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Murrumbidgee Ecological Monitoring Program

Part 3: Murrumbidgee Pump Station

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List of abbreviations

ACT – Australian Capital Territory
ACTEW – ACTEW Corporation Limited
AFDM – Ash Fee Dry Mass (periphyton)
ANOVA – Analysis of Variance (statistics)
ANZECC – Australian and New Zealand Conservation Council
AUSRIVAS – Australian River Assessment System
ECD – Enlarged Cotter Dam
EPA – Environmental Protection Authority
EPT taxa- Ephemeroptera; Plecoptera and Trichoptera
GL/a – gigalitres per annum
GPS – global positioning system
M2C – Murrumbidgee to Cotter
ML/d – Megalitres per day
MPS – Murrumbidgee Pump Station
NATA – National Association of Testing Authorities
NMDS – Non-metric Multidimensional Scaling (statistics)
OCD taxa – Oligochaeta; Chironomidae and other Diptera
QA – Quality Assurance
QC – Quality Control
TN – Total Nitrogen
TP – Total Phosphorus

Executive Summary

The Murrumbidgee Pump Station (MPS) is located just downstream of the Cotter River confluence with the Murrumbidgee River. It is adjacent to the Cotter Pump Station which currently abstracts up to 50ML/d, contributing to the water supply for the ACT. Construction is underway to increase the abstraction amount from the Murrumbidgee River (via the MPS) to 150ML/d through an upgraded pumping network.

The upgraded infrastructure will also provide a recirculating flow from the Murrumbidgee to the base of the proposed Enlarged Cotter Dam; this project is referred to as the Murrumbidgee to Cotter transfer (M2C). This program does not monitor the effects of M2C, which is being undertaken by others. MPS is currently expected to be commissioned in autumn 2010. Pumping will only occur when there is sufficient demand for the water (for M2C and/or potable water supply), and sufficient flow in the Murrumbidgee River.

The framework for this program responds primarily to requirements of ACTEW's Dec 2008 – Dec 2009 water abstraction licence (WU67 section D6). Water abstraction at the Murrumbidgee Pump Station (MPS), combined with a change of environmental flow releases from the Cotter Reservoir, require an assessment of the response of the river through monitoring methods that can quantify subtle impacts.

This program aims to establish the baseline river condition prior to the increased abstraction, then continue monitoring afterwards to determine what physicochemical and ecological changes occur.

The key aims of this sampling run were to:

1. *Establish current macroinvertebrate community data, upstream and downstream of the MPS*
2. *Provide ACTEW with river health assessments based on AUSRIVAS protocols at the key sites concerning the operation and the works concerned with the upgrade of the MPS*
3. *Establish baseline periphyton data that will be used as a guide to monitor seasonal and temporal changes*
4. *Report on water quality upstream and downstream of the MPS*

This report presents the results from biological sampling of the Murrumbidgee River for the monitoring of the MPS in autumn 2009. Sampling was completed in May 2009. Sampling was based on the AUSRIVAS sampling protocols, but was extended to include multiple replicates from each site where specimens were identified to genus level, instead of family level.

The purpose of this protocol was to:

a) establish biological signatures at each site prior to the commencement of pumping
b) enable subtle changes to be detected if there are impacts associated with reduced flows.

The key results from the autumn 2009 sampling of the MPS indicate that:

- *All sites were categorised as Band B "significantly impaired" or Band C "severely impaired" by the AUSRIVAS assessment;*

- *Water quality was generally good, with most water quality parameters at levels within ANZECC (Australian and New Zealand Conservation Council) guidelines. Several analytes (i.e. temperature, EC and D.O) showed responses to low flow and seasonal conditions that meant they were temporarily outside recommended ANZECC levels; and nutrient concentrations exceeded guideline targets at all sites.*

- *There were no statistical differences in periphyton AFDM or Chlorophyll-a measurements between the upstream and downstream sites; nor was there any clear difference between upstream and downstream sites in macroinvertrates community assemblages based on ANOSIM results. Low flows are thought to be degrading the ecological health in this section of the river, given that there is no evidence of any location-specific effects downstream of the MPS*
- *Improvements in macroinvertebrate communities and river health ratings are predicted with increased seasonal rainfall.*

It is recommended that the current sampling protocols remain as they are, but a review of the level of replication and taxonomic resolution may be necessary after the Spring 2009 sampling program is analysed.

1 Introduction

The Murrumbidgee Ecological Monitoring Program 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 timeline is to undertake sampling in spring and autumn over a three year period commencing 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 3: Murrumbidgee Pump Station.

The Murrumbidgee Pump Station (MPS) is located just downstream of the Cotter River confluence with the Murrumbidgee River. It is adjacent to the Cotter Pump Station which currently abstracts up to 50ML/d, contributing to the water supply for the ACT. Construction is underway to increase the abstraction amount from the Murrumbidgee River to 150ML/d via the MPS. The upgraded infrastructure will also provide a recirculating flow from the Murrumbidgee to the base of the proposed Enlarged Cotter Dam; this project is referred to as Murrumbidgee to Cotter (M2C) transfer.

This program does not monitor the effects of the M2C transfer.

The upgraded pump station is currently expected to be commissioned in autumn 2010. Pumping will only occur when there is sufficient demand for the water (for M2C and/or potable water supply), and when there is sufficient water flow in the Murrumbidgee River. The framework for this program responds primarily to requirements of ACTEW's Dec 2008 – Dec 2009 water abstraction licence (WU67 section D6).

The increase in abstraction at the Murrumbidgee Pump Station (MPS) may place additional stress on the downstream river ecosystem. This monitoring program has been established to monitor the condition of the Murrumbidgee River in terms of water quality and ecological condition at key sites both upstream and downstream of the extraction point (MPS), before and after the proposed abstractions are implemented.

The information derived from this program will support ACTEW's and the ACT Environmental Protection Authority's (EPA) adaptive management approach to water abstraction and environmental flow provision in the ACT.

1.1 Project objectives

The objectives of the MPS monitoring program is to provide ACTEW with seasonal assessments of river health effected by the operation and works during the upgrade of the Murrumbidgee Pump Station under the license requirements of ACTEW's licence to abstract water # WU67, section D6;

Specifically, the aims of the project are to:

1. Meet ACTEW's monitoring obligations under the requirements of its licence to abstract water (Licence # WU67, section D6);

2. Provide seasonal "river health" reports in accordance with the licence requirements;

3. Obtain baseline macroinvertebrate, water quality and periphyton data in order to ascertain whether the future abstractions from the MPS are impacting the ecology and ecological "health" of the Murrumbidgee System downstream of the MPS;

4. Provide ACTEW with river health assessments based on AUSRIVAS protocols at the key sites concerning the operation and the works concerned with the upgrade of the MPS;

5. Establish baseline periphyton data that will be used as a guide to monitor seasonal and temporal changes

6. Report on water quality upstream and downstream of the MPS.

1.2 Project scope

The current ecological health of the sites monitored as part of the Murrumbidgee Pump Station (MPS) monitoring program is estimated using AURIVAS 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 2009 sampling runs. Specifically, as outlined in the MEMP proposal to ACTEW Corporation (Ecowise, 2009), this work includes:

- Sampling from autumn 2009;
- Macroinvertebrate sampling from riffle and edge habitats;
- Riffle and edge samples collected as per the AUSRIVAS protocols;
- Macroinvertebrates counted and identified to the taxonomic level of genus;
- Riffle and edge samples assessed through the appropriate AUSRIVAS model;
- Some water quality measurements to be measured *in*-situ, and nutrient samples to be collected and analysed in Ecowise's NATA accredited laboratory.

1.3 Rationale for using biological indicators

Macroinvertebrates and periphyton are two of the most commonly used biological indicators used in river bio-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 indicies 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 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 flows. This feature of rapid response makes them a valuable 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 (Biggs, 1989, Biggs *et al.*, 1999, Whitton and Kelly, 1995). As changes in flow volume are expected with the proposed changes in the flow regime in the Murrumbidgee River, periphyton biomass and chlorophyll-a are included as biological indices.

2 Materials and method

The potential for impacts to arise during the implementation of M2G are dependant upon the pumping regime and the environmental flow rules adopted. Potential effects may include modification to the stream substrate through sedimentation, loss of riffle zones, changes in water chemistry and periphyton accumulation. These processes in turn may influence the composition of macroinvertebrate and periphyton communities downstream of the abstraction point.

To monitor for potential impacts, macroinvertebrates are sampled in two meso-habitats (riffle and pool edges) and organisms identified to family or genus level, to characterise each site. Periphyton is sampled in the riffle zones at each site and analysed for chlorophyll-a and Ash Free Dry Mass (AFDM), which will provide estimates of the algal (autotrophic) biomass and total organic mass respectively (Biggs and Kilroy, 2000).

At each site riffle and edge habitats were sampled where available, to provide a more comprehensive assessment of each site. The monitoring of both habitats potentially allows 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. Riffle zones, for example, are likely to be one of the first habitats affected by low flows and water abstractions (Boulton, 2003, Dewson *et al.*, 2007, Smakhtin, 2001), whereas the effects of reduced flows on the macroinvertebrate assemblages might not occur at the same magnitude and the effects may be less immediate. On the other hand the loss of macrophyte beds, trailing bank vegetation and bank scouring are more likely to immediately affect the edge habitats. Therefore, separating flow effects with other environmental stressors can be achieved by monitoring both habitats before and after the proposed abstractions and comparing data after the abstractions with the natural variation that occurs before hand.

2.1 Sampling details

Sampling occurred in May 2009 with flows indicated in Figure 1 (section 3.1). All sampling was carried out by AUSRIVAS accredited staff. The conditions during the days of sampling were fine and dry. Some localised rainfall occurred in the previous week (2 mm at Pierces Creek: 570825) but otherwise the most recent falls occurred in the third week of April (15 mm at Lobb's Hole: 570985).

2.2 Hydrology and rainfall

Murrumbidgee River flows and rainfall for the sampling period were recorded at ECOWISE gauging stations at Lobb's Hole (410761, downstream of Angle Crossing) and Mt. MacDonald (410738, downstream of the Cotter River confluence). Site locations and codes are given in Table 1.

Table 1. Location and details of continuous rainfall, water quality and flow stations

Site Code	Location/Notes	Parameters*	Latitude	Longitude
570825	Pierces Creek weather station	Rainfall	S -35.3322	E 148.9189
410738	M'bidgee River @ Mt. McDonald	WL, Q	S -35.2917	E 148.9565
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

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

2.3 Water quality

Baseline *in-situ* physico-chemical parameters including temperature, pH, electrical conductivity, turbidity and dissolved oxygen were recorded at each sampling site using a multiprobe YSI 556 surveyor. The surveyor was calibrated in accordance to QA procedures and the manufactures requirements prior to sampling. Additionally, grab samples were taken from each site in accordance with the AUSRIVAS protocols (Coysh *et al.*, 2000) for YSI verification and nutrient analysis. All samples were placed on ice and returned to the ECOWISE laboratory and analysed for nitrogen oxides (total NOx), total nitrogen (TN) and total phosphorus (TP) in accordance with the protocols outlined in A.P.H.A (2005). Collectively, this information on the water quality parameters will assist in the interpretation of biological data and provide a basis to gauge changes that can potentially be linked to flow reductions at these key sites following water abstractions.

2.4 Macroinvertebrate sampling

Riffle and edge habitats were sampled for macroinvertebrates and analysed in strict accordance with the ACT autumn riffle and edge AUSRIVAS (Australian River Assessment System) protocols (Coysh *et al.*, 2000) during autumn (May 6-8th) 2009. At each site, two samples were taken from the riffle habitat (flowing broken water over gravel, pebble, cobble or boulder, with a depth greater than 10cm; (Coysh *et al.*, 2000) using a framed net (350mm 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 bed directly upstream of the net opening was agitated by vigorously kicking, allowing dislodged invertebrates to be carried into the net by the current. The process continued, working upstream over 10 metres of riffle habitat. Samples were then preserved in 70% ethanol, clearly labelled with site codes and date, then stored on ice and placed in a refrigeration unit 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 using a framed net (350mm wide) with 250 µm mesh size. The nets and all other associated equipment were washed thoroughly between sampling events 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.

Site selection was based upon the recommendations outlined in ACTEW's Licence to take water WU67 section D6 (Table 2). Prior to sampling, comprehensive site assessments were carried out, including assessments of safety, suitability and granted access from landowners. As outlined in this document, there are no suitable reference sites in the proximity for this assessment, so a before – after / control – impact (BACI) design (Downes *et al.*, 2002) has been adopted.

Table 2. Sampling site locations and details

Site Code	Location	Landuse	Purpose
Mur 931	"Fairvale" approximately 4km upstream of the Cotter River confluence	Cattle grazing	Upstream control site
Mur 28	~100m upstream of the Cotter River confluence	Currently in the MPS construction zone. Grazing.	Upstream control site
Mur 935	Casuarina Sands	Recreation, construction upstream	Downstream impact site
Mur 937	"Huntly" ~3km downstream of the Cotter River confluence. Near Mt. MacDonald gauging station	Sheep and cattle grazing	Downstream impact site
Mur 29	U/S Uriarra Crossing	Recreation, sheep and cattle grazing, some pine forest	Downstream impact / recovery site

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 five sites selected, given 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, samples will be collected using the *in-situ* syringe method similar to Loeb (1981), as described in Biggs and Kilroy (2000). A 1 m wide transect was established across riffles at each site. The transects were marked using flagging tape and GPS coordinates taken. Along each transect, twelve samples were collected at regular intervals, using a sampling device of two 60 ml syringes and a scrubbing surface of stiff nylon bristles covering an area of ~637 mm^2. The samples were divided randomly into two groups of six samples to be analysed for Ash Free Dry Mass (AFDM 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).

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, 2000). Trend analyses of water quality parameters were 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 2.9.2 (R Development Core Team, 2009).

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 and the contents of randomly selected cells removed. Macroinvertebrates from each selected cell were identified to genus level. 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, all taxa were analysed at the family level except Chironomidae (identified to sub-family), Oligochaeta (class) and Acarina (order). The first 200 animals were identified (identification followed taxonomic keys published by Hawking (2000)) and if 200 were identified before a cell had been completely analysed, identification continued until the animals within the entire cell were identified. Data was entered directly into electronic spreadsheets to eliminate errors associated with manual data transfer.

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 is reduced to two. How well the patterns in the 2-dimensional NMDS plot represents the multivariate data is indicated by the stress value of each plot. 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 near zeros suggests that NMDS patterns are very representative of the multidimensional data, while stresses greater than 0.2 indicate a poor representation (Clarke and Warwick 2001).

An analysis of similarities (ANOSIM) was performed on the data to test whether macroinvertebrate communities were statistically different upstream and downstream of the MPS. Sites were nested within location for the purposes of 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. This procedure was also used to describe groups (i.e. which taxa characterised each group of sites) (Clarke and Warwick, 2001).

Several additional metrics to the 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 sensitive taxa (Ephemeroptera, Plecoptera and Trichoptera- EPT) and, tolerant taxa, (Oligochaeta and chironomids) were examined at family and genus levels.

In assessing the taxonomic richness of a site, high scores do not necessarily indicate better ecological condition at a given location. While in certain instances high scores can indicate favourable conditions, they can also indicate altered conditions, indicative of an ecologically impacted site. Where the disturbed conditions provide habitat that might not naturally occur; a new environment for previously absent taxa is provided. For the purposes of this program, taxa richness was quantified as baseline information from which further analyses, such as community stability, which assesses (as a percentage) temporal changes in community composition (turnover). For all analyses, alpha was set to 5%.

2.6.3 AUSRIVAS assessment

AUSRIVAS is a prediction system that uses macroinvertebrates 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 influenced by non-human characters, e.g. altitude) are then compared to the Observed fauna (O) and the ratio derived is used to indicate the extent of any impact (O/E). The ratio derived from this analysis is compiled into bandwidths (i.e. X, A-D; Table 3) 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 (Tables 4 and 5).

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 a Band A assessment in the edge and a Band B in the riffle would be given an overall site assessment of Band B (Coysh *et al.*, 2000). In cases where the bands deviate significantly between habitat (e.g. D – A) an overall assessment is 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 also be noted that the presence or absence of rare taxa does vary 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 rather than truly reflecting ecological change.

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

	Riffle	Edge	
Band	**O/E bandwidth**	**O/E bandwidth**	**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	14-0.48	Sever*ely 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 (as AFDM) and live content (Chlorophyll-a) were different between sites upstream and downstream of the MPS, t-tests were performed on Log_e-transformed data. Log transformation was necessary to meet the assumptions of normality. This did not correct for unequal variances, so the degrees of freedom are modified using Welch's extension of the t-test, to account for the unequal sample sizes and the unequal variances as well as small sample sizes. After the sample collection, six of the twelve samples were allocated for chlorophyll-*a* analysis, while the remaining six samples were used to estimate the total organic content of the periphyton sample by Ash Free Dry Mass (AFDM). Samples were then filtered onto individual glass filters.

Data were pooled from sites upstream and downstream because the current aim is to determine upstream (control) and downstream (impact) effects rather than site specific-effects. Data were back-transformed for graphical visualization.

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. To overcome losses associated with damage to intact organisms during vial transfer, attempts were made to obtain significantly more than 200 organisms.
- Identification was performed by qualified and experienced aquatic biologists with more than 100 hours of identification experience.
- When required, taxonomic experts 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)).

Ecowise field staff maintain current ACT AUSRIVAS accreditation.

3 Results

3.1 Hydrology and rainfall

Sample collection occurred in early May, approximately 3 weeks after the two largest events in April (Figure 1). In late April, 15 mm fell at Lobb's Hole, causing a small peak (90ML/d) in the hydrograph that subsided to < 60ML/d by the time of sampling.

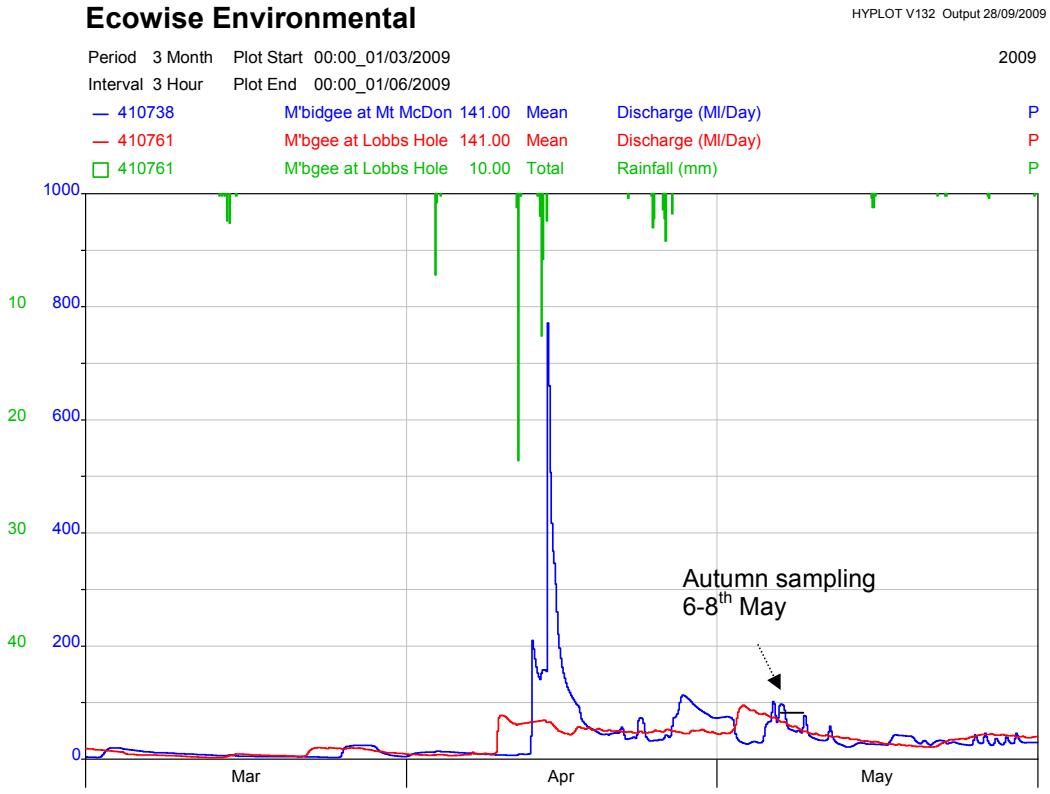

Figure 1. Autumn hydrograph of the Murrumbidgee River at Lobb's Hole (red) and Mount McDonald (blue). Total rainfall (mm) is shown in green.

Flows recorded at Mt. MacDonald (near site Mur 0937) during autumn 2009 were approximately 25% below the preceding year mean (Table 4). The average flows for the three months of autumn were 37.7 ML/d at Mt. MacDonald and 32.8 ML/d at Lobb's Hole. April had high rainfall with a total (at Lobb's Hole) of 71.8 mm; compared to March (6 mm) and May (4.6 mm).

Table 4. Autumn rainfall and flow summary for Lobb's Hole and Mt. MacDonald.

Flow values are daily means. Rainfall is total (mm).

Site	Lobb's Hole (410761)		Mt. MacDonald (410738)	
	Rainfall Total (mm)	Mean Flow (ML/d)	Rainfall Total (mm)	Mean Flow (ML/d)
March	6	10.3*	na	9.9
April	71.8	42.7*	na	64.9
May	4.6	45.6*	na	38.4
Autumn (2009) mean	27.4	32.8	na	37.7

* The flow value at Lobb's Hole is not considered to be as accurate as the Mt. MacDonald readings during periods of low flow.

3.2 Water quality

The continuous water quality data obtained from Lobb's Hole for the period 1/3/09-31/5/09 (Figure 2) show declines in all measured parameters. The average water temperature shows a seasonal trend, declining form 20.8°C in March to 11.3°C in May. Electrical conductivity was 48% lower in May (mean = 175.9 µs/cm) than in March (mean = 93.8 µs/cm). Turbidity readings were consistent over autumn, with monthly means only fluctuating by 2-3 NTU. NTU maximums were highest in May, which corresponded to rainfall events, but even these maximums (i.e. 18.8 NTU) were below the ANZECC water quality guidelines for healthy upland rivers.

The grab sample results are presented in Table 5. Nutrient levels (TN and TP) exceeded the ANZECC (2000) guidelines at all the sites sampled. The highest TP levels were recorded at Mur 0931 (0.05 mg/L), while all other a sites recorded 0.03 mg/L. TN ranged from 0.43 (Site Mur 0931) to 0.52 (MUR 0935). Dissolved oxygen exceeded the guideline values by 1.5% at site Mur 0937. All other parameters were below, or within the guideline limits. Electrical conductivity increased steadily downstream and the variation in water temperature, as expected was correlated to the time of day the measurements were made.

3.3 Periphyton

Average ash free dry mass (AFDM) was slightly higher downstream of the MPS (1372 mg/m^{-2}) compared to the upstream sites (1329 mg/m^{-2}), but these differences were not statistically significant (t_{28}= 0.35, P= 0.72; Figure 3). These results are supported by the qualitative on-site estimates. All the sites were assessed as having Category 4 (65-90%) or Category 5(>90%) levels of periphyton growth, with no obvious differences noted between locations.

The average chlorophyll-a concentrations were higher upstream of the MPS (mean = 8002 µg/m^{-2}) compared to downstream (mean = 5079 µg/m^{-2}), but these differences were not statistically significant (t_{28}= 1.513, P=0.14). This is supported by the large variation around the means at both locations. Mur 28 and 29 had the highest concentrations of Chlorophyll-a at the upstream and downstream sites respectively. There were no strong correlations between water quality variables and AFDM or Chlorophyll –a, but this is not surprising since there are no clear differences in the water quality parameters between sites. Habitat parameters including the percent coverage of each substrate type revealed a strong linear association between chlorophyll-a concentrations and the percentage of cobbles at each site. However, this was only evident using site mean values and should be treated with caution at this stage because of the small sample size (n=5).

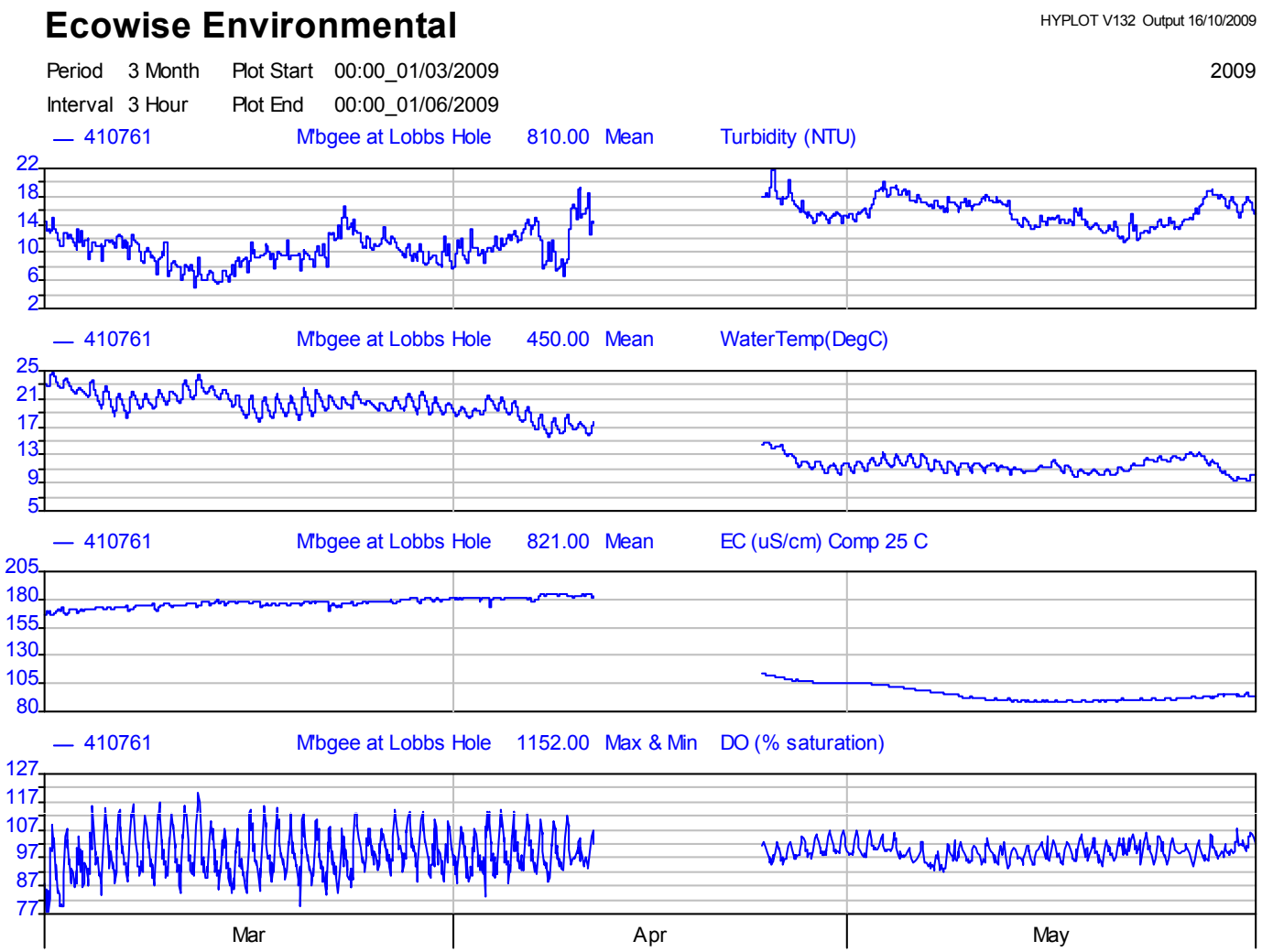

Figure 2. Water quality records from Lobb's Hole during autumn 2008

The break in the series, occurring from the12th to the 23rd of April was due to the cessation of flows recorded at Lobb's Hole.

Table 5. In-situ water quality and nutrient results from autumn 2009 (ANZECC guideline values are in bold). Yellow cells indicate values outside of ANZECC guidelines.

Location	Site	Time	Temp. (°C)	EC (µs/cm) **(30-350)**	Turbidity (NTU) **(2-25)**	pH **(6.5-8)**	D.O. (% Sat.) **(90-110)**	D.O. (mg/L)	Alkalinity	NOX (mg/L) **(0.015)**	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	Total Phosphorus (mg/L) **(0.02)**	Total Nitrogen (mg/L) **(0.25)**
Upstream	Mur 0931	10.00	11.8	130	13.8	8	98.4	9.9	59	<0.01	<0.01	<0.01	<0.01	0.05	0.43
	Mur 28	12.00	12.8	150	13.5	7.9	103.3	9.7	63	<0.01	<0.01	<0.01	<0.01	0.03	0.51
Downstream	Mur 0935	08.45	11.3	140	12.2	8	100.4	10.15	64	<0.01	<0.01	<0.01	<0.01	0.03	0.52
	Mur 0937	13.55	13.2	150	9.6	8	111.1	10.67	62	<0.01	<0.01	<0.01	<0.01	0.03	0.51
	Mur 29	14.00	15	150	16	8	104.1	10.5	61	<0.01	<0.01	<0.01	<0.01	0.03	0.51

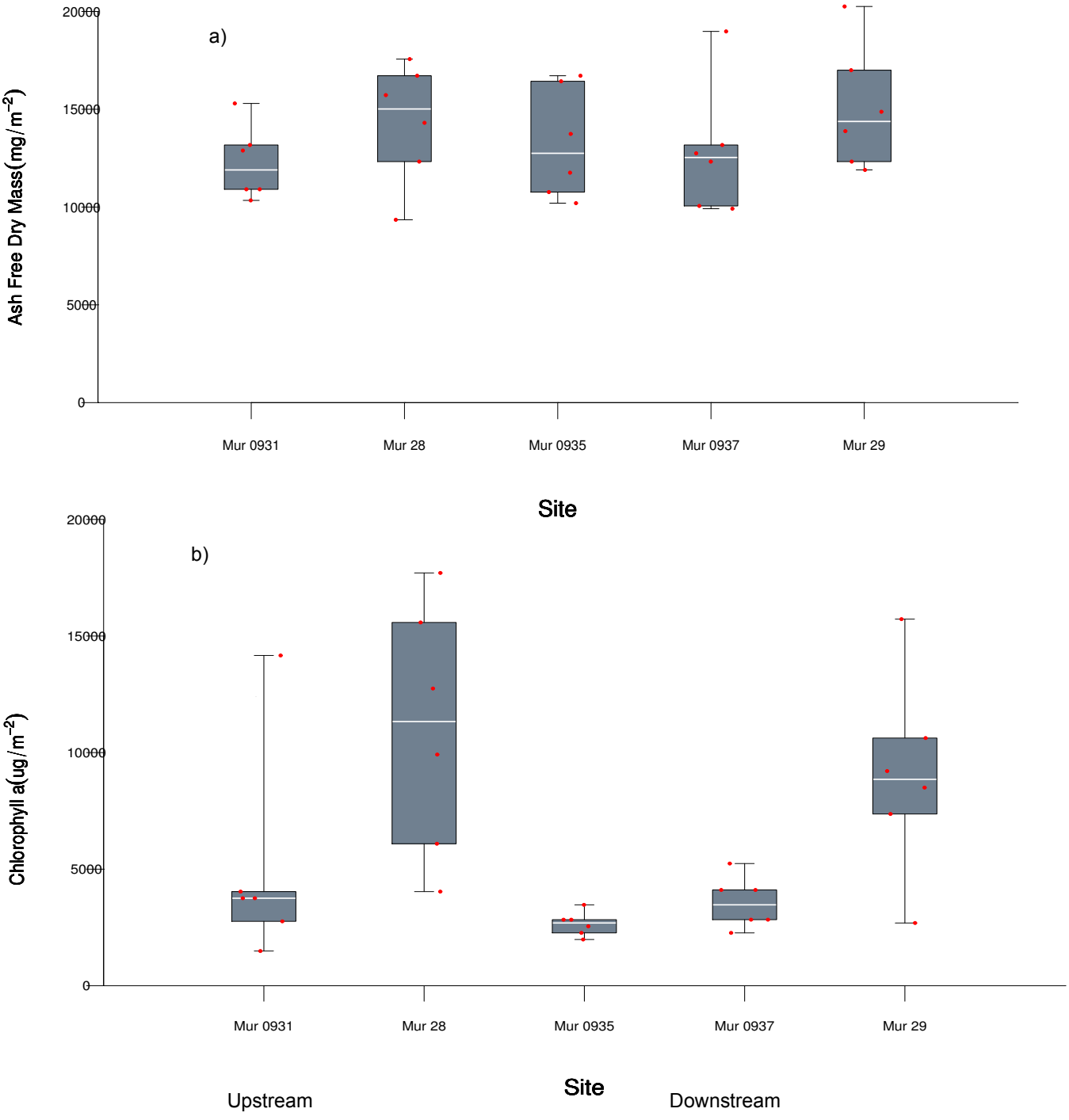

Figure 3. The distribution of a) Ash Free Dry Mass (AFDM) and b) Chlorophyll-a up - and downstream of the MPS.

Strip chart values (in red) represent the raw data values for each site. See Appendix A for an explanation of how to interpret the box and whisker plot

3.4 Macroinvertebrate communities

The ANOSIM analysis (see APPENDIX B) did not detect significant differences in the macroinvertebrate communities collected form the riffle zones between sites upstream and downstream of the Murrumbidgee Pump Station (R = -0.33; P = 0.9). This is evident by the apparent overlap of sites upstream and downstream of the MPS in the NMDS ordination plot (Figure 3). Similarly, there were no significant differences in edge community structure at sites upstream and downstream of the MPS (-0.417; P = 0.98) (Figure 4). Pairwise comparisons between sites were not carried out because of the non-significant global R-values for both habitats.

The low stress values in Figures 3 and 4 indicate a good fit of the data by the NMDS plots.

3.4.1 Riffles

All sites sampled in autumn were dominated by high abundances from three main family groups including Simuliidae (SIGNAL = 5); Caenidae (SIGNAL = 6) and Hydropsychidae (SIGNAL = 6). The apparent absence of the more sensitive taxa in the riffle zones is shown in Figure 6, where the macroinvertebrate communities at all sites (with the exception of site 29 - Uriarra Crossing) were comprised of ≥70% of Oligochaetes, Chironomids and other Dipterans and the sensitive taxa (i.e. Mayflies, Stoneflies and Caddisflies (EPT taxa)) only made up to 28% of the community (except site 29, where EPT was 48%). The number of invertebrate genera recorded in the riffle zones varied from 23 at site 937 (Casuarina sands) to 32 at site Mur 28 (upstream of the Cotter confluence). Family level richness was highest at site 29 with 18 families recorded and was lowest at site 28 with 14 families. The results from the nested ANOVA indicate no statistical difference between locations (i.e. upstream and downstream of the MPS) ($F_{1,3} = 1.94$, P = 0.15).

3.4.2 Edges

Genus and family level macroinvertebrate richness was highest at Mur 28 with 45 and 31 taxa recorded respectively; and lowest at Mur 0937 (Mt. MacDonald) recording 24 genera and 18 families (Figure 5). The number of invertebrate taxa appears to be higher upstream of the MPS but analyses for this data set were not performed because incomplete replication can result in unbalanced and less robust tests.

Edge samples were dominated by the genus *Micronecta* (Signal scores in parentheses) (Corixidae: (2); by Simulids (5), Atyidae (3), Caenidae (4) and Baetidae (5) all with intermediate SIGNAL scores, thus being relatively tolerant to poor water quality. All sites have the same suite of taxa, but their relative abundances differ between sites. Most notably, in the deeper pool/edges of site 28 and site 931, *Micronecta spp.* was the most abundant, but was completely absent from site 937 and reappeared at site 29 (Uriarra Crossing). Simulids, Baetidae and Hydropsychidae (6) increased in abundance at site 937 and combined contributed to ~71% of the macroinvertebrate community structure.

3.5 AUSRIVAS assessment

The AUSRIVAs assessment of river health indicates that all sites appear to be under environmental stress. Four of the five sites sampled in autumn were assessed as being "significantly impaired" (Band B) (Table 3). The fifth site, site 937, had an overall site assessment of Band C, or "Severely impaired". When both habitats are under assessment, the AUSRIVAs assessment protocols require that the overall assessment should be based on the lowest value of the two. In the case of site 937, the riffle was assessed as Band B and is consistent with all of the other four sites, but the edge habitat had a lower rating of Band C so this was the overall score of the site (details in Table 6).

Three sites (931, 935 and 937) were not assessed in spring 2008, so there is no comparable data to previous sampling runs. However, sites 28 and 29 were sampled in 2008. The indication for the previous assessment (Ecowise, 2008) suggest that since spring 2008 there has been a decrease in ecological health in the riffle zone at site 28, dropping from a Band A (close to reference) assessment in spring to a Band B for this sampling run. There was no change at site 29. The edge samples taken in spring were unreliable as the range of bands was irregular at site 29 so no reliable assessment was possible. The rating at site 28 for the edge habitat is unchanged.

The taxa predicted to occur with ≥50% probability, but absent from each habitat and site are presented in Appendix D. Site 937 recorded the most missing taxa in both the riffle and edge habitats with 4 and 10 taxa missing respectively. Gripopterygidae were absent from all sites sampled. This is a highly sensitive family of stonefly (Plecoptera; SIGNAL = 8), which requires cool, fast flowing water. Elmidae (7) were absent from ~65% of the samples. They were found at each site, but their absence from the majority of sub-samples suggest that their distribution was patchy rather than ubiquitous in quality riffle zones. Other missing taxa included the sensitive Synlestidae (7) from all of the edge samples and Tipulidae (5) from 96% of the riffle samples.

Table 6. AUSRIVAs and SIGNAL scores for autumn 2009

Site	Replicate	SIGNAL -2		AUSRIVAS O/E score		AUSRIVAS BAND		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
Mur 0931	1	*4.50*	*4.18*	*0.89*	*0.85*	A	A	**B**	**B**	**B**
Mur 0931	2	*4.14*	*3.80*	*0.78*	*0.78*	B	B			
Mur 0931	3	*4.00*	*4.22*	*0.67*	*0.70*	B	B			
Mur 0931	4	*4.50*		*0.89*		A				
Mur 0931	5	*4.50*		*0.89*		A				
Mur 0931	6	*4.86*		*0.78*		B				
Mur 28	1	*4.14*	*4.25*	*0.78*	*0.93*	B	A	**B**	**B**	**B**
Mur 28	2	*4.14*	*4.56*	*0.78*	*0.70*	B	B			
Mur 28	3	*4.14*		*0.78*		B				
Mur 28	4	*4.14*		*0.78*		B				
Mur 28	5	*4.14*		*0.78*		B				
Mur 28	6	*4.86*		*0.78*		B				
Mur 0935	1	*4.50*	*3.86*	*0.78*	*0.54*	B		**B**	**B**	**B**
Mur 0935	2	*4.14*		*0.89*		A				
Mur 0935	3	*4.00*		*0.78*		B				
Mur 0937	1	*4.14*	*3.67*	*0.78*	*0.47*	B	C	**B**	**C**	**C**
Mur 0937	2	*4.50*	*4.71*	*0.67*	*0.54*	B	B			
Mur 0937	3	*4.50*	*4.25*	*0.67*	*0.62*	B	B			
Mur 0937	4	*4.50*		*0.89*		A				
Mur 0937	5	*4.50*		*0.67*		B				
Mur 0937	6	*4.29*		*0.78*		B				
Mur 29	1	*4.25*	*4.88*	*0.89*	*0.62*	A	B	**B**	**B**	**B**
Mur 29	2	*4.50*	*4.11*	*0.89*	*0.70*	A	B			
Mur 29	3	*4.14*	*4.38*	*0.78*	*0.62*	B	B			
Mur 29	4	*4.50*		*0.89*		A				
Mur 29	5	*4.14*		*0.78*		B				
Mur 29	6	*4.50*		*0.89*		A				

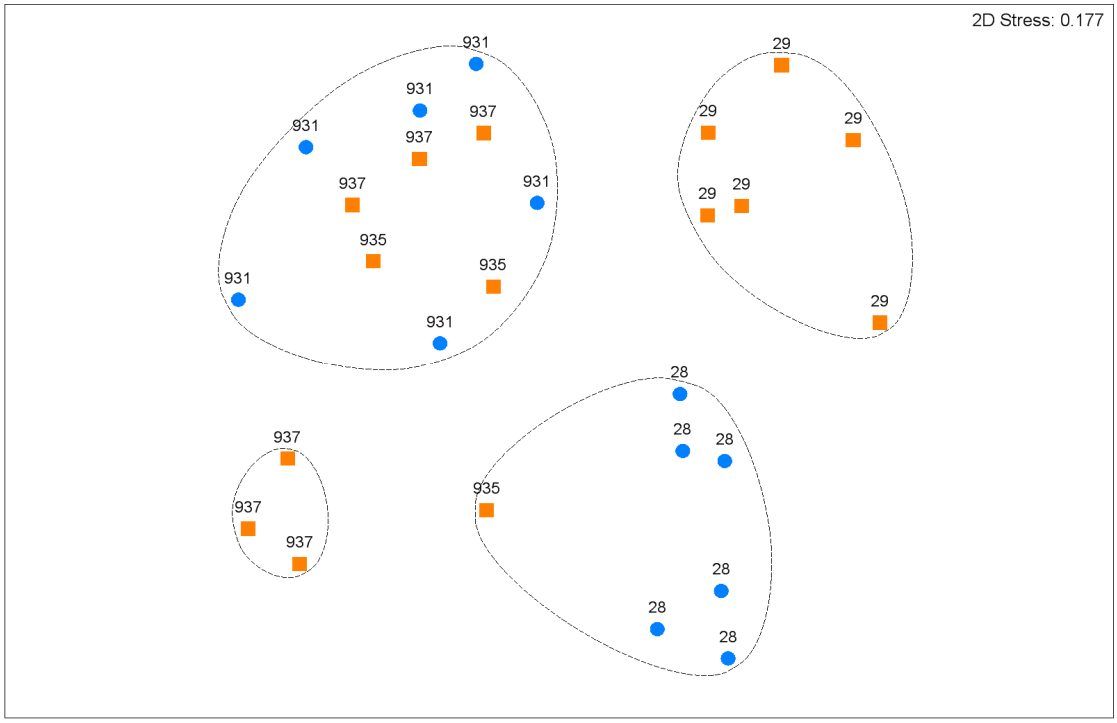

Figure 4. NMDS plot of riffle samples taken in autumn 2009. Blue circles are upstream of the MPS, orange squares are downstream.

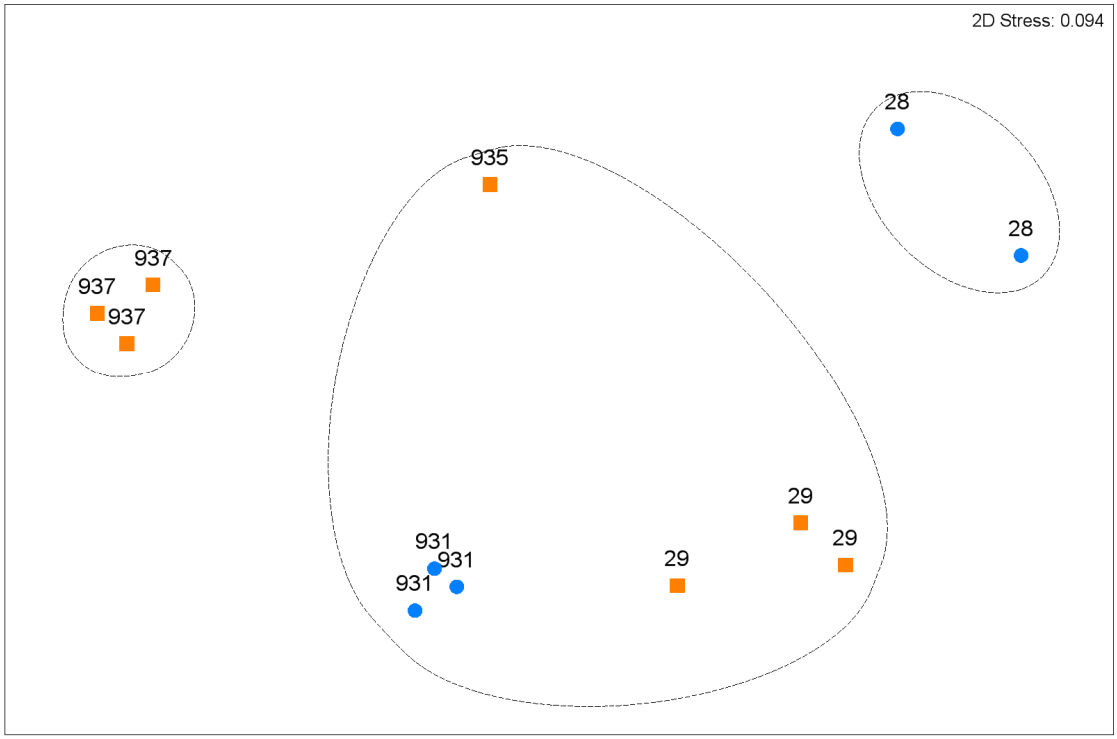

Figure 5. NMDS plot of edge samples taken in autumn 2009. Blue circles are upstream of the MPS, orange squares are downstream

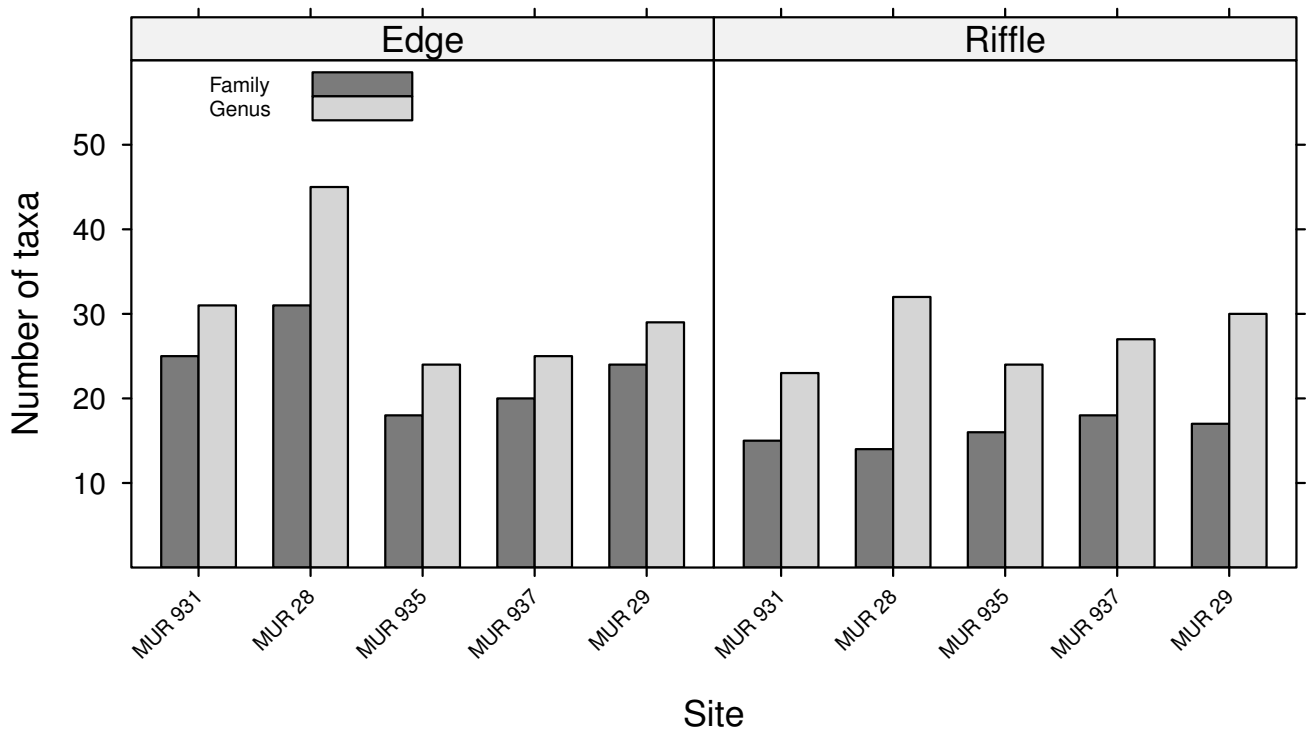

Figure 6. Family and genus richness from sites upstream and downstream of the MPS

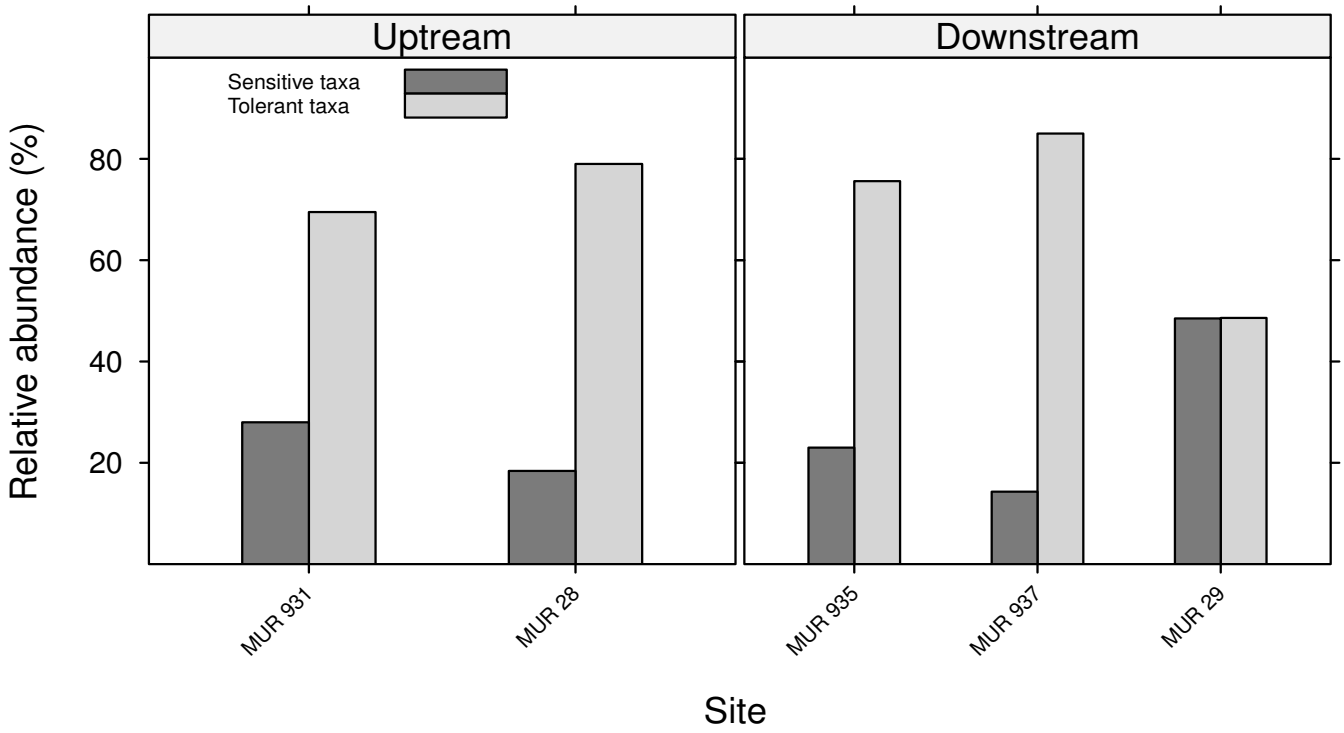

Figure 7. Relative abundances of sensitive (EPT)* and tolerant* taxa. EPT is a commonly used metric comprising the relative abundance of Ephemeroptera (mayflies); Plecoptera (stoneflies) and Trichoptera (caddisflies). Tolerant taxa are comprised mainly of Oligochaeta (worms); Chironomids (non-biting midges) and other Diptera (true flies).

Figure 8. Top: looking upstream towards the Cotter River confluence; **Bottom:** looking downstream towards Casuarina sands*

*At the time these photographs were taken (9/05/09), the flow recorded at Mt. MacDonald was **60 ML/d**.

4 Discussion

4.1 Water quality

The water quality parameters from continuous gauging at Lobb's Hole are indicative of responses to reduced flow (Figure 8) and seasonal changes. For example, low water temperatures at Lobb's correspond to declining ambient temperatures, but also to increased flows during sampling. It is likely that the slight increases in turbidity are related to re-suspended fines following rainfall, runoff, and inflow from tributaries, though these increases in turbidity are negligible and remain inside the ANZECC (2000) water quality guidelines for ecosystem health (Table 5). High EC prior to flow levels falling below the threshold for reliable readings in mid-April, implies a high groundwater contribution.

The results from the grab samples show that almost all the analytes were within the ANZECC (2000) water quality guidelines, except TN and TP concentrations. Nutrient values are more than double the guideline values in some cases which could be problematic if they remain high, during periods of low flows; as this will encourage algal growth. Total Phosphorus declined by 50% since spring 2008, while there was a <1% increase in TN since the last sampling period.

4.2 River health

The AURIVAS river health assessment indicates that the section of the Murrumbidgee River within the limits of this program was under considerable in May 2009. All sites sampled were significantly impaired, and site 937 was severely impaired. Sites upstream and downstream of the MPS have similar AUSRIVAs scores (Table 6). This, combined with the non-significant results from the ANOSIM analysis, the lack of separation between upstream and downstream sites in the NMDS ordination plots (Figures 4 and 5), similarities in the the periphyton analyses (Figures 3a & 3b), and similar diversity measurements (Figure 6), indicate reach-wide stressors on the sites rather than a point source impact such as preliminary works on infrastructure being conducted at the MPS.

The ubiquitous stressor on this section of the Murrumbidgee River appears to be the very low flows over summer which were prolonged to early May when sampling began. Declines in taxonomic richness (Boulton, 2003), loss of sensitive taxa through sediment deposition, and intolerances to flow related changes in water chemistry (Caruso, 2002) are all recognised responses to low flow conditions. At this stage, because only site 28 has previously been sampled it is not possible to determine the extent of these likely impacts on the macroinvertebrate communities because of the absence of data. However, a comparison of the AUSRIVAs assessment from spring 2008 does show a decline in condition at site 28 in the riffle zone from a Band A assessment to a B in this round of sampling with no apparent change in the edge habitat.

This result is consistent with the scenario that low flows are causing the decline in condition, because during receding waters, and the contraction of wetted widths, it is expected that the shallower riffle habitat would be the first to be affected. The absence of the sensitive riffle beetle larvae (Elmidae: SIGNAL 7) from all of the samples collected at site 28 in autumn further supports this view (APPENDIX D). This family was predicted to occur with >50% probability and was present in spring 2008. Riffle beetles, as the name implies, thrive in well-oxygenated, fast flowing riffles (Gooderham and Tsyrlin, 2005). Therefore their absence might suggest sub-optimal conditions in their habitat.

The edge habitat, had the most missing taxa predicted by AUSRIVAs, with >50% probability of occurrence (APPENDIX D). One explanation for this result is that when flows ceased in April, the edge habitats were isolated to the point where many of the most common taxa (e.g. Corixidae (2)) were stranded and could not relocate to more advantageous conditions. Subsequent effects, such as the deterioration of water quality through increased water temperatures and reduced oxygen through warming and increased bacterial activity may also have played a role. The isolation of the edges may

also have prevented or slowed recolonisation until connectivity between important sections of river was restored (e.g. Stanley *et al.*, 1997).

Periphyton communities are often used in biomonitoring programs because they respond rapidly to changes in water quality and can proliferate under low flow conditions. There was no evidence of upstream, (control) and downstream (impact) location differences in autumn 2009, There were some differences in the variation of Chlorophyll-a estimates between sites, but biomass estimates were similar across all sites. The slightly elevated levels of Chlorophyll-a recorded at sites 931, 28 and 29 are not directly related to any of the habitat variables, including water velocity (m/s^{-1}), degree of shading (%), substrate type & heterogeneity, nor any of the water quality parameters (particularly TN and TP), suggesting that these baseline data are representative of background within-site variation during low flows. Data from following seasons should facilitate interpretation of location and/or site specific process.

5 Conclusions

The results from autumn 2009 show evidence of a system under considerable stress from low flow conditions. The AUSRIVAS assessments delivered results indicating that four of the five sites are "significantly impaired" (Band B) and site 937 (~3km downstream of the MPS) as being "severely impaired" (Band B and C).

While the water quality during sampling was within ANZECC guidelines for most of the sampled parameters, there was evidence that that water quality had changed leading up to sampling. This is because some parameters appeared to be responding to low flows and seasonal cycles.

We consider the current river health assessment to be a result of reach-wide influences, such as low flows that potentially result in slow recruitment between drying periods, particularly in the edge habitat. There is little evidence at this stage to suggest that the works associated with the preliminary infrastructure upgrade of the MPS has any direct link to the current river health assessment.

The condition of these sites is likely to improve with increased flow, providing there are good winter and spring rainfall events.

6 Recommendations

A condition stated in the Murrumbidgee Pump Station monitoring proposal (section 4.1.5) is that the program is to be adaptive and that the methods, sites, and analysis in previous runs be reviewed so the objectives of ACTEW are being met satisfactorily.

As this is the first round of sampling, any limitations of the methods are not yet evident. However, there are some other issues that need addressing:

1) At some of the sites, only one replicate has been possible for a given habitat. This is due to low flows during this round of sampling. If this remains a problem, the level of replication may need reviewing and adjusting to facilitate a more balanced design when it comes time for an analysis of long term trends.
2) The substrate dominating the riffle zone at site 931 (~4km upstream of the Cotter confluence) is distinctly different from all the other sites, being predominately bedrock (see Appendix C). With biological data it is important to have sites that are as similar as possible so that any biological changes can be attributed to a given impact with more confidence and not confused with differences between habitats, for example. At this stage there does not appear to be a suitable substitute for this site due to accessibility issues.
3) The level of taxonomic resolution will be addressed more thoroughly when additional data are collected. Preliminary investigations of both the ordinations of family and genus data sets do suggest some overlap (redundancy) of information for the edge habitat data, but there were no such correlations apparent for the riffle data. In fact, the low genus / family ratio indicated in the riffle zone might suggest some loss of information (Lenat and Resh, 2001) if family level identification is perused. In light of this, it is advisable to continue monitoring to genus level with the view that that this be reassessed once two comparable seasons of data become available.

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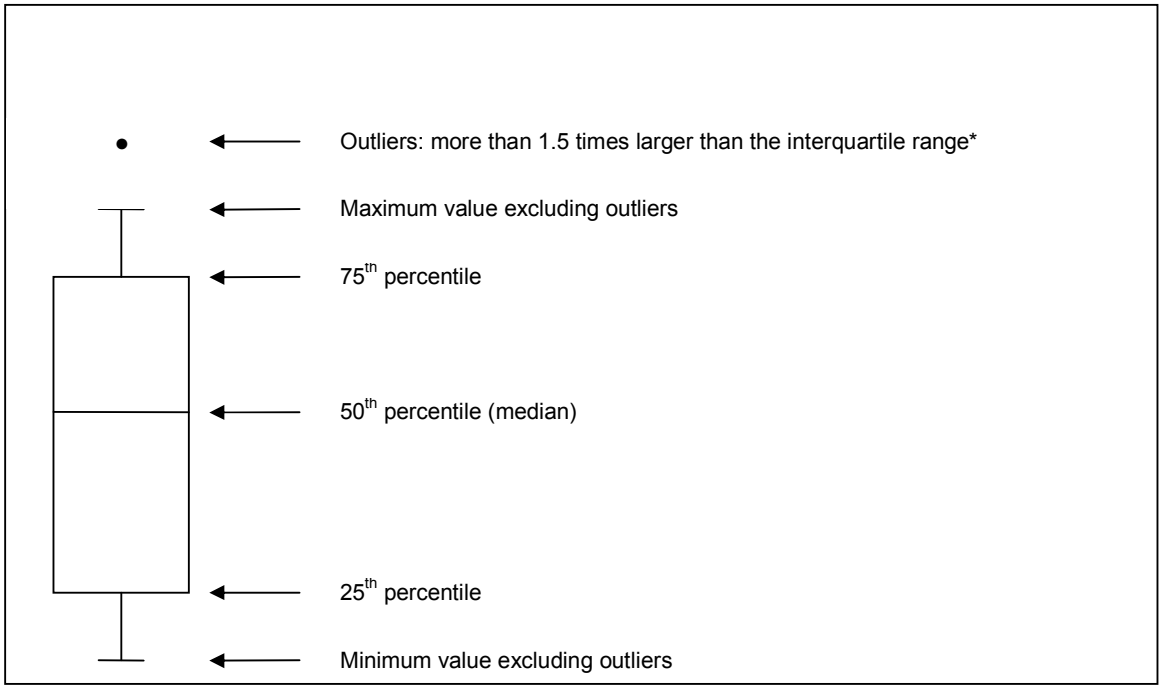
Appendix A –

Interpreting box and whisker plots

Appendix A. Interpreting box and whisker plots.

Box and whisker plots are intended as an exploratory tool to help describe the distribution of the data. The red 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 B– ANOSIM output for riffle and edge samples

Appendix B. Analysis of Similarity results for both riffle and edge habitats

ANOSIM
Analysis of Similarities

Two-Way Nested Analysis

Edge

```
TESTS FOR DIFFERENCES BETWEEN # site GROUPS
(across all # location groups)
Global Test
Sample statistic (Global R): 1
Significance level of sample statistic: 0.1%
Number of permutations: 700 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1

TESTS FOR DIFFERENCES BETWEEN # location GROUPS
(using # site groups as samples)
Global Test
Sample statistic (Global R): -0.417
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
```

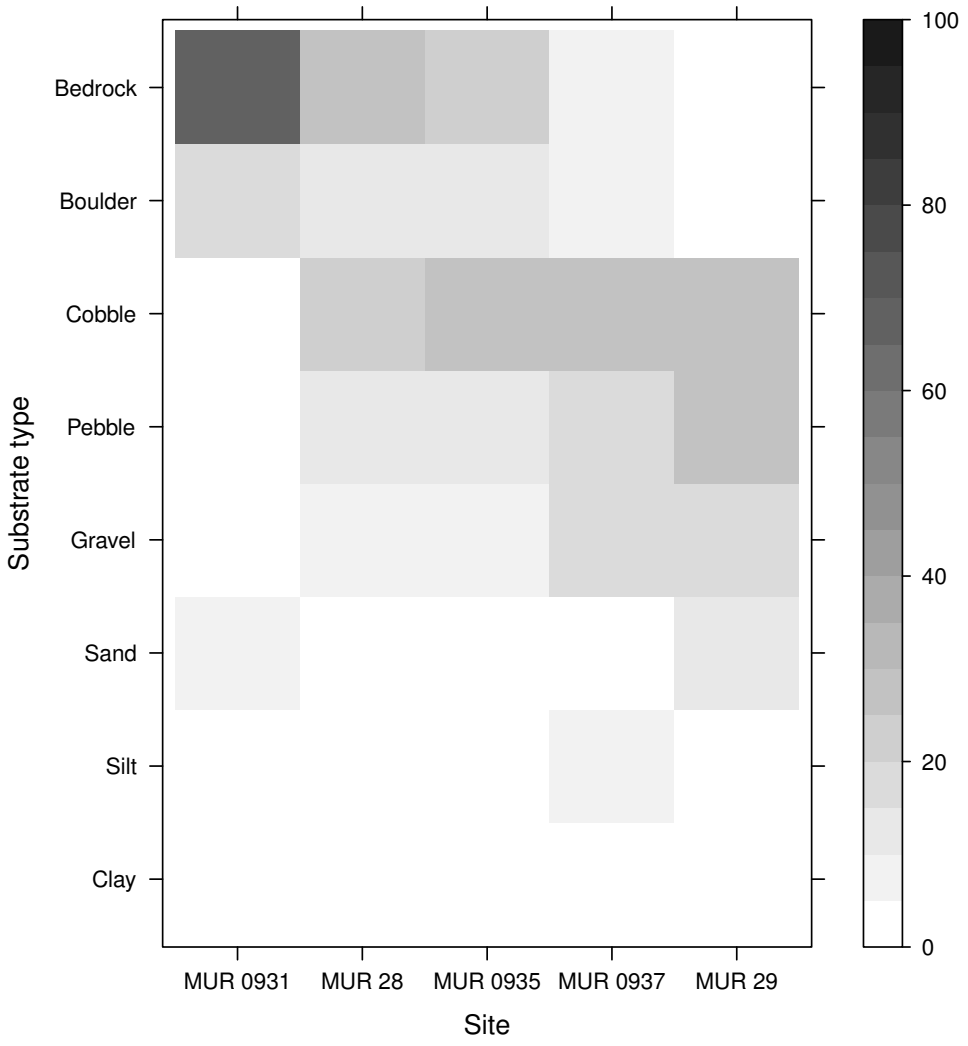
Riffle

```
TESTS FOR DIFFERENCES BETWEEN # site GROUPS
(across all # location groups)
Global Test
Sample statistic (Global R): 0.765
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 97117020)
Number of permuted statistics greater than or equal to Global R: 0

TESTS FOR DIFFERENCES BETWEEN # location GROUPS
(using # site groups as samples)
Global Test
Sample statistic (Global R): -0.333
Significance level of sample statistic: 90%
Number of permutations: 10 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 9
```

Appendix C– Relative substrate cover: details from the riffle zones sampled in autumn 2009

Appendix C. The percentage of each substrate type at each site (reading left to right sites are in order from upstream to downstream). The colour scale is in percent (%) coverage (darker colours indicate higher percentage cover). The plot shows that site 0931, for example has a less diverse substratum in its riffle zone than the other sites and is made up of predominantly of bedrock and boulders account for ~ 20% of the riffle zone, while sand occupies ~10% of the habitat).



Appendix D–
Taxa predicted to occur but not collected in the AUSRIVAS assessment

Appendix D. Taxa predicted to occur with >50% probability by the AUSRIVAS model, but were not collected in the edge habitat.

Site	Taxa	Planorbidae	Oligochaeta	Elmidae	Tanypodinae	Baetidae	Corixidae	Leptophlebiidae	Synlestidae	Gripopterygidae	Hydroptilidae	Ecnomidae	Conoesucidae	Leptoceridae	
	Signal score	2	2	7	4	5	2	8	7	8	4	4	7	6	**# taxa missing**
Mur 28	Edge								●	●	●		●		**4**
Mur 28	Edge	●			●				●	●	●	●	●		**7**
Mur 29	Edge	●	●				●		●	●		●	●	●	**8**
Mur 29	Edge	●						●	●	●	●	●	●		**7**
Mur 29	Edge	●	●					●	●	●	●	●	●		**8**
Mur 0931	Edge	●		●					●	●			●		**5**
Mur 0931	Edge	●		●				●	●	●			●		**6**
Mur 0931	Edge	●		●	●				●	●		●	●		**7**
Mur 0935	Edge	●	●	●		●		●	●	●		●	●		**9**
Mur 0937	Edge	●		●			●	●	●	●	●	●	●	●	**10**
Mur 0937	Edge	●		●	●		●		●	●	●	●	●	●	**10**
Mur 0937	Edge	●		●	●		●		●	●			●	●	**8**

Appendix D (cntd). Taxa predicted to occur with ≥50% probability by the AUSRIVAS model, but were not collected in the riffle habitat.

Site	Taxa	Oligochaeta	Elmidae	Tipulidae	Gripopterygidae	Simuliidae	Hydropsychidae	Total number of missing taxa
	Signal score	2	7	5	8	5	6	
Mur 28	Riffle		●	●	●			3
Mur 28			●	●	●			3
Mur 28			●	●	●			3
Mur 28			●	●	●			3
Mur 28			●	●	●			3
Mur 28			●	●	●			4
Mur 0931	Riffle		●	●	●			3
Mur 0931			●	●	●			3
Mur 0931			●	●	●			3
Mur 0931				●	●			2
Mur 0931				●	●			2
Mur 0931		●		●	●			3
Mur 0935	Riffle		●	●	●			3
Mur 0935				●	●			2
Mur 0935			●	●	●			3
Mur 0937	Riffle		●	●	●			3
Mur 0937		●	●	●	●			4
Mur 0937		●	●	●	●			4
Mur 0937			●		●	●	●	4
Mur 0937				●	●			2
Mur 0937		●	●	●	●			4
Mur 29	Riffle		●	●	●			3
Mur 29				●	●			2
Mur 29			●	●	●			3
Mur 29				●	●	●		3
Mur 29			●	●	●			3
Mur 29				●	●			2