine within-site variation as much as it is to describe patterns among sites. All multivariate analyses were performed using PRIMER version 6 (Clarke and Gorley, 2006). Univariate statistics were performed using R version 2.10.1 (R Development Core Team, 2009).

To test for differences in univariate metrics (SIGNAL-2 scores and AUSRIVAS OE50 ratios) upstream and downstream of Angle Crossing, mixed effect, nested ANOVA models were conducted (Quinn and Keough, 2002). Sites were considered random effects 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. 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.

Non-metric multidimensional scaling (NMDS) was also performed on the macroinvertebrate community data following the initial cluster-analysis. NMDS is a multivariate procedure that reduces the dimensionality of multivariate data and aids interpretation. It reduces the dimensionality of the data by describing trends in the joint occurrence of taxa. 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 suggests that NMDS patterns are very representative of the multidimensional data, while stress values greater than 0.2 indicate a poor representation (Clarke and Warwick 2001).

The analysis of similarities test (ANOSIM) was performed on the data to test whether macroinvertebrate communities were statistically different up 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.

2.6.3 AUSRIVAS assessment

In addition to assessing the composition and calculating biometrics from the macroinvertebrate data, riffle and edge samples, river health assessments based 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 4) 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 4).

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.*, 2000b). 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.

Table 4. 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	0.63-0.87	0.82-1.17	Similar to reference. Water quality and / or habitat in good condition.
B	0.63-0.85	0.48-0.82	Significantly impaired. Water quality and/ or habitat potentially impacted resulting in loss of taxa.
C	0.39-0.63	0.14-0.48	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.

2.6.4 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.

2.6.5 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. 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. The Pearson correlation coefficient measures the strength of the relationship between two variables (x and y). The correlation coefficient, denoted as "R", can 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 2.10.1 (R Development Core Team, 2009). Significance testing was not performed on these data because of low sample size (n=6 in all cases).

2.7 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 significantly 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.

2.8 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 maintain current ACT and NSW AUSRIVAS accreditation.

3 Results

Sampling for the autumn 2010 was carried out between 24th – 26th of May. At the time of sampling, the mean daily flow recorded at the closest gauging station (MURWQ09: Upstream of Angle Crossing) was 39 ML/d.

3.1 Hydrology and rainfall

The flows recorded for the autumn 2010 period indicate that the 50th percentile flows for March are the highest since 1993 for Lobb's Hole and the 50th percentile flows recorded in May were the highest since 1995. There were two events of significance occurring between the spring 2009 (October/November) and autumn 2010 (May) sampling periods. The first occurred in mid February and peaked at 26,000 ML/d, while the second occurred in early March and peaked at 870 ML/d.

March was the wettest month in autumn at both the upstream and downstream sites, with 114 mm of rainfall recorded at Lobb's Hole – 31.6 mm more than for the entire 2009 autumn period. A total of 75 mm fell upstream of Angle Crossing (MURWQ090). Although there was a difference in total monthly rainfall between the upstream and downstream sites in March, totals for April and May were within 5 % of one another (Table 5).

There were 23 wet days for the period at Lobb's Hole, averaging 7.6 per month, while upstream of Angle Crossing the station registered 30 wet days. At Lobb's Hole, the daily rainfall for the autumn period ranged from 0.2 (detectable minimum) to 39.6 mm in early March, upstream of Angle Crossing, the range was similar, but the highest total daily rainfall recorded was 31 mm in early March. Four consecutive wet days contributed to 65% of March's rainfall at both stations, resulting in a peak in the hydrograph early in the month (Figure 2). A second event, with an average recurrence interval (ARI) of 5 years (33,000 ML/d) occurred on the 31st of May, five days after the completion of autumn sampling (Figure 2). Both of the events originated in the Tinderry Ranges and drained through the Numerella catchment. During the February and May events, the Numerella gauge peaked at 2.8 and 3.9 metres respectively.

Table 5. 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	75.4	252.8	114	245.5
April	18.8	55.72	18.2	52.7
May	66.6	264.6	63.4	263.9
Autumn mean	160.8	191.1	195.6	187.3

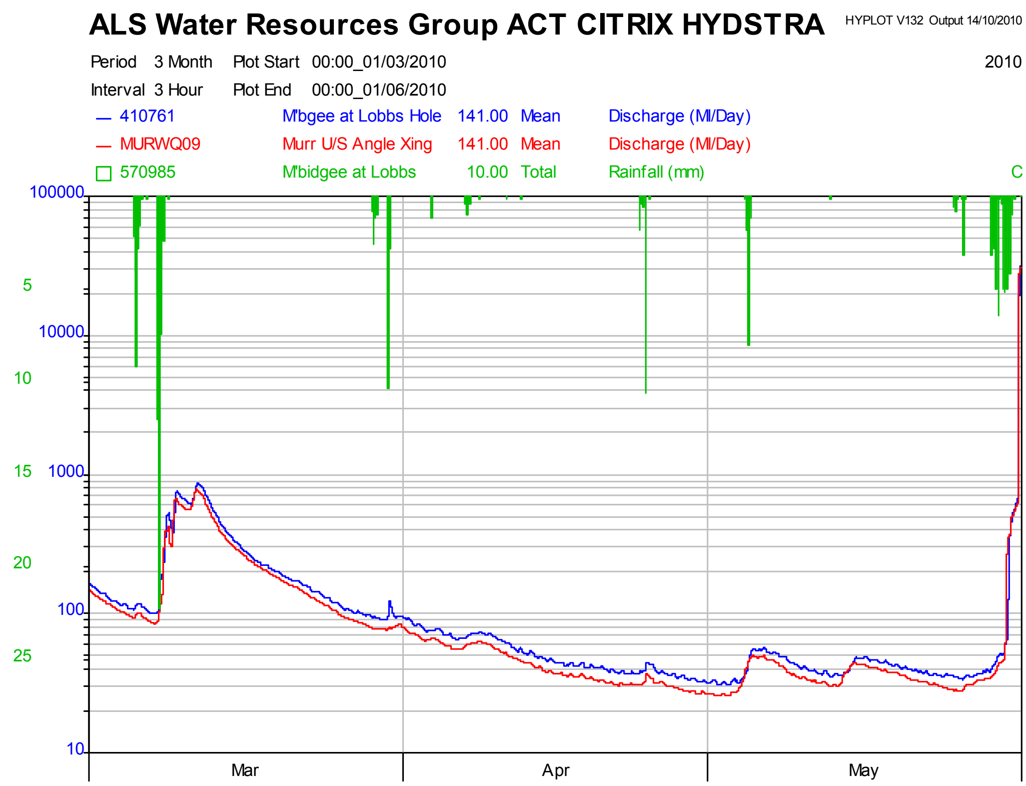

Figure 2.Autumn hydrograph of the Murrumbidgee River upstream of Angle Crossing (MURWQ09) and downstream of Angle Crossing at Lobb's Hole (410761).

- Total rainfall (mm) is shown in green.
- **Note the log scale for discharge on the y-axis**

3.2 Water quality

Data are missing from the continuous records for the first three weeks of March from Lobb's Hole, due to essential repairs required on the water quality probes. Therefore, the water quality responses to the event in early March are unclear (Figure 3). The data that is available shows that all of the physico-chemical parameters were within ANZECC and ARMCANZ guidelines (figures based on daily means) for the autumn period. The one exception was a turbidity spike in late March corresponding to a small rainfall event (10 mm) on the 30th. There were data gaps in the upstream Angle Crossing site (MURWQ09) in addition to the gaps at Lobb's Hole. The gaps upstream of Angle Crossing relate to sensor failure during the February flood.

The overall patterns in the continuous water quality data from both stations show a gradual decline in temperature, which corresponds to ambient temperatures decreasing towards winter (Figure 4). EC tended to fluctuate with changes in flow. The monthly average EC values were highly consistent over the three month period ranging between 115-121 us/cm^{-2}; monthly means ranged from 115 - 134 (Table 6). Both pH and DO (% sat.) showed strong diurnal trends. pH fluctuated more as the hydrograph was receding and as flows became more stable in May, the daily variation in pH became less apparent (Figure 3). DO trends throughout autumn were constant for the period, which is emphasised by the similarity in the monthly mean values (Table 6). Daily maximums did not exceed the upper, 110% trigger value while the average minimum saturation levels fell below the lower end of the guideline values of 90% during March, but only upstream of Angle Crossing. Lobb's Hole remained within the guidelines for the autumn period.

Grab samples collected in conjunction with the biological sampling show that total nitrogen concentrations were above the ANZECC and ARMCANZ (2000) guidelines at all of the sampling sites (Table 9). The highest concentrations were recorded at MUR 23 (Point Hut Crossing) with 0.4 mg/L and MUR 28 (upstream of the Cotter confluence) had a concentration of 0.39 mg/L. The remaining sites ranged between 0.32 and 0.35 mg/L. Total phosphorus (TP) guideline concentrations were exceeded only at MUR 23 (0.03 mg/L), while at the remaining sites, TP concentrations were on the cusp of the recommended ANZECC & ARMCANZ value of 0.2 mg/L. Nitrogen oxides were below detectable levels for all sites. The remaining physico-chemical parameters were similar across all sites. EC followed a longitudinal gradient ranging from 98.6-118.2 from upstream to downstream respectively, although the continuous records show a slightly different pattern with monthly EC values being consistently higher upstream of Angle crossing compared to the Lobb's Hole station (Table 6).

Table 6. Monthly water quality statistics from upstream and downstream 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 brackets		D.O (% sat.)	
	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S
March	20.8	20.8	133.8	115.9	8	7.7	1.5 (2)	6 (41)	80-89	96-99
April	17.2	17.5	129.2	118.7	7.9	7.7	8 (12)	6.8 (15)	81-91	93-98
May	11.3	11.5	127.2	115.8	7.9	7.7	13 (851)	7.7 (16)	88-97	95-98
Autumn	16.4	16.6	130.1	116.8	7.9	7.7	7.5 (851)*	6.8 (41)*	80-97	93-99

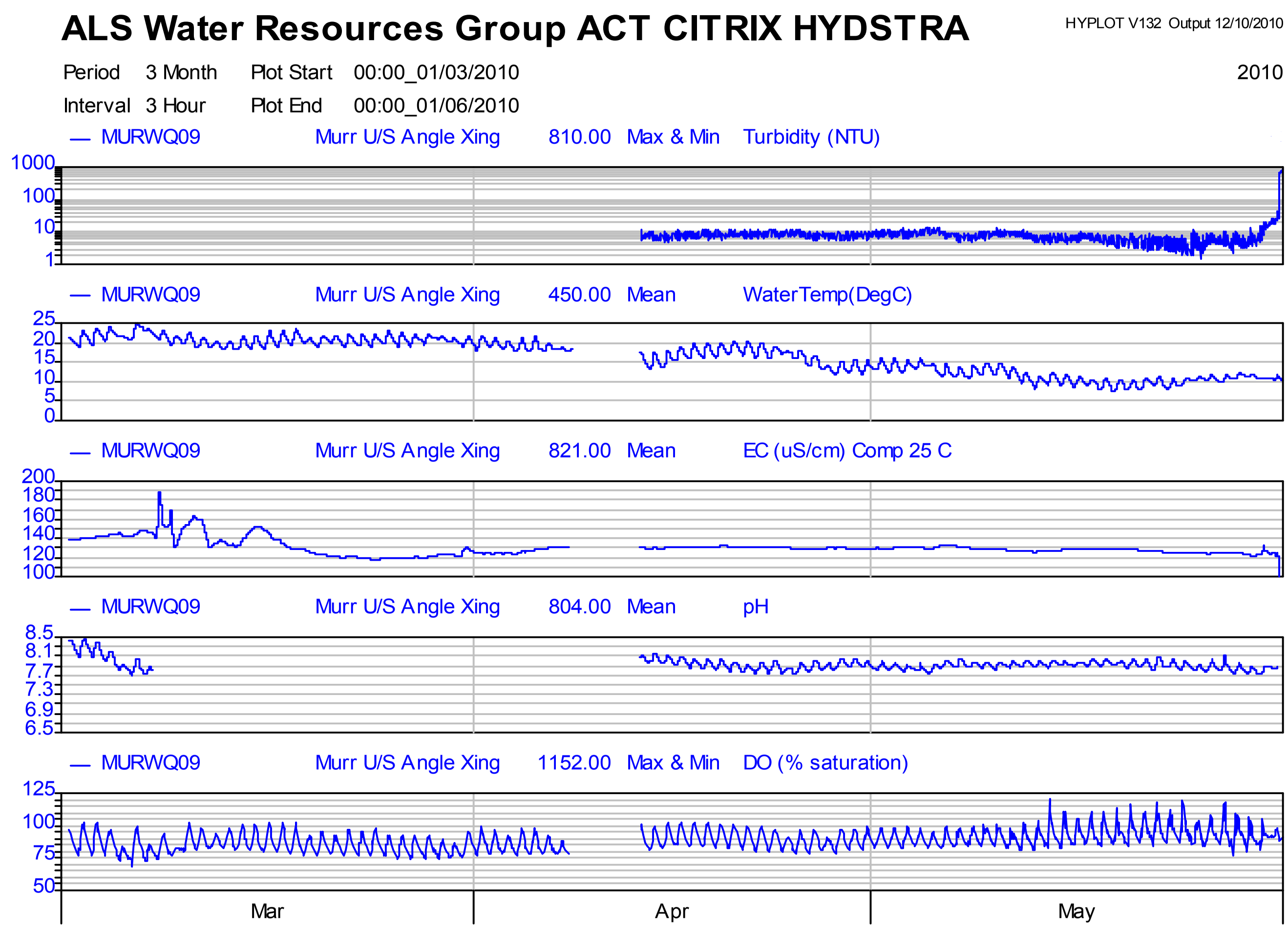

Figure 3. Continuous water quality records from upstream Angle Crossing: (MURWQ09) for autumn 2010

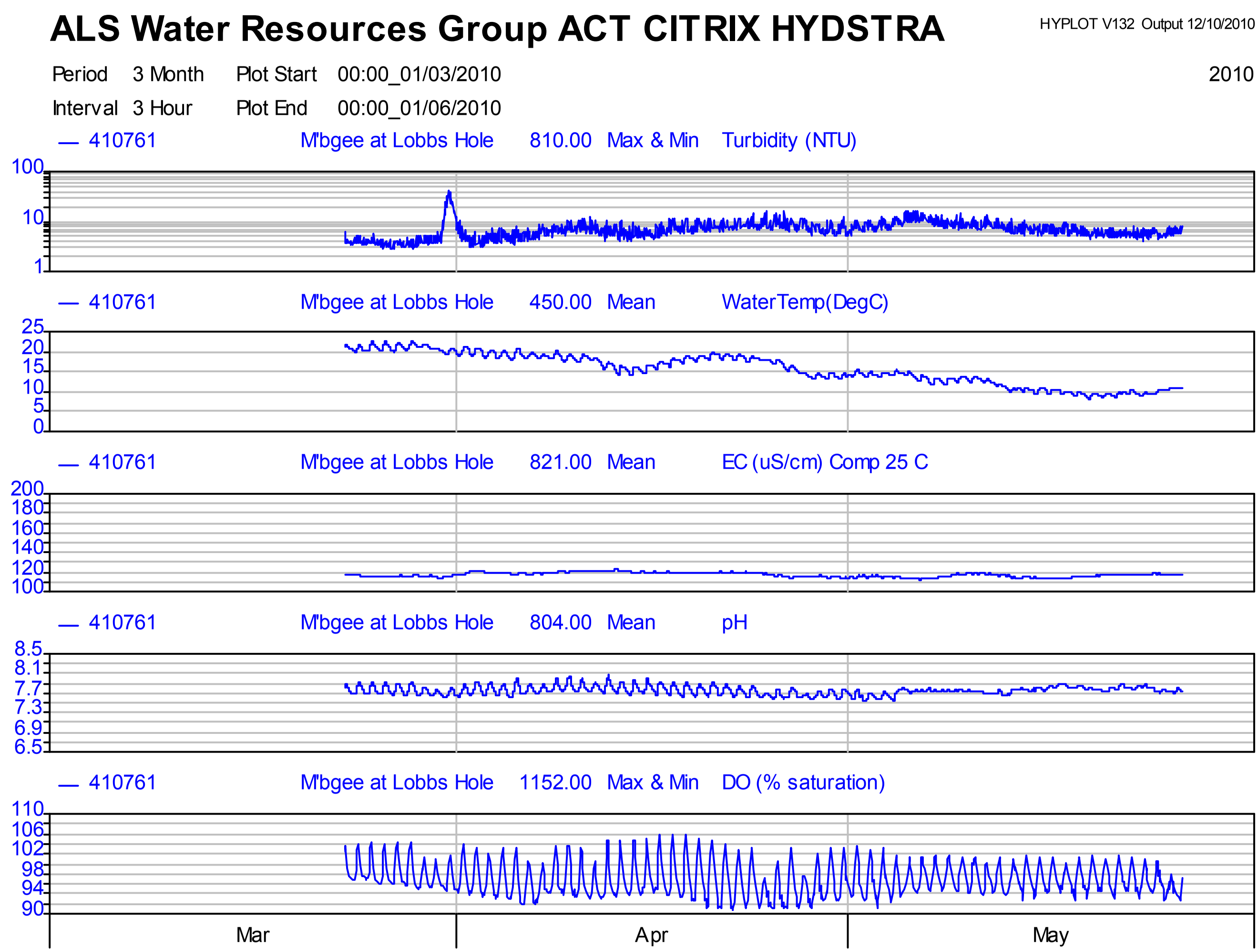

Figure 4. Continuous water quality records from Lobb's Hole (downstream Angle Crossing: 410761) for autumn 2010

3.3 Periphyton

Chlorophyll-a concentrations were highly variable between sites, ranging from 10 555 µs/cm^{-1} at MUR 19 to 47 365 µs/cm^{-1} at MUR 28 (Figure 5a). There was a sharp increase in average chlorophyll-a concentrations downstream of Point Hut Crossing (MUR 23) with concentrations peaking at MUR 28. As a result, the average concentration downstream (mean=33 987 ± 37 584 µs/cm^{-1}) were higher than the upstream sites (mean=15 151 ± 12 258 C.I µs/cm^{-1}) but due to the large spread of values, especially at the downstream sites, there was no significant location effect ($F_{1,4}$ = 0.36; P=0.57; Table 7) as indicated by the high standard deviation.

The relationship between the sites upstream and downstream of Angle Crossing was similar for the AFDM data (Figure 5b) in that there was no significant location effect detected from the ANOVA model ($F_{1,4}$ = 4.02; P=0.12; Table 7).However the distribution of values is right skewed at MUR 23, and downstream at MUR 28 due to two single large values at these sites. These values may have resulted from sampling error, but more likely are samples collected at the bank-side margin where algal patches and detrital matter tend to accumulate in lower velocities.

Qualitative assessments of the substrate indicate that the patches of filamentous algae, especially at MUR 23 were not restricted to the margins, as they have been previously, which indicates stable flows were a feature of the river channel prior to sampling. Following the spring sampling run, most of the filamentous algae growth was along the margins (with the exception of MUR 23) suggesting hydraulic disturbance after the high flow event in November.

In this study, there was a very weak relationship with the chlorophyll-a (R =-0.29) and AFDM (R = -0.17) data and mean velocity (Table 8). In previous sampling runs we have reported negligible relationships between AFDM and chlorophyll-a concentrations, however the results from this sampling run are highly correlated between mean values (R=0.87) suggesting that the detritus in these samples was probably algal derived. Given the strength of this relationship, it is not surprising then, that all of the physical and chemical parameters showed similar relationships with AFDM and chlorophyll-a data (Table 8).

The strength of the relationship between the other physical and chemical variables ranged from almost no relationship between ADFM and mean depth (R=0.07) to high correlations between bedrock and chlorophyll- a (R=0.89). Substrate composition influenced both chlorophyll-a concentrations and AFDM estimates. Chlorophyll-a increased with bedrock cover (R=089) and decreased as gravel (R=-0.65) and sand (-0.61) become more dominant, suggesting that substrate stability is an important factor for the growth and resilience of algae populations. In contrast to previous sampling runs, there were indications from our correlation coefficients that several of the water quality parameters were related to chlorophyll-a and AFDM standing stocks (Table 8). Total Nitrogen in particular was highly correlated to chlorophyll-a and AFDM; total phosphorus was also correlated to these indicators but to a lesser extent. There were also positive relationships between both AFDM and chlorophyll-a and water temperature and relatively weak relationships with pH.

We previously indicated a potential lag effect preventing the detection of any relationship between water quality parameters and our periphyton data. However, during low stable flows it is possible that the initial factors limiting algal growth prevailed throughout the low, stable conditions observed leading up to the time of sampling, and as such were identifiable.

Table 7. Nested analysis of variance results for chlorophyll-a and AFDM concentrations

Response	Source	DF	F-value	P-value
Chlorophyll-*a* (log)	Location	1	0.36	0.57
	Site [Location]	4	3.35	0.02
	Residual	30		
AFDM (log)	Location	1	4.02	0.12
	Site [Location]	4	0.88	0.48
	Residual	30		

Table 8. Pearson's correlation coefficients between mean AFDM, mean chlorophyll-a concentrations and the ten most important environmental parameters (based on the strength of the correlation)

Parameter	Mean AFDM	Mean Chlorophyll-a
Mean velocity	-0.17	-0.29
Mean depth	0.07	0.46
% Bedrock	0.73	0.89
% Gravel	-0.74	-0.65
% Sand	-0.35	-0.61
TP	0.68	0.56
TN	0.80	0.82
Turbidity (NTU)	0.51	0.53
pH	-0.38	-0.17
Water temperature	0.33	0.42

Table 9. In-situ water quality results from autumn 2010 (ANZECC guidelines are in red). Yellow cells indicate values outside of ANZECC and ARMCANZ (2000) guidelines.

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)	Turbidity(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	0915 26/5/10	8.9	98.6	6.4	6	7.54	94.1	11.01	48	<0.01	<0.01	<0.01	0.03	0.02	0.34
	MUR 16	1120 26/5/10	10.2	111.9	5.8	6	7.75	96.3	10.92	54	<0.01	<0.01	<0.01	<0.01	0.02	0.32
	MUR 18	1300 26/5/10	11.18	116.5	4.2	4	7.75	99.2	11.00	55	<0.01	<0.01	<0.01	0.02	0.02	0.35
Downstream sites	MUR 19	1415 26/5/10	11.2	116.7	7.9	10	7.73	97.7	10.80	55	<0.01	<0.01	<0.01	0.02	0.02	0.35
	MUR 23	1530 24/5/10	11.1	118.2	11	18	7.45	99.7	11.09	54	<0.01	<0.01	<0.01	0.01	0.03	0.40
	MUR 28	1200 25/5/10	11.2	115.4	7.0	7	7.8	99.30	11.00	54	<0.01	<0.01	<0.01	0.03	0.02	0.39

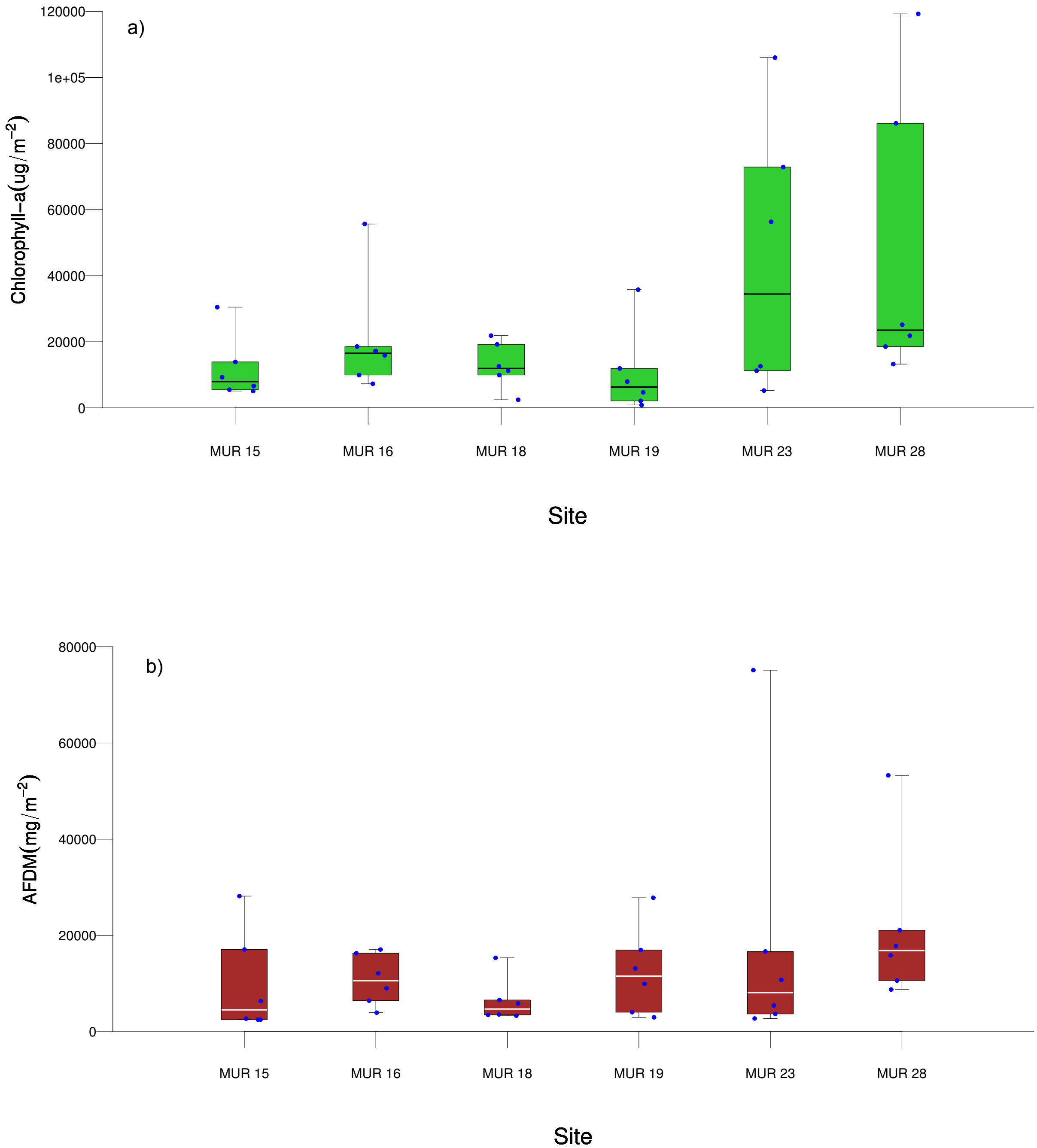

Figure 5. The distribution of a) Chlorophyll-*a*; and b) Ash Free Dry Mass (AFDM) upstream and downstream of Angle Crossing. Strip chart values (in blue) represent the raw data values for each site. See APPENDIX C for an explanation of how to interpret box and whisker plots.

3.4 Macroinvertebrate communities

Macroinvertebrate communities collected in the riffles did not vary significantly between upstream and sites downstream of Angle Crossing (R=-0.22; P=1; Figures 5 & 6). Similarly, there were no significant differences in edge community structure at sites upstream and downstream of Angle Crossing (R= -0.15; P=1: Figure 7 and 8) (see APPENDIX C for ANOSIM output). The negative R-values indicate that some samples taken downstream of Angle crossing were more similar to those communities upstream of the crossing. For example, from the riffle samples (Figure 7) MUR 16 and 18 are grouped closer to MUR 19 and 28 from the downstream location than they are to MUR 15, which is geographically the farthest site upstream. Similarly, from the edge samples, MUR 18 (Figure 8) is grouped with MUR 19 and MUR 23 which are both located downstream of the crossing. MUR 16 appears well separated from the main group, while MUR 15, despite being grouped on its own, is more similar to MUR 23 than any of the other upstream sites.

3.4.1 Riffles

There was a moderate degree of overlap in the macroinvertebrate community structure indicated by the relationship between sites inferred from the NMDS analysis (Figure 8). As in previous sampling runs, the main differences between sites appear to be differences in the relative abundances of certain taxa rather than the presence or absence of taxa between sites. There are some exceptions however, which are implied from the cluster analysis (Figure 7) and the NMDS analysis (Figure 8), which shows MUR 15 separated from the main cluster and MUR 23 on the outer margin of the main group. Tipulidae (Diptera) was absent from MUR 15 and the sub-family, Podonominae (Diptera: Chironomidae) was only collected at this site and two unique genera (*Neboissophlebia* sp. *and Nousia* sp.) from the Leptophlebiidae family were collected at this site only. Additionally the Hydrobiosidae genus *Austrochorema* sp. was also unique to this site, but was present in low numbers.

The community composition of the main ordination group (65% similarity; Figure 8) was dominated by Dipterans, in particular: Chironominae (SIGNAL=3) and Orthocladiinae (SIGNAL= 4), which made up to 47% of the total community composition. Simuliidae were another common Dipteran family but were less abundant than the other Dipteran families mentioned. Oligochaeta (SIGNAL = 2) were common across all sites, but were least abundant at MUR 15 (5% of the total estimated community abundance). Moderately tolerant Mayflies such as Caenidae (SIGNAL=4); and Caddisflies such as Hydropsychidae (SIGNAL =6) were also present in high numbers and were common at all of the monitoring sites.

The number of taxa was relatively even across all of the sampling sites (Figure 11). MUR 16 had the most macroinvertebrate families (23) and genera (30) while the least occurred immediately downstream of Angle Crossing at MUR 19, where 18 families and 25 genera were collected. Upstream of Angle Crossing (MUR 18) and Point Hut Crossing had the highest number of families in the EPT suite of taxa (9) and highest number of genera (16). These figures show an increase in the number of EPT taxa collected since spring 2009, but a decline in the number of genera by up to 45% (at MUR 23) since autumn 2009.

On average the upstream sites had a lower relative abundance of EPT taxa (mean=45.5%) compared to downstream (50.4 %). The percent of EPT taxa was evenly spread across the upstream sites (Figure 12). The spread of values was narrow upstream of Angle Crossing ranging from 44 – 46.5%. there was more variation between sites downstream of Angle Crossing with percentages ranging from 32.1% at MUR 28 to 63.4% at MUR 23. This pattern is caused by a shift in the community composition downstream of Angle Crossing and highlights one of the caveats of using the EPT biological metric as an indicator of stream health. The data shows that downstream of Angle Crossing (MUR 19) and Point Hut Crossing in particular (MUR 23) there is between a 11% and 19% increase in the proportion of EPT taxa owing to a sharp increase in the numbers of *Tasmanocoenis sp*. (Caenidae: SIGNAL = 4) and *Cheumatopsyche* sp. (Hydropsychidae: SIGNAL = 6); *Asmicridea* sp. (Hydropsychidae) accounted for approximately 10% of the Hydropsycids at MUR 23 but this genus was not collected from any of the other sites in this program. The increases of Hydropsychidae and Caenidae downstream of Angle Crossing correspond to a decrease of Dipteran taxa at these sites, most notably individuals in the family Simuliidae, which declined by 30% at MUR 23 with increasing numbers of Hydropsycids and Caenid macroinvertebrates.

3.4.2 Edges

Family and genus richness was highest at MUR 28 with 27 and 37 taxa collected respectively. The least number of taxa were collected at MUR 16 (19 families and 22 genera). Mean depth in the edge habitat was highly correlated with the number of genera (R=0.73) but not the number of families (R=0.42) suggesting that increased depth facilitated genus radiation, potentially due to increased habitat diversity.

The ordination analysis shows that the edge samples have a higher between site dissimilarity than the riffle samples. The Bray-Curtis similarity measurement indicates that all sites form one group at 50%, while at 70% each site is grouped by within site subsamples. At 65% (Figure 10) the edge samples are grouped into four groups. The main group contains sites MUR 18, 19 and 23 and the remaining sites are grouped by themselves. Taxa separating these groups were Leptoceridae (SIGNAL =6), showing greater diversity and abundances than MUR 15, 16 and 28; Corixidae (SIGNAL =2) were absent from MUR 18 and 19 and common taxa such as *Micronecta sp*. in the family Corixidae (SIGNAL =2) were missing from MUR 18 and 19 and in 2 of the 3 of sub-samples at MUR 16 and 28. They were present however at sites MUR 15 and MUR 23 in all of the subsamples, which is contrast to spring and autumn 2009 where they were found to be one of the most dominant species. *Macrobrachium sp.* (Palaemonidae) were absent from MUR 15 and 16, but were found in the riffle samples at MUR 16. Another, usually common taxon that was sparse or missing from the autumn 2010 samples was Simuliidae, which was absent from all edge samples except at MUR 15, where it was present in very low numbers compared to autumn and spring 2009.

Similar to observations made in relation to riffle-habitat above (section 3.4.1), edge samples were dominated by pollution-tolerant taxa with low to intermediate SIGNAL scores, such as Oligochaeta (SIGNAL = 2), Chironominae (SIGNAL=3) and Ceratopogonidae (SIGNAL =4). Chironominae were the most dominant taxa in all of the edge samples, making up to 61% of the total abundance at MUR 15, but contributing between 35-48% of the total abundance across the remaining sites. Individuals in the family Caenidae (SIGNAL=4) were common, and were the most abundant Mayfly from the edge samples, particularly the genus: *Tasmanocoenis sp.* Caddisflies (Trichoptera) were the most dominant and diverse taxa in the EPT suite. Leptoceridae (SIGNAL= 6) showed the greatest diversity of the Caddisflies with 4 genera collected from MUR 18; there were also three genera collected from the family Hydroptilidae (SIGNAL = 4).

3.5 AUSRIVAS assessment

Taxa predicted to occur with ≥50% probability, but absent from each habitat and site are presented in **APPENDIX D**.

The AUSRIVAS results for autumn 2010 are similar to previous sampling events in that all of the sites had an overall assessment of BAND B ("significantly impaired") (Table 10). There appears to be an improvement in the AUSRIVAS assessment of the riffle habitat at MUR 16, given its BAND A assessment in this sampling run. It should be pointed out that owing to the limited number of subsamples at this site in autumn 2010 (only one sample was possible due to low flows – see PLATE 1: MUR 16) the overall site assessment may have been over- estimated in this case. For example, in both previous assessments, and indeed in this sampling run, sites with the full set of replicates often have a mixture of BAND A and BAND B samples. Furthermore, these AUSRIVAS bands have been shown to group together so that all of the BAND A results are in the first replicate and the BAND B's are in the second, or vice versa. This can result from patchy distributions of macroinvertebrates within a site, or non-uniform habitat structure a given habitat type (i.e. riffle or edge) – in which case additional replicates should be collected to capture this variation.

Aside from this minor inconsistency, the nested ANOVA model found no difference in the observed to expected ratios (O/E50) from the AUSRIVAS analysis between sites upstream and downstream of Angle Crossing for either the riffle ($F_{1,4}$ = 0.13; P=0.74) or the edge habitats ($F_{1,4}$ = 2.43; P=0.19) (Figure 13). SIGNAL-2 scores, which are incorporated because they provide an indication of the water pollution, showed no difference between locations for the riffle samples ($F_{1,4}$ = 0.49; P=0.52) or the edge samples ($F_{1,4}$ = 0.83; P=0.41) (Figure 14).

Although the AUSRIVAS assessments for the riffle habitat are almost identical between autumn 2009 and autumn 2010, there were fewer taxa missing from the autumn 2010 samples. In autumn 2009, there were a total of seven taxa missing across all of the sampling sites and at MUR 28 up to five of these were missing. These taxa had a range of SIGNAL scores including highly sensitive taxa such as Gripopterygidae (SIGNAL=8) to the more tolerant and usually very common Oligochaeta (SIGNAL=2) and Caenidae (SIGNAL=4). During this round of sampling, only three taxa were missing from any one site and two the three had high probability scores for occurring at these sites. Elmidae, (SIGNAL = 7) for example was predicted with 100% probability, but was only found in one sub-sample at MUR 23. Tipulidae as predicted with 80% probability and was missing from most sites with no apparent pattern attached to the distribution.

Edge samples resembled those from autumn 2009, having a similar number of taxa missing across all of the sites. The highest number of missing taxa were from MUR 16 where 8 taxa predicted by the AUSRIVAS model were absent. The average across all sites in this sampling run was 6. Sensitive taxa including Synlestidae (SIGNAL=7), Conoesucidae (SIGNAL =7) and Gripopterygidae (SIGNAL=8) were missing from all of the sampling sites. Elmidae was missing from 83% of the samples, and were only found at MUR 28. Tolerant taxa that were predicted were, for the most part, present at all of the sites. MUR 28 recorded the highest number of missing, tolerant taxa (APPENDIX D) and Corixidae (SIGNAL=2) was absent from the shallowest edge sites (where mean depth was <30cm) with the exception of MUR 23, where they were found in a single sub-sample.

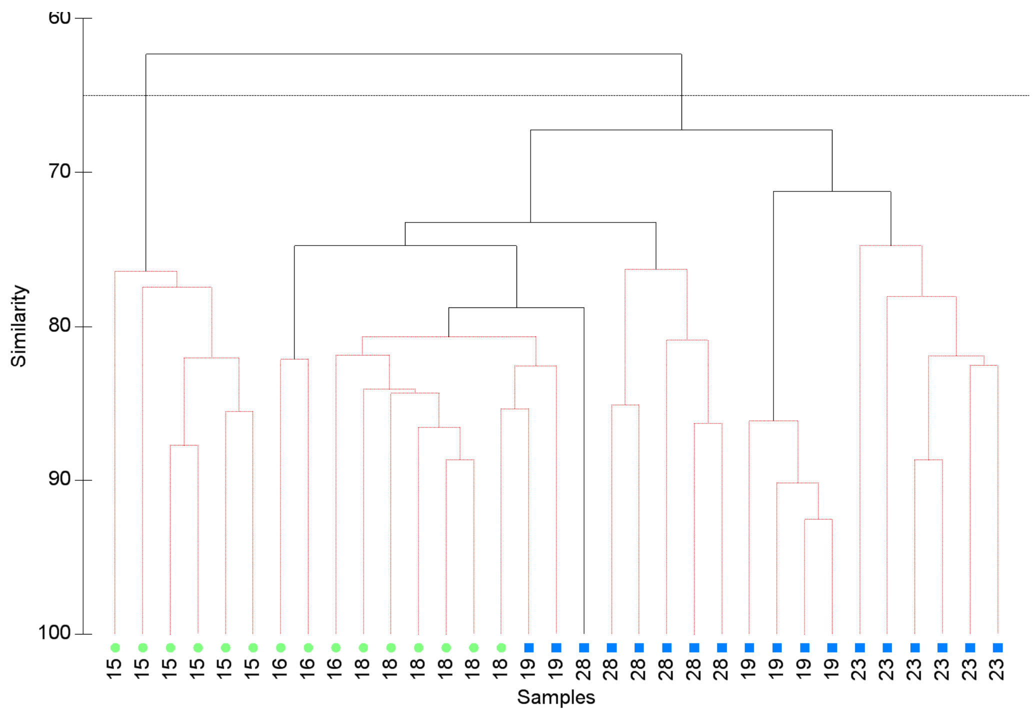

Figure 6. Cluster analysis based on genus level data from the spring riffle samples. Blue squares indicate sites downstream of Angle Crossing; green circles are upstream of Angle Crossing.

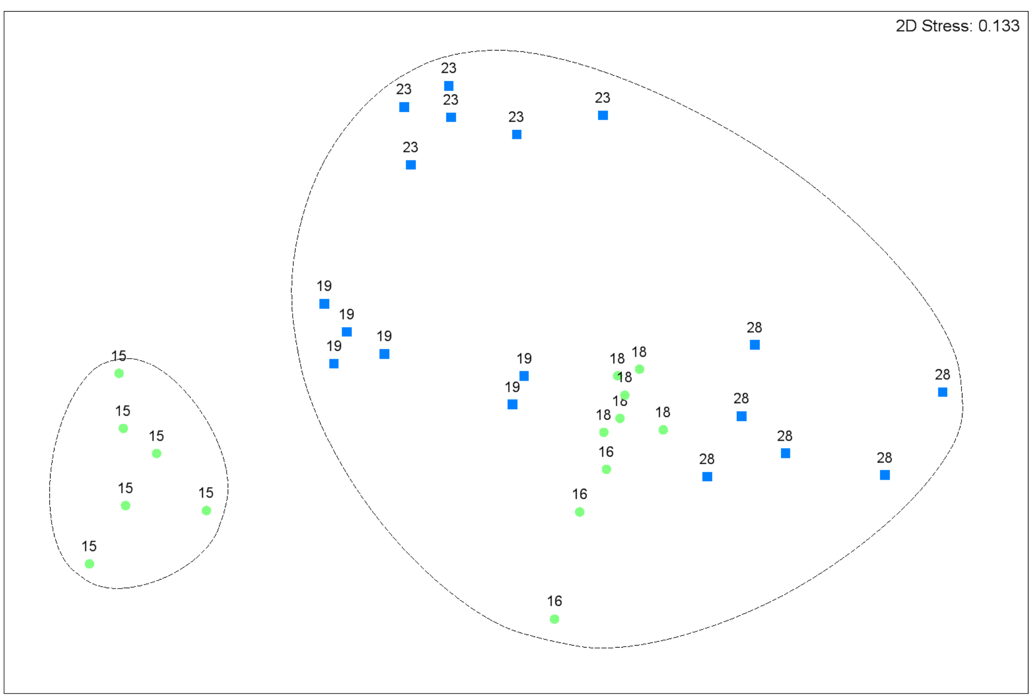

Figure 7. Non-metric multidimensional scaling of genus data from the spring riffle samples. Ellipses represent the 65% similarity groups superimposed from the cluster analysis (above)

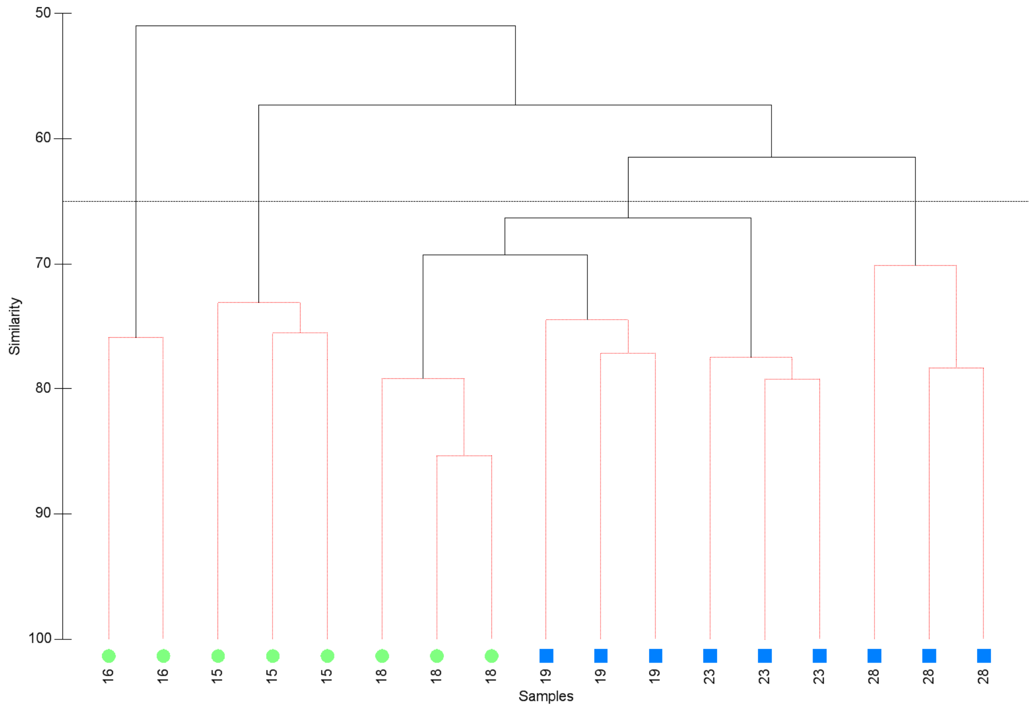

Figure 8. Cluster analysis based on genus level data for autumn edge samples. Blue squares indicate sites downstream of Angle Crossing; green circles are upstream of Angle Crossing.

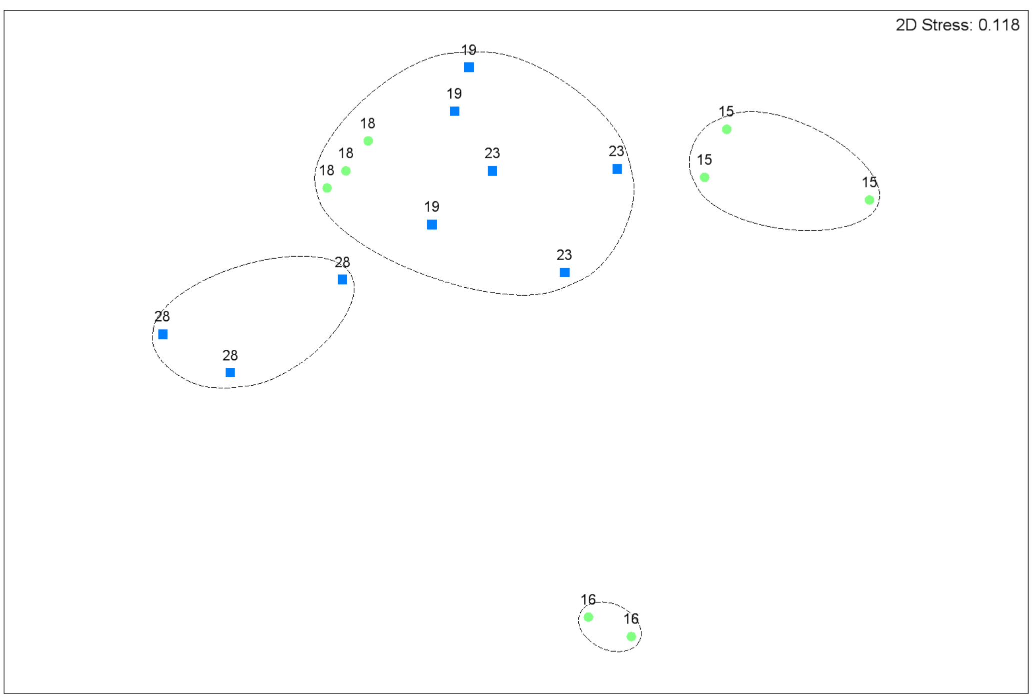

Figure 9. Non-metric multidimensional scaling of genus level data from autumn edge samples. Ellipses represent the 50% similarity groups superimposed from the cluster analysis (above)

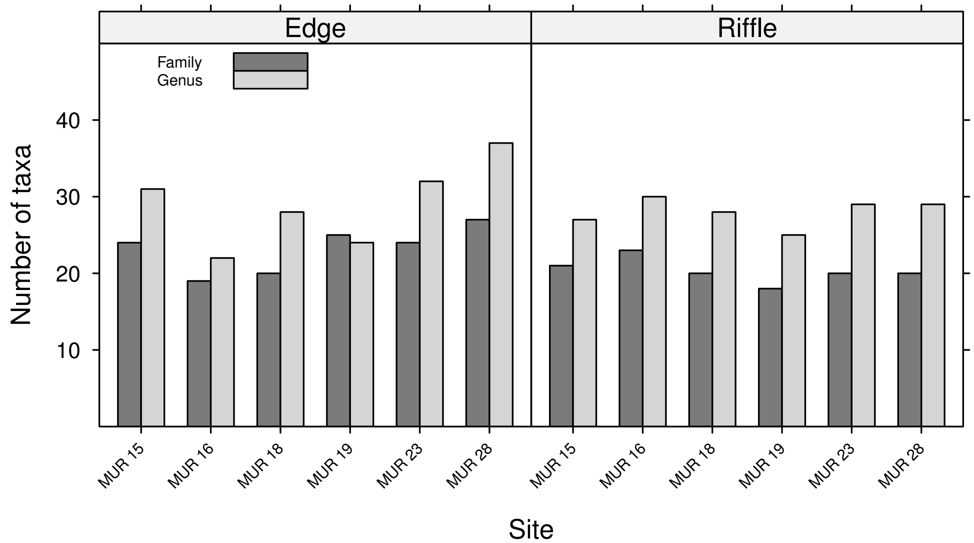

Figure 10. Total number of taxa at genus and family levels in the riffle and edge habitats.

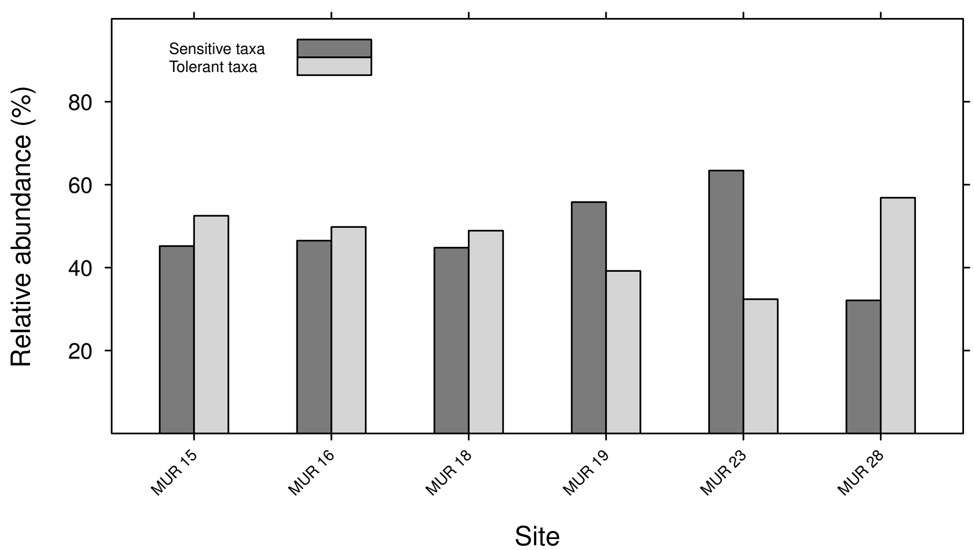

Figure 11. Average relative abundances of sensitive and tolerant taxa from sites upstream and downstream of Angle Crossing.

Table 10. AUSRIVAS and SIGNAL scores for autumn 2010

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	4.14	4.2	0.78	0.78	B	B	B	B	B
Mur 15	2	4.14	4.2	0.78	0.78	B	B			
Mur 15	3	4.14	4.2	0.78	0.78	B	B			
Mur 15	4	4.63	na	0.89	na	A	na			
Mur 15	5	4.14	na	0.78	na	B	na			
Mur 15	6	4.14	na	0.78	na	B	na			
Mur 16	1	4.25	4.18	0.89	0.85	A	A	A	B	B
Mur 16	2	4.67	4.25	1	0.62	A	B			
Mur 16	3	4.25		0.89		A	na			
Mur 18	1	4.14	4.4	0.78	0.78	B	B	B	B	B
Mur 18	2	4.67	4.44	1	0.7	A	B			
Mur 18	3	4.14	4.4	0.78	0.78	B	B			
Mur 18	4	4.67	na	1	na	A	na			
Mur 18	5	4.67	na	1	na	A	na			
Mur 18	6	4.14	na	0.78	na	B	na			
Mur 19	1	4.14	4.4	0.78	0.78	B	B	B	B	B
Mur 19	2	4.14	4.4	0.78	0.78	B	B			
Mur 19	3	4.14	4.4	0.78	0.78	B	B			
Mur 19	4	4.67	na	1	na	A	na			
Mur 19	5	4.63	na	0.89	na	A	na			
Mur 19	6	4.14	na	0.78	na	B	na			
Mur 23	1	4.14	4.4	0.78	0.78	B	B	B	B	B
Mur 23	2	4.14	4.18	0.78	0.85	B	A			
Mur 23	3	4.14	4	0.78	0.93	B	A			
Mur 23	4	4.89	na	1	na	A	na			
Mur 23	5	4.25	na	0.89	na	A	na			
Mur 23	6	4.14	na	0.78	na	B	na			
Mur 28	1	4.25	4.4	0.89	0.78	A	B	B	B	B
Mur 28	2	4.25	5	0.89	0.7	A	B			
Mur 28	3	4.25	4.64	0.89	0.85	A	A			
Mur 28	4	4.14	na	0.78	na	B	na			
Mur 28	5	4.14	na	0.78	na	B	na			
Mur 28	6	4.56	na	1	na	A	na			

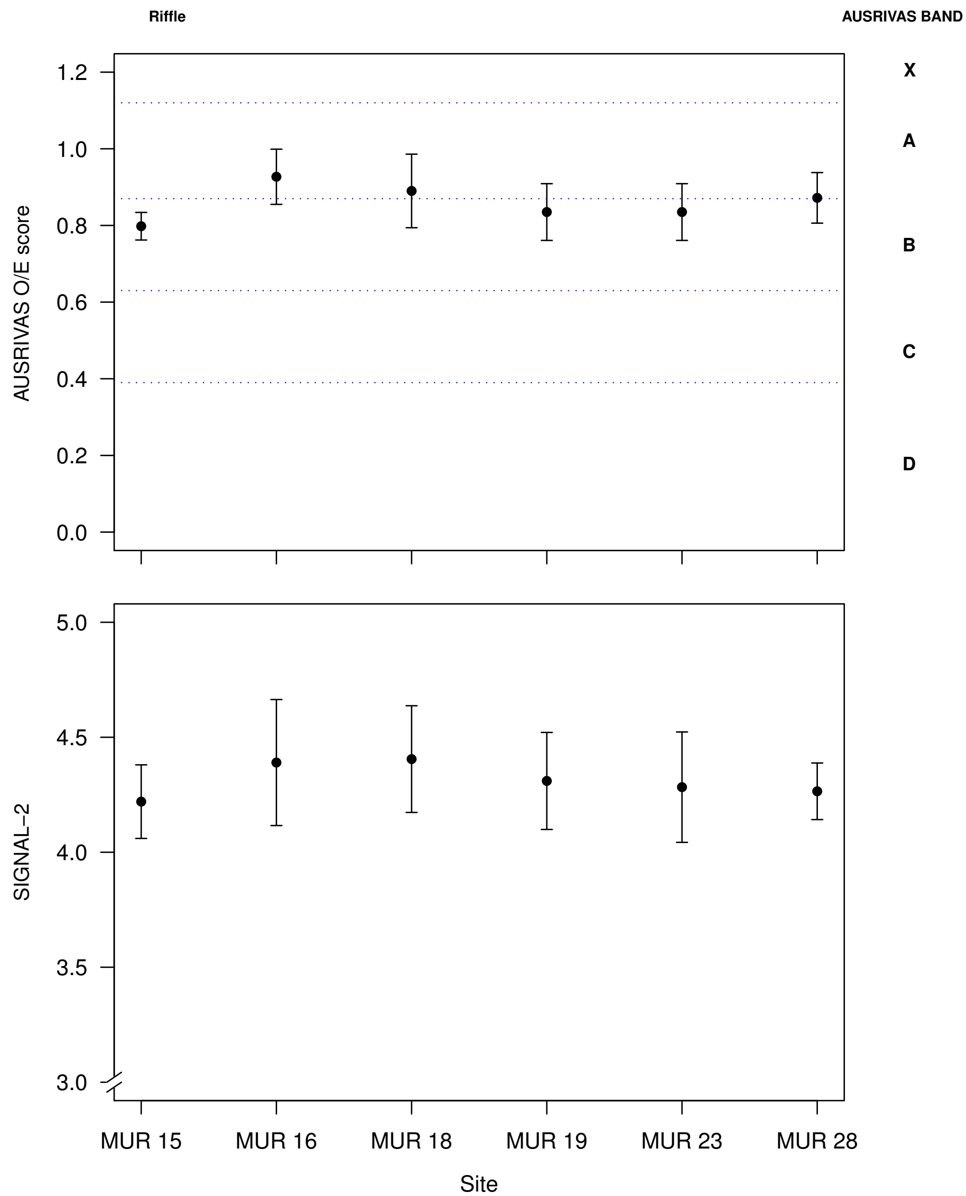

Figure 12. Average AUSRIVAS OE50 scores (top) and average SIGNAL-2 scores for RIFFLE samples upstream and downstream of Angle Crossing. Error bars are 95% confidence intervals

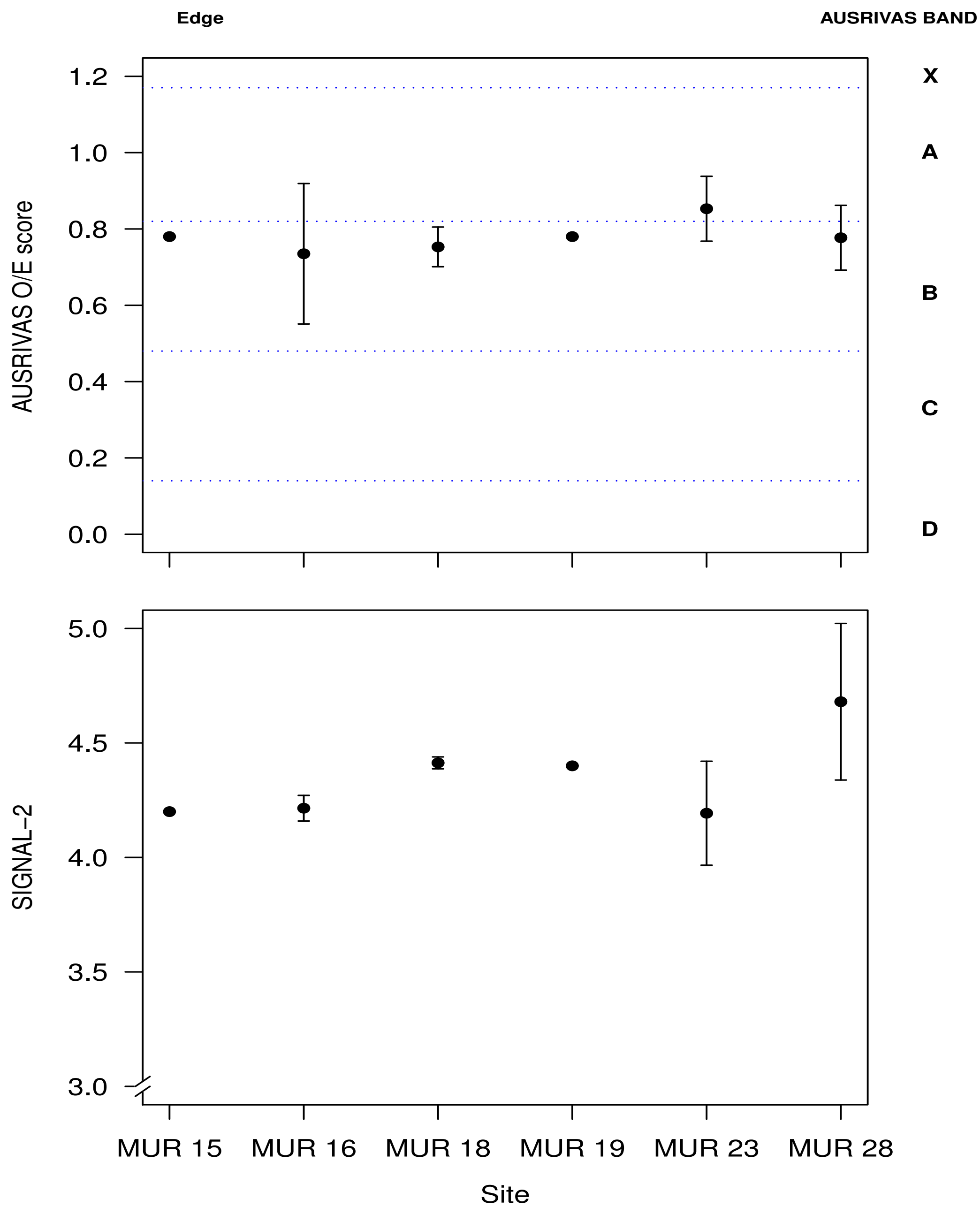

Figure 13. Average AUSRIVAS OE50scores (top) and SIGNAL-2 scores for EDGE samples upstream and downstream of Angle Crossing. Error bars are 95% confidence intervals

4 Discussion

4.1 Water quality and periphyton

After peaking at 760 ML/d in March, flows decreased steadily over the autumn period resulting in stable water quality parameters during mid to late autumn. All of the collected water quality parameters were within ANZECC and ARMCANZ (2000) guidelines, based on daily means for the period. Maximum daily dissolved oxygen (% Sat.) exceeded the 110% recommended under the guidelines, but these values were only exceeded late in May when flows were at their lowest for the season and probably correspond to increased algal growth during this period of low stable flows. The remaining water quality parameters were all depended on flow, although pH tended to increase and show lower diurnal variation with decreasing water temperatures.

The water quality results from our grab samples are comparable to the values taken from the gauging stations in that there were no obvious differences between any of the sites, apart from the progressive longitudinal increase in EC values (Table 5). Total nitrogen values exceeded the recommended values at all of our sampling sites; however total phosphorus was only exceeded at Point Hut Crossing (MUR 23). The total nitrogen values are similar to those collected during autumn 2009 with comparable daily flow estimates; during the high flow event of spring 2009, the TN concentrations were up to four times higher than during the low flow values in autumn. Moreover, it is apparent from monthly water quality data collected by ALS environmental for ACTEW, that 85% of the samples taken since 2001 have shown total nitrogen concentrations in excess of the guideline values; illustrating the fact that background concentrations in the Murrumbidgee are generally higher than the guidelines; and the values recorded in this, and previous sampling runs are well inside the values which have been recorded over the past nine years.

Although there were no statistical differences found in either AFDM or chlorophyll-a concentrations between sites upstream and downstream of Angle Crossing, there were notable increases in the upper limits of these concentrations downstream of Point Hut Crossing (Figures 5*a* and 5*b*). This pattern of increased concentrations downstream of MUR 23 is similar to spring, although during the spring sampling run we did not find a relationship between any of the water quality parameters, despite our hypothesis that nutrient concentrations entering the system at point hut crossing were stimulating algal growth. The lack of correlation between these variables was explained as being the result of a lag effect preventing the detection of any relationship between water quality parameters and our periphyton data. However, it is also possible that during the spring period, relationships between background nutrient concentrations and biomass estimates (AFDM and chlorophyll-a) were not detected because of higher transportation rates during the period of high flows, resulting in ubiquitously high TN and TP concentration across all of the sampling sites despite higher chlorophyll-a and AFDM concentrations downstream of MUR 23. In other words, the equally high TN and TP concentrations at each of our sites did not differ enough to distinguish between the periphyton biomass estimates.

In contrast to spring however, there was a strong relationship in autumn 2010 for TN, and to a lesser extent TP, with chlorophyll-a and AFDM (Table 6). Longer periods of nutrient retention during low flow conditions could also explain the strong correlations observed in this study, coupled with multiple spillages from Point Hut Pond during these low flow periods (compared to multiple spillages during high flow periods) (APPENDIX E). Urban storm water often delivers phosphorus and nitrogen to water ways (Paul and Meyer, 2001) and during periods of low flows these nutrients can be retained for longer periods (Allan and Castillo, 2008) thereby increasing their probability of detection and their availability for uptake by algae and macrophytes. However, nutrient concentrations alone may not explain all of the variation associated with the elevated concentrations downstream of Point Hut Crossing as we also found strong positive correlations with bedrock and negative relationships with the smaller fractioned substrate such as gravel and sand (Table 6) indicating that bed instability is also an important determinant of periphyton biomass. Increased water temperatures from the spillway may also be a key component to understanding these patterns, despite only showing a moderate relationship with AFDM and chlorophyll-a, the discharge from Point Hut Crossing is on average 2°C warmer than the Murrumbidgee water over the same period, which may provide more optimal growing conditions during the autumn months when the Murrumbidgee water is cooler (DeNicola, 1996).

4.2 River health and patterns in macroinvertebrate communities

The overall community assemblages from the riffle samples in this program were dominated by black fly larvae – Simuliidae (SIGNAL =2) and non-biting midges - Chironominae (SIGNAL =3). Although, at MUR 19 - downstream of Angle Crossing - we found a sharp decline in the number of Simulids, with a corresponding increase in the number of Oligochaetes (SIGNAL =2) and Hydropsychidae (SIGNAL =6), which is indicated by the increase in EPT relative abundance compared to tolerant taxa (Figure 11). This pattern was also observed in autumn 2009 (Ecowise, 2009) and was explained by the proximity of MUR 19 to the low level crossing, which is flanked by an unsealed road on either side of the river. It is likely that during runoff events, changing water quality and habitat conditions has increased the opportunity for the proliferation of Hydropsychidae, which can become extremely abundant in response to mild organic enrichment (Wiederholm, 1984); conversely, the decline in Simuliidae may be due to their preference to clean substrates (Downes and Lake, 1991) and therefore they do not thrive in areas such as this where there is regular sediment delivery. Alternatively, they may have declined in numbers because they are out-competed by Hydropsycids (e.g. Zhang *et al.*, 1998).

The edge samples contained very low numbers of Simulids, and were dominated by Chironominae and Orthocladiinae, which might indicate some sediment deposition during the recession curve of the previous high flow events (Figure 2). Chironomids tend to be tolerant to sedimentation (Gooderham and Tsyrlin, 2005), while Simulids prefer clean substrates for attachment and filter feeding (Downes and Lake, 1991). Further support for this comes from the increase in Oligochaetes at MUR 19 and MUR 23 which are located downstream or Angle Crossing and Point Hut Crossing respectively. This is consistent with Hogg and Norris (1991) who found increased numbers of Oligochaetes downstream of Tuggeranong Creek on the Murrumbidgee River. The authors argue that this pattern is likely due to increased siltation from stormwater runoff. We suggest that MUR 19 and MUR 23 are also likely to be prone to sediment deposition for similar reasons at MUR 23 but also because of the low level crossing at MUR 19 (discussed above) and therefore the increased abundance and shifts observed in the community structure (particularly in the riffle habitat) are likely in response to these impacts.

We did not find statistical differences between upstream and downstream locations in either habitat based on the ANOVA results for AUSRIVAS OE50, or SIGNAL -2 scores (Figure 11 and 12). The subtle differences that we found in community structure, namely at MUR 19 and MUR 23, were due to shifts in the relative abundance which are suggested by the location of these sites in relation to the main group (Figure 7). MUR 15 is separated from this group and is the result of a) the absence of Hydroptilidae (SIGNAL = 4); and b) the presence of Podonominae (DIPTERA: SIGNAL=6), which were not found at any of the other sampling sites. Podonominae are adapted to cold, well oxygenated water and are commonly associated with moss and higher altitudes (Pinder, 1995).

Riparian shading was highest at MUR15, which probably keeps diurnal water temperatures lower than unshaded areas; however, during this sampling run we found no clear difference between any of the water quality parameters, and differences between environmental variables (such as latitude) were negligible. Another possible explanation is that Podonominae were transported downstream to MUR 15 during the high flow events However, there is no evidence of these taxa being collected from any of the sites upstream of MUR 15 during sampling . While there are several possible explanations why this taxa was collected only at this site (Cao *et al.*, 2001), and despite no obvious differences between other suitable sites, these reasons remain unclear and are currently outside of the scope of this component of the project.

The multivariate analysis of the edge samples shows high dissimilarity scores between the sites, suggesting more site specific processes interacting with the observed community structure and perhaps a reduction of connectivity between the sites during periods of low flow when riffle zones tend to retreat. This is supported by evidence from the preceding sampling events, where we found similar scores during the low flows in autumn 2009. We attributed this to the gradual deterioration of water quality and loss of habitat within each site caused by reduced connectivity and depth in the water column. In this sampling run, it is clear that the riffle zones have retreated from normal base flow conditions (Plate 1 & 2); although this is most obvious at the upstream sites (MUR 15, 16 and 18). The severe low flows at MUR 15 and 16 might account for their location in the ordination plot (Figure 9), resulting from the absence of common edge taxa such as *Macrobrachium* sp. (Palaemonidae) at MUR 15 and 16 and Corixidae (Hemiptera) at MUR 16. Interestingly, the freshwater prawn, *Macrobrachium* sp*.,* were collected in the riffle zone at MUR 16, which suggest that during periods of edge habitat contraction, the riffle zone may provide a temporary refuge to certain taxa. This is in contrast to the "normal" scenario of drying, where it is usually assumed that edges are more buffered to drying because of their depth (Stanley *et al.*, 1997).

The AUSRIVAS results from this sampling period indicate that all sites upstream and downstream of Angle Crossing are in moderate ecological condition, with all sites being assessed as "*significantly impaired*" (AUSRIVAS - BAND B). These results are equivalent to the health assessment for the same sites in autumn 2009 and the similarity between these sites is also suggested from the multivariate analysis, which groups riffle community data at four of the five sites as approximately 65% similar to one another (Figure 7). The suite of missing taxa is similar across all of these sites, as indicated by similar richness scores (Figure 10) and mean observed to expected scores and SIGNAL scores (Figure 12). This indicates that since the previous high flow events, macroinvertebrate communities at these sites have followed a similar recolonisation trajectory, and have been influenced by similar environmental processes.

There were not any obvious patterns in AUSRIVAS assessment for autumn 2010. Most of the missing taxa from both the riffle and edge habitats were similar across all of the sites, especially the riffle samples (APPENDIX D). The high probability of occurrence of Elmidae (riffle beetles) is almost certainly related to the low flow conditions occurring during and in the weeks leading up to sampling. Elmidae require cool, fast flowing water; and while they are sensitive to polluted water (SIGNAL =7), the water quality throughout the reaches in this project are not outside of the bounds of previous sampling events where Elmidae have been collected, suggesting flow, rather than water quality as the most likely factor causing their absence. Elmidae were also absent in most of our samples last autumn, when flows were also very low. Gripopterygidae (SIGNAL=8) was predicted to occur at our sampling sites. This highly sensitive stonefly has been collected in previous sampling runs, but usually in low numbers. However, the distribution of this family was wider for this autumn period compared to the previous (autumn 2009), which might be a reflection of improved habitat and/or water quality conditions following the preceding high flow events in February and March.

As stated above, all sites had a similar suite of taxa missing, which were predicted by the AUSRIVAS model. Taxa missing from all the samples tended to have SIGNAL scores >7, indicating that either background water quality parameters are exceeding tolerance levels of these taxa, or habitat conditions are below the requirements of habitation at these sites. The combined absence of Elmidae (SIGNAL =7) and Synlestidae (SIGNAL =7) from most of our sampling sites suggests that a lack of detrital matter and large woody debris at these sites (Gooderham and Tsyrlin, 2005), which may have been flushed during the February high flow event. Conoesucidae (SIGNAL =7) was also missing from the autumn 2009 samples (Synlestidae and Elmidae were present) indicating water quality, specifically warm temperature, may be a likely cause for their absence (Gooderham and Tsyrlin, 2005).

The key difference between this sampling event and the spring sampling run is, there has been an increase in the number and abundance of EPT taxa collected (especially the ubiquitous Baetidae and the sensitive Leptophlebiidae), which support our predictions following the high flow events in spring. Scouring and dislodgement of free living taxa due to high shear stress were cited as the likely leading causes for the depauperate EPT fauna in the spring samples, coupled with the very short time (8d) since flows receded and sampling commenced. It is proposed (for reason cited above) that the increase in EPT taxa are likely to be a function of the timing of our sampling program since the most recent disturbance (Caruso, 2002).

Although seasonality is another likely factor accounting for the variation in taxa richness (Hynes, 1970), comparisons between the two autumn events indicate considerable increases in the number of EPT taxa and their relative abundances in this study compared to autumn 2009. It is likely that these increases are due to a combination of factors between sampling events. For examples, the low taxonomic richness scores in autumn, coupled with low relative abundances were likely due to very low flows over an extended period leading up to the sampling run, resulting in some isolation from the main channel, increased fine sediment deposition and deteriorating water quality. In contrast, the two events that occurred 93 days and 71days respectively, prior to this sampling run may have removed some of the fine sediment build up in both the riffle and edge habitats. The effects of this scouring action may have increased the heterogeneity of the riverine habitat by “unblocking” the interstitial spaces amongst the benthic substrate, which is necessary for maintaining diverse macroinvertebrate communities – particularly EPT taxa which are sensitive to fine sediments and generally require a more diverse and complex habitat for survival (Hynes, 1970; Wood and Armitage, 1999; Kaller and Hartman, 2004).

5 Conclusions

The results from this component (Part 1: Angle Crossing) of the Murrumbidgee Ecological Monitoring Program shows no change in the overall site assessments based on the AUSRIVAS modelling since spring 2009. All of the sampling sites, both upstream and downstream of Angle Crossing were assessed as being *"significantly impaired"* or BAND B according to the autumn ACT model. Despite the same AUSRIVAS assessments as spring 2009, there was an increase in the diversity of sensitive (EPT) taxa since the spring sampling run. Although seasonal fluctuations can explain this to a certain degree, comparisons to our previous sampling run in autumn, where EPT taxa were comparable to spring, suggest that the increase observed in this sampling run is likely due to improved habitat and water quality parameters, resulting from the flushing flows of early February, followed in quick succession by a second high flow event in early March.

Water quality parameters were generally within the ANZECC and ARMCANZ guidelines, although there were some exceptions to this. Total Nitrogen was over the recommended guidelines at all sites and Total Phosphorus was at the upper threshold level recommended for healthy ecosystems at all of the sites, and was exceeded at MUR 23 (Point Hut Crossing). Despite Total Nitrogen exceeding the trigger values, these concentrations are the lowest recorded since the inception of this program. The water quality results from autumn 2010 represent stable, low flow conditions, while the higher concentrations recorded in previous runs are likely a result of the timing of the sampling – which was conducted within 3 weeks of the last runoff event meaning that nutrient loads were still being conveyed through the system.

Elevated periphyton biomass estimated downstream of MUR 23, was highly correlated to TP and TN concentrations and tended to increase with substrate size, indicating nutrient limitations to algal growth. Also, during high flow periods, where larger substrates resist scouring, larger standing stocks of periphyton are able to persist flowing flushes . High correlations between the nutrient concentrations, AFDM and chlorophyll-a may reflect longer retention times coupled with multiple spill events from the Point Hut Pond during this period of low flows in the Murrumbidgee.

The impaired health rating given to all sites in this study resulted from two to three taxa with moderate to high SIGNAL scores missing from all of the sampling sites. These taxa have not been collected regularly in any of the previous sampling runs, especially the taxa predicted with SIGNAL scores ≥ 7, suggesting that outside of the hydrological differences between seasons, the background environmental conditions of the Murrumbidgee River (e.g. landuse, water quality, sediment quality) may not be suitable for the long term establishment of these taxa compared to the reference site predictions of the AUSRIVAS model. These factors should be considered when interpreting the outputs generated by the AUSRIVAS model.

6 Recommendations

The Angle Crossing monitoring proposal (section 5.1.5) requires that the program to be adaptive and allow for methods, sites, and analysis in previous runs to be reviewed so the objectives of ACTEW can be met satisfactorily.

The recommendations made in spring 2009 are again supported for this assessment, and are detailed below (points 1 & 2). Based on the current assessment we also provide a further recommendation, which involves the incorporation of environmental data into the macroinvertebrate community analysis.

1. The high within-site variation found in this, and previous sampling runs suggests that a single replicate might not be adequate to describe the sites in this assessment. This is consistent with the findings of (Nichols *et al.*, 2006), who recommended taking replicate samples at impaired sites for biological assessments. Taxonomic diversity and abundances differed considerably between replicates and subsamples, resulting in considerable variability in the AUSRIVAS bioassessment of a given site. It is recommended that this level of replication be maintained.
2. Continuous water quality monitoring is restricted to Lobb's Hole (410761) and upstream of Angle Crossing at MURWQ09, missing the potential impacts of water entering the Murrumbidgee River at Point Hut Crossing from Point Hut Pond. Grab samples taken during storm events should help explain the distinctly different composition of macroinvertebrates at this site and additional nutrient sampling in the lead-up to the next round of sampling is also recommenced. This would enable the assessment of any nutrient-biota interactions in a way that captures any lag effect.
3. The information collected to date shows considerable environmental variability, apparently coinciding with changes in the macroinvertebrate community. We suggest that the integration of the two data sets, using additional multivariate ordination techniques will provide ACTEW with a better understanding of the association of various environmental parameters, with the biological data. Biological relationships with hydrological parameters, water quality data and other physical stream characteristics can be quantified and formally tested using these techniques and should assist ACTEW in making informed decisions regarding flow rules and other environmental impacts expected from the M2G project.

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7 Literature Cited

ACT Government (2006). 2006 Environmental Flow Guidelines.

Allan, J.D. & Castillo, M.M. (2008) Stream Ecology: Structure and Function of Running Waters., Springer., The Netherlands.

ANZECC & ARMCANZ (2000) Australian Guidelines for Monitoring and Reporting, National Water Quality Management Strategy Paper no. 7. Australia and New Zealand Environment and Conservation Council /Agriculture and Resource Management Council of Australia and New Zealand.

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

A.P.H.A. (2005) Standard methods for the examination of water and waste water.21st Edition. American Public Health Association. Washington.

Allan, J.D. & Castillo, M.M. (2008) Stream Ecology: Structure and Function of Running Waters., Springer., The Netherlands.

Biggs, B.J.F. (1989) Biomonitoring of organic pollution using periphyton, South Branch, Canterbury, New Zealand. *New Zealand Journal of Marine and Freshwater Research,* **23,** 263-274.

Biggs, B.J.F. (2000) New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams. Ministry for the Environment, Wellington.

Biggs, B.J.F. & Kilroy, C. (2000) Stream Periphyton Monitoring Manual. NIWA, Christchurch. NIWA. Christchurch.

Biggs, B.J.F., Smith, R.A. & Duncan, M.J. (1999) Velocity and sediment disturbance of periphyton in headwater streams: biomass and metabolism. *Journal of the North American Benthological Society,* **18,** 222-241.

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

Caruso, B.S. (2002) Temporal and spatial patterns of extreme low flows and effects on stream ecosystems in Otago, New Zealand *Journal of Hydrology,* **257,** 115-133.

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

Clarke, K.R. & Gorley, R.N. (2006) *PRIMER v6: User Manual/Tutorial*. PRIMER-E: Plymouth.

Clarke, K.R. & Warwick, R.M. (2001) *Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition*. PRIMER-E: Plymouth.

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

Coysh, J.L., Nichols, S.J., Simpson, J.C., Norris, R.H., Barmuta, L.A., Chessman, B.C. & Blackman, P. (2000b) Australian River Assessment System (AUSRIVAS) National River Health Program Predictive Model Manual. Co-operative Research Centre for Freshwater Ecology, Canberra.

Denicola, D.M. (1996) Periphyton responses to temperature at different ecological levels. In: *Algal Ecology: Freshwater Benthic Ecosystems.* (R.J. Stevenson & M.L. Bothwell & R.L. Lowe). Elsevier (USA).

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

Downes, B.J. & Lake, P.S. (1991) Different colonization patterns of two closely related stream insects (*Austrosimulium* spp.) following disturbance. *Freshwater Biology,* **26,** 295-306.

Ecowise Environmental. (2009) Murrumbidgee Ecological Monitoring Program. Autumn 2009. Part 1: Angle Crossing. Report to ACTEW Corporation.

Ecowise Environmental. (2009) Murrumbidgee Ecological Monitoring Program. Part 1: Angle Crossing. Proposal to ACTEW Corporation.

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

Hawking, J.H. (2000) Key to Keys. A guide to keys and zoological information to identify invertebrates from Australian inland waters. Identification Guide No.2 Cooperative Research Centre for Freshwater Ecology.

Hogg, I.D. & Norris, R.H. (1991) Effects of Runoff from Land Clearing and Urban Development on the Distribution and Abundance of Macroinvertebrates in Pool Areas of a River. *Australian Journal of Freshwater and Marine Research,* **42,** 507-518.

Hynes, H.B.N. (1970) The Ecology of Running Waters*,* Liverpool University Press, Liverpool.

Kaller, M.D. & Hartman, K.J. (2004) Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. *Hydrobiologia,* **518,** 95-104.

Keen, G. (2001) *Australia - Wide Assessment of River Health: Australian Capital Territory Bioassessment Report (ACT Interim Final Report)*, Monitoring River Health Initiative Technical Report no 3, Commonwealth of Australia and Environment ACT.

Kruskal, J.B. (1964) Multidimensional scaling by optimizing goodness of fit to a non-parametric hypothesis. *Psychometrika,* **20,** 1-27.

Loeb, S. (1981) An in-situ method for measuring the primary productivity and standing crop of the epilithic periphyton community in lentic systems. *Limnology and Oceanography***,** 394-399.

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

Nichols, S.J., Robinson, W.A. & Norris, R.H. (2006) Sample variability influences on the precision of predictive bioassessment. *Hydrobiologia,* **572,** 215-233.

Paul, M.J. & Meyer, J.L. (2001) Streams in the Urban Landscape. *Annual Review of Ecology Evolution and Systematics,* **32,** 333-365.

Pinder, L.C.V. (1995) The habitats of chironomid larvae. In: *The chironomidae: biology and ecology of non-biting midges.* (P.D. Armitage & P.S. Cranston & L.C.V. Pinder). Chapman & Hall, London.

Quinn, G.P. & Keough, M.J. (2002) Experimental Design and Data Analysis for Biologists.

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Stanley, E.H., Fisher, S.G. & Grimm, N.B. (1997) Ecosystem expansion and contraction in streams. *Bioscience,* **47,** 427-435.

Talsma, T. & Hallam, P.M. (1982) Stream water quality of forest catchments in the Cotter River Valley, ACT.

Whitton, B.A. & Kelly, M.G. (1995) Use of algae and other plants for monitoring rivers. *Australian Journal of Ecology,* **20,** 45-56.

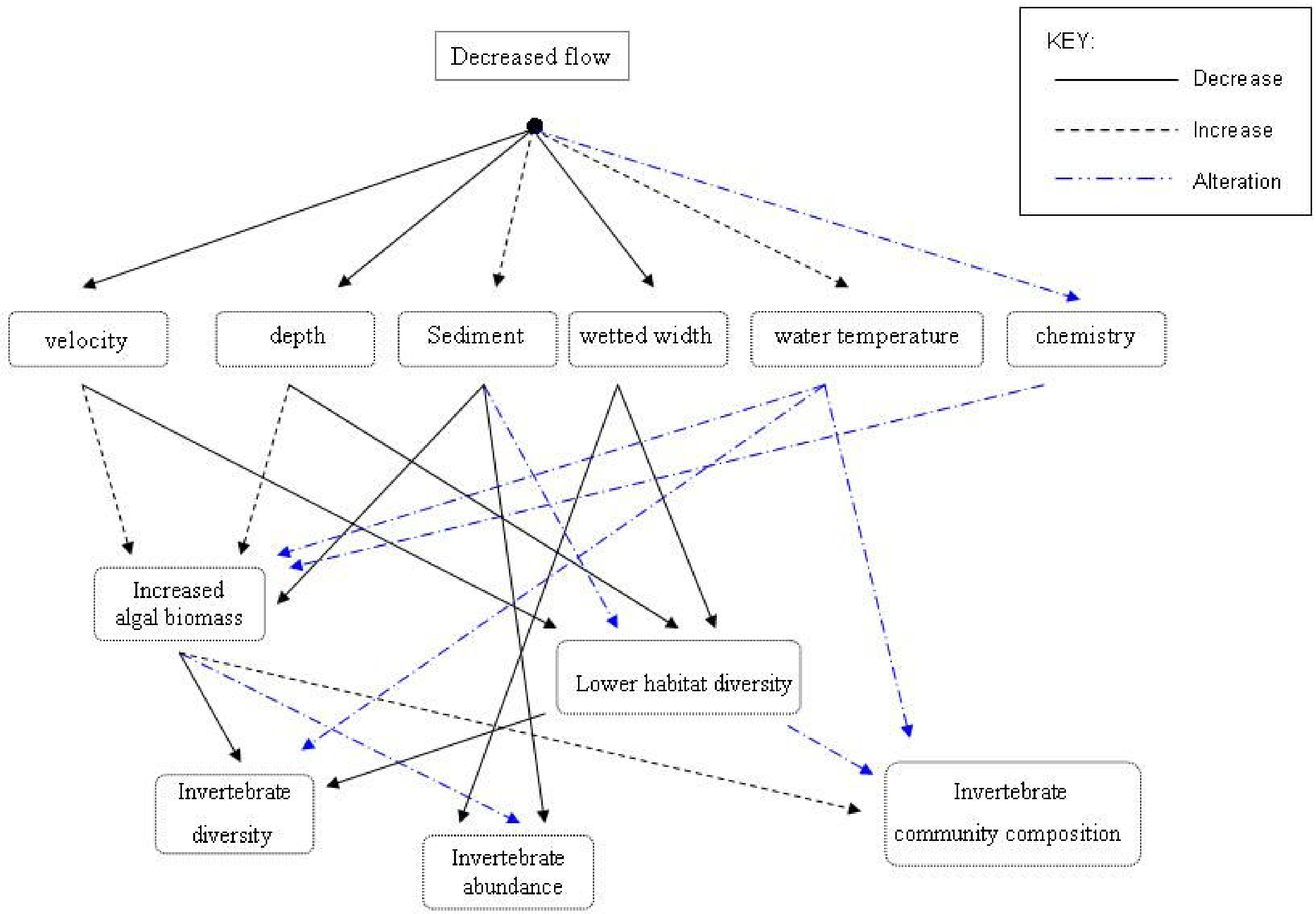
Wiederholm, T. (1984) Responses of Aquatic Insects to Environmental Pollution. In: *The Ecology of Aquatic Insects.* (V.H. Resh & D.M. Rosenberg), pp. 509-543. Praeger, NY.

Wood, P.J. & Armitage, P.D. (1999) Sediment deposition in a small lowland stream - management implications. *Regulated Rivers Research & Management,* **15,** 199-210.

Zhang, Y., Malmqvist, B. & Englund, G. (1998) Ecological processes affecting community structure of blackfly larvae in regulated and unregulated rivers: a regional study. *Journal of Applied Ecology,* **35,** 673-686.

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)*.

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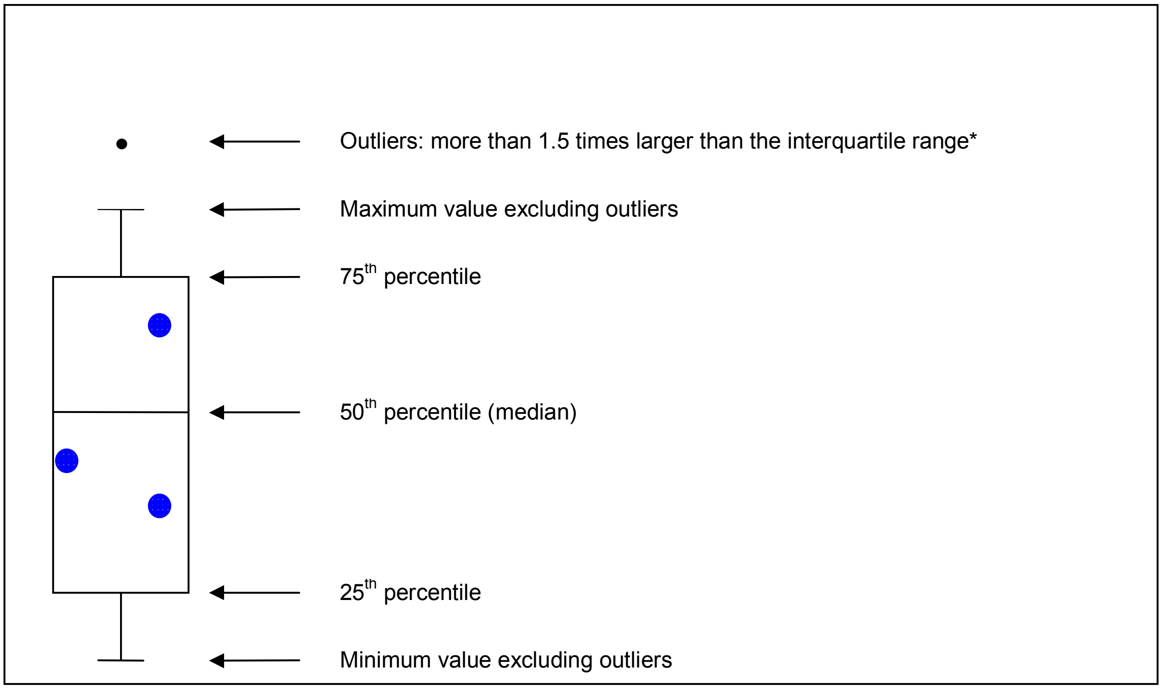
Appendix B –

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

ANOSIM
Analysis of Similarities

Two-Way Nested Analysis

RIFFLE

```
TESTS FOR DIFFERENCES BETWEEN # site GROUPS
(across all # loc groups)
Global Test
Sample statistic (Global R): 0.922
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

TESTS FOR DIFFERENCES BETWEEN # loc GROUPS
(using # site groups as samples)
Global Test
Sample statistic (Global R): -0.222
Significance level of sample statistic: 100%
Number of permutations: 10 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 10
```

EDGE

```
TESTS FOR DIFFERENCES BETWEEN # site GROUPS
(across all # loc groups)
Global Test
Sample statistic (Global R): 0.977
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 78400)
Number of permuted statistics greater than or equal to Global R: 0

TESTS FOR DIFFERENCES BETWEEN # loc GROUPS
(using # site groups as samples)
Global Test
Sample statistic (Global R): -0.148
Significance level of sample statistic: 100%
Number of permutations: 10 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 10
```

Appendix D –

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

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

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

APPENDIX D (cntd.). Taxa expected, but not collected in the edge habitat spring 2009

Site	Taxa	Planorbidae	Tanypodinae	Baetidae	Oligochaeta	Corixidae	Synlestidae	Conoesucidae	Elmidae	Ecnomidae	Hydroptilidae	Gripopterygidae	Leptoceridae	Total number of missing taxa
	SIGNAL	2	4	5	2	2	7	7	7	4	4	8	6	
MUR 15	Edge	0.58					0.65	0.59	0.62	0.59		0.69		6
MUR 15		0.58					0.65	0.59	0.62	0.59		0.69		6
MUR 15		0.58					0.65	0.59	0.62	0.59		0.69		6
MUR 16	Edge	0.58					0.65	0.59	0.62			0.69		5
MUR 16		0.58				0.62	0.65	0.59	0.62		0.97	0.69	0.97	8
MUR 18	Edge	0.58				0.62	0.65	0.59	0.62			0.69		6
MUR 18		0.58				0.62	0.65	0.59	0.62	0.59		0.69		7
MUR 18		0.58				0.62	0.65	0.59	0.62			0.69		6
MUR 19	Edge	0.58				0.62	0.65	0.59	0.62			0.69		6
MUR 19		0.58				0.62	0.65	0.59	0.62			0.69		6
MUR 19		0.58				0.62	0.65	0.59	0.62			0.69		6
MUR 23	Edge	0.58				0.62	0.65	0.59	0.62			0.69		6
MUR 23		0.58					0.65	0.59	0.62			0.69		5
MUR 23							0.65	0.59	0.62			0.69		4
MUR 28	Edge	0.58	0.9	0.9			0.65	0.59				0.69		6
MUR 28		0.58	0.9		0.97		0.65	0.59				0.69		6
MUR 28		0.58					0.65	0.59				0.69		4

Appendix E–

Point Hut Pond Hydrograph: spring 2009

Appendix E. Hydrograph of Point Hut Pond and Lobb's Hole for the past 15 months. Seasonal flow averages and number of spill events from Point Hut Pond indicated under season banners. Arrows indicate spill events on enlarged plot for the most recent sampling period.